GROUNDWATER GOVERNANCE IN THE CENTRAL BEKAA, LEBANON

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Groundwater governance in the Arab World

Marie-Hélène Nassif

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Table of Contents

Figures

Tables

List of Acronyms

BWE	Beqaa Water Establishment
CDR	Council for Development and Reconstruction
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
LRA	Litani River Authority
LRBMS	Litani River Basin Management Support Program
MoE	Ministry of the Environment
MEW	Ministry of Energy and Water
NGO	Non-Governmental Organization
NWSS	National Water Sector Strategy
ULRB	Upper Litani River Basin
UNDP	United Nations Development Programme
UN-ESCWA	United Nations Economic and Social Commission for Western Asia
USAID	United States Agency for International Development
RWE	Regional water Establishments

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Executive Summary

What first comes to mind when thinking about the Upper Litani River Basin's (ULRB) hydrology is the large surface water basin formed by the Litani River and its tributaries. The less known fact is that groundwater constitutes a large resource in this basin and provides the largest share of its actual water needs, including 65% of water supply for irrigation and the largest share of domestic and industrial water supply.

Groundwater has long been used by ULRB residents and facilitated populations without access to rivers and springs to ensure their irrigation and domestic water needs. Prior to the 1960s, water tables were very shallow in all of the basin's aquifers. Groundwater used to resurge in large wetlands and small springs in the plain (the Quaternary aquifer), and discharge through many medium and large springs from both mountain ranges surrounding the Bekaa Valley (the carbonate aquifers). Outside the command areas of the spring and river-based irrigation systems, farmers would dig shallow wells in the alluvium areas, which allowed them to extract important amounts of water and ensure a constant supply of water for irrigated agriculture during the summer season. Groundwater was also an important resource for livestock owners, especially the Bedouin tribes crossing the Bekaa Valley and who used to dig ditches in the plain to water their animals.

Following the expansion of drilling technology in the early 1960s that went parallel to the mechanization of agriculture and the surge of agricultural demand in the Gulf countries, groundwater started to be heavily exploited by individual users. During this period, while shallow wells were still being used in the plain, tube wells expanded rapidly in the carbonate aquifers and contributed to the substantial increase of irrigated areas between the 1960s and the 1970s.

In the meantime, the Lebanese Government was planning the development of large-scale modern irrigation systems, projected to be partly supplied by the Qaraoun artificial reservoir and to a large extent by groundwater. With the support of the US Government (in the 1950s), and the French Government (in the 1960s and 1970s), a substantial number of hydrological studies and engineering plans were produced, which resulted in the establishment of an 'Irrigation Plan for the South-Bekaa'. The ULRB's hydro-geologic potential was also largely investigated by the national assessment produced by UNDP, resulting in the first major characterization of aquifers across the country. The Lebanese War (1975-1990), hindered the execution of irrigation systems planned by the government. During the reconstruction period (1990-2005), only a small part of the South-Bekaa Irrigation Project was executed (2,000 ha). However, the command area, projected to be entirely supplied by surface water from the artificial reservoir in Qaraoun, is still irrigated to a large extent through private individual wells (more than 1,000 ha), which is due to an under-sizing of the pumping stations.

From the 1960s until today, private irrigation wells expanded widely, allowing to put into irrigation most of the rain-fed lands that did not have access to surface water. Their number is difficult to appraise, but was estimated to be somewhere between 5,000 and 10,000. Municipalities drilled domestic wells where state supply was absent or unreliable. House domestic wells also widely proliferated and thousands of them can now be found on the ULRB. During the reconstruction period, the Lebanese State drilled more domestic wells as part of a rehabilitation project for domestic water supply systems. In the last 4 years, the influx of Syrian refugees further increased pressure on water demand and, as a result, required the drilling of new wells both in municipalities and refugee settlements. Over the years, increased groundwater abstractions led to a situation of groundwater overexploitation. Water tables

began lowering in all aquifers of the basin and resulted in the drying-out of many small and medium springs. Shallow wells dug in the plain dried out since the mid-1970s and were replaced by tube wells.

However, the situation of groundwater resources in the ULRB and the impact overexploitation has had on users has remained almost unknown by decision and policymakers for more than 40 years, since the period of the early hydro-geological studies (1960s to 1970s). In recent years, substantial studies assessing the current situation of groundwater were conducted with the support of international organizations. The UNDP and the Ministry of Energy and Water conducted a new national groundwater assessment in 2014. In cooperation with the Litani River Authority, a USAID-funded program focused on supporting the development of the ULRB and conducted a hydro-geologic assessment for the basin in 2012 and 2013. It located and characterized around 125 production wells across the basin, established potentiometric maps (water levels) and a groundwater model estimating future drawdown on water tables.

These studies have provided an updated understanding of the current physical situation of groundwater resources after many years of almost a total lack of scientific assessments, raising the alarm about the risk of further water table drawdown and the necessity to improve groundwater management and reduce abstractions. They also revealed information gaps related to many of the essential aspects to be taken into account, in order to develop a comprehensive and informed reflection on groundwater management policies. At the level of groundwater use, these include: withdrawal rates for both private and public wells; the management types of private and municipal wells; the costs of well drilling, operation and maintenance; the impacts water-level declines had on users; the adaptation strategies developed by users; their perception of the problem; their non-compliance with state regulations; their readiness to compromise their current individual access to water and reduce their water consumption, etc. At the level of state management, although many studies address the general institutional problems pertaining to the water sector, a direct focus on groundwater policies and the organizational aspects of groundwater management is missing.

The present research focuses on the drivers of groundwater use and the impact of groundwater overexploitation on users. It takes (as a specific case study) a limited geographic area of the basin identified with an important water table drawdown. It traces back the evolution of groundwater use in space and time since the 1960s, with a focus on irrigation supply based on interviews with farmers (50), mayors and municipal officials (21) and other informants (8), as well as on a literature review, compilation of well data and direct field observations. It also looks at the institutional framework of groundwater management and its problems based on a literature review and interviews with state officials from the different water authorities (11 persons from The Ministry of Energy and Water [MEW], the Bekaa Water Establishment [BWE], the Litani River Authority [LRA] and the Ministry of Agriculture [MOA]).

The study area is located between the Litani River and the Anti-Lebanon Mountain Chain. It is bounded by the towns of Ryak to the north and Anjar to the south. It includes several important rivers (Hala Yahfoufa and Litani), large springs (Anjar and Chamsine), several dried-out springs (Ras-El-Ain of Terbol and Nabeh El Faour) and three groundwater sources (the Quaternary, Eocene and Cretaceous aquifers). It has a total area of around 14,000 ha including 8,000 ha of agricultural lands. It was further divided into seven sub-areas identified according to their own specific groundwater use evolution. The evolution of groundwater use and its impacts on and between users in each of these sub-areas can be summarized as follows:

1. Sub-area Hala Yahfoufa: Water for irrigation and domestic use remained mainly supplied by gravity from Hala Yahfoufa River until the 1970s. Around this period, water availability from the river was substantially reduced due to increased upstream abstractions, pushing users to drill wells in the Quaternary aquifer. At present, farmers mostly rely on wells. Residents have been using house wells to complement domestic water supply from the public network, until a new municipal well was drilled in the Eocene aquifer. Water levels in the Quaternary aquifer decreased from 1-5 m in the 1960s to 15-20 m at present. Well depths vary between 50 and 150 m. Given the important water capacity of the Quaternary aquifer in this area, well yields are still sufficient to irrigate water consumptive crops throughout the summer. However, users request the equitable allocation of water from this river to reduce their pumping costs. In the upcoming years, the Bekaa Water Establishment (BWE) plans to increase allocation for domestic supply from Hala Yahfoufa River as part of its recent 'Water Supply and Wastewater systems Master Plan for the Bekaa Water Establishment (2015). However, this would further reduce surface water availability for irrigation and increase groundwater abstraction. Farmers in this area contribute to the overexploitation of the Quaternary aquifer. Hala Yahfoufa users also have an indirect impact on the Eocene aquifer users, since a substantial amount of the latter aquifer recharge comes from infiltration from the former river.

2. Sub-area Litani-Fourzol: Water for irrigation used to be supplied by the Litani River (first by gravity, then pumping). Starting in the mid-1970s, farmers started to drill wells in the Quaternary aquifer as an alternative to the reduction of water availability from the Litani River. Due to the poor capacity of the Quaternary aquifer, well yields are low and most of the area is planted with grapes. With increased abstractions over the years, water levels now reach 40 m b.g.l in the summer and well depths range between 50 and 100 m. Well yields have been reduced further, leading to drilling more wells and building storage infrastructure. Some large-scale farmers were also reported to have accessed the deeper aquifer (Eocene). In the upcoming years, water shortage in the Quaternary aquifer is expected to further decline. However, most of the farmers will not be able to afford to drill deep wells, which would force them to decrease their irrigated areas. The farmers of this area are negatively impacted by upstream users of the Litani River and contribute to the overexploitation of the Quaternary aquifer. Accessing the Eocene aquifer would increase the pressure on that aquifer and negatively impact its current users.

3. Sub-area Litani-Maallaqa: The reduction of water availability from the Litani River, which started in the mid-1970s, also necessitated farmers to rely on the Quaternary aquifer. The important water capacity of that aquifer allowed farmers to cultivate all types of crops throughout the summer. However, water levels have been decreasing steadily and now reach 25 m b.g.l in the summer. Well depths vary between 50 and 200 m. In recent years, well yields have substantially reduced, especially at the middle of the irrigation season, which has compelled farmers to reduce their cropping areas. Wells have not multiplied since most of the farmers are tenants renting lands from absent landlords. Accessing of the deeper aquifer was not reported. It is, however, being considered as a solution by the rare land owners still cultivating their lands. The farmers of this area were also negatively impacted by upstream users of the Litani River. They contribute to

the overexploitation of the Quaternary aquifer. Accessing the Eocene aquifer in the upcoming years would also have a negative impact on its users.

4. Sub-area Litani-Barr Elias: In this area, the poor capacity of the Quaternary aquifer did not allow the use of groundwater as an alternative to the reduction of water availability from the Litani River. Several wells were drilled but did not provide sufficient yields, and were thus abandoned. Moreover, the predominance of land tenancy is also a constraint to the multiplication of wells. The only alternative for farmers is to irrigate with wastewater, which accumulates in the Litani River during summer. However, this represents a serious risk of crop contamination. The farmers in this area are the most negatively impacted both by upstream water users and polluters.

5. Sub-area Ghozayel: Until the early 1970s, water for irrigation was provided by gravity from the Naher El Faour River originating from springs located in the Eocene aquifer. With the increased abstractions in that aquifer, water tables were substantially reduced leading to the permanent drying-out of these springs. This forced farmers to start pumping water from the Ghozayel River located downstream. Only some wells were drilled in the small part of the Eocene aquifer that has protruded in to this area. Over the years, the large flow of the Ghozayel River facilitated in extending irrigated areas and cultivating all types of crops throughout the summer. In recent years, however, water availability in this river has substantially decreased due to increased pressure on the river springs (Anjar and Chamsine). Only few farmers are able to rely on groundwater as an alternative due to financial and logistic constraints, while most of them are already forced to reduce the extent of their agricultural areas, especially in years of low rainfall. The BWE is also planning to increase water allocation from Anjar and Chamsine springs for domestic supply. This would substantially reduce surface water availability and force farmers, either to further reduce their irrigated areas or to ensure their access to groundwater. Farmers of this area are thus directly impacted by upstream users of Anjar and Chamsine springs.

6. Sub-area Anjar-Chamsine: This area is characterized as important because of the availability of water both from surface water (Anjar and Chamsine springs originating from the Cretaceous aquifer) and groundwater (the Cretaceous aquifer). The Chamsine Spring has long been used by the state to supply domestic networks in several villages in Central and South-Bekaa. The Anjar Spring has been used by the Anjar community since the settlement of the Armenian community (in the late 1930s), both for irrigation and local domestic supply. The large water availability of the Cretaceous aquifer has been exploited since the 1970s for irrigation purposes in Kfarzabad, and to a lesser degree in Anjar. Water tables in the Cretaceous aquifer have substantially reduced since the 1970s and pushed farmers to deepen their wells. Well yields are still sufficient to practice irrigation throughout the irrigation season, but are substantially reduced in the dry years. Both spring discharges seem to be negatively impacted, and it has led to the drilling of wells in spring vicinities to complement, both domestic supply (next to Chamsine) and irrigation supply (next to Anjar Spring). The most important driver of future pressure on groundwater is the BWE Project to reallocate water from the Anjar Spring. This, however, would deprive Anjar farmers from a substantial discharge of the Anjar Spring, and will push them to look for groundwater sources.

7. <u>Sub-area Eocene:</u> Three different evolutions in groundwater use were identified in this area. They depend on the different social histories of the villages of Hoshmosh, Terbol and Faour and are closely linked to their respective land organizations. The common trend is the evolution of water supply from surface water (Hala Yahfoufa for Hoshmosh and springs originating from the Eocene for Terbol and Faour) and groundwater (wells in the Quaternary aquifer) strictly restrictive to groundwater. The heavy exploitation of the Eocene aquifer starting the 1960s led to the drying-out of the springs, but allowed an important extension of irrigated areas and the establishment of large family farms. The Quaternary aquifer is also an important resource that has allowed the establishment of small and medium farms. Today, water tables in the Eocene have substantially decreased and reach 30 m in years of normal rainfall. Wells have been deepened and sometimes reaching more than 200 m b.g.l. In Terbol, however, irrigation from Eocene wells was reduced due to land fragmentation and, it had led to the multiplication of wells in the Quaternary aquifer. The latter aquifer is also overexploited, resulting in substantially lowering the well yields. In this area, most farmers are able to drill more wells and many have shifted to cultivating grapes. However, further groundwater abstractions are likely to lead to a water shortage in the upcoming years.

The unpacking of drivers and impacts of groundwater overexploitation in each of the seven sub-areas (as mentioned above) revealed clear interrelations, both between the users of the same sub-area and between users of the different sub-areas: groundwater overexploitation in a certain sub-area is often a result of surface water and/or groundwater use and abstraction in another (upstream) sub-area, and can in turn impact water availability in a third (downstream) hydraulically interconnected sub-area. This creates a complex system of interrelated water uses, where reducing groundwater overexploitation and balancing its negative impacts among the different users requires the integrated understanding and management of surface and groundwater resources.

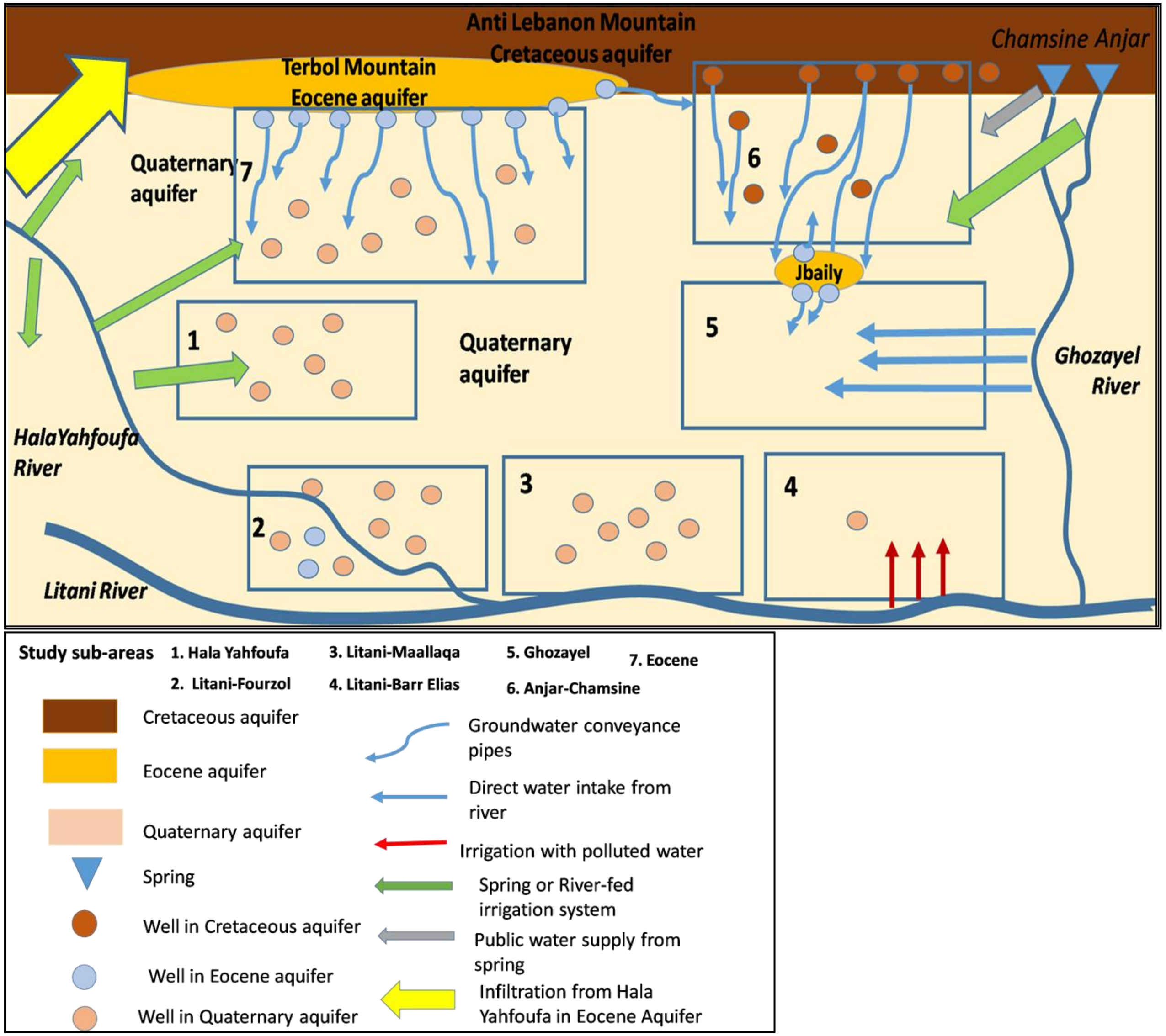
Looking at the management strategies developed by users on the one hand, and by the different water authorities on the other, reveals many obstacles to establishing and enforcing appropriate and coordinated allocations from both surface and groundwater. At the user level, the obstacles to collective groundwater management are linked to the individualistic nature of groundwater use and the lack of clarity of water rights, and are reinforced by the general absence of collective action among users of the same community, or between the different user communities. This reveals that substantial challenges pertaining to water planning are to be faced by the state in the upcoming years.

However, examining the actions of the different water authorities responsible showed that many problems hinder the needed integrated planning and coordination of abstractions. These obstacles include inadequate groundwater regulations adopted by the MEW, an almost absence of enforcement on the part of the MEW (Ministry of Energy and Water) and the MI (Ministry of Interior), delayed/limited groundwater monitoring by LRA (Litani River Authority) and, most importantly, the current incapacity of the BWE (Bekaa Water Establishment) to coordinate water abstractions at the level of its territory. The underlying problems are linked to structural problems of the water sector's institutional framework (dilution of responsibilities and absence of coordination mechanisms) in addition to the general lack of human, technical and financial capacities of water authorities.

In conclusion, analyzing the historical drivers of groundwater overexploitation and its governance framework showed that, the problem of groundwater management is broader than a problem of inadequacy of groundwater legislation and of its enforcement, and must be looked at as a result of a wider problem of water supply and uncoordinated water abstractions and access. A number of general recommendations can be drawn from this study and add to those commonly issued by studies and research addressing water management problems in Lebanon. They include the strengthening of public institutions in terms of human resources and technical capacities, defining clearer responsibilities and removing overlaps and duplication, improving coordination between authorities, updating obsolete legal texts, etc.

In the short term, two main points must be addressed by decision-makers and discussed with water user representatives during the upcoming dialogue that will be held as part of the current IWMI project. The first concerns the importance of reviewing the future water allocation projects planned as part of BWE Master Plan, in the light of the revealed situations of surface water over allocation and groundwater overexploitation. The second is to make use of these concrete examples of groundwater exploitation to reflect on more constraining and better adapted conditions for provision of permits.

A conceptual figure of the actual state of water use in the study area



1 Introduction

What first comes to one's mind when thinking about the Upper Litani River Basin's (ULRB) hydrology is the large surface water basin formed by the Litani River and its tributaries. The less known fact is that groundwater also constitutes a large resource in this basin and provides the largest share of its water needs. In fact, the locals explain that the name '*Bekaa'* is due to the fact that it is used to be all covered by 'spots' (the translation of the Arabic word '*Bekaa'*), large wetlands formed by natural groundwater resurgence. Since the 1950s until today, however, water tables have gradually declined due to groundwater abstraction from wells drilled to supply the growing domestic water demand in the basin and irrigation needs for agriculture in the Bekaa Plain. This led to increased groundwater abstraction costs and, in springs, to a substantial flow reduction or the drying-out of several of them, causing indirect impacts on downstream users (USAID-LRBMS 2012b, d, f).

For more than 40 years since the first general study on groundwater in Lebanon was conducted by the UNDP and the Lebanese Government (UNDP 1970), there has been a lack of comprehensive assessments of the country's groundwater resources. After this period, several studies have recently been conducted by Lebanese public authorities in cooperation with international projects, with the purpose of assessing the present situation of groundwater resources in Lebanon (USAID-LRBMS 2012b, d, f; 2013; UNDP 2014). At the level of the ULRB, two recent technical studies have collected new field data on groundwater wells in the basin. These new observations included the geo-referencing of productive wells, water level measurements, and observations about the general geographic distribution of wells, giving an updated picture of the general situation of groundwater levels in the basin's aquifers. They also provided a general estimate of groundwater volumes abstracted for different uses (irrigation, domestic and industrial) and established a model simulating what groundwater levels will be by the year 2030.

This study aims to present a more complete picture of groundwater use and management both at the level of the ULRB and at the local level, with the purpose of proposing better tailored management strategies. These will be discussed by users and decision-makers during a 'dialogue' that will be organized within the framework of a USAID-funded International Water Management Institute (IWMI) Project to be launched in April 2016. By focusing on a particular area of the basin, identified by the above-mentioned hydrological studies as experiencing serious water table drawdown, the objective of this study is to understand the different drivers leading to the situation of groundwater over-exploitation and the factors hindering its management both for users and decision-makers.

The hydrogeology of the basin is complex, resulting in regionally interrelated impacts in groundwater use and the connection between groundwater and surface water. This creates a complex system, which calls for strong coordination between both groundwater and surface water management. One of the objectives of this research is to identify the type of users exploiting common or interconnected water resources, understand their water needs, assess the impact their groundwater abstractions have on other users of the system, and/or how they are being impacted by other users. Furthermore, this study also looks at the drivers and actors of groundwater over-exploitation, the impact it has had on water access and supply, and actors' knowledge and perception of the problem. It also examines the strategies developed by users to adapt to lowering water tables, the reasons why most of them do not conform to or follow regulations, and their readiness to engage in collective action with each other or with decision-makers in order to reduce groundwater abstraction. At the level of decision-making, the study questions the difficulty faced by water authorities to enforce groundwater legislation on the ground and explores the institutional factors impeding groundwater monitoring and abstraction control, assessing their readiness to engage in a dialogue with users.

The final objective of this report is to analyze in detail the interrelations between users in order to identify concrete situations of present or projected groundwater overexploitation that would require improved coordination between water uses and possibly, higher-level regulatory action. The results are to be presented to both decision-makers and water users in a dialogue to be held in the framework of this project and are expected to serve as material for improving the ongoing water management plans for the Upper Litani River Basin.

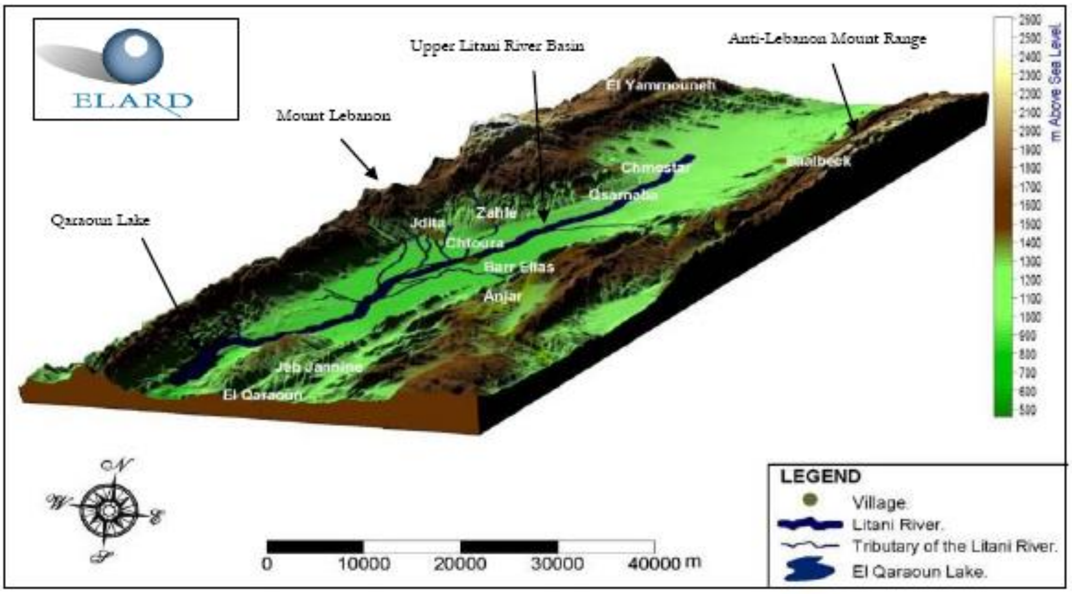
2. The general state of groundwater resources in the ULRB

2.1. Water supply on the Upper Litani River Basin

Covering 20% of the Lebanese territory, the Litani River Basin is the largest river basin in Lebanon. The Litani, sprouts from several springs located in the Town of Alleik, next to Baalbek in the northeast of the basin. The river is then gradually fed by several lateral tributaries originating from both Mount-Lebanon and Anti-Lebanon mountain ranges, respectively, (the name of the western and eastern Lebanese mountain chains) before it discharges in to the Mediterranean Sea, next to the Town of Tyre.

The study area is the Upper Litani River Basin (ULRB), limited by the Alleik Springs to the north, the Qaraoun artificial lake to the south, and bounded to the east and west by the two mountain chains (Figure 1). It comprises the major and most fertile part of the Bekaa Plain (around 40,000 ha). The latter is the largest agricultural region of the country and extends over the northern limits of the basin, to the region of Hermel (Upper Orontes basin).

Figure 1. The Upper Litani River Basin.



Source: USAID-LRBMS 2013b.

There are about 400,000 residents living in the ULRB, distributed in around 100 small and medium-sized towns with populations ranging from a few hundreds to more than 75,000 (USAID-LRBMS 2013b). Administratively, most of these towns are in the *cazas* of Zahle and West-Bekaa, part of the Bekaa Governorate (*Mohafaza*). The rest of the towns are in the Caza of Baalbeck, which is part of the Baalbek-Hermel Governorate.[1]

Agriculture is the main economic sector in the Bekaa, followed by the industrial sector and services. Agriculture was developed between the 1960s and the 1970s. During that period, the industrial and services sectors also developed due to the strategic geographic location of the Bekaa near the border with Syria, and also because Lebanon's liberal economy contrasted with the controlled Syrian one at that time. The service sector experienced important growth rates during the Lebanese War (1975-1990), due to accessibility problems of Beirut's commercial and banking facilities for the Bekaa residents. The industrial sector mainly developed during the post-war period (1990-2005) with the establishment of several new dairy industries and wineries. Migrant remittances are also a substantial source of income for the Bekaa residents (Bennafla 2006).

Nowadays, with the increase in population and the development of agricultural and industrial activities, the Litani River Basin suffers from many problems. The most pressing and visible one is water pollution, as most of the towns and industries remain unequipped with water treatment plants (USAID-LWWSS 2015a). With the discharge of substantial volumes of untreated domestic and industrial effluents into the rivers, the Litani River and several of its tributaries have become polluted and, as such, pose a threat to public health and have turned out to be an obstacle to the socioeconomic development and the well-being of riparian communities (USAID-LRBMS 2011; USAID-LRBMS 2012b).

The lack of funds and governance problems at the level of water authorities is the cause for the delay in implementing water-treatment plants and the control of pollution. During the last decade, many aid organizations have attempted to address the problem through diverse actions, ranging from technical studies, cleaning of river beds, conducting awareness campaigns, technical assistance to water authorities, to the implementation of large-scale water treatment plants (USAID-BAMAS 2005; USAID-LRBMS 2011 a, b, c, d; USAID-LWWSS 2015 a, b, c). However, despite the substantial efforts and money invested, most of the waterways remain highly polluted. The problem has been further exacerbated by the arrival of Syrian refugees to the Bekaa and the establishment of thousands of refugee families in settlements next to river banks, which has resulted in causing direct discharges of more untreated domestic sewage into the rivers.

Water supply in terms of quantity is also a major problem. With regard to drinking/domestic water supply, only two-thirds of the Bekaa population is connected to state water supply networks. In Zahle and West-Bekaa, the two principal cazas of the Upper Litani Basin, 25% and 27% of the villages, respectively, are not served by any public water network (USAID-LWWSS 2015a). Even in the villages connected to public networks, water supply is not reliable due to the deterioration of old networks, electricity rationing limiting pumping hours, and the struggle of the Bekaa Water Establishment (the state authority responsible for the provision of domestic

[1] The Bekaa Governorate comprises the three cazas of Zahle, West Bekaa and Rachaiya, while the Baalbeck/Hermel Governorate comprises the two cazas of Baalbeck and Hermel. According to the Water Supply and Wastewater Master Plan produced by USAID-LWWSS (2015 c), the total population of the two governorates is 1,058,903 residents.

and irrigation supply in the Bekaa) to provide good operation and maintenance (O&M) services due to financial, technical and understaffing problems (USAID-LWWSS 2015a; 2015c).[2]

There is only one state-run irrigation system in the ULRB. This system, known as 'Canal 900', is the first phase of the South Bekaa Irrigation System, a long-planned state irrigation system projected to irrigate around 22,000 ha in the South and Central Bekaa with water from the Qaraoun reservoir, springs, and groundwater. Its current command area (2,000 ha spanning across the towns of Joub Jannine, Kamed El Loz, Lala, Baaloul and Qaraoun) is, however, modest compared to the total planned area (around 21,500 ha, according to CDR 2003). Currently, less than half of it is irrigated by the Qaraoun Lake due to undersized pumping stations, whereas the rest of the command area is irrigated by private wells (Hill 2010; USAID-LRBMS 2012g).

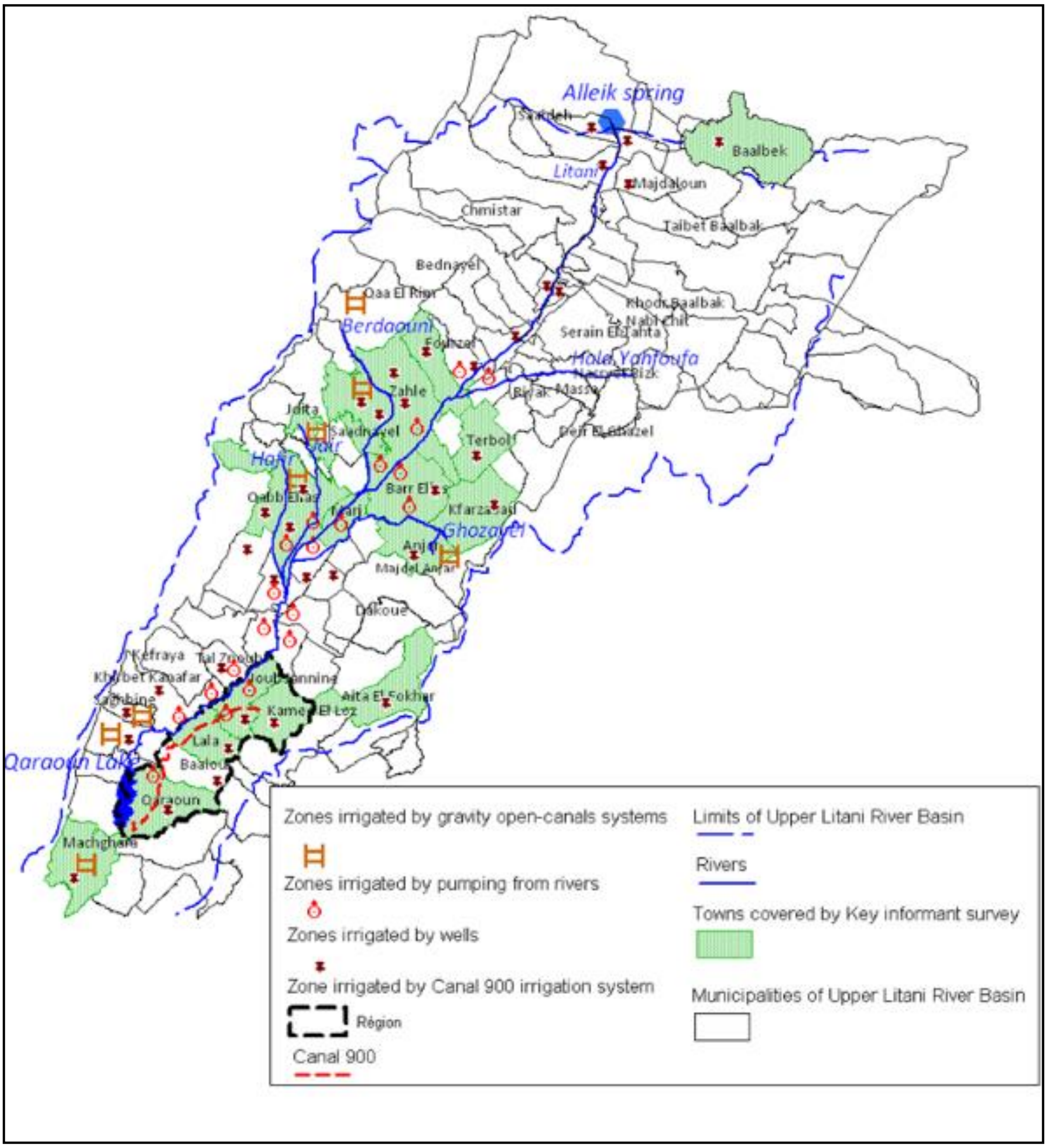
The remaining irrigated areas are supplied by three types of irrigation systems. The first type includes long-established collective open-canal irrigation systems diverting water by gravity from springs and rivers. These systems are managed by committees of local farmers with more or less cooperation with their respective municipalities, and generally originate from historical spring-fed irrigation systems.[3] The second type includes land irrigated by individual or collective pumps abstracting water from rivers (observed to occur mainly from the Litani at the level of Zahle Maallaqa, Barr Elias and Marj, and from the Ghozayel at the level of Barr Elias and Marj). The third type is irrigation by private wells which makes up the largest share of irrigated lands in the Upper Litani River Basin (Verdeil et. al. 2007). The different types of irrigation systems are shown in Figure 2.

Although less apparent (yet) than the problem of pollution, quantitative water supply has gradually declined due to increasing demand and the lack of proper allocation management. Several large rivers that used to flow all year round (such as the Litani and the Berdaouni) now dry-out in the summer and turn into open sewers. Groundwater tables that used to be very shallow before the 1960s (less than 10 m in the plain) have seriously declined in all of the aquifers of the ULRB, resulting in flow reduction and permanent drying-out of several springs (USAID-LRBMS 2012b, 2012d, 2012f). Today, groundwater over-exploitation can be added to the problems of waterways pollution and water supply management as a major concern in the ULRB.

[2] Most of the mayors and municipal officials we interviewed reported that their municipalities contribute to a large extent to the operation and maintenance of water supply facilities that are theoretically under the responsibility of the Bekaa Water Establishment. These municipalities are, Qabb Elias, Kfarzabad, Lala, Qaraoun, Saadnayel and Jdita. These mayors or municipal officials have been interviewed, respectively, on 26/6/2013; 18/9/2013; 23/11/2013; 27/11/2013; 9/12/2013; and 15/12/2014.

[3] The main spring-based systems are in Zahlé and Saadnayel, irrigated from the Berdaouni Spring; Qabb Elias, irrigated from the Qabb Elias Spring; in Jdita and Chtaura from the Jdita Spring; Anjar from the Anjar Spring; Sarraine, Nassryeh and Ryak from the Hala Yahfoufa River.

Figure 2. Irrigation types on the Upper Litani River Basin.



Source: Author.

2.2. The importance of groundwater in the history of water supply in the Bekaa

2.2.1. Groundwater as the main engine of irrigation development

Before the 1950s and the introduction of modern drilling technology, the Bekaa Plain was characterized by shallow groundwater levels. This allowed communities without access to springs and rivers to abstract water for irrigation, drinking and domestic use, by digging shallow wells in the alluvial plain of the Bekaa. At that time, agriculture was not very developed outside of the areas irrigated by surface water, but abstracting groundwater through shallow wells allowed a relative level of agricultural development in these areas (Baldy 1960).

Starting in the 1950s and not long after Lebanon's independence, the government, assisted by American and French engineering firms, conducted several technical investigations with the purpose of harnessing the Litani Basin's water resources for hydro-power production and agriculture development. While surface water constituted the largest share of the projected supply, the basin's geologic units were also subjected to several investigations aiming at assessing the potential of aquifers from which groundwater abstraction for irrigation would be feasible. The principal technical investigation was conducted at that time by the US Bureau of Reclamation for the Lebanese Government and led to the establishment of a 'Development Plan for the Litani River Basin' (Bureau of Reclamation, 1954). A few years later, another assessment targeting more specifically groundwater use and availability in Central Bekaa, was conducted by a French Mission in cooperation with the Lebanese Agriculture Research Center, to assess the potential of using springs and groundwater by building smaller infrastructure facilities (Baldy 1960).

In the early 1970s, the Lebanese State contracted a French consulting firm to conduct a feasibility study based on the study produced by the Bureau of Reclamation. This led to the establishment of an 'Irrigation Plan for the South-Bekaa', where groundwater was projected to supply the South Bekaa Irrigation System in addition to water pumped from the Qaraoun Lake and diverted from springs (Mission Gersar 1972). The plan was adopted by the Lebanese Government. A presidential decree (No. 14522) was issued in 1970, which defined the amount of water to be abstracted from various water sources of the basin for the implementation of this project. Groundwater was a major resource to be harnessed, since the plan allocated 30 MCM from the Qaraoun Lake and 95 MCM from groundwater (CDR 2003, P36). However, the outbreak of the Lebanese War in 1975 stopped the implementation of this project.

Meanwhile, since the early 1960s, groundwater began to be heavily exploited by private initiatives in different areas of the Bekaa following the introduction of drilling technologies and the mechanization of agriculture and general expansion of agriculture. These initiatives were dependent on groundwater availability and investment capacity. Between the 1960s and the 1970s, irrigated areas substantially increased, fed by groundwater abstraction from shallow dug wells and tube wells. During the Lebanese War, in the absence of state control, the number of irrigation wells further increased, bringing most of the rain-fed agricultural areas under irrigation. After the end of the Lebanese War in 1990, the Irrigation Plan for the South Bekaa was updated, and its first phase was implemented and operational in 2001 (the 2,000 ha described above). The study for the second phase (6,700 ha) was conducted in 2003 and projected to abstract 14 MCM from groundwater sources (CDR 2003). Due to lack of funds, this project was never executed and its actual status remains unclear. In this context, groundwater availability, even though heterogeneous in space, hence, not accessible equitably to all communities to the same degree, was an alternative to the absence of state irrigation services for communities having lands outside of the areas historically supplied by spring-based systems, or located next to river-banks.

Nowadays, groundwater irrigates the largest share of agricultural areas in the Bekaa, estimated at 65% of the total irrigated area in 2007, against 35% by surface water (Verdeil et al. 2007). The number of irrigation wells on the Upper Litani River Basin is unknown and difficult to estimate, as most of them are unlicensed. The Litani River Basin Management Support Program, which recently conducted various studies on different aspects of water management at the level of the Upper Litani River Basin, estimated that there are between 5,000 and 10,000 wells in the Upper Litani Basin, including approximately 2,000 licensed private wells (USAID-LRBMS 2012b). The last general assessment targeting groundwater resources conducted by UNDP (2014) and the Ministry of Energy and Water at the level of the Lebanese territory counted 2,732 private licensed wells in the area managed by the Bekaa Water Establishment (i.e., in the two Mohafazas of Bekaa and Baalbek-Hermel), and estimated the number of private unlicensed wells at 18,228 (UNDP 2014). The total volume abstracted yearly for irrigation use is consequently difficult to estimate and, is somewhere between 130 MCM/year (Verdeil et al. 2007) and 200 MCM/year (USAID-LRBMS 2012d).

2.2.2. Groundwater, the major resource for domestic supply

Potable and domestic needs are also supplied to a large extent by groundwater. As described by the 'Water Supply and Wastewater Systems Master Plan' that was recently conducted for the Bekaa Water Establishment, "*Until the adoption by the Council of Ministers of Resolution 35 dated 17/10/2010 of the NWSS [National Water Sector Strategy], no systematic strategy had existed in Lebanon for the management of water resources and the provision of a potable water supply to the population. Water supply and distribution systems developed historically in an organic fashion around population centers as the needs increased. Local springs were tapped when available and wells were dug when the need increased"* (USAID-LWWSS 2015c: P8). Hence, just like in the case of irrigation supply, municipalities drilled wells for potable supply wherever surface water was not available. Out of a total number of 196 independent potable water supply systems identified by the same study, "*up to 36 systems are supplied from small, medium or local springs, whereas the other 160 systems are supplied from an estimated 238 wells. Small village systems are typically supplied from a single well whereas larger systems are supplied by group of wells"* (USAID-LWWSS 2015c: P6).

In addition to the municipal collective wells that supply domestic/drinking water, there are hundreds of house wells established individually by the residents in most of the towns of the Upper Litani River Basin as an alternative to the unreliable public network supply. These were reported in most of the towns we visited during our 'Key Informant Survey'.[4]

Moreover, groundwater is also a major resource for the population of Syrian refugees settled in the Bekaa. Since the beginning of the 'Syrian Crisis', many new wells have been drilled, and older ones have been equipped with larger pumps and connected to the public networks of several towns hosting Syrian refugees. For example, an emergency aid program managed by OTI/Chemonix drilled and equipped three wells for domestic use in Qabb-Elias, Ghazze and Kherbet Kanafar during the summer of 2014, according to the engineer that was in charge of the project. A substantial number of wells have also been drilled inside the settlements with the support of many local and international non-governmental organizations (NGOs). The total volume abstracted from groundwater for drinking water was estimated at 21 MCM/year (USAID-LRBMS 2012d).

Supplying irrigation water to the largest share of the Upper Litani Basin's agricultural area, and providing its growing population with domestic water has resulted in groundwater over exploitation. Today, the water table has substantially lowered compared with the situation in the 1960s, thereby impacting springs' flows, wetlands (hence, ecosystems) and access to water for farmers and local residents. Addressing the problem of groundwater over-exploitation requires a good understanding of the basin's hydrogeology. In the Upper Litani River Basin groundwater cannot be considered as a single resource exploited by all users. Groundwater is, in fact, found in several aquifers with different hydro-geologic characteristics. Understanding these characteristics, as well as the geographic location of these aquifers and their interconnectedness is a prerequisite to analyzing, both the relation of users to their environment and their relations with one another.

[4] See below section on methodology for details on key informant surveys.

2.3. Hydrogeology, geographic distribution of wells, and drawdown of water tables

2.3.1. Past and present knowledge about the ULRB hydrogeology

Research on the hydrogeology of the Litani Basin started with investigations launched by the Lebanese State in cooperation with western states (mainly the US and France), aimed at harnessing the basin's water resources for the development of irrigation and hydro-electric production. Between the 1950s and 1970s, several hydrogeologic studies were conducted by the Lebanese state institutions, public research centers, and universities with the purpose to characterize the country's aquifers and assess their exploitation potential (Antoine 1964; Abd-el-Al, 1967; Bureau of Reclamation 1954; Din 1971; UNDP 1970; Mission Gersar 1972; Hours et al. 1982; Williaime 1967). The most comprehensive evaluation of the Upper Litani River Basin's hydrogeology was conducted in 1970 by the UNDP within the framework of a nationwide assessment. This 9-year project, involving international technical expertise and substantial technological and financial resources, conducted an exhaustive investigation of Lebanon's aquifer units, with a focus on the Coastal and the Bekaa aquifers. The project resulted in important reports and maps that remain the main references for understanding Lebanon's hydrogeology (UNDP 1970).

As the main agricultural region of the country, the Bekaa was a strategic area, notably its southern and central parts. The Lebanese Government was interested in investigating the groundwater abstraction potential to supply projected large-scale irrigation projects therein (UNDP 1970: P75). Drilling and pumping tests and geophysical surveys produced considerable data and allowed the characterization of the main aquifers of the Bekaa. To date, however, the hydrogeology of the Bekaa continues to be poorly understood at many levels, including the depths of the different geologic formations, their recharge mechanisms, their relations to springs and their interconnectedness both to each other and to transboundary groundwater basins (El Hakim 2005; Kehdy 2013; USAID 2012d; UN-ESCWA and BGR 2013). Knowledge of the karst geology, the main constituent of both Mount-Lebanon and Anti-Lebanon Mountain ranges bordering the Bekaa Valley, is described to be very general, notably in the Anti-Lebanon, "the least known geologic sector in the whole country" according to El Hakim (2005: P18).

The alluvial aquifers (Quaternary and Neogene formations) forming the youngest layers of the Bekaa Plain, are also insufficiently known in terms of their geologic constituents, depths and hydraulic characteristics, according to Dr. Naji Kehdy.[5] After the 1970s period in which extensive research was done on Bekaa's hydrogeology by the Lebanese Government and public research institutes, studies have been very limited or even absent. Although several academic projects were conducted, they were mainly concerned with specific aquifer units or particular hydrogeologic phenomena (Chalhoub et al. 2009; El Hakim 2005; Chreim et al. 2012; Kehdy 2013).

Recently, the UNDP conducted a 'Groundwater Assessment and Database Project' for the Ministry of Energy and Water with the objective of assessing groundwater resources at the national level after more than 40 years since the 1970 previous UNDP study. The project also initiated a groundwater resources database and identified sites for potential recharge. The project was much shorter and involved substantially limited financial resources (2.5 years with

[5] Dr. Naji Kehdy is a Researcher and Professor of Hydrology at the Faculty of Geography at the Lebanese University in Zahle. He has been monitoring water levels variations in the Quaternary aquifer since 2011. He conducts real time measurements in four monitoring wells drilled in the Quaternary aquifer in Terbol, Ryak, Qoussaya and Ablah, using a monitoring device that he invented himself and for which he obtained an invention certificate from the Ministry of Economy. His results have not been published yet. He was interviewed on March 17, 2015.

USD 2,400,000) compared to the study conducted in 1970 by UNDP (9 years and USD 20,275,000) (UNDP 2014: P5).

The second UNDP project focused on surveying the number of wells and their characteristics, reviewing and grouping existing information in order to identify gaps and assessing artificial recharge sites. It produced a substantial number of reports and maps, visited and located 13,000 licensed wells across the country, and surveyed the characteristics of 841 wells. In the Bekaa, the project located around 1,700 wells, and monitored variations in water levels during one year in two wells in the towns of Zahle and Labwe (Central and North Bekaa).

Additional technical studies, recently conducted within the framework of the Litani River Basin Management Support Program, provide the most recent and detailed understanding of the actual state of groundwater resources in the basin. They summarized technical information from previous hydrogeologic studies, performed pumping tests in all aquifers (although limited in number) and conducted two water level measurement campaigns (dry and wet seasons) for 125 wells across the basin's different aquifers, from which they developed an understanding of groundwater flow conditions. The project also developed a groundwater model that was used to estimate future water level variations (USAID-LRBMS 2012d; USAID-LRBMS 2013b), and established 14 monitoring wells that are now being monitored by the Litani River Authority (USAID-LRBMS 2012f; USAID-LRBMS 2013a). These reports have been published by USAID, along with the complete data base of the surveyed wells. The data generated constitutes an important reference in this study, especially as it provides a general idea of the geographic distribution of wells and areas of significant water table drawdown, the basis for the selection of our case study.

2.3.2. Aquifer characteristics and geographic distribution of wells

The characteristics of the different aquifers and their location play a major role in understanding the geographic distribution of wells and their characteristics. The geographic distribution of aquifers and their description as well as spring discharges are presented in Figure 3 and Table 1, respectively.

The Quaternary aquifer: This aquifer constitutes most of the agricultural soils of the Bekaa and covers the central part of the ULRB north of Joub Jannine. It is composed of unconsolidated sediments constituted of fine-grained silts and clays with sand and gravel, which have mainly been eroded from the mountains over the last 2.5 million years. The depth of the Quaternary formation varies in space and remains unknown due to the absence of geophysical surveys (El Hakim 2005). It is assumed to vary between 200 and 2,500 m (depending on the location), with estimations differing from one study to another. It is described in many studies to be constituted by several layers (Baldy 1960; UN-ESCWA and BGR 2013).[6] Its lithology is also very heterogeneous, resulting in different hydraulic characteristics (water capacity and transmissivity), and are translated into a wide range of well yields. According to the survey conducted by USAID-LRBMS (2012d), well yields drilled in the Quaternary aquifer vary from 5 to as much as 30 liters per second (LPS).

Through fieldwork and interviews it was possible to observe a wide heterogeneity in the distribution of wells across the Quaternary formation, with some areas covered with wells drilled within very close proximity, and other areas (where surface water resources are inaccessible) almost completely devoid of wells. Yet, we were able to identify areas where well

[6] According to Dr. Naji Kehdy, the Quaternary aquifer comprises three independent strata, each constituting an independent aquifer unit. They are separated by an impermeable clay layer and are located at 14 m, 45 m and 85 m depths, respectively.

yields were in a close range. In the Barr Elias Plain, for example, several farmers have tried drilling wells in the plain and in lands located along the Litani River reaching depths of 100 m, without obtaining more than 5 LPS, a discharge judged in most cases as insufficient to use the well.[7] In Zahle Maallaqa and Dalhamyeh, just north of the Barr Elias Plain, many wells are found along the Litani River and were reported to yield from 30 to 40 LPS[8] whereas, just further north in Fourzol along the Litani River, water availability decreases again with well yields ranging from 5 to 10 LPS.[9] The former area, which is neighboring Zahle Maallaqa and Dalhamyeh, is well known for its exceptional water availability and has been already identified in the 1960s and surveyed, with "*a layer of sediments that could reach 1,000 m*" (Baldy 1960: P3). This exceptionally deep layer of sediments explains the abundant water availability in this area, in contrast to other areas of the Quaternary aquifer that are also subject to water infiltration from the Litani River, without retaining much water. There are other examples of the heterogeneity of water availability in the Quaternary aquifer observed during our discussions with farmers and informants. A very limited number of wells was reported, for instance, in the towns of Marj and Saadnayel, despite several attempts made by farmers to drill wells with sufficient yields.[10]

In spite of these heterogeneities, at the basin level, the Quaternary aquifer is an important source for irrigation and for domestic wells. Since collective wells require higher yielding wells, municipal and state wells are drilled in more important water-bearing aquifer units such as the Cretaceous, Eocene and Jurassic units. Until the 1970s and 1980s many small springs used to flow from the Quaternary aquifer. The *Alleik* Springs at the origin of the Litani River is an example, albeit recharged from deeper aquifer layers that sprout from the Quaternary formation (Baldy 1960: P62). As with many others, these springs have, however, dried out due to heavy groundwater abstractions from deep wells located near the springs.[11]

<u>The Neogene aquifer:</u> This aquifer lies below the Quaternary aquifer and consists of older alluvial deposits and conglomerates deposited over 20 million years ago. The outcrop area of the Neogene formation is smaller than the Quaternary formation and is, for the most part, found in the eastern part of the basin. On the east side of the Upper Basin, the Neogene is present north of Rayak up to Baalbek and on the west side from Chtaura up to the Chmistar area. The Neogene is less extensive on the west side of the Upper Basin. There is also a small Neogene outcrop area located southwest of the basin area (Figure 3). The depth of the Neogene layer is poorly known at many places, but it is described to be up to 300 m thick or more (USAID-LRBMS 2012d). The Neogene formation serves as an important aquifer system for irrigation purposes, with hundreds of irrigation wells drilled reaching this formation and reportedly with a wide range of yields, varying from less than 10 LPS to as much as 30 LPS (USAID-LRBMS 2012d).

<u>The Eocene aquifer:</u> This aquifer is located below the Neogene aquifer, separated by a low transmissivity layer (the Upper Eocene Marl). It is constituted of older sediments deposited 30 to 50 million years ago and has been transformed into karstic limestone. It has a depth of around 250 m. It outcrops in bands that are generally less than 1 km on both the east and west sides of the Bekaa Valley, and in a broader area in the southern part of the valley in the region

[7] According to Farmer No. 2 and Farmer No. 25 interviewed, respectively, on June 23, 2014-November 27, 2015 and January 23, 2015-November 18, 2015.

[8] According to Farmer No. 5 from Zahle Maallaqa, interviewed on June 25, 2014 and November 26, 2015.

[9] According to Farmer No. 7 from Fourzol interviewed on June 26, 2014 and November 27, 2015.

[10] According to Farmer No. 1 from Saadnayel, interviewed on September 12, 2013 and the Mayor of Marj interviewed on November 10, 2013.

[11] According to Farmer No. 9, there are seven wells drilled in Alleik with a depth of 150 m. These wells usually yield around 100 LPS each. However, their yield was reduced to 35 LPS at the time of the survey, because of an exceptionally dry year.

of Joub Jannine and Kamed El Loz. On the eastern side of the Upper Basin, the Eocene outcrops from the Terbol area up to Baalbeck, and on the west side from Zahle to Chmistar. As per its karstic nature, the Eocene aquifer has higher levels of transmissivity and specific capacity when compared to the Quaternary and Neogene aquifers, translating in substantially higher well yields (around 50 LPS).

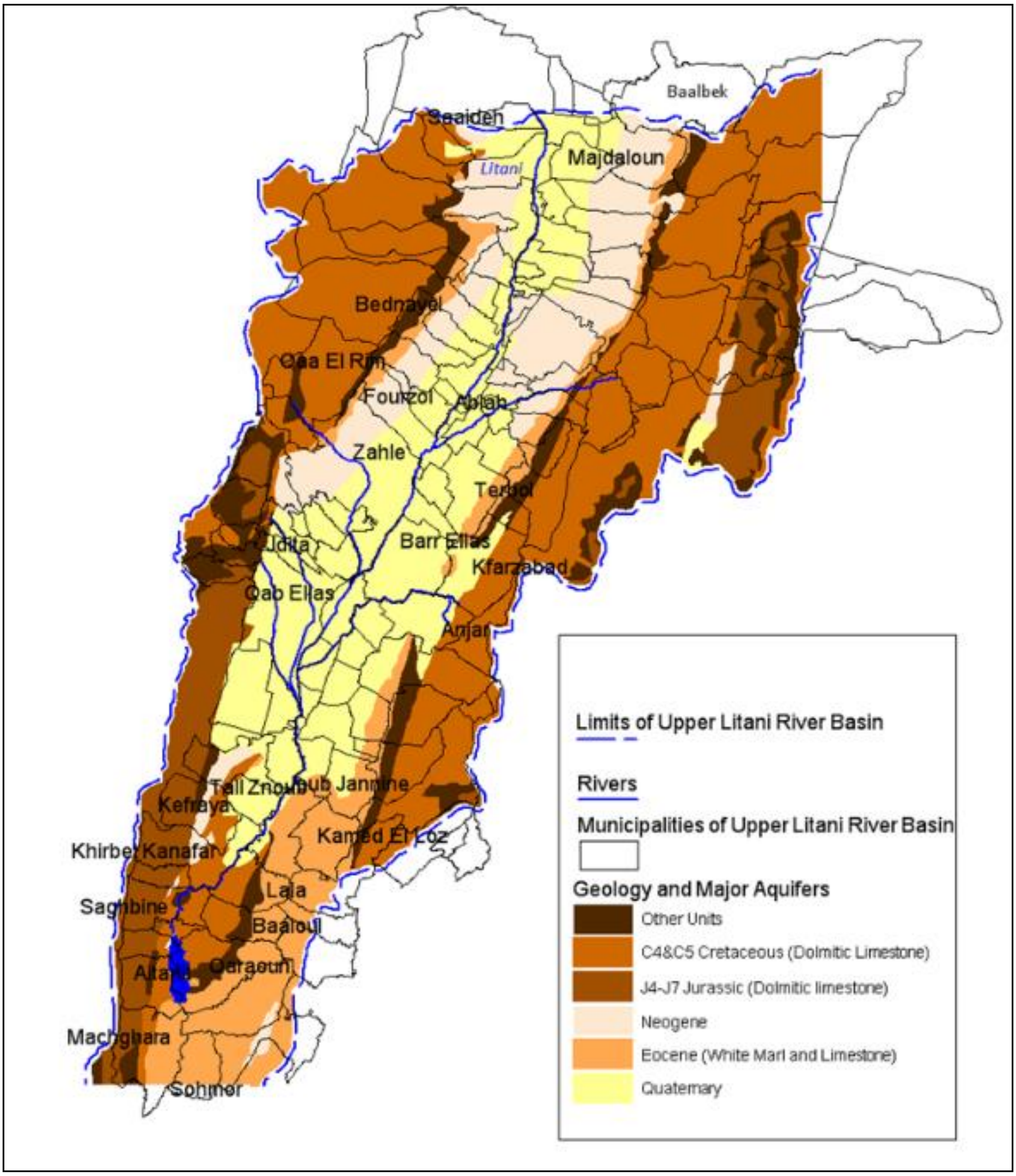
There are hundreds of high-yielding irrigation wells completed in this formation, with the most significant development being on the east side of the Upper Litani River Basin, i.e., from Baalbeck down to Kamed El Loz (USAID-LRBMS 2012d). Described later for the Terbol region, these wells are typically drilled at the border of the Eocene hills and convey water through pipes, sometimes for more than 2 km, in order to irrigate lands located in the plain (on the Quaternary aquifer). The Eocene aquifer is also an important source of domestic water. For example, in Hoshmosh (an administrative territory only constituted of agricultural lands and having no residential area), one well supplies the Town of Ryak-Haouch Hala with domestic water (USAID-LWWSS 2015a: P106). In Terbol, two municipal wells drilled in the Eocene aquifer supply the town with drinking and domestic water. In Faour, a village located south of Terbol's administrative territory, many house wells are drilled in the Eocene aquifer to provide the residents with domestic and drinking water as the area is not connected to the public drinking water supply network.[12] Before the 1960s, several springs used to flow from the Eocene formation from Hoshmosh to Faour, and also at the level of the small outrcrop of the Eocene aquifer in Barr Elias (called the hill of '*Jbaily*'). Three of these springs, which used to flow permanently no longer flow today, except during the spring season if it has been preceded by abundant snowfall in the winter.

<u>The Cretaceous aquifer:</u> This aquifer is located below the Eocene aquifer and is also constituted of karstic limestone dating from 65 to 145 million years ago. It is up to 600 meters thick and outcrops extensively on both the west and east sides of the Upper Basin in relatively higher elevation areas, and in the southern part of the Upper Basin under and north of Lake Qaraoun. The Cretaceous aquifer is characterized by high infiltration rates and important levels of specific capacity and transmissivity. Wells drilled in this aquifer have important yields that can reach 150 LPS. Many irrigation and municipal wells are drilled in this unit (USAID-LRBMS 2012d). Many high yield springs flow from the Cretaceous aquifer on the eastern side of the Upper Litani River such as Yahfoufa, Anjar and Chamsine springs.

<u>The Jurassic aquifer:</u> This aquifer is constituted of limestone and dolomite rocks, which are 145 to 200 million years old. It surfaces in the western part of the Upper Litani Basin from Chtaura down to Lake Qaraoun. It is characterized by the highest levels of specific capacity and transmissivity, translating into high yielding wells that can reach 150 LPS. As for the Eocene and Cretaceous aquifers, many irrigation and municipal wells are drilled in the Jurassic aquifer, notably in the region located between Chtaura and Lake Qaraoun (USAID-LRBMS 2012d). The Jurassic aquifer is a source of high yielding springs such as the *Ras El Ain* Spring of Qabb Elias, and Ammiq Spring.

[12] This information has been obtained from farmers residing in this zone, during a 'Focus Group' meeting that took place in the center of Beirut Arab University on January 23, 2015.

Figure 3. Aquifers' distribution on the Upper Litani River Basin.



Source: Adapted from USAID-LRBMS (2012d).

Table 1. Description and hydraulic characteristics of the ULRB aquifers.

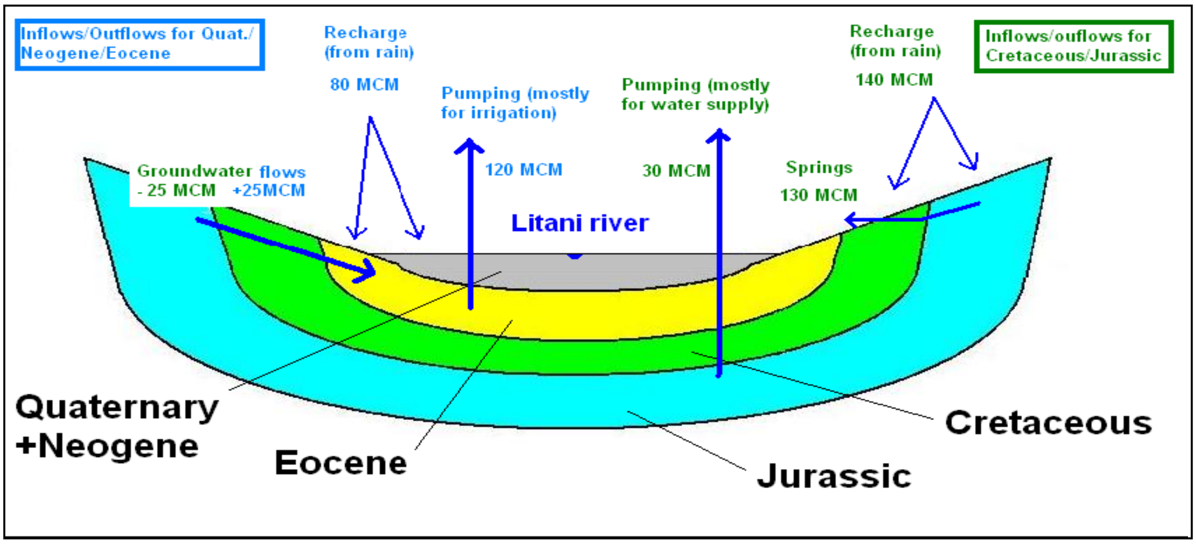
Aquifer Units	Lithology	Thickness (m)	Transmissivity (m^2/s) (UNDP 1970)	Transmissivity (m^2/s)-Pumping tests	Surface area (Km^2)	% of infiltration from precipitations (UNDP 1970)
Quaternary Aquifer	Alluvial deposits (gravel, sand, silt and clay)	More than 500	10^{-4} to 10^{-3}	3.4×10^{-4} to 2.0×10^{-4}	415	~5
Neogene Aquifer	Sand conglomerates, limestone and marls	Up to 300	Less than 10^{-3}	$1.3 \times 10^{-4} – 2.2 \times 10^{-4}$	186	~5
Eocene Aquifer	Nummelitic and cherty limestone, marly limestone and chalky marl	Up to 250	$10^{-4} – 10^{-2}$	$3.9 \times 10^{-4} – 2.9 \times 10^{-3}$	110	38
Cretaceous Aquifer	Alternating sequence of finely bedded limestone and dolomitic limestone	750-950	$10^{-2} – 1$	$3 \times 10^{-4} – 9.15 \times 10^{-3}$	564	41
Jurassic Aquifer (J4)	Limestone-Dolomitic limestone	~ 1,000	$10^{-3} – 1$	$2.35 \times 10^{-4} – 1.6 \times 10^{-1}$	124	41

Source: USAID-LRBMS (2013b).

2.3.3. Understanding aquifer recharge, a prerequisite to analyze groundwater governance

The basin's total groundwater recharge has been estimated in several studies following different methodologies. The most extensive methodologies have been used by UNDP (1970) and the recent USAID-LRBMS studies (2012d; 2013b). These studies have estimated groundwater recharge, respectively, at 200 MCM/Yr and 220 MCM/Yr.[13] Most of the recharge takes place in the three carbonate aquifers, given their permeable structure (140 MCM), while lower precipitation volumes infiltrate and recharge the Quaternary and Neogene aquifers, given their alluvial structure (80 MCM). These shallow aquifers are also recharged from water infiltrating from surface water sources and from the carbonate aquifers. Water infiltration coming from carbonate aquifers occurs both from the surface in a downward direction (from zones where carbonate aquifers outcrop toward shallow aquifers located at lower levels) and from the underground in an upward direction (from deep layers of carbonate aquifers toward shallow aquifers) where water is under pressure in the carbonate aquifers (Figure 4). At the level of the Jurassic and Cretaceous aquifers, even though generally separated by thick aquiclude formations, water exchange also occurs between them due to faulting and erosion (El-Hakim 2005; UN-ESCWA-BGR 2013).

Figure 4. General aquifers' recharge and water balance.



MCM/year	Recharge from precipitation	Pumping	Springs	Transfers + to GW	Balance
Quaternary-EoceneEocene	80	-120	0	17 (-7 to Litani River, +24 from lateral aquifers)	-21
Cretaceous-Jurassic	140	-30	-130	- 24 (laterally to upper aquifers)	-44
Total	220	-150	-130	-7	-65

Source: USAID-LRBMS (2013b).

[13] Two other studies gave substantially higher estimations: USAID-BAMAS (2005) with 388 MCM/Yr and JICA (2003) with 484 MCM/Yr. These numbers were demonstrated by USAID-LRBMS (2012d: P5) to be overestimated.

Importantly, given the heterogeneity of the disposition of aquifers and surface water courses in space, and within the hydrogeologic characteristics in each of the aquifers, water exchange mechanisms are complex and vary from one place to another. Previous studies have attempted to understand some of these mechanisms in some specific areas, believed to be suitable for groundwater exploitation in the 1960s and 1970s. They delineated several areas with specific recharge mechanisms limited in space and identified them as independent aquifers; we can cite among these zones the Ammiq Aquifer (UNDP 1970), the Terbol Aquifer (Baldy 1960; UNDP 1970; Mission Gersar 1972), the Anjar-Chamsine Aquifer (El-Hakim 2005), and the Ryak Aquifer (Kehdy 2013). These recharge mechanisms need to be well understood for aquifer and groundwater management at the basin level. Moreover, the interconnectedness of some of these aquifers with others located in Syria would require establishing transboundary agreements for groundwater allocation (UN-ESCWA and BGR 2013).

The reduction of flow from a source recharging an aquifer not only impacts its capacity but also water availability at the level of the water source recharged by that aquifer. As will be illustrated later, this interconnectedness between different water sources translates into an interdependency between different water uses and, consequently, between the respective users. Analyzing groundwater governance starts with the identification of the different users accessing and using common or interdependent water resources. Thus, locating the physical interconnectedness between surface courses and aquifers, and/or among aquifers being used by different users is a prerequisite for understanding the governance framework and improving groundwater management. In our case study there are several zones that are connected to others through interrelated recharge mechanisms:

<u>Terbol Aquifer (part of the Eocene aquifer):</u> This aquifer was identified in the framework of the 1970 UNDP study. It is located between Terbol and Haour Tala and has a surface area of 27 Km^2. Its main recharge sources were found to be water infiltrating from the Neogene aquifer located at the level of Ryak as well as losses from the Hala Yahfoufa River. The volume infiltrating from these two water sources was estimated at 15 MCM/year, against only 6 MCM/year originating from rainfall (UNDP 1970: P110).

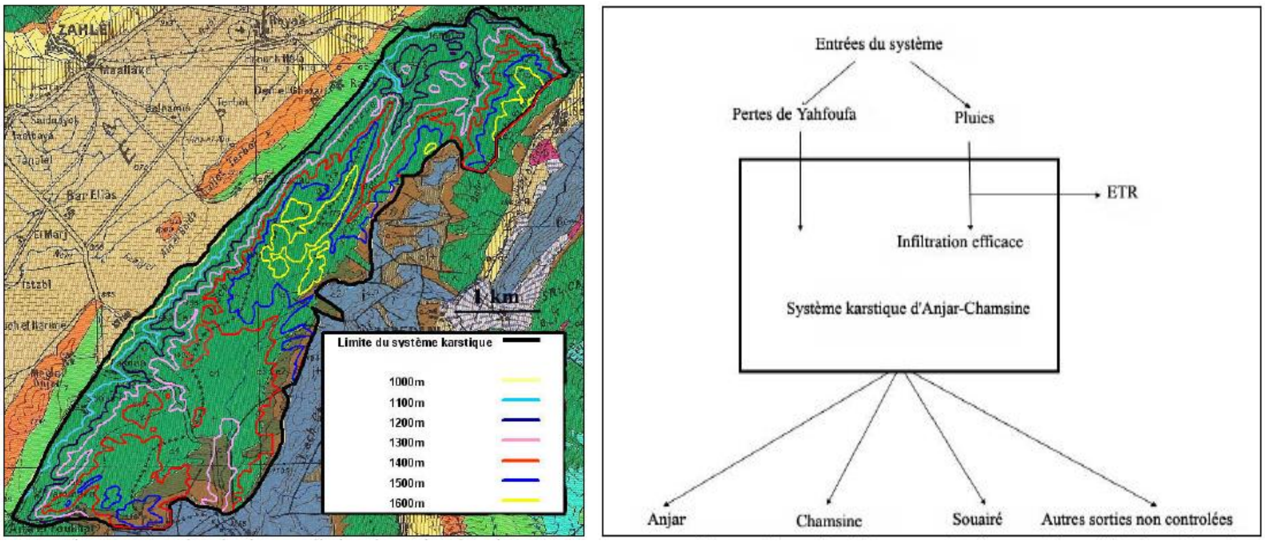
<u>Ryak Aquifer (part of the Quaternary aquifer):</u> It was studied as part of a PhD thesis and was described to be recharged partially with water infiltrating from the Hala Yahfoufa River and from the Sarghaya Aquifer in Syria, while the major part of the recharge comes from local sources (Kehdy 2013: P50-52).

<u>Dalhamyeh Aquifer (part of the Quaternary aquifer):</u> Identified and explored by Baldy (1960) in Central Bekaa, it is a small aquifer located south of Ryak-Ablah Road along the Litani River. This aquifer has a substantially larger storage capacity compared with surrounding Quaternary aquifer areas as mentioned earlier. It is described as a multilayer aquifer with an important sedimentation area and with a storage capacity of 3 MCM (200 m^3/day/well). Recharge was not quantified, but was assumed to be partly constituted by water infiltrating from the Berdaouni River (on the right bank of the Litani), and from deeper aquifers located under the Quaternary aquifer (Baldy 1960: P60)

<u>Anjar-Chamsine Aquifer (part of the Cretaceous aquifer):</u> It was studied in depth by El-Hakim (2005) as part of a modeling exercise carried out to understand the functioning of the Cretaceous Basin discharging through Anjar and Chamsine springs. It was also included in the 'Inventory of shared water resources in West Asia' developed by UN-ESCWA and BGR (2013). It is described as a karstic basin extending over 216 Km^2, limited by the Yahfoufa River to the north, Aita El Foukhar to the south, the Quaternary aquifer to the east and a fault separating it from the Jurassic aquifer to the west (El-Hakim 2005: P54). Most of the recharge comes from precipitation

(51 MCM) and a relatively small part as losses from the Hala Yafoufa River (4.75 MCM). Water budget calculations indicated that further recharge may take place from the Jurassic aquifers or from the C4-C5 aquifers at the bottom of the Bekaa Plain. The limits and conceptual recharge mechanisms of this aquifer are presented in Figure 5.

Figure 5. Limits and conceptual recharge mechanisms of the Anjar-Chamsine Aquifer.



Source: El Hakim (2005).

2.3.4. Water level drawdown

Over the past decades, the exploitation of the ULRB aquifers ensured domestic and irrigation water needs to its growing population, even in the absence or unreliability of public services during the war and the delays in the reconstruction of infrastructure services. Similarly, private groundwater abstraction led to the wide development of irrigation in the Upper Basin since the 1960s, and allowed farmers without access to surface water not only to sustain their agricultural practices but also to increase yields through irrigation. Today, as described by the recent technical assessments, water tables have significantly declined and are expected to come under extreme stress given the increasing rates of abstraction through time (USAID-LRBMS, 2013b). Yet, water levels have not decreased in a similar fashion across the basin due to the heterogeneity of aquifers and their specific hydrogeologic characteristics. Additionally, different abstraction rates linked to the natural accessibility of surface and groundwater as well as the specific social and economic development trajectories of the different groups of water users (as it will be later presented) are also responsible for such heterogeneity in abstraction levels.

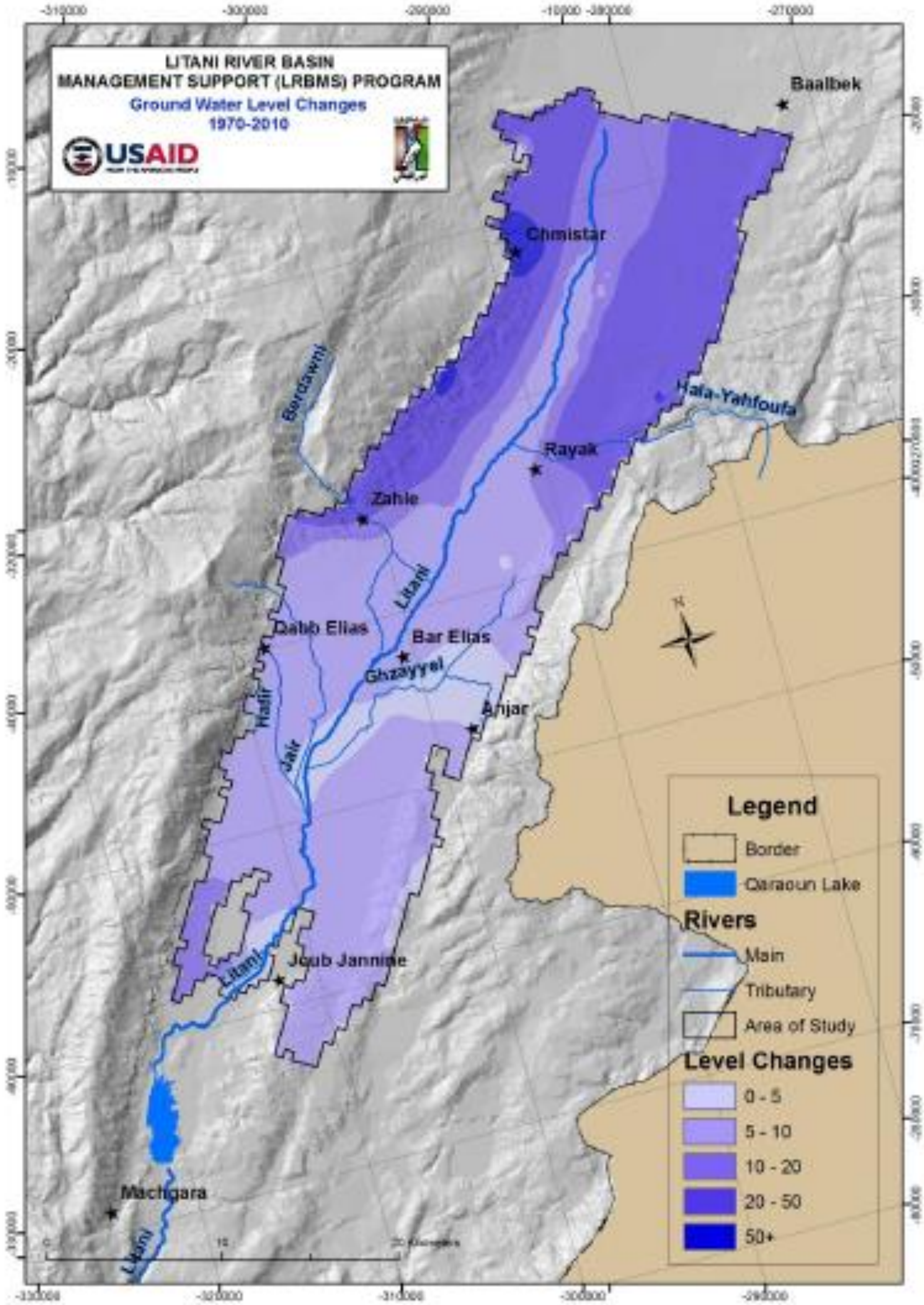
The last survey[14] conducted by the LRBMS Project noted that in the Quaternary aquifer water levels are still relatively shallow (between 7 to 14 meters below surface level) in the northern and southern parts of the basin. Also, for the Neogene aquifer in the central part of the basin, there are more important decreases in water levels, with a reduction ranging between 20 and 50 meters since the 1970s. For the Eocene and Cretaceous aquifers, located in the eastern part of the basin between Terbol region and South of Anjar, water levels were reported to have dropped more than 30 meters over the past 10 years, resulting in the drying-out of several springs sprouting from the Eocene aquifer. However, water table levels had not dropped

[14] The survey was based on water-level measurements in about 200 wells distributed among the different aquifers and information given by farmers and drillers (USAID-LRBMS 2012d).

significantly in the southern part of the basin near Joub Jannine and Lake Qaraoun. In the southwest side of the basin near Ammiq, in the Jurassic and Cretaceous aquifers, water levels were reported by drillers to be around 50 to 60 meters to the surface level but had limited knowledge about historical water levels (USAID-LRBMS 2012d).

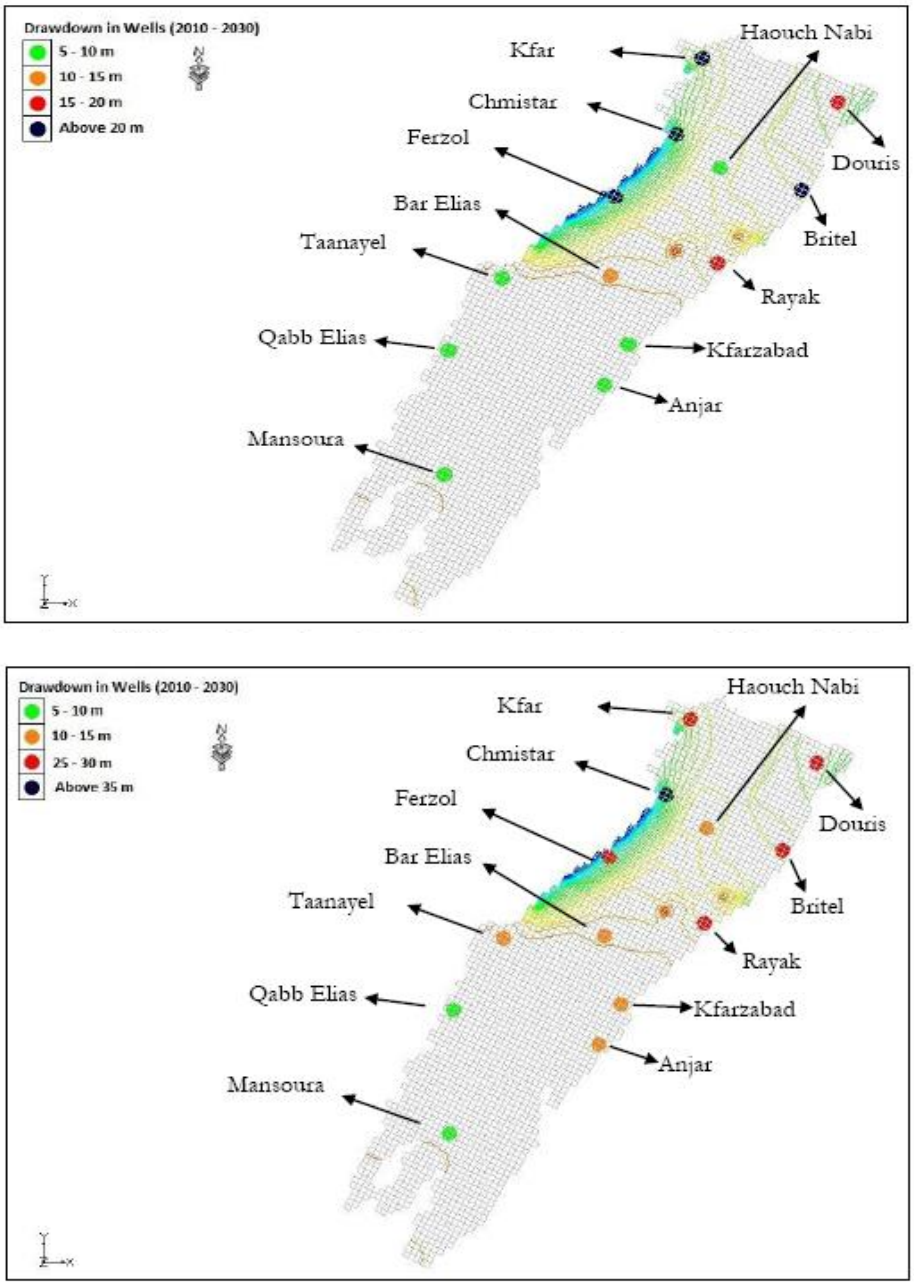
Following this survey, a model was developed to simulate water level variations between 1970 and 2010, and also to project future water level variations for 2030 based on past and current available measurements (Figure 6). However, the model only took into consideration the Quaternary, Neogene and Eocene aquifers due to the lack of available data and hydrogeologic knowledge of the Cretaceous and Jurassic aquifers. The model found that the maximum groundwater drawdown occurs in the Quaternary and Neogene aquifers along the north western boundary near Temnine and along the north eastern boundary near Britel and Sarrain, which it attributed to the low hydraulic conductivity of the aquifers. Minimum drawdown levels were identified in areas in the central and eastern parts of the basin along the Litani River, which acts as a stabilizing influence due to recharge and in the southern part of the basin, as the area is supplied by a public irrigation system and by wells drilled in the Jurassic aquifer (Figure 6). Projections of future water level variations in the three aquifers were modeled for four different scenarios (combining two different rates of abstraction and two different rates of recharge), showing that the maximum drawdown would take place in the northeast and the northwest of the basin (Figure 7) (USAID-LRBMS 2013b).

Figure 6. Groundwater level changes between 1970 and 2010.



Source: USAID-LRBMS (2013b).

Figure 7. Minimum and maximum projected drawdown of water tables between 2010 and 2030.



Source: USAID-LRBMS (2013b).

3. Research objectives, presentation of case study and methodology

3.1. The importance of unpacking groundwater governance for the general water planning of the ULRB

Recent technical studies concluded that groundwater is being depleted in several areas of the basin and strongly recommended improving groundwater management, in order to prevent negative impacts on water users and ecosystems (UNDP 2014; USAID-LRBMS 2012b, d, f; 2013a, b). These recent technical studies provide important general information on the actual state of the water tables and the geographic distribution of wells, however, they need to be complemented with substantial material in order to enable a more holistic and concrete reflection on groundwater management policies. Information gaps about groundwater use are numerous and they include:

1- The number of private irrigation wells;
2- Groundwater withdrawal rates for both private irrigation and public wells (USAID-LRBMS 2012d 2013b);
3- The management types of wells (notably private wells, but municipal and state wells in several towns of the basin as well) (USAID-LWWSS 2015a);
4- The costs of well drilling, operation and maintenance;
5- The impacts that water-level declines had and would have on users' accessibility to water (both concerning irrigation and domestic use); and
6- The adaptation strategies developed by users following the reduction in groundwater availability, their perception of the problem, their non-compliance with state regulations, their readiness to compromise their current individual access to water and reduce their water consumption, etc.

These questions are of increasing importance today as state institutions seem to be following a process of re-orienting water allocation at the level of their territory, which would very likely increase groundwater abstraction for irrigation purposes. In fact, in the 'Water Supply and Wastewater Systems Master Plan' that was recently adopted by the Bekaa Water Establishment, springs currently used for irrigation purposes are projected to be "*partially or totally diverted to potable supply*" (USAID-LWWSS 2015a: P8). This means that a substantial part of the basin currently irrigated by springs (estimated to be about 35% of the total irrigated areas) will be relying only on already declining groundwater resources in the future. The plan does not elucidate how the actual spring-based irrigation systems will be irrigated. However, it is evident that the communities relying on them for irrigation will be substantially impacted by this policy in terms of costs and access to water, organizational systems and allocation, and future groundwater availability. In this context, groundwater management becomes a central question to be addressed and understood by decision-makers as part of the ongoing general planning of water management in the ULRB.

As described earlier, the hydrogeology of the basin is complex, resulting in a series of interrelated impacts on groundwater use, and between aquifer and surface water use. These create a complex system that calls for strong coordination between both groundwater and surface water abstractions. Our main objective in this section is to identify the users exploiting common or interrelated water resources, understand their water needs, assess the impact their groundwater abstractions have on other users of the system and/or how they are being impacted by other users. The final purpose is to bring in to the open the interrelations between users in order to identify concrete situations of present or projected groundwater overexploitation that would require improving coordination between water uses. The results will be presented to both decision-makers and water users at the 'dialogue' projected to be held in the framework of this project, and are expected to serve as material for improving the ongoing water management plans for the Upper Litani River Basin.

3.2. Presentation of the study area

3.2.1. Selection of the study area

The study area of this report is located between the Litani River and Anti-Lebanon Mountain Chain, bounded by the towns of Ryak-Haouch Hala to the north, and Anjar to the south (Figure 8 for a schematic representation). It was selected as it included several groundwater and surface water sources, both important for irrigation and domestic use. Several of these resources had been identified by recent technical studies as being subject to significant decline (USAID-LRBMS 2012d). These include: 1) the Eocene aquifer, where three important springs have dried out and important cones of depression have recently appeared in potentiometric maps; 2) the Cretaceous aquifer, where an important development of irrigation wells also leading to significant cones of depression has been observed (USAID-LRBMS 2012d). During preliminary field surveys, farmers and other informants also reported significant reductions in well yields located in different parts of the Quaternary aquifer. Moreover, in areas traditionally irrigated by surface water a decline in surface water availability was identified, leading to an increased reliance on groundwater. Furthermore, the selected study area comprises several cases of hidden hydraulic interconnectivity between water sources that illustrates the complexity of the basin's hydrogeology and the interrelation it creates between water users in different zones. These areas include the aquifers of Terbol, Anjar-Chamsine, Ryak and Dalhamyeh (described earlier). Importantly, the area comprises three important surface water sources (Hala Yahfoufa River, Chamsine and Anjar springs) currently tapped for irrigation use and projected to be partly re-allocated for domestic use in the up-coming years as part of the Bekaa Water Establishment (BWE) Master Plan. This, however, would add major pressure on groundwater resources.

3.2.2. Division into sub-areas

The selected area comprises several towns including, Ryak, Hala Yafoufa, Hoshmosh, Terbol, Dalhamyeh, Barr Elias, Kfarzabad, Anjar, and the lands of Fourzol and Zahleh Maalaqa, located east of the Litani River. The study area has been further divided into seven sub-areas, identified according to their own specific groundwater use characteristics (Figure 8).

1- <u>Sub-area *Hala-Yahfoufa*</u>: It covers the area that used to be irrigated by the Hala Yafoufa River and where wells were gradually drilled in the Quaternary aquifer, following the decrease of the Hala Yafoufa River flow. It includes the towns of Haouch Hala, Ryak and a part of Hoshmosh. Domestic water needs for the residents of Ryak-Haouch Hala were also used to be met by this river, however, they are now mostly covered by groundwater. Given the characteristics of the Quaternary aquifer in the area, wells give relatively high yields (around 20 LPS). As part of the BWE recent Master Plan, the public domestic networks supplied by this river are to be rehabilitated and extended through an increased supply from Hala Yahfoufa River.

2- <u>Sub-area *Litani-Fourzol*</u>: It covers the part of Fourzol that is located east of the Litani River. These lands used to be irrigated by the Litani River and are now irrigated by wells drilled in the Quaternary aquifer. These wells are much less prolific in this area than in Hala-Yahfoufa, and have lower yields as well (between 2 and 5 LPS). It is only an agricultural area and does not include any domestic supply sources (Fourzol's housing area is located west of the Litani).

3- Sub-area *Litani-Maalaqa*: It covers around half of the Zahle Maalaqa area that is located east of the Litani River and around half of Dalhamyeh. Lands in this area used to be irrigated by the Litani River, but are now irrigated by wells drilled in the Quaternary aquifer. Being located in the previously described prolific 'Dalhamyeh Aquifer', most of the wells drilled in this area give substantially higher yields (between 10 and 20 LPS). Domestic use is only significant in Dalhamyeh (Maalaqa's residential area that is located west of the Litani) and is made secure by private house wells drilled in the Quaternary aquifer. However, only the evolution of irrigation use will be addressed in this sub-area.

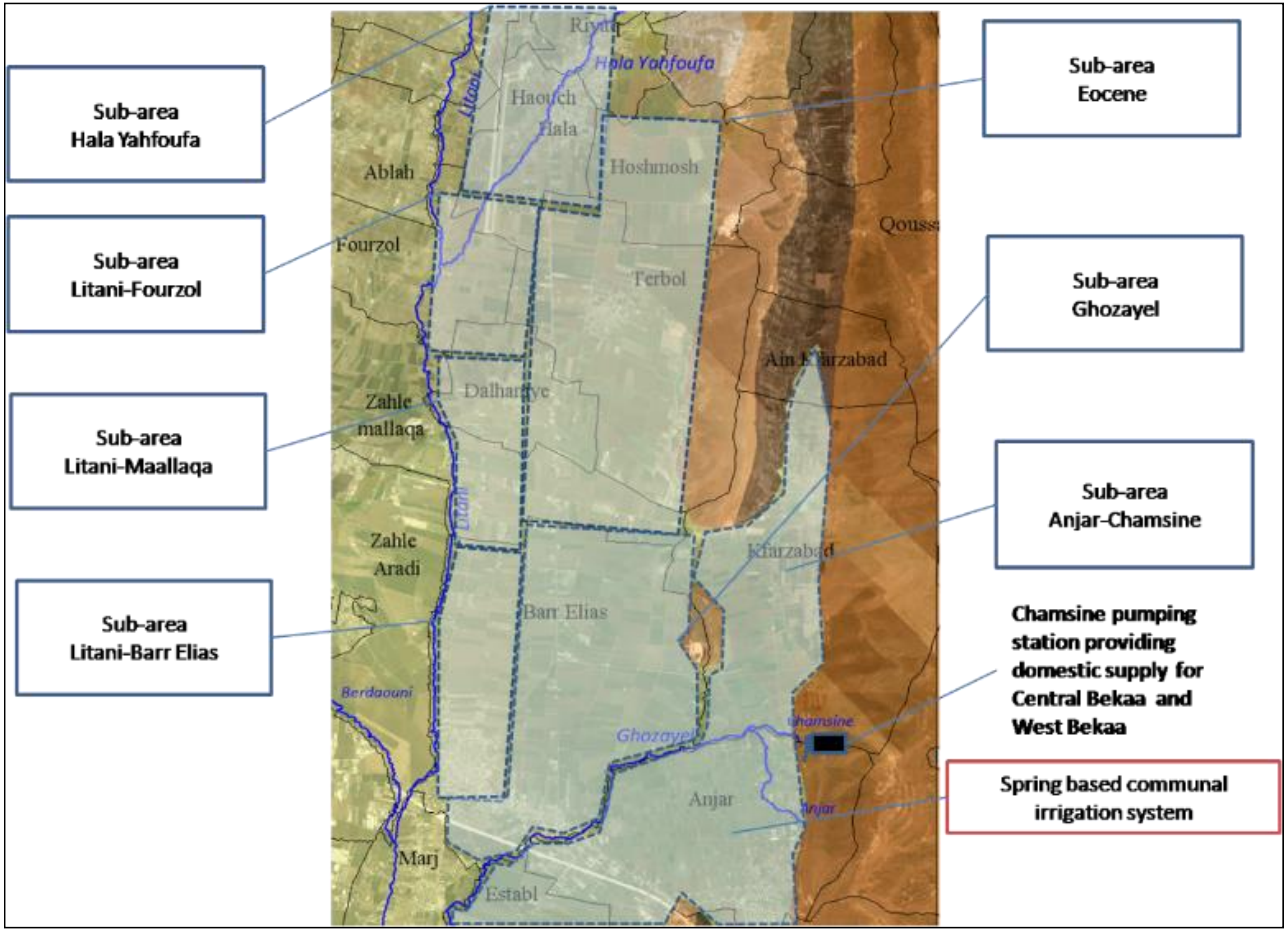
4- Sub-area *Litani-Barr Elias*: It covers around one-third of the Barr Elias Plain and is still partly irrigated by the Litani River, despite the fact that its flow is mainly constituted of sewage water during the summer. Only few and low-yielding wells (between 2 and 4 LPS) were drilled due to insufficient water availability in this part of the Quaternary aquifer. This area is only agricultural and does not include any domestic supply sources or domestic demand.

5- Sub-area *Ghozayel*: It covers around two-thirds of Barr Elias Plain. Most of this area used to be irrigated from the Faour River, a tributary to the Ghozayel originating from springs issuing from the Eocene aquifer in Terbol, Faour and Barr Elias. After the drying-out of these springs, this sub-area is now mainly irrigated by pumping from the Ghozayel. In recent years, with the reduction in water availability from this river, some farmers started to rely on wells drilled in the Eocene aquifer's outcrop in the eastern part of Barr Elias, on its frontier with Kfarzabad (known as '*Jbaily*'). Being drilled in the Eocene aquifer, they have substantially higher yields than wells drilled in the Quaternary aquifer (between 30 and 50 LPS). This sub-area includes the residential area of Barr Elias Town, concentrating the largest population of our study area. Domestic water is provided by a public domestic network supplied by the Chamsine Spring as well as house wells.

6- Sub-area Anjar-Chamsine: It mainly covers the agricultural plains irrigated from the Anjar-Chamsine Aquifer, including lands irrigated from wells drilled in the Cretaceous aquifer in the towns of Kfarzabad and Anjar, and land irrigated by the Anjar Spring as part of the collective gravity irrigation system. Wells drilled in the Cretaceous aquifer give high yields (between 30 and 50 LPS). Recently, irrigation and domestic wells were drilled next to the Anjar Spring in order to complement the decreasing water availability from the spring. Chamsine, the second spring of this sub-area, is an important source of domestic supply for several towns in Central and West Bekaa and the Caza of Rachaiya. Several domestic wells were also recently drilled next to the Chamsine Spring as part of an ongoing state project to extend the domestic supply network. Furthermore, as part of the BWE recent Master Plan, the Anjar Spring is projected to be re-allocated to the domestic supply.

7- Sub-area Eocene: This area covers Terbol, Hohmosh, Faour and the east of Zahle Maallaqa and Dalhamyeh. Since the late 1960s, following the drying-out of Ras El Ain Spring, this area is strictly irrigated from groundwater, both by high yielding wells drilled in the Eocene aquifer (Between 30 and 50 LPS) and by lower yielding wells (Between 1 and 5 LPS). Substantially different evolutions in irrigation groundwater use were identified between three geographic regions of this sub-area and will be described in detail. Domestic supply is mainly supplied from the Eocene aquifer and also varies depending on the region: while Terbol community receives water collectively from two municipal wells drilled in the Eocene aquifer, Faour community relies on individual house wells.

Figure 8: Presentation of the study area and divisions of sub areas.



3.2.3. Towns and population

Along with understanding the hydrogeologic characteristics and the specific physical interrelations they create between users, reflecting on groundwater governance requires identifying the social relations between the different communities sharing these water resources. Our study area comprises several communities with particular social histories, which led to the actual town and land divisions. One town can be constituted of more than one cadastral area and often includes several religious groups sharing the same territory and belonging to the same village or municipality. Furthermore, as in other regions of the Bekaa, there is a relatively recent population of Bedouin origin (since the 1960s) that has settled in several towns of the study area (notably in Terbol, Dalhamyeh and Barr Elias), and have grown into independent communities while still being administratively attached to these towns. Therefore, it is important to distinguish between towns, cadastral areas and communities:

- **Ryak-Haouch Hala** is constituted of two cadastral areas (Ryak and Haouch Hala), but includes one single village and is administered by the same municipality. It groups two different religious groups, Christian and Muslim Chiaa.
- **Faour** does not have official cadastral boundaries; it has been formed by the settlement of a Bedouin Tribe south-east of Terbol. The community belonging to this tribe is known as *A'rab El Hrouk* and is of the Sunni religion.
- **Dalhamyeh** is a cadastral area attached to the Municipality of Zahle and also includes some settlements of a population belonging to the same tribe.
- **Hoshmosh** is a cadastral area attached to the Municipality of Rait without including any residents. Most of the land owners belong to two traditional Christian feudal families originally from Joub Jannine and Nassryeh.
- **Terbol, Fourzol, Barr Elias and Kfarzabad** are old towns of the Bekaa, each having its own municipality. Terbol's community is entirely Christian, while the communities of Fourzol, Barr Elias and Kfarzabad are constituted of both Christian and Muslim Sunni groups.
- **Anjar** is a relatively new town established in 1939 for the settlement of an Armenian population that was displaced during the Second World War. The town, including an open-canal irrigation system, was built by the French Government at the time of the Mandate.
- The towns' total and agricultural areas, population and number of farmers are given in Table 2**.** It must be noted that the population has substantially increased in most of the towns of the study area due to the influx of Syrian refugees. An illustrative example is the Town of Barr Elias, where the number of Syrian refugees (either renting houses or living in settlements) is reported to be higher than the original Barr Elias population.[15]

3.3. Methodology

Walk-through Survey

Given the very limited understanding of the different types of irrigation taking place from the different water sources found in the basin, a 2-week field campaign was conducted during the summer of 2014 along the Litani River and its tributaries. This survey involved observing and locating the different irrigation infrastructure being used to abstract water from the different water sources. It included: counting and locating pumps used for direct irrigation from rivers;

[15] According to Barr Elias Mayor interviewed on November 18, 2015.

estimating their discharge; and observing the different types of water conveyance systems. This campaign also consisted of observing, as well as locating and estimating the discharge of some of the wells located close to the rivers. During these field surveys, several farmers irrigating from the different water sources of the basin were interviewed.

Key-informant Survey

Very limited data is available concerning agricultural practices and irrigation management at the municipality level. Information gathered by the FAO's national agricultural assessments is usually analyzed and presented at the Caza level. Interviews were conducted with 21 mayors and municipal officials from 19 towns of the Upper Litani River Basin. This survey was conducted in collaboration with the Beirut Arab University, and gathered data both for this study and for another ongoing research project on the impact of agricultural inputs on groundwater conducted as one of the projects of the Environmental Observatory (OLIFE) of Lebanon and France.

Interviews with Farmers

After the selection of the study area, two types of questionnaires were propounded:

- General interviews in six sub-areas were conducted with several farmers from *Hala Yahfoufa, Litani-Fourzol*, *Litani-Maallaqa*, *Litani-Barr Elias*, *Anjar-Chamsine* sub-areas, with the objective of gathering general information about the evolution and actual use of groundwater resources in each of these areas.

- Interviews for the *Eocene* sub-area targeted more specifically three groups of farmers (Hoshmosh, Terbol and Faour) using wells in the Eocene and Quaternary aquifers in these regions. These interviews focused on understanding the influence of agrarian change on the evolution of groundwater use and on the costs of accessing land and groundwater.

Interviews with State Officials: These were conducted with water authorities at the national level (the Ministry of Energy and Water), regional level (the Bekaa Water Establishment and the Litani River Authority) and local level (Chamsine Water Office), and at the Ministry of Agriculture. It must be noted that water authorities intervene in the process of groundwater management as water users, decision-makers and law enforcers.

Interviews with Additional Relevant Stakeholders: These were conducted with a well driller, a president of cooperative, two consultants with development projects related to water and sanitation, a professor of hydrogeology conducting research on the Quaternary aquifer, an author of a book about Terbol, and the director of Anjar Irrigation Committee.

Table 3 summarizes the list of persons interviewed in each type of survey. The complete lists are given in Annex 1, 2, 3 and 4.

Data for Historical Wells Comprised: 1) the wells surveyed in the framework of LRBMS Project in 2010 and 2011 (USAID-LRBMS 2012d); 2) the monitoring wells drilled and equipped by LRBMS Project (USAID-LRBMS 2012e; 2013b); 3) the domestic wells surveyed by LWWSS Project (USAID-LWWSS 2015a); 4) The irrigation wells drilled in 2014 in Anjar; 5) the wells surveyed by BAU as part of their research activities; 5) the wells observed during our field surveyed. The list of wells and their characteristics is given in Annex 6.

Table 2: Presentation of the towns included in the study area.

Town or Territory	Population	Municipality	Total area (ha)	Agricultural area (ha)	Agricultural area included in our study zone	Number of farmers	Religious/ Ethnic communities
Ryak **Haouch Hala**	19,274	Ryak-Haouch Hala	900	500	500	100	Christian (Majority) and Muslim Chiaa
Hoshmosh	0		700	530	530	10	Land owners are from Joub Jannine and Nassryeh Farmers are from Terbol and Ryak essentially
Terbol	10,000	Terbol	1,670	1,018	1,018	74	Christians (Catholic and Maronites)
Faour	10,000	Terbol	1,670	180	180	39	Tribe of " Arab El Hrouk", Muslim Sunni
Fourzol	10,435	Fourzol	1,700	1,200	350	Not available	Christians (majority)
Zahleh Maalaqa	Not clear	Zahle	1,990	2,400	560	Not available	Christians (majority) Land owners are mostly absent. Farmers are from Terbol and the Bedouin community
Dalhamyeh	1,756	Zahle	520	500	500	Not available	Christians (majority) Land owners are mostly absent. Farmers are from Terbol and the Bedouin community
Barr Elias	100,000	Barr Elias	2,330	2,100	2,100	Not available	Muslim Sunni (majority) and Christians
Kfarzabad	6,178	Kfarzabad	2,470	2,300	2,300	200-300	Christians and Muslim Sunni
Anjar	11,409	Anjar	1,620	1,232	1,232	344	Armenian (ethnic and religious belonging)

Source: Compilation based on USAID-LWWSS (2015c), field information and estimation. Information was compiled from different sources; population numbers were taken from our interviews with mayors when available. When unavailable, they were taken from the USAID-LWWSS (2015c). It is to note, however, that we found the latter highly underestimated compared to the information given by mayors, and not including the significant numbers of Syrian refugees. Agricultural areas were taken from different sources (Kehdy (2013) for Ryak, USAID-LRBMS (2012g) for Anjar, disaggregated data from the FAO census (2010) for Terbol, Faour and Hoshmosh or estimated by GIS when unavailable. Numbers of farmers are based on the Key-informant Survey.

Table 3: Presentation of surveys and interviews.

Walk-through Survey	Farmers: Survey by Zone	Farmers: Survey for Zone Eocene – Individual Interviews	Farmers: Survey for Zone Eocene – Focus Groups	Mayors and Municipal Officials	State Officials	Other Informants
13 Farmers	14 Farmers	21 Farmers	14 Farmers	21 Mayors and Officials	11 Officials	8 Informants
Barr Elias, Zahle Maallaqa, Haouch El Oumara, Fourzol, Saideh, Marj, Nassryeh, Tal Dnoub	5, 1, 1, 1, 7 farmers, respectively, in the Zones of Hala Yahfoufa, Litani 1, Litani 2, Ghozayel and Anjar-Chamsine	From the towns of Terbol, Hoshmosh, Faour, Barr Elias, Maallaqa, Kfarzabad, Fourzol and Ryak-Haouch Hala	From the towns of Terbol and Faour	For the towns of Barr Elias, Qab Elias, Baalbek, Kfarzabad, Zahle, Kamed El Loz, El Marj, Machghara, Lala, Qaraoun, Aita El Foukhar, Saadnayel, Temnine El Tahta, Anjar, Jdita, Terbol, Ryak and Jenta	In the Ministry of Energy and Water, Ministry of Agriculture, Bekaa Water Establishment, Litani River Authority, Chamsine Pumping Station	-Well driller -President of cooperative -Employees at ICARDA -Consultants in Emergency Program -Professor of Hydrology -Director of Anjar Irrigation Committee -Author of a book about Terbo Town

3.4. Water authority and water rights

3.4.1. Governmental and public bodies

Water management responsibilities in the ULRB are shared among several water bodies.

The Ministry of Energy and Water (MEW) is the highest public authority in the water sector and has responsibilities in planning, infrastructure development (directly or through autonomous water bodies), and water resource protection at the national level. It is responsible for studying water supply and demand in the country, developing hydraulic and electric projects, overseeing the work of autonomous authorities operating water and energy projects (the Regional Water Establishments and the Litani River Authority), and conserving and controlling the country's water resources.

With groundwater management, it has two important roles. The first is to study groundwater resources and develop public groundwater supply projects (via the Department of Groundwater and Hydrogeology). The second is to protect the resource by regulating private groundwater use via legislation, issuing permits and enforcing compliance to regulations (the task of the Department of Water Rights and Expropriation).[16] The MEW is located in Beirut and has a local office in Zahle.

The Bekaa Water Establishment (BWE) is one of the four Regional Water Authorities (RWEs) covering the entire geographic area of Lebanon. The RWEs were created in 2000 (by Law 221)[17] and were the consolidation of 21 local water authorities responsible for domestic water supply. They were also assigned the responsibility of planning, implementing and operating water supply (both for irrigation and domestic use) and wastewater projects within their jurisdictions. Since the enactment of Law 221 in the year 2005, the RWEs started to implement their assigned tasks but are not fully operational yet (USAID-LRBMS 2012e; USAID-LWWSS 2015c).

At the level of the ULRB, the BWE currently only manages domestic supply facilities and wastewater treatment plants. Although being officially responsible for the provision of irrigation services in Central and North Bekaa, it does not play (yet) any role pertaining to irrigation, neither in water allocation nor in the management of existing irrigation systems. As will be illustrated for each of the sub-areas; rivers and springs are currently tapped by public water supply infrastructure and management arrangements by users, while the only public irrigation system of the ULRB is managed by the Litani River Authority (LRA). The BWE is located in Zahle.

In our study area, the BWE has a small office responsible for the operation of a pump station (known as Chamsine Pump Station) supplying water from the Chamsine Spring to several towns in Central Bekaa, including Barr Elias and Kfarzabad that are in our study area. The BWE also operates water supply and distribution infrastructures in Ryak-Haouch Hala, while domestic water supply in Anjar and Terbol is still managed locally by their respective communities.

As part of its recent Master Plan for the Bekaa (developed with the support of a USAID funded project USAID-LWWSS 2015), the BWE intends to develop large domestic supply infrastructures by reallocating water from existing spring-based irrigation systems and drilling new wells. Public irrigation development is not addressed by this Master Plan, which was identified as an issue to

[16] The Department of Groundwater and Hydrogeology is also involved in the procedure of well licensing. It revises the license applications in order to verify that the projected wells would not have a negative impact on public water sources. Both of these departments act under the Office of Technical Studies, the latter being part of the Directorate of Hydraulic and Electric Equipment.

[17] Dated May 29, 2000.

be addressed in the near future, according to the Director and President of the Administrative Board of the BWE.[18]

The BWE is the main public authority directly using groundwater since it operates a number of public wells on the ULRB. However, it does not play any role in groundwater management or in its monitoring (the latter being the task of the LRA). Since 2010 (Decision 118/2010 issued by the MEW), the RWEs were assigned a new role in the procedure of well licensing. This role consists of giving their approval on license requests by first making sure that the needed private water supply cannot be provided by the RWEs, and that the planned well does not impact negatively on any public water source.[19]

The Litani River Authority (LRA) was established in 1954 as a project implementation authority. It was assigned the responsibility of putting in place the projects of the 'Development Plan for the Litani River Basin', which was developed by the US Bureau of Reclamation.[20] In 1996, a presidential decree expanded the LRA's mandate to include responsibility for planning and managing new irrigation schemes in the Litani River Basin and South Lebanon. The LRA currently manages hydroelectric plants supplied by that Qaraoun Lake, and irrigation schemes in South Bekaa (Phase 1 of the Canal 900 Irrigation Project) and South Lebanon (Qasmieh-Ras El Ain Irrigation Project and Jezzine Pilot Project).

Other responsibilities have been assigned to the LRA over the years, typically by delegation from the MEW rather than by formal legislation, which include surface flow monitoring across the country and water quality monitoring in the Litani Basin (USAID-LRBMS 2012e). More recently, the LRA initiated a groundwater monitoring program. According to an employee in the LRA Water Monitoring Department,[21] 21 private irrigation wells distributed on the ULRB were selected and started to be monitored for water levels.[22] Most recently, with the help of the USAID-LRBMS Project, the LRA initiated a groundwater monitoring program in the ULRB. As described earlier, 14 monitoring wells were established in 2012 and 2013 in different regions and aquifers of the ULRB. These wells are equipped with data loggers recording water levels every 4 hours (USAID-LRBMS 2012e; USAID-LRBMS 2013a). Two of these monitoring wells are located in our study area, respectively in the cretaceous aquifer in Anjar (sub-area Anjar-Chamsine) and in the Eocene aquifer in Terbol (Sub-area Eocene). Two other wells are close to two other sub-areas, respectively located in the Quaterary aquifer in Tel-Amara (close to Hala Yahfoufa sub-area) and in Fourzol (close to Litani-Fourzol sub-area).

With the support of USAID-LRBMS Project, the LRA developed a more integrated approach for water management in the ULRB (based on the concept of Integrated Water Resources Management [IWRM]) and proposed two 'River Basin Management Plans' that were endorsed by 12 municipalities of the basin (USAID 2012b). To be able to put these plans in place, the LRA requested to be assigned new responsibilities, including water quality regulation, groundwater regulation, water allocation and risk management (USAID 2012b). It proposed an update of its

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[18] Met on April 1, l2015.

[19] Article 2 of Decision 118 stipulates that the RWEs should revise the well license application following the technical review of the Department of Groundwater and Hydrogeology, fill a form devoted to him in that application and send it back to the MEW. No elaboration on what aspect is to be revised and what should be addressed in this form is described in the text. The latter information was obtained from the Head of the Department of Groundwater and Hydrogeology interviewed on December 6, 2014.

[20] The Litani River Authority (LRA) was established in 1954 (Law 14 dated August 14, 1954). Its purpose, according to the legislation, was to: 1) execute irrigation, drainage, and potable water projects on the Litani River; 2) create a transmission network linking the major generating facilities in the country; 3) create a nation-wide electrical distribution network.

[21] Interviewed on January 13, 2015.

[22] Water levels are measured manually from these wells every 2 weeks.

mandate including these roles to the MEW and the Lebanese Government, but it has not been adopted yet.

The Council for Development and Reconstruction (CDR) was established in 1977 in order to fast-track the investments needed for the reconstruction of the country after the war. Today, the CDR remains as the link between external donors and large-scale infrastructure development projects in Lebanon. It is in charge of planning infrastructure development, mobilizing funds for major developments projects and supervising project execution. Given its role in planning and developing water infrastructure (both supplied by surface and groundwater resource) the CDR has a substantial impact on water allocation.

From the 1990s to early 2000s, it drilled many public domestic wells in the Eocene, Cretaceous and Jurassic aquifer systems (USAID-LRBMS, 2012d). In our study area, it established several wells next to the Chamsine Spring in order to increase domestic water supply in the public networks fed by this spring.

Municipalities have historical responsibilities in water and wastewater management. A number of laws and decrees have successively entrusted them with responsibilities in irrigation management, protection of water infrastructure, planning and implementation of wastewater infrastructure and control of water pollution (El Haj 2011). However, following the restructuring of the water sector (Law 221) and the centralization of water management at the level of the RWEs, and despite the fact that the new legislation conserved these competences, the distribution of these responsibilities between municipal and state institutions is subject to disagreements and remains unclear (Machayekhi et al. 2014). Moreover, the public funds they receive from the state and the level of tax collection from residents are generally insufficient for project implementation and exercise enforcement (El Haj 2011; Machayekhi et al. 2014). Nevertheless, with the financial, technical and understaffing problems faced by the RWEs, municipalities often have to implement small-scale water supply and wastewater infrastructures, and typically contribute to a large extent to the operation and maintenance of existing water facilities.

At the level of the ULRB, municipalities remain as the major groundwater users. Many municipal domestic wells were transferred to the BWE following its creation in 2005, but several wells are still owned and operated by the respective municipalities. In our study area, both the municipalities of Anjar and Terbol are still in charge of managing their respective domestic wells. There are, however, ongoing negotiations between the Terbol Municipality and the BWE concerning the management of wells in Terbol, as described later. Moreover, as described later, many municipalities have recently drilled new wells through international aids and funds in order to respond to the increased water demand following the ‘Syrian Crisis’. Others are also considering this option and are looking for funds. Concerning groundwater conservation and protection, the municipalities can also prevent the drilling and use of unlicensed wells.

The Ministry of Interior and Municipalities (MIM) is involved in enforcing groundwater regulations through the Directorate of Internal Security Forces (ISF). When the MEW has information about the use or the drilling of unlicensed wells, it requests the intervention of the MIM. The ISF may then approach the user and force him to regularize his situation with the MEW. On the other hand, the ISF can also intervene without a request from the MEW. When infringements of the regulation are observed, the ISF should report it to the MEW and follow up with enforcement. From our interviews, the ISF appears to be the only authority directly approaching users.

3.4.2. Water rights linked to surface water

Water in Lebanon has long been considered and regulated as a public utility. The first legislation organizing water use is the 'Mejelle Code' was promulgated by the Ottoman Authorities in the second half of the eighteenth century, and was based on old customary rules. Under the French Mandate, the French Governors issued a number of orders regulating water, beginning in 1925 and 1926. The Decree 144 (issued in 1925) defines water as the property of the state and remains the legal framework adopted by the Lebanese State for the definition of water rights. However, this legislation conserved many traditional water rights for the communities that were traditionally benefiting from water sources, and also some private water rights. These rights were linked to land property (plots having rights to benefit from a certain surface water resource) and are still registered on property titles.

In the ULRB, including our study area, water rights attached to all surface water abstraction are currently being used. However, with the recent evolution of water use in the country, water abstractions from rivers and springs do not correspond to these old water rights anymore. Many plots (such as in Litani-Barr Elias and Litani-Zahle Maallaqa sub-areas) that are still registered as 'rain-fed' (because they did not have natural access to surface water at that time) are now irrigated by pumping water from the river. Other plots, as described later, are currently irrigated by surface water or groundwater sources following the disappearance of some springs, or due to the reduction of surface water availability caused by increased abstraction by upstream communities. Water rights are thus largely obsolete and do not define the way water is being used on the ULRB and in our study area.

3.4.3. Water rights linked to groundwater

Groundwater is also considered the property of the state. Starting with the French Mandate, several laws were successively issued to organize private groundwater use. The first legal text imposing limits on private groundwater use is Decree No.320 (issued in 1926). It imposed the need to obtain a permit for wells exceeding depths of 150 m and with withdrawals exceeding 100 m^3 per day.

In 1970, following the rapid expansion of wells in the country, a new Decree (No.14438) was issued in order to reduce private groundwater withdrawals. This Decree describes the administrative procedure to obtain permits and is still considered as the reference legislation for the MEW. It distinguished between two types of permits: the first is the "drilling permit" and is required prior to the establishment of wells exceeding 150 m in depth, and/or a 100 m^3/day discharge (the same conditions were defined in 1926); the second is called the "use permit" and should be obtained before the user starts to operate the well (licensed with a drilling permit). The legal text introduced a fixed fee to be paid for the obtention of the "drilling permit" (one time), and fees per abstracted water volumes to be paid annually for the "use permit". These fees have been gradually increased over the years and are set now at USD 333/year (500,000 L.L/year) for the fee of the drilling permit, USD 0.066/m^3 (100 L.L/m^3) for irrigation use and USD 0.4/m^3 (600 L.L/m^3) for industrial use. Importantly, in order to keep track of all wells being used, the 1970 Decree imposed on all well would-be-owners to register a notification prior to drilling a well, even if their well depth and/or the withdrawal volumes do not require applying for permits.[23]

[23] It must be noted that in 1963, a legal text forbidding any well digging/drilling in the Bekaa for 2 years was issued by the MEW. This limitation was probably put in place following an episode of drought that occurred during this period, as described by Baldy (1960).

In 2010, under the initiative of a new Minister for Electricity and Water, a new Decision (No.118) was issued with the purpose of better organizing the enforcement of groundwater regulations. This initiative was among a number of reforms the new minister attempted to make within the MEW. In response to the understaffing problem and lack of technical capacity of the Department of Groundwater and Hydrogeology, the Decision entrusted private firms with the role of assisting in the technical aspects of permit applications. These firms were also assigned the responsibility of conducting field visits and equip wells with meters (for wells requiring a permit). This reform also dramatically changed the administrative procedure to be followed by users and the cost for applying for well permits. Prior to submitting their request at the MEW, users have to submit their application to one of the private companies in order to get their technical advice. A fee of USD 935 is directly paid to the company.

3.5. Agriculture practices

3.5.1. Crop types

The ULRB is characterized by a wide variety of crops including cereals (representing around 20% of the total cultivated area in 2011), fruit trees (18%), vineyards (17%), and field crops (45%) (USAID-LRBMS 2012c). The main cultivated cereal is durum wheat (*triticum durum*). It is used for the preparation of wheat semolina[24] (*borghol*), which is the main ingredient for numerous Lebanese local meals (such as *Kechek*, *Tabbouleh* and others). Being subsidized by the state, it generally generates stable incomes (between 100 and 200 USD/du[25],[26] depending on the yield) and is consequently planted each year on a substantial part of the basin. Barley is the second most important cereal crop but occupies a substantially smaller area, compared with wheat. It is mainly grown as a fodder crop in the northern part of the Basin and is less present in Central and South Bekaa (FAO and MoA 2012). Fruit trees are very diverse and include several cultivars of apple, plum, peach, nectarine, pear, cherry, almonds, persimmon, and olive trees. They generally have a relatively high added value (between 650 and 800 USD/du of income) and are cultivated for both local consumption and export. Vineyards are planted both for grapes and wine production; table grapes are sold both on local and international markets and provide high revenues (around 1,000 USD/du), while wine grapes are less profitable when sold without transformation (200 USD/du); they are generally grown on large areas by wineries.

Field crops include a wide variety of tuber and bulb crops (potato, garlic, onion, radish and turnip), leafy vegetables (lettuce, cabbage, cauliflower, spinach, mint, parsley and others), fruit vegetables (tomato, cucumber, eggplant, watermelon and melon), leguminous crops (green peas, fava beans and other types of beans) and corn, which is cultivated both for human consumption and as a fodder crop. Similarly to the general agricultural land use of the ULRB, crops found in our study area include wheat as a major cereal, and a large variety of fruit trees and vegetables.

More than one crop can be planted on the same plot in the same year, depending on the length of their production cycle. Cropping calendars generally include a winter and a summer season. Winter crops are planted during the winter months (from November to March, depending on the types of crop) and are harvested in the beginning of the summer (June to July). These crops typically include wheat (November-June), early season potato (February-July), garlic and onion (October-May), green peas and fava beans (January-May). Summer crops are planted after the first harvest of the season and can last as long as December, depending on the type of crop,

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[24] This type of wheat is not suitable for the preparation of wheat flour

[25] Production costs were obtained from several farmers and are detailed in Annex 5.

[26] One dunum (abbreviated as 'du') = 0.10 hectares.

water availability and climatic conditions. They include potato (August-October), tomato and eggplant (May-October) and other summer vegetables. Some vegetables have short production cycles and can be planted more than twice a year, e.g., the iceberg lettuce (four times a year), radish (six times a year), or cycles longer than one year, such as mint crop that can be kept for up to 4 years. In most of the cases, the land is typically kept fallow during the second season after the wheat crop in order to let the land rest and preserve soil nutrients for the following season.

In general, farmers cultivating wheat separate their cropping pattern into two parts: one part is planted with wheat and kept fallow after harvesting, and the other part is planted for two or more seasons of vegetables. The following year, vegetables are planted in the fallow plot and wheat replaces vegetables. Among annual crops, potato, onion, garlic, tomato and iceberg are the most profitable crops. Potato crops generate around USD 850/du/cycle if access to international markets is available for farmers, which means that planting two cycles of potato could generate USD 1,700/du/year. Onion and garlic both generate between 1,000 and USD 1,200/du/cycle, and are generally followed by short-cycled vegetables such as radish, spinach, lettuce or cauliflower, the latter generating between 200 and USD 300$/cycle. The iceberg lettuce is the most profitable among all crops, generating up to USD 3,200/du/year (it generates around USD 800/du/cycle and can be planted up to four times a year). Choices of cropping calendars were observed to depend on different factors: soil types and water availability; farmers' investment and/or technical capacity; marketing opportunities and market prices; as well as land tenure characteristics. As described later, groundwater shortage was observed to be an important limiting factor in some areas, and translates into the choice of shorter cycle crops and/or the reduction of the number of cycles.

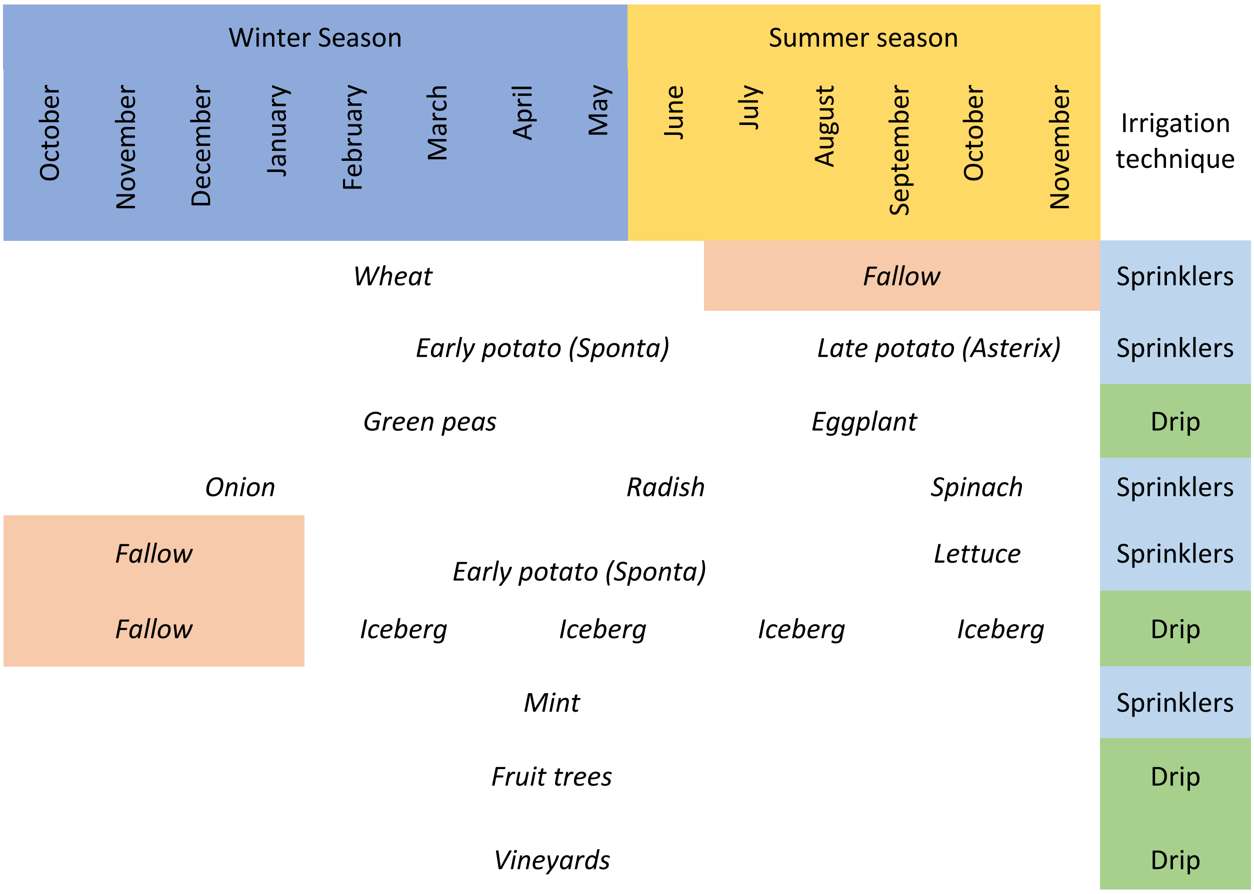
3.5.2. Irrigation techniques

Irrigation techniques include mainly sprinklers and drip irrigation systems. In 1959, some farms began to adopt sprinkler irrigation system (Baldy 1960). They were later proposed, in the early studies of the South Bekaa Irrigation Project, to be used as the main type of farm irrigation system (Mission Gersar 1972) and expanded widely during the 1980s. Drip irrigation systems started to be used two decades later and are now widely adopted to irrigate many vegetables (e.g., tomato, lettuce, eggplant and iceberg), fruit trees and vineyards that used to be irrigated either by surface or sprinkler irrigation.

The adoption of drip irrigation systems for potato crop was recently intensively promoted by international development programs, by involving farmers in field experiments, aiming to demonstrate the benefits of drip systems in improving water efficiency, increasing crop yield, reducing pumping and labor costs, and lessening vulnerability to the wind (USAID-LRBMS, 2012a). However, farmers were described to be generally unresponsive to these initiatives due to the high costs needed to purchase drip systems, coupled with their reluctance to change their traditional irrigation methods (Karam 2011). Conversely, micro sprinklers are now being increasingly used and were observed to be used on potato and vegetable cultivation in some fields.

The following figure (Figure 9) shows different cropping calendars adopted by some of the farmers interviewed. Surface irrigation (flooding and furrow irrigation) is only found in the Anjar Spring-based Irrigation System, where farmers receive water by gravity and pay a fixed rate for irrigations (Al-Jawhary 2012; USAID-LRBMS 2012g). However, in the last years, the Anjar Irrigation Committee supported by a development program, has been encouraging farmers to adopt water-saving irrigation techniques to reduce the length of water turns.[27] As described later, this is related to the decline of the Anjar Spring flow.

Figure 9: Examples of the general agricultural calendars and irrigation techniques adopted in the study area.



Source: Author, based on interviews with farmers.

3.5.3. Land tenure

Land organization in the ULRB is complex and differs from one area to another, depending both on the specific history of each town and on the types of land reform put in place by the successive governments that administered the Bekaa (Blanc 2006; Ghiotti and Riachi 2013). While lands in some towns such as Terbol, Kfarzabad, Barr Elias, Fourzol, Ryak-Haouch Hala and Zahlé Qabb Elias are shared by a large number of families, who gradually appropriated plots and divided them over the generations. Other towns such as Hoshmosh, Ammiq, Tal-Dnoub and Deir-Tahnish are respectively owned by one or few families, who acquired them through the different episodes of land reforms, put in place at the end of the nineteenth century, and/or bought them from small owners during historical periods of economic crisis (Blanc 2006). Today, this translates into two main types of agricultural land tenure: owner-occupation and land tenancy.

[27] This has been done in the framework of a development project, developed by Sociéte Pour la Protection de la Nature au Liban. The information was given by Dr. Elias Ghadban, who was responsible for this activity. He was interviewed on March 16, 2015

In the case of owner-occupation, land owners are originally from the same town and cultivate their own plots. In the case of land tenancy, owners rarely practice agriculture and are often originally from other towns (in or outside the Bekaa) and rent their plots on a yearly basis to farmers from neighboring areas. According to the last agricultural census, around half of the Bekaa agricultural area was under tenancy in 2010 (FAO and MOA 2012). First, this is explained by the importance of agricultural lands still owned by traditional families of importance. Second, many land owners who used to practice agriculture, migrated to the city or left the country during the Lebanese War, or shifted to other professions with the development of other economic sectors and the general decline of the agricultural sector (Augiers and Blanc 2009). These two factors combined led to a significant increase in land rental. Land selling was also reported to have been significant following the years of reconstruction, with important amounts of agricultural plots sold to people accumulating capital from working in other sectors or working abroad. This phenomenon also increased the rate of land tenancy, as most of these investors lease the acquired plots to local farmers.

Sharecropping agreements can also be found. In this type of agreement, the owner is generally a resident providing access to land (and often also access to water) to the farmer, while the latter provides the remaining production factors (labor and agricultural inputs). Revenues are generally divided equally among them.

The towns of our study area are representative of the diversity of land organization and land tenure characterizing the Bekaa. In Ryak-Haouch Hala, Terbol, Maallaqa-Dalhamyeh, Barr Elias, Kfarzabad, Anjar and Fourzol, plots are owned by numerous families belonging to their respective long-established communities. Hoshmosh, however, represents a relatively large area (500 ha) and was originally owned by two affluent and locally reputable families. Land rental was described to be predominant in Maallaqa-Dalhamyeh, as most of the land owners left during the war or were harassed by the Bedouin population that settled in this area and prevented them from cultivating their lands, as reported by some interviewed informants.[28] This issue also became relevant in Terbol, following the selling of a large amount of land in recent years, as detailed later, and was also reported to have substantially increased in Barr Elias and Ryak-Haouch Hala, with land owners either proposing share-cropping arrangements or selling their lands to investors who lease them in turn.

Land tenancy limits the choice of crops for farmers, as reported by most interviewed farmers. Since most rental agreements are done on a yearly basis, many farmers have to rent different land plots from one year to another. This reduces the choice of crops that would be suitable for planting following the previous crop season. Land tenancy is an obstacle for growing perennial plants such as fruit trees and vineyards, since it requires renting agreements of 15-20 years minimum. Fruit trees and vineyards are, in fact, concentrated in villages where lands are under owner occupation, e.g., in Anjar, Kfarzabad and Fourzol, while they are rare in Dalhamyeh and Faour where farmers are mostly tenants. Conversely, it was reported to be an advantage for farmers to specialize in one type of annual crop since it allows them to practice land rotation without keeping their land fallow every other year, like in the case of land owners. Two examples of this second trend are: one large potato farmer from Terbol, cultivating lands in different areas in the Central and South Bekaa; and the manager of a large company specializing in iceberg salad production in Terbol.[29]

[28] Informant No. 6, author of a book about Terbol history and farmer No. 5, during the interview of November 26, 2015.

[29] Farmers No. 20 and No. 21 interviewed, respectively, on November 18 and 19, 2014.

3.5.4. Problems in agriculture

During the interviews, all farmers complained about the same problems: high and annual increases of input prices, difficulty in finding markets and high instability of market prices that makes agriculture like a 'game of poker'. The absence of extension services was also mentioned as a limitation. Most of the farmers typically purchase their agricultural inputs on credit at the beginning of the season, and are not able to pay back until they have sold their products. They constantly live under stress because market selling prices have become very unpredictable and any extreme climatic condition or accident can bring about huge losses. In this context and in the absence of agricultural banks, informal money lenders have proliferated, imposing very high interest rates. Many of the farmers we interviewed were in debt to money lenders and were worried about how to pay their debts.

4. The evolution of groundwater use since the 1950s: Spatial heterogeneity and interrelated impacts

4.1. Hala Yahfoufa sub-area

Between the 1950s and the 1970s, groundwater was little exploited in this area. The River Hala Yahfoufa was the main source of water supply, both for irrigation and domestic use for most of Ryak and Haouch-Hala agricultural lands, around half of Hoshmosh territory, and a small part of Fourzol lands.[30] The Quaternary aquifer, underlying all of these regions, was also exploited through shallow wells but only in a relatively smaller area without access to surface water from the Hala Yahfoufa River. There were also some lands that used to be planted with rain-fed crops or kept fallow.

4.1.1. Evolution of water supply for irrigation

Hala-Yahfoufa River sprouts from springs located in the towns of Jenta and Yahfoufa, and joins the Litani River at the level of Fourzol, 17.5 Km downstream of its source (Kehdy 2013). It has an average yearly flow of 940 LPS and a maximal flow of 2,100 LPS (Kehdy 2013; USAID-LWWSS 2015b). The Hala-Yahfoufa River has been traditionally exploited to irrigate several areas through collective irrigation systems supplied by gravity. At its source, the river flows through a narrow valley, irrigating small cultivated areas in Jenta and Yahfoufa towns (150 and 200 du of orchards, respectively) located on the banks of the River.[31] The following area is the plain of Sarraine and Nassryeh, where water is conveyed through a long irrigation canal diverting water from the river at Jenta. The third region is in Ali El Nahri, and is supplied by a canal located upstream of the town and is followed by our sub-area, which is the most downstream one.

In our sub-study area, we identified three collective irrigation systems supplied by three different intakes from the Hala-Yahfoufa River and corresponding primary canals. The first system is the largest and covers a part of Hoshmosh, and it is supplied by a canal located upstream of this region. The second one covers a substantial part of Ryak and Haouch Hala agricultural lands, and is supplied by another canal located upstream to Ryak. The third system is found in Fourzol, where there are only a few plots supplied by this river through a small canal,

[30] Most of the Information obtained for this sub-area was obtained from three farmers we interviewed in Ryak (No. 48 on March 7, 2015, No. 49 on March 17, 2015, No. 50 on April 1, 2015 and one farmer in Fourzol (No. 7 on 27 November 2015).

[31] These infrastructures were directly observed during a field survey conducted along the upper part of the Hala Yahfoufa River River. The information concerning water management from these infrastructures was reported by the Mayor of Jenta who was accompanying us. The field survey and interview with the mayor took place on March 23, 2015.

as reported by our informant in this town. These three systems were irrigated from Hala Yahfoufa only until the 1970s.

As reported by our informants in this area, the river flow reaching Hoshmosh, Ryak and Fourzol canals decreased significantly at the beginning of the 1970s, until it completely dried out every year in the month of June, starting in the 1990s. This pushed farmers depending on these systems to start using groundwater as an alternative. While the Eocene aquifer became the main irrigation source for Hoshmosh (this will be developed in the section concerning the Eocene sub-area), plots traditionally irrigated by the Hala Yahfoufa River in Ryak-Haouch Hala and Fourzol started to be irrigated by wells tapping the Quaternary aquifer. First, these wells were shallow dug wells but were later replaced by tube wells after the water level decreased below 15-20 m.

Similarly, to other areas of the Bekaa without access to surface water, shallow wells were already widespread in the 1960s in the lands not supplied by the Hala Yahfoufa River. The data gathered by Baldy (1960) during the summer of 1959 is very informative about the number and characteristics of wells being used at that time in the region east of the Litani, going from Hosh Barada in the north to Dalhamyeh in the south (Table 4). In the regions of Ryak-Tell Hezzine and Ryak-Terbol-Dalhamyeh,[32] 33 and 98 dug wells, respectively, were counted, most of them were earthen ditches and dug by hand or tractor to a lesser extent. Wells were mostly equipped with centrifugal water pumps supplied by individual diesel generators. Except for very few circular wells usually used for domestic supply, irrigation wells had a rectangular shape and were of varying sizes (lengths varied from 2 to 500 m and width from 1 to 10 m), with most of the lengths being between 2-10 m and width between 1-7 m. At that time, their depth varied from 4 to 40 m but most of them were typically from 4 to 10 m deep since water levels were still very shallow (between 1 and 5 m).

These wells had different discharges, ranging from 0.5 to 10 LPS depending on the well dimension as well as the characteristics of the alluvial aquifers. Wells had the capacity to irrigate plots of varying sizes (from 50 to 100 du in the region of Ryak-Tell Hezzine and from 5 to 200 du in the region of Ryak-Terbol-Dalhamyeh), but their exploitation was limited, with half of the irrigated plots being smaller than 20 du, and only few of them exceeding 50 du (21% in Ryak-Tell Hazzine and 9% in Ryak-Terbol-Dalhamyeh). This limited development of irrigation before the 1960s, is linked to the relative under-development of agriculture in the Bekaa in this period, when access to mechanization was still limited and commercialization opportunities were modest, before the demand for agricultural products from the Gulf countries, which boosted Lebanon's agricultural sector in the following decades.

In Central Bekaa, agriculture development was further favoured by the proximity of the Ryak Railway Station that used to serve as an outlet for the agricultural products (Baldy 1960: P6). During this period, the expansion of irrigated areas and intensification of agriculture were mainly ensured by shallow wells dug in the Quaternary aquifer and by the supply of surface water from the Hala Yahfoufa River. Tube wells had also started to be drilled since the mid-1950s, but remained very limited in number in the alluvial aquifers until the mid-1970s since water was still accessible through shallow wells, as reported by one of our informants.[33]

[32] Baldy (1960) divided his study area in three parts: Hosh Barada, Ryak-Tell Hazzine and Ryak-Terbol Dalhamyeh. We were not able to locate these areas due to the absence of maps. The latter are described to have been produced and attached as annexes but were not found in the book.

[33] The informant (Farmer No. 50) recalled that there were no more than 15-20 tube wells in Ryak-Haouch Hala plains until the mid-1970s compared to many shallow wells.

With the development of agriculture in the 1960s, groundwater abstraction from the alluvial aquifers substantially increased, resulting in a rapid lowering of water levels. Shallow wells were consequently deepened to almost 20 m, until they completely dried out and required to be replaced by tube wells in the late 1970s. The historical well data available for this study shows one irrigation well drilled in 1981 and one domestic well drilled in 1999. Following our interviews, we identified three tube wells located in plots that used to be irrigated by the Hala Yahfoufa River. The first well irrigated a 25 du orchard and was drilled in 1980 following the drying-out of a shallow well. The other two wells were drilled by another farmer in 1997 when he established his farm of 54 du of fruit trees and 26 du of vegetables. Prior to that, the plot used to be cultivated by a different farmer and irrigated by two shallow wells that have dried-out, as reported by the current farmer.

Today, the total number of wells currently being used in Ryak-Haouch Hala Plains is estimated at around 100 wells with depths varying from 50 to 130 m. Of the five wells for which it was possible to obtain information, there are two wells with depths of 50 and 55 m, and three wells at 110, 125 and 130 m. This difference in depth is linked to the hydrogeologic differences rather than to the well use, since the two wells drilled at 110 and 55 m are used to irrigate the same land plot and give the same discharge (7.5 LPS). Discharges also vary from one well to another, but farmers reported that most of the wells give a sufficient discharge for irrigating areas between 40 and 50 du. Water levels are reported to vary between 13-15 m in the winter and 20 m in the summer. The synoptic measurements conducted in the framework of USAID-LRBMS (2012d) survey show a variation of 10 m between the winter and summer seasons (water levels were 16 and 24 m in the winter season, and 27.5 and 35.5 m in the summer in the two wells with 130 and 125 m depths, respectively).

Figure 10: Irrigation systems in the Hala Yahfoufa sub-area.

Notes: 1. Intake from Hala Yahfoufa at Jenta Village in March 2015. 2. Irrigation canal part of Hala Yahfoufa River-based system at Ryak now used to convey groundwater. 3. Hala Yahfoufa River bed empty at Ryak in March 2015.

Table 4 : Characteristics of shallow wells used in 1959 in North and Central Bekaa.

Region	Number and type	Type of use	Dimensions	Depth	Depth to water	Discharge	Irrigable areas	Irrigated areas	Convey system
HoshBarada	117 Only 3 circular wells	Mostly for the irrigation of vegetables. Orchards to smaller extent	Length from (2-310 m) the majority between (10-50 m) Width from (2-10 m)	Between (3-15 m) The majority between (2-5 m)	Between [2-8 m]	Between (50 -- 1,000m^3/day) i.e., between (0.5-10 LPs)	50% of the plots >50 du 25%> 100 du	50% of the plots < 20 du 40% from (20-50 du) 10% from (50-140 du)	90% earthen ditches Very few cement canals and metallic pipes
Ryak- Tell Hazzinel	33 Only 6 circular wells	Mostly for the irrigation of vegetables Orchards to a smaller extent	Length from (2-500 m) The majority between (2-10 m) Width from (1-7 m)	Between (4-40 m) The majority between (4-10 m)	Between (2-38 m) The majority between (2-5 m)	Between (150 -1,000 m^3/day) i.e., between (1.5-10 LPS) Some wells reported as 'abundant'	All plots between (50-200 du)	47% of the plots < 20 du 32% from (20-50 du) 21% from (50-150 du)	70% earthen ditches 30% metallic pipes
Ryak- Terbol-Dalhamyeh	98 Only 7 circular wells	Mostly for the irrigation of vegetables Orchards to a smaller extent One well for drinking	Length from (3-150 m) The majority between (3-10 m) Width from (2-10 m)	Between (4-37 m) The majority between (4-10 m)	Between (1-13 m) The majority between (1-5 m)	Between (50-900 m^3/day) i.e., (0.5-0.9LPS)	65% of the plots< 100 du 35% > 100 du	63% of the plots < 20 du 28% from (20-50 du) 9% from (50-100 du)	70% earthen ditches 20% cement canals from (200-1,700 m) 10% metallic pipes

Source: Author, based on Baldy (1960).

Table 5 : Characteristics of tube wells used in 1959 in North and Central Bekaa.

Region	Number and type	Type of use	Diameter	Depth	Depth to water	Discharge	Irrigable areas	Irrigated areas	Convey system
Hosh Barada	4; of which 2 were under establishment	Mostly for the irrigation of vegetables Orchards to a smaller extent One well for domestic use	Not available	Domestic well: 42 m and Irrigation well: 352 m	Not available	Domestic well: 0,011 LPS and Irrigation well: 1-2 LPS	Irrigation well: 400 du	Irrigation well: 400 du	Not available
Ryak-Tall Hazzine	15	Mostly for the irrigation of vegetables Orchards to a smaller extent One well for domestic use	From 6" to 12"	From 32 to 100 m	From 17 to 43 m	From 50 to 2,000 m^3/day i.e., from 0,5 LPS to 20 LPS Most of the wells yield more than 10 LPS	Only available for one irrigation well: 800 du	50% between (50-200 du) 20% between (20-50)	Mostly earthen ditches Few cement canals
Ryak Terbol-Dalhamyeh	35	Mostly for the irrigation of vegetables Orchards to a smaller extent One well for domestic use	From 4" to 12"	From 30 to 90 m	Not available	Available only for two wells: 125 LPS 15 LPS	Between 130 and 1,200 du	Less than 50% of irrigable areas	Mostly earthen canals

Source: Author, based on Baldy (1960).

4.1.2. Evolution of domestic water supply

Similarly to irrigation, the sources of domestic water supply (potable and domestic use) in Ryak-Haouch Hala shifted from surface water to groundwater. In the 1960s, domestic supply infrastructures were constructed in several towns following the development of state services in the Bekaa. The Hala Yahfoufa River was one of the water sources harnessed for the establishment of spring-based domestic supply systems. As described by the Mayor of Jenta, two pipes, still in use, were set up on the river: the first one (8 inches in diameter) supplies the villages of Jenta, Yahfoufa, Ali El Nahri, Ryak-Haouch Hala and Hay El Fikani. The second one (4 inches in diameter) supplies the military base in Ablah. Water is conveyed to local reservoirs in each of the villages from which it is distributed to the houses through a collective network.

As in the case of irrigation, our informants in Ryak-Haouch Hala reported that domestic water supply from the Hala Yahfoufa River remained sufficient in the town only until the mid-1970s. At that time, water supply from the public network was significantly reduced and led to the multiplication of private house wells, estimated today at 1,000 wells (by Kehdy 2013). In 2003, in order to supplement the amount of water taken from the Hala Yahfoufa River, a well was drilled in the Eocene aquifer in Hoshmosh and connected to the water reservoir at Ryak. This well is 292 m deep, and provides a discharge of 20 LPS (USAID-LWWSS 2015a: P106).

However, water supply from this new water source does not seem to ensure the town's domestic water needs. Moreover, our informants reported water rationing that compelled residents to use their own agricultural wells for domestic use. Furthermore, it was reported that water from both the domestic network and house wells was only used for domestic purposes and not for drinking due to its poor quality. As an alternative, as in many other towns in the Bekaa Valley, residents buy bottled water to ensure their drinking water needs are met. As part of the recent Master Plan of the BWE, the existing public networks are projected to be rehabilitated. Importantly, the Bekaa Water Establishment also plans to significantly extend the domestic supply from the Hala Yahfoufa River. This would include six additional towns (Nassryeh, Haouch El Ghanam, Niha, Fourzol, Nabi Ayla and Ablah) to the actual system in the Caza of Zahle and Baalbeck. The evolution of irrigation and domestic supply in Hala Yahfoufa sub-area are summarized in Table 6.

Table 6 : Evolution of groundwater use in the Hala Yahfoufa sub-area and its impact on users.

	Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (By year 2035)
Irrigation	Irrigation from Hala Yahfoufa by gravity and Arabic wells to a lesser extent **Limited development of agriculture**	Irrigation from Hala Yahfoufa Multiplication of Arabic wells and increase in the use of the existing ones Drilling of few wells **Significant increase of irrigated areas**	Significant reduction in water supply from the Hala Yafoufa Drying out of Arabic wells Start of their replacement by tube wells drilled in the Quaternary aquifer in Ryak and in the Eocene in Hoshmosh	Deepening of tube wells The major part of the supply in Ryak is still ensured by Quaternary tube wells	Increased reliance on tube wells as a result of the reallocation of water from the Hala Yahfoufa River for domestic supply
Domestic	Domestic supply from Hala Yahfoufa and Arabic wells to a lesser extent No public network?	Increased domestic supply from Hala Yahfoufa after the construction of a public network	Significant reduction in water supply from the Hala Yahfoufa Multiplication of housing wells drilled in the Quaternary aquifer	Substantial part of water supply provided by housing wells **2003: Drilling of municipal well in Eocene aquifer**	Increased domestic supply from the Hala Yahfoufa is projected to be ensured by the Bekaa Water Establishment
Well depths (m b.g.l)	4-10 m	Between 10-15 m for shallow wells Between 50 and 100 m for tube wells	Data was not found	Present: Wells between 50 and 150 m	**Drilling the Eocene** Possibly 200 m and deeper
Water levels (m b.g.l)	1-5 m	Data was not found	Data was not found	15 m in winter 20 m in summer	**Unknown**
Impacts on users	Groundwater ensured the irrigation of agricultural areas without access to the river-based system		Groundwater ensured as an alternative to the reduction in surface water availability. However, users consider it as an infringement to their water rights by upstream communities Until now, groundwater was sufficient for practicing irrigation throughout the summer		Likely significant reduction in water levels, which will result either in the reduction of irrigated areas or accessing the Eocene aquifer

Source: Author.

4.1.3. Impacts on direct users

Successively, the reduction of water allocation from the Hala Yahfoufa River and the gradual decrease in groundwater levels required several adaptation measures. The first measure was to dig shallow wells and equip them with pumps as an alternative to surface water irrigation. This was considered to be expensive at that time in terms of human labor, given the limited access to mechanical digging (Baldy 1960). Centrifugal water pumps and diesel generators were available in the Bekaa and were easy to purchase as illustrated by the "*broad variety of imported brands*" as described by Baldy (1960: P26).

The drying-out of shallow wells in the late 1970s required drilling and equipping tube wells. Drilling technology has been present in the Bekaa since the early 1960s, and was financially accessible to farmers in most of our study area as illustrated by the number of tube wells already observed by Baldy in 1959 (Table 5). As described later, many farmers were able to pay for tube wells through partnerships with investors from Zahle, the most economically developed town of the Bekaa at the time. In Ryak-Haouch Hala, access to capital was also available due to its economic development at that time with the railway station and the French military base, and also given the early development of agriculture ensured by surface irrigation from the Hala Yahfoufa River.

Following the establishment of tube wells, the decrease in water levels required several additional adaptation measures. Several wells were deepened to maintain access to water and preserve sufficient yields and modern irrigation techniques were adopted, both to reduce water consumption and to decrease pumping costs. Today, well yields still ensure that crop water needs are met throughout the summer in this sub-area. The choice of cropping pattern does not seem to be impacted by the reduction of water levels. Potato crops, one of the most water consumptive, still occupy most of the agricultural land use, while fruit trees represent only 10% (Kehdy 2013).

Despite well yields being sufficient for crop requirements, water levels will continue to decrease if consumption is not reduced. Based on the ULRB groundwater model described earlier, a minimum drawdown of 15-20 m and a maximum drawdown of 25-30 m in water tables are projected to occur by 2030 in Ryak (USAID-LRBMS 2013c). Future impacts would include further increase in pumping costs as a result of lower groundwater levels and/or reduction of irrigated areas as a result of decreasing well yields. Moreover, if after the doubling of pumping costs agriculture would still be profitable, it is possible that groundwater will not be available anymore in the Quaternary aquifer, similarly to what has happened in other parts of our study area. While it is difficult to know the depth of the Quaternary aquifer in Ryak, further decreases in groundwater levels are likely to result in wells being drilled in the Eocene aquifer.

Another important impact resulting from the conjunctive use of groundwater in this sub-area is the development of community divisions between downstream and upstream users. The Ryak farming community perceives this as an infringement on their water rights, as they have to pay for groundwater abstraction through private wells instead of irrigating through gravity systems from the Hala Yahfoufa River. All the interviewed informants accused the upstream communities of illegally diverting most of Hala Yahfoufa's water to the irrigation canals of Sarraine and Ali El Nahri and to restaurants located on the banks of the river. They stated that they are not able to intervene since these communities are more powerful politically and claimed that the state should be responsible for enforcing an equitable distribution of water. On the other hand, the Mayor of Jenta categorically refuted the alleged inequity in water allocation between Saraine-Ali El Nahri and Hoshmosh-Ryak. During our field visit, he showed us the intake from the canal conveying water to the Sarraine Plain and insisted that it distributes water equally between both upstream and downstream villages. He claimed that both Sarraine and Ali El Nahri farmers are also deprived from the river flow during most of the irrigation season and that they are forced to rely on wells, arguing that the problem is a reduction of the spring flow itself caused by the drilling of wells in Sorghaya region in Syria.

Another allocation conflict seems to exist between farmers using the Ryak Canal and farmers using the Hoshmosh Canal, as reported by the town's municipality officer. The latter described an argument that had recently occurred between a farmer in Ryak and other farmers in Hoshmosh, because the latter diverted most of Hala Yahfoufa water arriving at the beginning of the season into the Hoshmosh Canal,[34] leaving almost no flow to the Ryak Canal. Interpretations also varied for the case of domestic water allocation: while Ryak informants also linked it to water being captured upstream, the Mayor of Jenta claimed that it is due to a general problem of illegal tapping and piping leakage.

4.1.4. Identification of competing users

Users can impact each other's access to water in two ways: 1) by direct impact as common users of the same water source (same aquifer, river or spring) or; 2) by indirect impact as respective users of two water sources (or more) hydraulically connected. In each of our sub-areas, users are directly linked to each other by using the same resource(s) and can also be indirectly linked to users in other sub-areas, as sharing hydraulically connected resources. These direct and indirect links will be unpacked for each of the sub-areas in order to identify the different users contributing to groundwater overexploitation, and to asses in which way and to what extent they are impacting each other. In the case of Hala-Yahfoufa sub-area:

Direct relations

1- Ryak-Haouch Hala farmers and residents commonly use the Quaternary aquifer in Ryak and have direct impacts on each other. Along with the other users of the basin's Quaternary aquifer, they all contribute to groundwater overexploitation, with farmers being responsible for the largest share of water abstractions. Although it is difficult to assess the impact of the different abstractions over space due to the hydrogeological heterogeneity of the Quaternary aquifer and the limited knowledge of its characteristics, both in space and depth, it will be assumed that users of the same aquifer impact each other, and that the importance of the impact is proportional to the distance between them.
2- Farmers and residents of Ryak-Haouch Hala, Hoshmosh, Nassrye, Ali Nahri, Jenta and Yahfoufa towns all have legal rights to use the Hala-Yahfoufa River for irrigation and domestic use. Although it is difficult to understand whether the conjunctive use of groundwater and surface water is general to all users and linked to a reduction in Hala Yafoufa Spring flow, it is likely that downstream users are indeed more impacted than upstream users because of their naturally weaker position. Having a project to extend the domestic network supplied by the river, the BWE is also considered an important user of this river. The increase in water allocation from the Hala Yahfoufa River resulting from this project would clearly decrease surface water availability for irrigation, hence,

[34] The group of farmers benefiting from this canal manages the maintenance of the main canal, and the cost is then paid by the municipality. They hire an employee ('shawwa' in the farmers' language)' who organizes the water turns. Each farmer pays a certain amount to be able to irrigate from this canal.

increase the reliance on groundwater. Being a state institution, with decision-making powers, the BWE is considered the strongest user.

Indirect relations

1- It is likely that the users of the Eocene aquifer in Terbol are indirectly impacted by the reduction of flows in the Hala Yahfoufa River, given that a significant share of the aquifer's recharge originates from water infiltrating from this river as described earlier (UNDP 1970: P110). This creates an interrelation between Hala Yahfoufa River users and those of the Eocene sub-area (including Hoshmosh, Terbol and Faour farmers and residents), the latter being negatively impacted by the former users' water abstraction from the river.
2- Users of the Anjar-Chamsine Aquifer are also likely to be indirectly impacted by the reduction of flows in the Hala Yahfoufa River. Similarly to Terbol Aquifer, a significant part of Anjar-Chamsine Aquifer recharge originates from water losses occurring at the level of this river (El-Hakim 2005). This creates an (unexpected) interrelation between the users of Hala Yahfoufa River users and those of the Anjar-Chamsine Aquifer.

4.2. Litani-Fourzol sub-area

4.2.1. Evolution of water supply for irrigation

Irrigation use in this sub-area on the eastern bank of the Litani River also evolved from surface water supply to groundwater supply. As reported by one informant,[35] the Litani River served as the main irrigation source[36] for this sub-area until the mid-1970s. First, during the 1950s and 1960s, when the water level in the Litani River allowed the diversion of water by gravity to this part of Fourzol[37] through two ditches dug parallel to both sides of the river. Water used to be conveyed by gravity from the river to the eastern ditch (at the level of the studied sub-area), and by pumping to the western ditch, and distributed by gravity from these ditches to the plots through secondary and tertiary earthen canals. Following the development of agriculture in the 1960s, the water flow in the Litani River was gradually reduced as a result of increased upstream abstractions. As a result, farmers had to use motor-pumps in order to pump water to the eastern ditch. Starting the late 1970s, water flows from the Litani River were not sufficient anymore to irrigate crops throughout the season and farmers complemented their water needs with groundwater.

Unlike the case of the Hala Yahfoufa sub-area, the first wells drilled in this area were tube wells as the Quaternary aquifer was found to have a very low yield in this area. The informant recalls that he established his first tube well in 1986, drilled to a depth of 80 m. Wells drilled in this sub-area provide relatively much lower yields compared to wells drilled in the Hala Yahfoufa sub-area. This is due to the natural lower water storage capacity characterizing the Quaternary aquifer in this region. According to our informant, most of the wells have always produced low yields (between 2 and 5 LPS) ever since they were first drilled and with no significant increase in water availability proportionally to depth (when well depths does not exceed that of the

[35] Most of the information concerning this sub-area was obtained from Farmer No. 7, interviewed on the June 26, 2014 (during the Walk-through Survey) and on November 27, 2015. Some information was also given by Farmer No. 6 who was interviewed on the same day of the Walk-through Survey.

[36] Although it joins the Litani at the level of Fourzol, Hala Yahfoufa was not an important water source in the Fourzol Plain. It was only used to irrigate 80 du of land through direct intake from the river during the period that it used to still flow during the summer season.

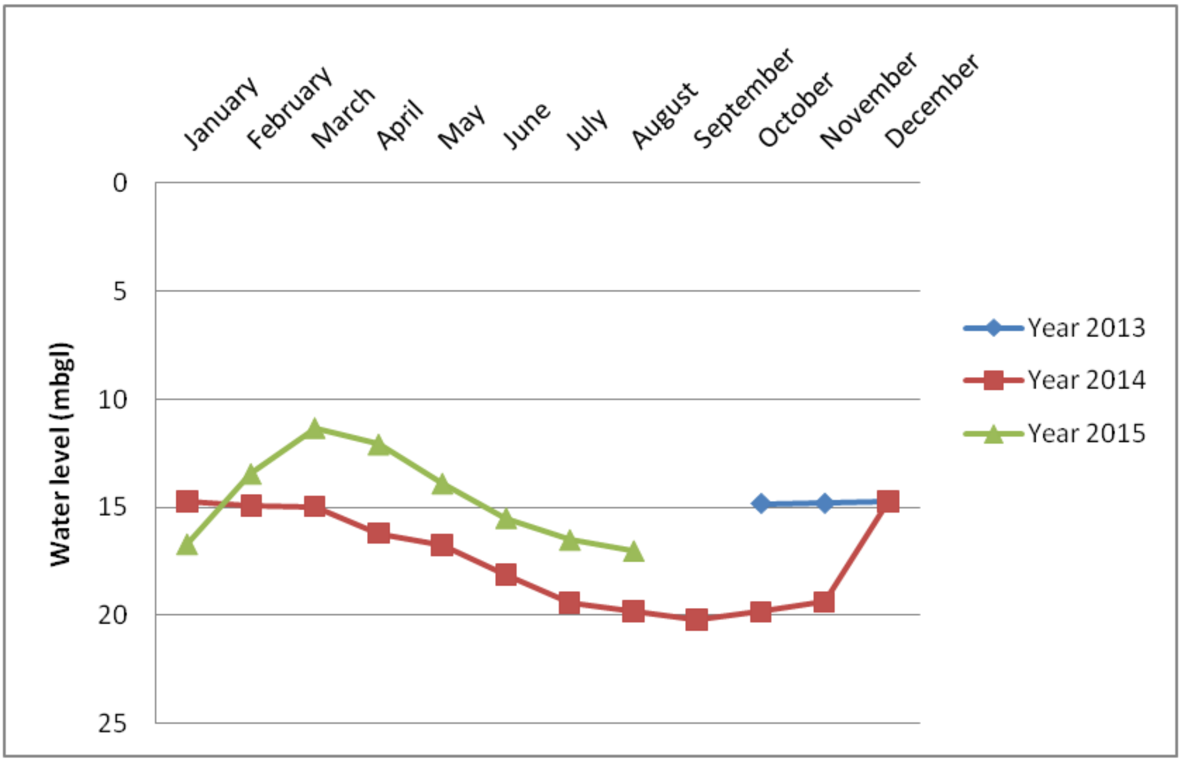
[37] Being located several meters higher, lands of the western part of the Litani only started to be irrigated by the river following the introduction of motor-pumps.

Quaternary aquifer). He described that this is not only the case for wells drilled in this sub-area but in all of Fourzol agricultural plain. These low yields translate into small irrigation capacities, with one well only irrigating 5 to 10 du at best. This has resulted in the multiplication of wells: according to our informant, "*there is at least one well in every 10 du plot.*" In fact, during our 'walk-through survey' in this sub-area, many wells were observed to be found in the same land plots, sometimes drilled very close to each other (50 up to 200 m). Considering the ratio given by our informant, the number of wells in this 3,500 du sub-area can be estimated at around 350 wells.

Data concerning water levels found for wells located in this sub-area was very limited, with only one well measured in the framework of the USAID-LRBMS Survey (USAID-LRBMS 2012d). This well is 70 m deep and had a water level at 2.87 m b.g.l (below ground level) at the beginning of the irrigation season (June 6, 2011). Nevertheless, since well characteristics have been described to be relatively homogenous in Fourzol, water level variations can be extrapolated from the measurements recorded at the Fourzol monitoring well (located on the western bank, 2 Km from the Litani River). The water table is much shallower in Fourzol than in Ryak-Haouch Hala. While the shallowest water level in Fourzol was 2 m b.g.l in 2013 (recharged water level in a normal year), it was as low as 11 m b.g.l in Tel-Amara monitoring well for the same year. On the other hand, water level fluctuationsvariation are much higher in the Quaternary aquifer in Fourzol as compared to Tel-Amara. Wile the difference in water levels between the wet and dry season can exceed 40 m in Fourzol, it remains in a range of 6 m in Tel Amara. . Given that water abstractions for irrigation are substantial for both these sub-areas, these differences are clearly linked to the physical properties of the Quaternary aquifer rather than groundwater use.

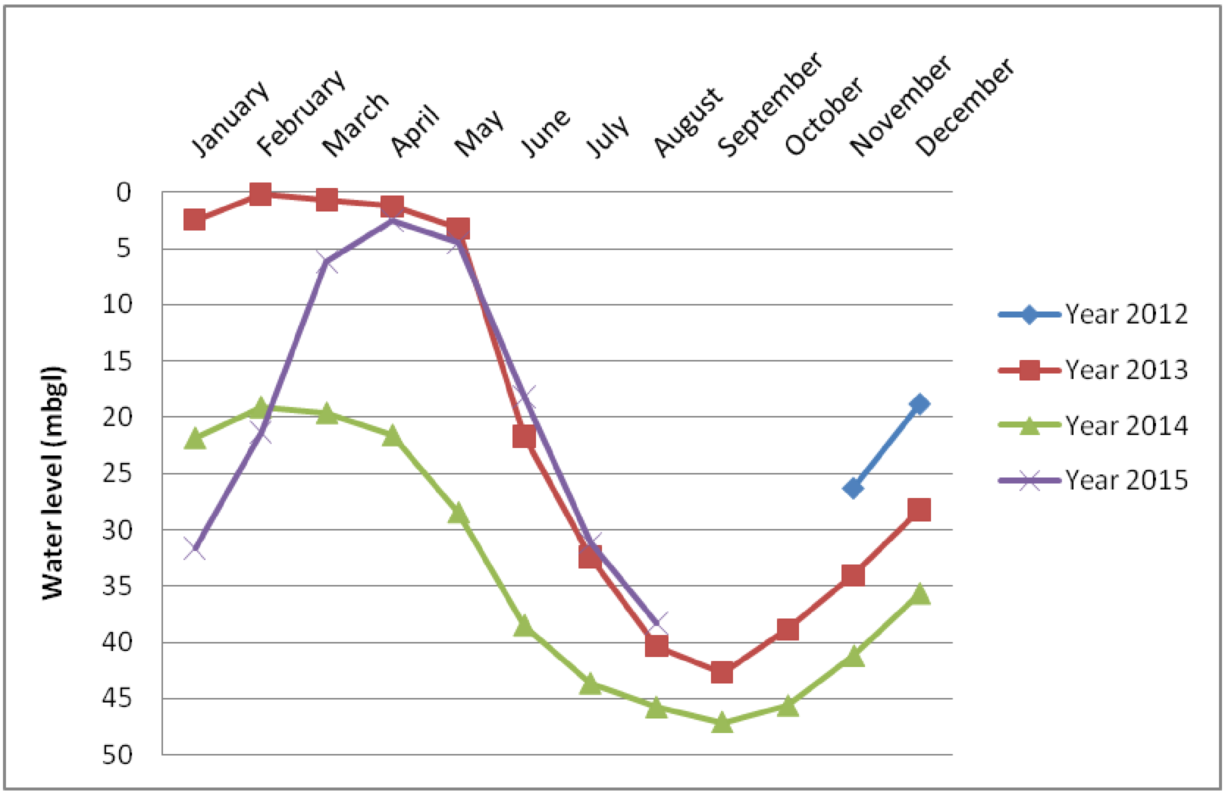
Water level variations for Tel Amara and Fourzol Monitoring wells are presented in Figure 11 and Figure 12. It is also to be noted that some farmers still irrigate from the Litani River during the first cropping season, when water is still available. During our Walk-through Survey in June, only two pumps were observed in this sub-area of the Litani River. According to our informant, Fourzol farmers have stopped irrigating from the Litani a long time ago due to pollution. "*How could we pollute with sewage the crop we eat ourselves*?" he says. He accuses some tenant farmers, belonging to the Bedouin group to be the owners of these pumps. This accusation seems biased as other local farmers have been observed to be irrigating with polluted water from the Litani at many places downstream.

Figure 11: Water level variation in the Tel Amara Monitoring Well (Quaternary aquifer).



Source: Author; based on data given by LRA Water Monitoring Service.

Figure 12: Variation of water levels in the Fourzol Monitoring Well (Quaternary aquifer).



Source: Author; based on data given by LRA Water Monitoring Service.

4.2.2. Impacts on direct users

Similarly to what has been described for the Hala Yahfoufa sub-area, the first negative impact on users, i.e., the lack of surface water, was the necessity to start relying on groundwater as an alternative to surface water depletion. However, due to their naturally disadvantaged position in terms of groundwater availability, farmers in this area developed different adaptation strategies and, are relatively more impacted by groundwater overexploitation than the users of the Hala Yahfoufa sub-area.

The most apparent consequence of Fourzol's poor water endowment is the cultivation of grapes and orchards. These crops were dominant in the landscape during our Walk-through Survey, while annual crops were much less cultivated, except for watermelons and wild cucumber, which were sometimes grown between fruit trees and vines. If cultivating grapes generally generates a high income for the farmers, limited water availability reduces their crop choice, reduces marketing opportunities and adaptation of strategies to meet the extreme climatic conditions. For example, our informant complained about the increasing difficulty to sell grapes and the frequent episodes of frost that often leads to substantially lower yields.

Other impacts are linked to the cost of accessing and abstracting groundwater. First, users had to multiply their wells in order to get sufficient well yields (since well deepening did not reflect an increase on water availability). Our informant described how he had to drill three wells to irrigate a 12 du plot. Furthermore, pumping costs in this sub-area are relatively high compared to other areas in the Quaternary aquifer with better water capacity, such as in the Ryak-Haouch Hala sub-area. First, this is due to the drop in the water table during the irrigation season requiring pumping from deeper levels. Second, the lower well yields require a longer irrigation time frame, i.e., longer pumping time, as reported by our informant. Third, in addition to generating higher pumping costs, low well yielding capacity leads to frequent interruptions of irrigations since a lot of wells dry-out after a short time (3-4 hours), which pushes farmers to stop irrigating and wait for wells to recharge before completing the required irrigation hours (a minimum of 6 hours/irrigation are required for grapes). This implies more time and labor, and is often an obstacle to proper irrigation scheduling.

In order to remedy this issue, some farmers have built small reservoirs (mostly earthen reservoirs) to stock water in order to complete irrigation. Most of these reservoirs are of small size and used individually. Only one collective reservoir used by four farmers was observed in our field visits. Water is pumped from their respective wells to the reservoir and then used alternately.

Naturally, all farmers switched to water-saving irrigation techniques in order to both reduce their consumption and their pumping costs. Elevated drip irrigation systems were observed in all vineyards during our field visits and were reported by our informant to have been adopted more than 15 years ago in Fourzol.

Finally, these obstacles in accessing and abstracting groundwater from the Quaternary aquifer seem to have pushed some farmers of this sub-area and other farmers in Fourzol to access the Eocene aquifer. According to our informant, some large farmers, using rotary technology, have drilled wells of 200-300 m depth and succeeded in getting substantially higher yields (up to 40 LPS). However, considering the important capital required for drilling deep wells, the number of farmers with the resources to use such wells seems to be limited. Our informant did not want to share much information about this subject (since drilling wells deeper than 150 m is illegal). He only said that one farmer drilled such a well in the sub-area studied and also mentioned a large potato industry in Fourzol that also might be using one. These commentaries could not be confirmed further.

Figure 13: Irrigation systems in the Litani-Fourzol sub-area.

Notes: 1. Fourzol agricultural plain planted with grapes and orchards under drip irrigation (Quaternary aquifer). 2. Well in Quaternary aquifer irrigating a vineyard. 3. Collective storage infrastructure built due to water shortage.

Table 7: Evolution of groundwater use in the Litani-Fourzol sub-area and impacts on users.

	Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (year 2035)
Irrigation	Irrigation from the Litani by gravity and Arabic wells to a lesser extent **Limited development of agriculture**	Irrigation from the Litani by pumping and Arabic wells to a lesser extent Drilling of few wells **Significant increase of irrigated areas**	Significant reduction in water supply from the Litani Start of drilling tube wells drilled in the Quaternary aquifer	Gradual multiplication of tube wells as a result of decrease in their discharge **Some wells drilled in the Eocene aquifer**	Further decrease in Quaternary well discharges Further decrease in water levels of wells drilled in the Eocene aquifer
Well depths (m b.g.l)	4-10 m	Between 10-15 m for shallow wells Between 50 and 100 m for tube wells	Data was not found	Present: Quaternary wells between 50 and 100 m since well deepening does not increase discharges Some wells drilled in the Eocene aquifer at more than 200 m	**Further drilling of wells in the Eocene**? Possibly 200 m and deeper
Water levels (m b.g.l)	1-5 m	Data was not found	Data was not found	2 m in the winter 40 m in the summer	**Unknown**
Impacts on users	Gradual shift from irrigation by gravity to pumping from the Litani		Groundwater ensured an alternative for the reduction in water availability from the Litani	The low water capacity of the aquifer resulted in the multiplication of wells, adoption of water saving techniques, building of storage infrastructure	Likely significant reduction in water levels, which will result either in the reduction of irrigated areas or accessing the Eocene aquifer

Source: Author.

4.2.3. Identification of competing users

Direct relations

1- Farmers of this sub-area cause direct impacts on each other as users sharing the Quaternary aquifer.
2- They are also directly linked to other farmers and residents using the Quaternary aquifer in the other sub-areas. However, due to the poor water capacity of that aquifer in their region, they are more negatively impacted by groundwater overexploitation than the other users.

Indirect relations

1- Farmers of this sub-area are negatively impacted by the Litani River up-stream users as the reduction of river flows has pushed them to use groundwater.
2- Farmers of this sub-area by using the Eocene aquifer might be contributing to the general overexploitation of that aquifer at the level of the whole study area. Accordingly, they are indirectly linked to the users of the Eocene aquifer in other sub-areas (mainly the Eocene sub-area).

4.3. Litani- Maallaqa sub-area

4.3.1. Evolution of water supply for irrigation

Being also located on the eastern side of the Litani River, surface water use evolved in this area similarly to what has been described for the Litani-Fourzol sub-area. According to a long established farmer and land owner,[38] the Litani remained the main source of irrigation for most of Dalhamye lands and this area of Zahle Maallaqa until the 1980s. First, as in Fourzol, water used to be diverted by gravity from the river and conveyed to plots through ditches. With the reduction in the Litani flow, motor-pumps started to be used and allowed irrigating a larger area, reaching the road of Deir Zanoun, which is 2 km away from the Litani. Gradually, with further reduction in surface water availability, wells started to be dug to complement irrigation needs. According to our informant, the first wells to be established were Arabic wells dug in lands located far from the Litani River. These wells would be used in late summer, when the river flow would become insufficient. However, the tube wells began expanding in all the sub-area, starting in the 1970s.

The USAID-LRBMS Survey for this region shows that most tube wells were drilled between 1970 and the early 1980s (Annex 6) (USAID-LRBMS 2012d). On the other hand, several tube wells were drilled very close to one another along the Litani in the region of Dalhamyeh in 1959, leading to the "*discovery*" of the "*Dalhamye Aquifer*" (Baldy 1960: P18 and 59-60). In fact, unlike in Fourzol, these wells were producing the highest yields from the Quaternary aquifer at that time, with discharges as high as 30 LPS. It is hard to identify the exact location of this prolific spot identified by Baldy, but it clearly was close to the Litani River. As described by our informant, the most prolific wells of this region are located along the Litani from Zahle Maallaqa Dalhamyeh. In fact, during our 'Walk-through Survey', more than 10 tube wells were identified in this region next to the Litani.

[38] Most of the information concerning this sub-area was given by Farmer No. 5, interviewed on June 25, 2014 (during the Walk-through Survey) and on November 26, 2015. Some information was also given by Farmer No. 4 who was interviewed on the same day of the Walk-through Survey.

Concerning well yields, the information given by our informant corresponds to Baldy's description. According to him, the first tube wells drilled in this area used to give average yields of 30 LPS, with some of them sometimes reaching 40 LPS. However, starting in the 1980s, yields began to decrease substantially by mid-July to around 20 LPS. In the 1990s, following further reductions in well yield, some of these wells were deepened to an average depth of 150 m b.g.l. Others, as reported in USAID-LRBMS Survey, are still between 50 and 90 m deep. No monitoring well has been found close to this sub-area, however, based on the synoptic measurements conducted for five wells in the framework of the latter survey, water levels seem to vary from 1-4 m in the winter to 20-24 m in the summer (early June 2011). As reported by our informants, no wells seem to have been drilled in the Eocene aquifer in this sub-area.

4.3.2. Impact on direct users

Following the depletion of surface water from the river, groundwater access allowed farmers in this sub-area to sustain agriculture. Until the 1980s, they were able to cultivate all types of vegetable crops throughout the irrigation season. With wells yielding around 30 LPS, they were clearly better endowed with groundwater than the Fourzol farmers. This gave them first of all a broader choice of crops and allowed them to cultivate water-thirsty crops throughout the irrigation season for several years. However, as it had been predicted by Baldy when observing new wells drilled in that aquifer in the summer of 1959, the intensive groundwater abstraction rapidly led to the drawdown of groundwater levels (Baldy 1960: P60).

The first impact was the reduction in water levels and well yields, which required the deepening of wells. This allowed farmers to sustain agriculture for a few more years, but caused the further lowering of groundwater levels and the reduction of well discharges. A major impact recently felt is the significant reduction in agricultural areas during the summer irrigation season. As described by our informant, "*6-8 years ago, well yields started to be significantly low starting on July 15, preventing farmers to practice a second season of vegetables.*" This is linked either to the insufficiency of well yields in comparison to crop water needs, or to the increase in pumping water. In fact, as in the case of the Litani-Fourzol sub-area, our informant describes that when farmers decide to plant a second season, they need to operate their well 24/7 from July to September in order to irrigate properly.

However, land tenure in Zahle Maallaqa and Dalhamye is an obstacle to the strategy of drilling more wells in the Quaternary aquifer or planting fewer perennial water-thirsty crops in response to water shortage, as done earlier in Fourzol. Most land owners in this sub-area are absentees and sometimes not even collecting the rent. They are not interested in increasing water availability in their plots or establishing vineyards or orchards. Furthermore, even if some tenants from the Bedouin tribe have illegally appropriated some plots during the war, as alleged by our informant, most of them lack the capital needed for drilling and equipping wells, especially considering the instability of sale prices and increasing production costs in agriculture.

Finally, drilling wells in the Eocene aquifer is also hindered by land tenure and the capital needed. The latter is a more limiting factor than for drilling wells in the Quaternary aquifer, not only due to higher capital needs for investment but also since farmers are not certain of the depth wells have to attain in order to reach the Eocene aquifer, and the fact, even after doing so there is no assurance that the will '*find water*' at all. Our informant further stated "*I will definitely be ready to drill a deep well if sufficient water is sure to be found at 200-250 m.*" He is encouraged by other high-yielding wells that have reached the deep aquifers in Zahle Maallaqa (on the other side of the Litani) or other neighboring regions in the plain. However, due to the limited number of such wells, he said "*I prefer to seek technical advice that would ensure groundwater availability before taking the decision to get the rotary in.*"

Table 8: Evolution of groundwater use in the Litani-Maallaqa sub-area and impacts on users.

	Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (year 2035)
Irrigation	Irrigation from the Litani by gravity **Limited development of agriculture**	Irrigation from the Litani by pumping Drilling of tube wells in the 'Dalhamye Aquifer' **Significant increase of irrigated areas**	Significant reduction in water supply from the Litani Multiplication tube wells drilled in the Quaternary aquifer	Deepening of tube wells as a result of decrease in well yields	Further decrease in Quaternary well discharges **Possibility of drilling wells in the Eocene aquifer**
Well depths (m b.g.l)		Tube wells between 50 and 100 m	Tube wells between 50 and 100 m	Tube wells between 50 and 200 m	**Possibly 200 m and deeper for wells in the Eocene aquifer**
Water levels (m b.g.l)		Data was not found	Data was not found	1-4 m in the winter 20-24 m in the summer	**Unknown**
Impacts on users	Gradual shift from irrigation by gravity to pumping from the Litani		Groundwater ensured as an alternative for the reduction in water availability from the Litani. The importance of water capacity of the 'Dalhamye Aquifer' allowed the cultivation of a broad diversity of crops	The importance of water capacity of the 'Dalhamye aquifer' allowed the cultivation of a broad diversity of crops. Well deepening sustained well yields. However, in recent years, further reduction in well yields resulted in the reduction of irrigated areas. Multiplication of wells was not possible due to land tenure constraints	Likely significant reduction in well yields which will result in further reduction of irrigated areas. Drilling the Eocene aquifer seems unlikely due to financial and land tenure constraints

Source: Author.

4.3.3. Identification of competing users

Direct relations

1- Farmers in this sub-area have direct impacts on one another as they are users sharing the Quaternary aquifer in this region.
2- They are directly linked to other farmers relying on the Quaternary aquifer in other sub-areas. Due to the relatively high capacity of the Quaternary aquifer in their region, they experienced the negative impacts later than farmers of Litani-Fourzol. Presently, however, even if water availability in their region is relatively higher in terms of well yields, they are constrained in their adaptation to water shortage by land access and property.

Indirect relations

1- Similarly to the users of Litani-Fourzol, farmers of this sub-area are negatively impacted by up-stream users of the Litani River, since the reduction in river flows pushed them to use groundwater.
2- Drilling wells in the Eocene aquifer and underlying the Quaternary aquifer contributes to the general overexploitation of that aquifer, and also creates indirect links with the users of the Eocene aquifer in other sub-areas. However, the conditions to drill such wells (direct-occupation of land, capital, and technical knowledge in water availability in deep aquifer) are not met at the present moment.

Figure 14: Irrigation systems in the Litani-Maallaqa sub-area.

Notes: 1. Well equipped with axial pump drilled in the Quaternary aquifer. 2. Well in concrete building next to the Litani River at Maallaqa (Quaternay aquifer). 3. Well irrigating vegetables under green-houses next to the Litani River (Quaternary aquifer). 4. Women laborers preparing a plot for planting.

4.4. Litani-Barr Elias sub-area

4.4.1. Evolution of water supply for irrigation

The evolution of irrigation with surface water from the Litani River occurred in a similar way as in the other two sub-areas mentioned above. As described by our informant,[39] lands located on the banks of the river used to be irrigated by gravity until the early 1960s. With the expansion of the usage of motor-pumps coupled with the general development of agriculture, the area irrigated with surface water from the Litani rapidly increased, constituting approximately one-third of the total agricultural area in the Barr-Elias Plain (between 10,000-15,000 du as estimated by our informant).

However, the reduction in Litani River flows and high surface water pollution[40] levels did not systematically lead to the conjunctive use of groundwater and surface water at a general scale, as it happened in Litani-Fourzol, and Litani- Mallaqa. This is due to a combination of two factors, found also in each of the previous sub-areas analyzed. The first factor is linked to the natural lack of groundwater availability. As in Fourzol, this region of the Quaternary aquifer is characterized by low groundwater capacity and transmissivity, leading to yields that do not exceed 5-7 LPS per well. According to our informant, "*Some farmers have attempted to go as deep as 150 m, without getting more than 1 ½ inch of water.*"

Second, as described for Zahle Maallaqa and Dalhamye, the predominance of land tenancy hindered the multiplication of wells as a means of adapting to water shortage. Although more land owners from Barr Elias remain as residents of the town (unlike in Zahle Maallaqa), most of them have left agriculture and rented their lands. The tenants (largely belonging to the 'Arab El Hrouk Bedouin' tribe) rent plots on a yearly basis, which prevents them from establishing permanent wells as they would have to bear the cost of the investment since they do not own the land they cultivate. The only alternative remains irrigating with polluted water from the Litani River. As described by our informant, there are still around 15 to 20 farmers who use the river to irrigate crops during the first irrigation season. As observed during our Walk-through Survey, water is pumped from the river to ponds or ditches and then conveyed by gravity or pumping to the plots (depending on the plot location), where it is pumped again to the irrigation systems. Following the first season's harvest, the plots are kept mostly fallow due to the lack of groundwater availability to be used as an alternative. In fact, the rare wells found are used only during the first irrigation season. For example, our informant uses five wells that produce a total yield of 30 LPS until the beginning of the summer. These wells allow him to plant 150 du of vegetables until July, after which water is not sufficient anymore to plant another season. He reports that there are no more than ten wells in total in this sub-area, the smallest number of wells (less than one well for 100 du) when compared to the other sub-areas without access to surface water.

[39] Most of the information concerning this sub-area is given by Farmer No. 2, interviewed on June 23, 2014 (during the Walk-through Survey) and on November 27, 2015. Some information was also given by Farmer No. 3 who was interviewed on the same day of the Walk-through Survey.

[40] Based on the water quality survey conducted by USAID-LRBMS (2011), the highest levels of surface water contamination were found in the mid-upper basin between Ryak and Barr Elias, which concentrates the largest share of the population and industries of the basin. Pollution sources are numerous and include untreated wastewater discharges as a primary source of pollution and agriculture over-fertilization.

Table 9: Evolution of groundwater use in the Litani-Barr Elias sub-area and impacts on users.

	Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (year 2035)
Irrigation	Irrigation from the Litani by gravity **Limited development of agriculture**	Irrigation from the Litani by pumping **Significant increase of irrigated areas**	Significant reduction in water supply from the Litani No drilling of wells due to the poor capacity of the Quaternary aquifer	Irrigation from the Litani River	Reduction in irrigation from the Litani
Well depths (m b.g.l)	No wells	No wells	No wells	Only some tube wells between 50 and 100 m	**Possibly 200 m and deeper for wells in the Eocene aquifer**
Water levels (m b.g.l)		Data was not found	Data was not found	Data to be completed	**Unknown**
Impacts on users	Gradual shift from irrigation by gravity to pumping from the Litani		No alternative for the reduction in water availability in the Litani due to the poor capacity of the Quaternary aquifer	Gradual decrease in irrigated areas. At present, water is only sufficient for planting one irrigation season. Irrigation is done from sewage water	Further decrease in irrigated areas and/or irrigation from sewage, if the pollution problem is not addressed

Source: Author.

4.4.2. Impact on direct users

The poor groundwater capacity of the Quaternary aquifer, together with the type of land tenure and the lack of capital in this sub-area, leave no alternative for most of the farmers but to keep irrigating from the Litani despite its pollution levels. During our Walk-through Survey, it was possible to observe that the Litani River was very unclean with residue and garbage, and was receiving direct sewage effluent from adjacent houses and settlements. The farmers we met during the survey were embarrassed to let us know that they too were using it. Most of them acknowledged the risk associated with irrigating with sewage water, but claimed that their lands have legal rights to be irrigated from it. They blamed the state for not controlling sewage effluent discharge and for not putting in place water treatments plants. Some of them, such as our informant, chose to plant tuber or bulb crops to reduce the risk of pollution, but many of them were observed to be irrigating leafy vegetables (such as lettuce) with edible parts directly exposed to pollutants. Here too, the Bedouins were accused of irrigating with polluted water, but it was observed that some local farmers were also doing the same.

Groundwater unavailability has had an impact in the reduction of the cultivated area during the second irrigation season, and in limiting the choice of cropping patterns. Most of the farmers keep their lands fallow from July onwards. Moreover, they are often forced to plant short-cycle crops (radish and lettuce) to avoid the risk of water shortage (either from the Litani River or from the rare wells found in the area).

Even though it is relatively cheaper in terms of energy costs than irrigation from wells, irrigation from the Litani River also involves significant labor and time costs, as water is often pumped several times in order to be conveyed to the plots. Furthermore, the limited amount of water in the river often leads to conflicts between farmers. During our Walk-through Survey, a group of farmers reported a conflict that had occurred the preceding week: one farmer had cut the plastic pipes belonging to another farmer who was using them to convey water from the Litani to his plot. The first farmer justified his act by saying that the second farmer had no rights to irrigate with Litani River water.

During periods of drought some farmers are forced to buy water from other sources. In the summer of 2014, some farmers reported to have conveyed water from wells located in the Eocene aquifer in Faour in order to save their crops. Other farmers were reported to rely on wells located in Zahle Maallaqa on the other side of the Litani River during periods of high drought, when water in the Litani is not sufficient to meet their requirements during the first irrigation season.

Although it is very likely that water availability in the Litani River will be further reduced in the coming years, conveying water from the Eocene aquifer cannot be expected to be adopted as a permanent strategy by the farmers of this sub-area. As for farmers in the Litani-Maallaqa sub-area, most of them are tenants with low investment capacity "*No farmer can afford to buy 3,000 m of 6 inch plastic pipes in order to convey water from Faour; and this is without counting the high cost of energy that it involves to pump water*" said our informant. Land owners are more present than those of Maallaqa and Dalhamyeh. Hence they could increase their benefits from land rent revenues if they ensured water availability for tenants. However, drilling wells in the Eocene aquifer underlying the alluvial plain, or renting Eocene wells in *Jbaily* or Terbol Mountain and conveying water to their plots do not seem to be worth the investment. This could be explained by several factors such as the lack of financial profitability on the long term (due to the small size of plots to be rented), the risk associated with investing in drilling a deep well without finding water, and the legal requirements for well drilling.

4.4.3. Identification of competing users

Direct relations

1- Although small in numbers, farmers of this sub-area, have direct impacts on each other as they are sharing the Quaternary aquifer in this region.
2- If they were using wells more extensively, they would be the most vulnerable to the overexploitation of the Quaternary aquifer by users in other sub-areas, due to the relatively low capacity of this aquifer in their region.

Indirect relations

1- Farmers of this sub-area are the most negatively impacted by up-stream users in the Litani River. Given their limited access to groundwater, they are forced to irrigate with polluted water and to keep their plots fallow, starting July.
2- Financial, land tenure and legal constraints hinder the access of users in this sub-area to the Eocene aquifer, at the present moment. If these conditions are met in the future, relying on the Eocene aquifer (by accessing the Eocene aquifer locally or conveying water from the Eocene aquifer outcropping in Barr Elias or in Terbol Mountain) would contribute to the general overexploitation of that aquifer and consequently impact the users of this aquifer in the other sub-areas.

Figure 15: Irrigation systems in the Litani-Barr Elias sub-area.

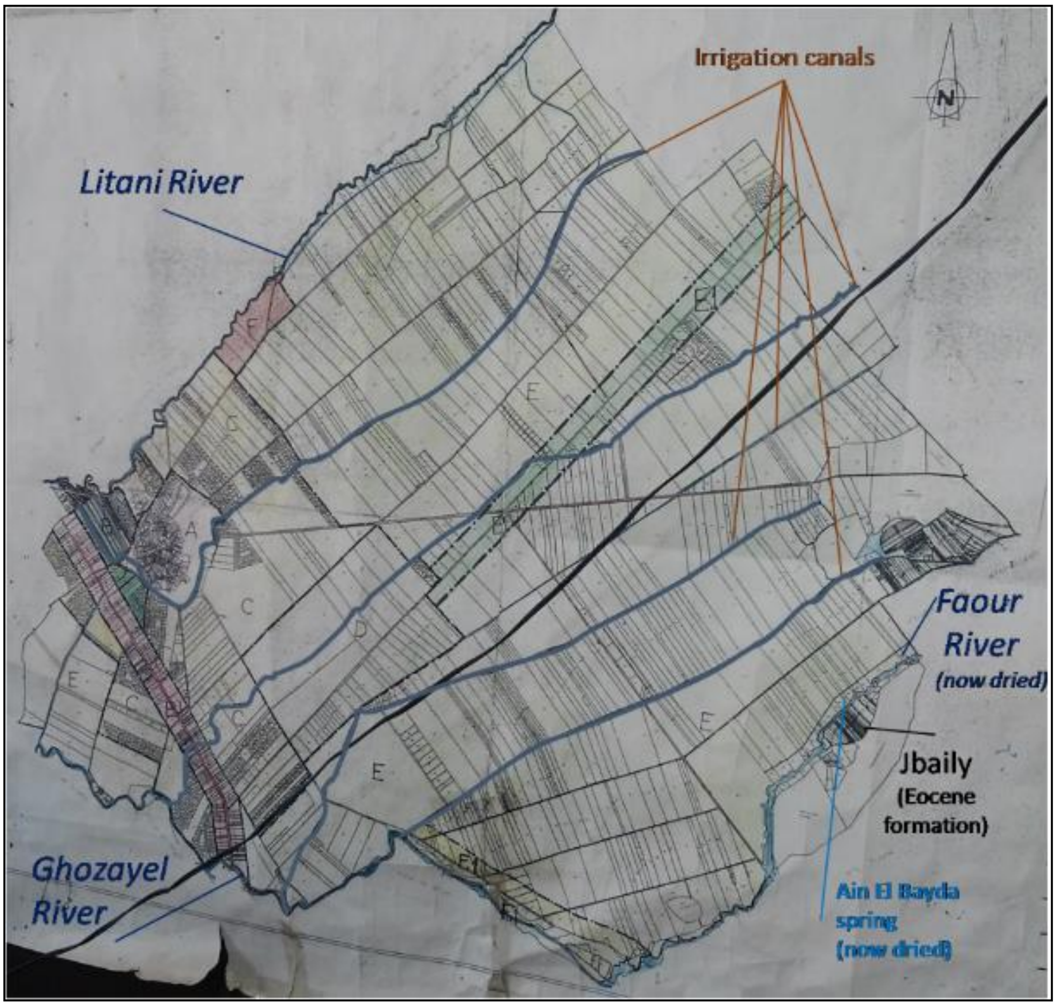
Note: Individual pumps abstracting polluted water from the Litani River at Barr Elias.

4.5. Ghozayel sub-area

4.5.1. Water supply for irrigation

Until the late 1960s, the '*Nabeh Ras El Ain*' Spring of Terbol and the other small springs that used to sprout from the Eocene aquifer at the foot of the mountain range, formed a permanent river known as the '*Naher El Faour*'. This river used to flow in a southern direction along the Terbol Mountain, pass along *Jbaily* where it used to be fed by other springs flowing from this small outcrop of the Eocene formation, before joining the Ghozayel River at the level of Barr Elias. The river also used to irrigate a substantial part of the Barr Elias Plain. According to interviews and as illustrated by an old map of the town, water used to be diverted by gravity through four large earthen ditches, from where it was distributed to plots (FFigure 16). According to our informants,[41] the Faour River flow used to be abundant until the month of June, ensuring irrigation for most of the Barr Elias Plain during the first irrigation season. During the summer it used to decrease, requiring the organization of longer water turns that used to lead to violent disputes between farmers.

Figure 16: Barr Elias old irrigation system supplied by the Faour River.



Source: Barr Elias Municipality (modified).

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[41] Most of the information concerning this sub-area is given by Farmer No. 33, interviewed on January 23, 2014 (Focus Group 1) and on November 18, 2015. Some information was also given by the Mayor of Barr Elias and some employees in the municipality that we met on that same day.

With the rapid expansion of wells drilled in the Eocene aquifer in Terbol in the 1960s, the flow of *Ras El Ain* and the other springs arising from the Eocene started to decrease substantially (Baldy, 1960). Starting in the 1970s, these springs stopped flowing in the summer, leading to the disappearance of the main water source for irrigation in this sub-area. As an alternative, farmers started pumping water from the Ghozayel River. At first, this river was used only to complement irrigation from the Faour River during the summer planting season, but following the further decrease of water table in the Eocene aquifer, it rapidly became the only surface water resource.

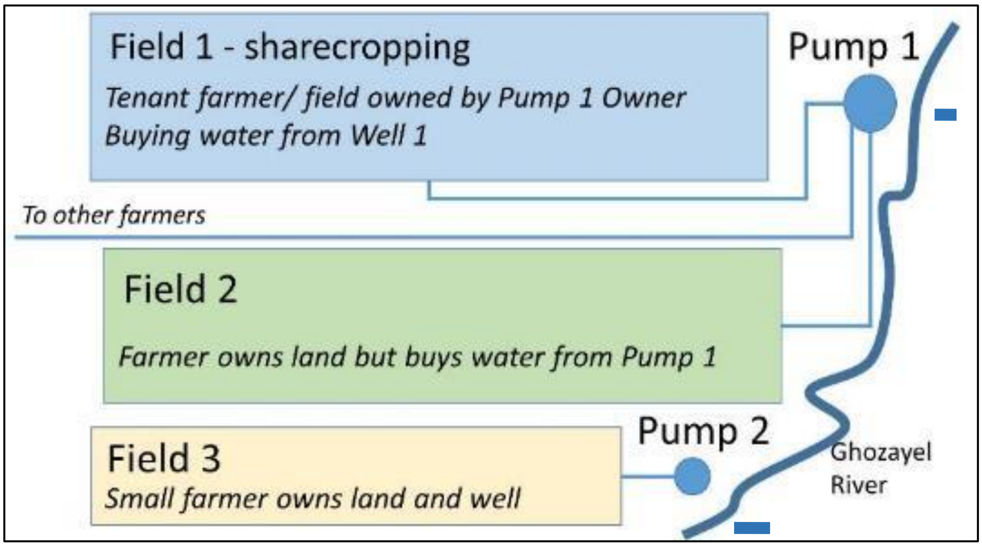
The substantial flow of the Ghozayel River allowed Barr Elias farmers to establish important irrigation infrastructure and further extend their irrigated areas. In the late 1960s, some of the farmers owning large plots started to replace mobile motor-pumps with fixed pumps. Underground pipe systems[42] were built, conveying the pressurized water into ditches dug in different locations in the plain (depending on the plot location) where it was stored and pumped again and conveyed to the plots through smaller pipes. During our Walk-through Survey, we counted more than 20 large fixed pumps on the Ghozayel and observed the outlets of underground pipes discharging water into the ditches in the plain. Pumps have high discharges and can irrigate from 300 to 600 du. Today, around 70% of Barr Elias Plain is estimated to be irrigated from the Ghozayel River through these systems. Crops are planted throughout the irrigation season and include all types of annual vegetables. Fruit trees are also planted but to a smaller extent.

Pumps are mostly owned by a few land owners from Barr Elias, and each one of them operates several pumps. There are different types of arrangements for the use of pumps that vary according to the type of land occupation.[43] The most common type is a share cropping arrangement proposed by the pump owner. The pump owner provides access to land and water, and the tenant-farmer pays for the other production factors. Profit is equally shared (one pump can be used by several sharecroppers). There are also several cases where pump owners lease their lands and provide access to water at a cost. Farmers can also cultivate their own land plot and have access to water from the pump owners by paying a fee. The less common type (linked to small land owners) is when land is under direct occupation and the farmer uses his own pump. These different types of arrangements are summarized in Figure 17.

[42] The first conveyance systems were made by concrete (*eternite*) pipes and were later replaced by metallic pipes.

[43] These types of arrangements have significantly changed from the time the first farms were irrigated by the Ghozayel until today. Similarly to the use of wells in Terbol, as it will be later developed, these arrangements are closely linked to the type of land-occupation and evolved as part of the general agrarian transformations that occurred since the development of irrigation in the 1960s: The general trend seems to be that direct use of pump and land by the pump owners is giving place to tenancy and share-cropping arrangements, where pump owners provide access to land and water.

Figure 17. Pump arrangements in Barr Elias.



Groundwater use in Barr Elias is less compared to surface water use from the Ghozayel River, but it ensures water for irrigation for a significant agricultural area. According to our informants, there are around 10 wells used in this sub-area owned by six or seven owners, all located at the foot of the *Jbaily*. Drilled in the Eocene aquifer, they provide high discharges (average of 40 LPS, with some of them reported to reach 60 LPS) and can irrigate large plots (between 200 and 300 du depending on the yields). The total area irrigated by these wells is around 2,000 du (5% of Barr Elias agricultural land use), and is cultivated with potato and vegetables throughout the irrigation season. The first well was drilled in the 1970s by a large land owner and farmer who used to irrigate his plots from '*Naher El Faour*'. The high yields given by this well allowed him to increase his irrigated area and, later, he drilled another well and further increased his farm size. At the present moment, the heirs rent out the farm to a large farmer (from Beirut) who cultivates some 1,000 du of potato and vegetable crops. Another example is a local family who drilled wells in the 1990s and, today, produces around 500 du of corn and vegetables in the same area he cultivates. In this case, wells and land are used by the owner.

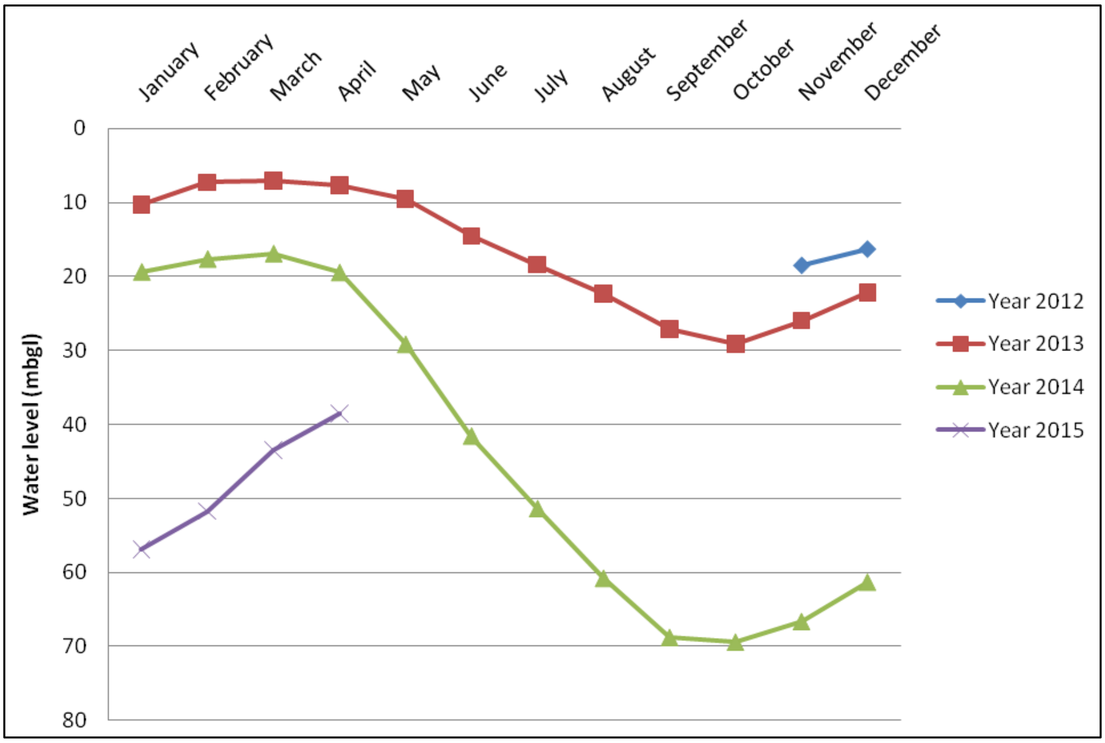
In addition to these wells used as a main source of water supply for irrigation, there are one or two wells used to complement irrigation from the Ghozayel during the periods of drought. They were established by one of the pump owners[44] on the Ghozayel River Basin in the 1970s, and have been described as used several times during years of drought. They were reported to have been used for irrigation during the summer of 2014, and also at the end of the summer in 2015.

Wells in this area range between 100 and 130 m in depth and have not been deepened further since they were drilled. According to one of our informants, depths might be greater but kept secret by well owners due to the legal consequences. Unlike the wells of the Quaternary aquifer, discharges from these wells have not been reduced owing to the substantially higher water capacity of the Eocene aquifer. However, water levels are reported to have significantly decreased since the beginning of well use and they vary substantially between winter and summer, especially in the last couple of years. For example, one of the well owners has been reported to have lowered his pump from 35 m in the winter to 80 m the summer (2015) in order to be able to maintain sufficient yields.

[44] This is also one of the informants of this study.

No historical or current water level data have been found in this area of the Eocene aquifer. However, recent water level variation in the Eocene aquifer in the area of Terbol was registered by the LRA monitoring well (6 Km away from *Jbaily*). These variations are likely to be closely linked to the water level variations of the Eocene aquifer in this area. Differences in water levels recorded showed changes of more than 20 m between winter and summer during years of normal rainfall. The shallowest water level measured was 7 m b.g.l in March, and the deepest water level was 30 m b.g.l in October. During the extremely dry year of 2014, a 54 m water level variation was recorded, with 16 m b.g.l being the shallowest level in March and 70 m the deepest level recorded in October (Figure 18).

Figure 18: Water levels variation in the Terbol monitoring well (Eocene aquifer).



Source: Author based on data given by LRA Water Monitoring Service.

4.5.2. Domestic water supply

As in many towns in the Central Bekaa, the main source of domestic water supply for Barr Elias is the Chamsine Spring, from which water has been provided through domestic piped water networks for a long time. However, similarly to what has been described for Ryak-Haouch Hala, private house wells (drilled in the Quaternary aquifer) have proliferated due to frequent water supply cuts in the public network, especially during the summer. One of our informants, a resident from Barr Elias, reported that "*there are thousands of housing wells in Barr Elias, at least one well for every house in Barr Elias,*" which brings the number of wells to at least 5,000. These wells were reported to be either old dug wells or more recently drilled tube wells with shallow depths (varying between 9 and 11 m). As described for the irrigation wells drilled in the Quaternary aquifer in the agricultural lands located close to the Litani, private house wells have low yields (3-4 LPS) but can provide sufficient water as an alternative to public network supply. As in Ryak-Haouch Hala, these wells are only used for domestic supply, while drinking water needs are covered by bottled water.

In recent years, several projects have aimed at increasing the domestic water supply from the Chamsine Spring by drilling more wells next to the spring pond in the Cretaceous aquifer. Three wells were drilled in 2006 by the Red Cross Association (as part of an aid program after the 2006 'July War' with Israel). Moreover, as part of a larger plan, the government through the Council for Development and Reconstruction (CDR) and funds obtained from the Kuwaiti Fund, started the rehabilitation and extension of the piped water networks supplied by Chamsine. This project aimed to improve the water supply in the towns already connected to the public water networks, and also to extend the public supply to more towns. The essential part of the project has been implemented, including six wells drilled next to the spring, and a central reservoir located at the level of Anjar.

In the last couple of years some wells have started to be operated in the summer in order to complement the water supply from the spring. However, as reported by our informants, the result of which has been only a slight improvement in the water supply. "*From July to October, we use our wells at least 3 days a week*" reports our informant. The main reason is the substantial increase in water demand caused by the flow of Syrian refugees (among which a significant share has rented apartments in Barr Elias and are, therefore, supplied by the public network). Another problem reported by the Mayor of Barr Elias is the general poor service provided by the BWE regarding the operation and maintenance of domestic water supply infrastructures. Importantly, a noteworthy discovery is the unexpected decrease in the discharge of the pumping from the Chamsine Spring as a result of the operation of the new wells, as reported by the director of the Chamsine Pumping Station.[45] This will be further developed in the section describing the evolution of groundwater use in the Anjar-Chamsine Aquifer.

4.5.3. Impacts on users

The farmers in this area were negatively impacted by the exploitation of the Eocene aquifer in the area of Terbol. With the drying-out of Naher El Faour, they were deprived from a water source that naturally arrived to their area and was distributed to plots by gravity. However, the flow of Naher El Faour alone would not have been sufficient to sustain the development and intensification of agriculture that occurred in the area. This area was favored by its location upstream on the Ghozayel River, one of the largest rivers of the Litani Basin. Although accessing the Ghozayel River required substantial private investments and significant pumping costs, and despite the fact that some farmers probably benefited more than others given their position as pump and land owners, in general, users of the Ghozayel River were among the best positioned in terms of water access in the study area.

This situation is not likely to last as farmers seem to be handicapped by serious water shortages at the beginning of the second irrigation season. While it is not possible to confirm if water shortage problems are linked to a reduction in the Anjar and Chamsine spring flows as a result of groundwater abstraction in the Anjar-Chamsine Aquifer (this will be developed in the following section), the reallocation of water from these springs for domestic water supply as projected by the BWE Master Plan would certainly reduce water availability in the Ghozayel. These plans, however, threaten water access for these farmers who will be forced to look for other sources of water supply.

With the low water capacity of the Quaternary aquifer in Barr Elias, farmers would have to rely on the Eocene aquifer. Depending on the location of their plots, farmers would either have to drill wells in the *Jbaily* outcrop or access the Eocene aquifer underlying the alluvial plain. If this is

[45] Interviewed on January 14, 2015.

financially possible, groundwater abstraction from the Eocene aquifer will likely be unsustainable in the future (if we consider the evolution of wells used in the Eocene aquifer).

At the level of Barr Elias, *Jbaily* was a windfall for farmers owning plots next to this small outcrop of the Eocene aquifer. First, pumping locally from this aquifer saved time and labor for conveying water from the Ghozayel. Second, the capacity of the Eocene aquifer allows the irrigation of large areas of water-thirsty crops throughout the irrigation season. Unlike the users of wells drilled in the Quaternary aquifer, they did not have to suffer from a water shortage during the drought season as they were able to sustain the yields despite the significant lowering of the water table. However, compared with their situation 30 years ago (when they could use the Faour River water by gravity), at present, they have to meet substantially higher pumping costs and are much more vulnerable to drought. And, of course, such a shift to the Eocene aquifer further increases the overall pressure on this resource.

Figure 19: Irrigation systems in the Ghozayel sub-area.

Notes: 1.2. Large pumps on the Ghozayel River in an exceptionally dry summer (2014). 3. An irrigation ditch in Barr Elias Plain supplied from the Ghozayel pumps. 4. Outlet of a pipe conveying water from Ghozayel pumps to the Barr Elias Plain.

Table 10: Evolution of groundwater use in the Ghozayel sub-area and impacts on users.

	Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (year 2035)
Irrigation	Irrigation from the Faour River by gravity **Limited development of agriculture**	Gradual decrease of irrigation from Faour River and start to pump water from the Ghozayel River **Significant increase of irrigated areas**	Establishment of large irrigation systems relying on the Ghozayel Drilling of some wells in the Eocene aquifer at the level of *Jbaily*	Irrigation from the Ghozayel River. Reduction in water availability from the Ghozayel in the recent years	Further reliance on Eocene wells as a result of the reduction in water availability from the Ghozayel River
Well depths (m b.g.l)	No wells	No wells	100-150 m	100-150 m	**Possibly 200 m and deeper**
Water levels (m b.g.l)		Data was not found	Data was not found	7-30 m b.g.l	**Significant decrease**
Impacts on users	Gradual shift from irrigation by gravity from the Faour River to pumping from the Ghozayel River		The large water availability in the Ghozayel River allowed the cultivation of a broad diversity of crops throughout the summer Relying on the Eocene aquifer also allowed the establishment of large farms However, water availability from both the Ghozayel River and wells drilled in the Eocene has been significantly reduced		Increased pumping costs as a result of further reliance on Eocene wells

4.5.4. Identification of competing users

Direct relations

1- Until now, the Ghozayel River allowed farmers of this sub-area to irrigate their lands through different types of individual and collective systems. Globally, farmers succeeded in ensuring a collective use of this river. However, the reduction in water availability experienced in recent years and, which is very likely to be exacerbated in the future years, will require collective arrangements among these farmers and with upstream and downstream users in order to manage water scarcity.
2- The most important user with whom they will share their actual resource with is the Bekaa Water Establishment (BWE). At present, the latter is supplying water from the Chamsine Spring for domestic water supply and is projecting to reallocate a significant amount of water both from this spring and the Anjar Spring for future domestic supply projects.
3- They are also directly linked to upstream farmers, i.e., farmers using the Anjar Spring (represented by Anjar Irrigation Committee). The latter are favoured by their upstream position but, as discussed later, will also be competing with the BWE on the use of the spring.
4- Finally, they directly impact downstream uses, i.e., farmers of Marj and Establ with whom they already have allocation conflicts periods of drought.

Indirect relations

1- Using the Eocene aquifer as an alternative for the reduction in surface water availability would increase the negative impacts on the actual users of the wells in *Jbaily.*
2- This will also increase the pressure on the use of the Eocene aquifer in all other sub-areas. The most negatively impacted farmers would be the users of the Eocene aquifer in the Terbol region (i.e., mainly the farmers of Terbol, Hoshmosh and Faour, and few farmers in Kfarzabad using wells drilled on the other side of *Jbaily)*.

4.6. Anjar-Chamsine sub-area

4.6.1. Water supply for irrigation

The farmers in this sub-area rely on the Cretaceous aquifer as a main source of irrigation supply, either from the Anjar Spring or from wells drilled in Cretaceous formation. The Quaternary aquifer covers most of the agricultural area but seems to have a small depth, as all of the identified wells located on the alluvial plain are described to be accessing the Cretaceous rocks underlying it (USAID-LRBMS 2012d). The Eocene aquifer (the part of *Jbaily* found in Kfarzabad) is also used by some farmers in Kfarzabad, but to a lesser extent. The Anjar Spring is a large spring discharging from the Cretaceous aquifer at the level of Anjar Town. It has a large flow (yearly average of 2,200 LPS) and forms with the Chamsine Spring (average discharge of 440 LPS) the Ghozayel River (El Hakim 2005).

Irrigation from the Anjar-Chamsine springs is described to have been already developed since the eighth century through "*large stone blocks raising the spring outlet and distributing water throughout the valley via channels*" (UN-ESCWA and BGR 2013, P49). Today, the springs are independently used. While the Chamsine Spring is harnessed by the government for domestic water supply, the Anjar Spring is exploited by the Anjari community for irrigation use. Unlike the other historical spring-based irrigation systems supplying the Bekaa villages (e.g., Qabb-Elias, Zahleh, Ryak-Haouch Hala and Khrayzet), the actual irrigation system and village are relatively recent. They date back only to the early 1940s, and were built by the French Government for the settlement of an Armenian community that was displaced from their original region in Turkey during World War 2 (USAID-LRBMS, 2012g).[46]

The area irrigated by the system was originally 8,000 du and, at present, has been reduced to 5,300 du due to urbanization. It has a unique land organization compared to the other villages of the Bekaa. It is divided into plots of 7 du each, where each plot is the land unit irrigated by one water turn. From the establishment of the system until the early 1960s, water used to be conveyed from the spring pond to the canal system by gravity. The management of the irrigation system is also unique as compared to the other spring-based systems of the Bekaa. Since its establishment, it has been managed by an ‘Irrigation Committee’ representing farmers and employing persons from the village to perform operation, maintenance and administration tasks (USAID-LRBMS 2012g; Al-Jawhary 2012).[47]

Water supply to this system also evolved from gravity supply from the spring, to pumping from the spring pond, until recently when groundwater started to be needed. In the early 1960s drought episode, the spring flow started to be reduced significantly during the summer and rapidly reached a point where pumping water from the spring was required in order to ensure the needed discharge for the irrigation system. According to our informant,[48] two large pumps (60 HP each) were established in 1962 by the Anjar Irrigation Committee and have been used ever since when the spring flow was found to be insufficient.

In 1983, following an episode of drought, the 'Irrigation Committee' had to rent the use of a nearby well because the pumps alone were not sufficient. The following year, the power of one of the pumps was increased in order to ensure sufficient water during a drought. In 2014, within the framework of a development project aiming at improving water access to the Syrian refugees, two wells (at a depth of 70 and 65 m b.g.l, respectively,) were drilled next to the spring pond in order to secure an alternative supply for the spring whenever needed, and were used during the exceptional drought that summer. However, the pumps are not used every year as the spring flow is closely correlated to the amount of yearly rainfall. Records kept by our informant (since 2007) show that pumps were used 5 out of 9 years starting at different dates each year, going from as early as April 10, 2014 to July 2 , 2015 (Table 11).

The village also includes a significant agricultural area that was not initially included in the irrigation system, as it is located at a higher elevation from the spring (south-east of Anjar). This area is divided in to smaller plots of 5 du each. Our informant recalls that this area used to be planted with rain-fed crops until the early 1960s, when a farmer from Zahle established a motor-pump on the Ghozayel and started irrigating some plots (reportedly not more than 200 du) through sharecropping arrangements with Anjari land owners. With the beginning of the war in 1975, this farmer left the area. Thereafter, the local farmers started to drill wells in this area. Some of these wells are directly drilled in the Cretaceous aquifer, which is located

[46] The modern village of Anjar was created in 1939 by the French Government for the resettlement of 5,000 Armenian refugees coming from the Mussaler area in Turkey (*Moussadagh* in Turkish), after this region was granted to the Turkish Government by the French in return to their neutrality in World War ii preparation. The land (1,800 ha) was purchased by the French from a local Turkish Bey, with the financial contribution of an Armenian Foundation. Anjar began as an Armenian camp established in mid-1939 over swampland and ended up as a city with 1,062 houses and 1,250 families by mid-1941 (USAID-LRBMS 2012).

[47] A detailed description about the organizational set-up of Anjar Irriation Committee is given in the Master’s thesis of Al Jawhary (2012) and USAID-LRBMS (2012).

[48] This informant is the person in charge of O&M employed by the Anjar Irrigation Committee and was interviewed on November 27, 2015.

upstream of this region and convey water to the plots through piping systems, while others are drilled inside the plots, through the Quaternary aquifer. As described by our informant, they were first drilled at a depth of 50 m and were later deepened to around 100-120 m due to the lowering of water levels. They have significant discharges (between 30 and 40 LPS) that allow them to irrigate up to 200 du. However, each well does not irrigate more than 100 du (20 plots) due to land use constraints.[49]

Three types of wells and land-use arrangements have been reported. In the first, plots are rented by well owners who generally only own a small number of plots. The second type of arrangement is sharecropping where well and land owners, respectively, apportion in common their well and water and share the revenues. The third type of arrangement is water sales, where well owners sell water (by the hour) to three or four land-owners cultivating their plots under direct-occupation. In total, there are no more than ten wells owned by six or seven persons. Given the high and stable well discharges, these plots are generally planted with vegetables throughout the irrigation season.

In Kfarzabad, groundwater is the main source of irrigation supply. Although the Chamsine Spring is located on the border of the town, it used to irrigate only part of the Kfarzabad Plain until the 1940s-1950s as recalled by one of the farmers we met in this area [50]. Since the construction of the pumping station and the domestic water supply networks, the Chamsine Spring is only used for domestic water supply. There is also a wetland south of Kfarzabad, but it is only used to irrigate few plots located next to it, and that too, through mobile pumps. According to our informants in Kfarzabad, the first wells started to be drilled in the 1960s and had expanded progressively from the 1970s until the 1990s. Today, there is an estimated 100 wells.

Most of the wells surveyed by the USAID-LRBMS Project were drilled in the Cretaceous aquifer, either directly or through the Quaternary aquifer. Similarly to Anjar wells, they all have high discharges (between 40 and 50 LPS). Depending on the specific land tenure (and also possibly linked to well discharges), these wells can be located directly on the cultivated plots or drilled on other land plots and, be equipped with piping systems conveying water to the plots. As reported by our informants, most of the wells and lands are under direct use, but there is also a significant number of wells being rented-out along with land plots or used under sharecropping arrangements. Thanks Owing to the relatively flat topography of the mountain, large parts of the Cretaceous formation were excavated and turned into agricultural fields.

Well depths vary from 100 to 140 m and mostly have significant yields allowing the cultivation of all types of crops throughout the irrigation season. Both in Anjar and Kfarzabad, fruit trees occupy a significant part of the cultivated land since direct-occupation of lands is the prevalent land-tenure arrangement. Based on USAID-LRBMS synoptic measurements (only conducted for five wells in Kfarzabad), there seems to be a substantial variation in water levels between wells (between 10 m b.g.l and 70 m b.g.l with no correlation with well elevations). Insufficient measurements do not allow the determination of water level variations between summer and spring seasons. A monitoring well was established by the LRBMS Program in Anjar, but real time data could not be obtained due to technical problems in the data logger. Synoptic measurements (for three wells) identified variations as high as 41 m and as low as 4 m.

[49] In order to irrigate 200 du of lands, 40 plots located one next to another must be available, which is difficult to be ensured since land owners generally do not own more than one or a small number of plots.

[50] Informants of Kfarzabad include: a former mayor interviewed on September 18, 2013 as part of the Key informant Survey. Farmers Nos. 24, 25, 26 and 27 were interviewed on December 11, 2015 and Farmers Nos. 28, 29, 30 and 31 were interviewed on December 15, 2015, during our field visits.

Table 11: Years and starting dates of the use of pumps at the Anjar Spring.

Year	Starting Date
2007	June 13
2008	June 6
2009	**Not used**
2010	July 16
2011	**Not used**
2012	**Not used**
2013	**Not used**
2014 (two wells added)	April 10
2015	July 2

Source: Author, based on information from Anjar Irrigation Committee.

4.6.2. Domestic water supply

As described earlier, this sub-area includes a historical source of domestic supply, the Chamsine Spring, which has for a long time provided water to several towns in Central and West-Bekaa. As part of the on-going project implemented by the CDR (and endorsed in the BWE Master Plan), the supply of domestic water in the Caza of Zahle and West Bekaa is expected to be provided by the Chamsine Spring together with existing wells drilled in its vicinity. Additionally, more wells are projected to be drilled in the upcoming years, along with three storage tanks located in Anjar and Terbol, to serve domestic water networks. This would increase the total amount of towns supplied by the Chamsine Spring and wells to 24 towns,[51] representing a total water demand of 625 LPS by year 2030 (USAID-LWWSS 2015b: P75). This does not seem to be consistent with the fact that discharge in summer months frequently varies between 200 and 400 LPS only.

In Anjar, domestic water supply is currently provided by two municipal wells drilled in the Cretaceous aquifer and connected to the town's water network. As for the case of irrigation, domestic supply is managed by a Domestic Water Committee consisting of resident representatives and working under the supervision of the municipality. However, as part of the BWE Master Plan, the Anjar Spring water is projected to be re-allocated to provide domestic supply for a section of the town of Zahle and other towns of the Caza of Zahle,[52] representing an average daily demand of 327 LPS by the year 2035 (USAID-LWWSS 2015b, P74).

The current situation of domestic water supply differs depending on the type of water system that is in place. While water supply has been described to be satisfactory in Anjar, it has been reported to be unreliable in Kfarzabad, despite its proximity to the pumping station. As in the other towns described earlier, residents have drilled private house wells and/or buy water from

[51] These towns are divided into three sub-networks including: 1) Anjar, Rawda, Barr Elias, Cheberqiej, Haouch El Harime, Khiara will be supplied by one reservoir located in Anjar; 2) Majdel Anjar, Saouiri, Dakoue, Es Salamiyeh, Er Rachidiyeh, Tal El Za'za'a, Sultan Yacoub El Tahta, Mansoura, Ghazze, Sultan Yacoub El Faouqa, Aita El Foukhar, and Hammara (Manara) will be supplied by another reservoir in Anjar; 3) Terbol, Ain Kfarzabad, Kfarzabad, Massa, Faour, and Qousseya will be supplied from a reservoir in Terbol (USAID-LWWSS 2015b).

[52] These towns include: Dalhamye, Karak Nouh, Maallaqa, Zahle and Maallaqa Aradi (USAID-LWWSS 2015b).

private vendors. Additionally, during fieldwork, it was reported that the Chamsine Spring was exposed to serious problems of illegal tapping. Due to the irregular water supply from public networks in most of the surrounding towns, water-vendors have multiplied, and have begun to withdraw water from public sources. During our visit to the pumping station at Chamsine, the director of the office reported that several water-vendors regularly come filling their trucks with water from some of the unused wells drilled by the CDR. He deplored not having authority to prevent them from doing so. Moreover, he has requested the establishment of a police station next to the Chamsine office, so that security forces can help him enforce the regulations. A similar problem was reported in Anjar, where the mayor also complained about a large number of water-vendors that come filling their trucks from the main canal of the collective irrigation system in the summer. He also states his frustration not having the authority to prevent this, and explains "*avoiding conflicts with the neighboring villages due to Anjar's politically weak position.*"

4.6.3. Impacts on users

Farmers in this sub-area have relatively easy access to water, depending on the water source (surface or groundwater), the type of water management (private or collective use) and the types of water and land use (in case of well use). Given the availability of groundwater in the Anjar-Chamsine Aquifer, farmers can have access to water and maintain irrigation practices for both seasons. However, as in the other sub-areas, the continuous water withdrawal from that aquifer has had a negative impact on water availability both from surface water and groundwater. On the one hand, due to the reduction of the flow in the Anjar Spring, irrigation costs have been increasing for Anjar farmers. This is mainly because of the necessity to pump water from the spring and also due to the fact of having to pump from the new wells, which are of recent origin. On the other hand, the reduction of water levels in wells drilled in the Cretaceous aquifer has also led to well deepening and the gradual increase in pumping costs for both Kfarzabad and Anjar farmers using groundwater. Being independent of the state supply, the community of Anjar was not negatively impacted by water rationing in the public network and, as such, has been able to ensure its needs by using groundwater. The existence of a well organized by the Domestic Water Irrigation Committee allowed the collective use of municipal wells and, thereby, avoided having to resort to private house wells.

The most important impacts are those arising from the implementation of several water supply projects planned by the state. First, the strategy of allocating water from the Anjar Spring to domestic use would deprive the Anjar farmers from their irrigation water source and push them to rely on wells, which will add a substantial pressure on the already declining water levels of the aquifer. Moreover, an important share of the domestic water demand is projected to be ensured by drilling more wells, which also represents new pressure on the groundwater of this aquifer. Importantly, as described earlier, wells drilled in the vicinity of the Chamsine Spring reduced spring discharge when operated, resulting in a lower volume of water supply than the one that was planned for the villages. Given that many wells were drilled next to the Chamsine and Anjar springs, the total water volumes that were projected to be added to the current supply through harnessing groundwater are likely to be significantly lower than expected. This would eventually result in private reliance on groundwater resources, as is presently the case in many villages. Most importantly, illegal tapping represents an important factor of reduction in surface water availability and should be addressed in order to ensure adequate water distribution among its many users.

Table 12: Evolution of groundwater use in the Anjar-Chamsine sub-area and impacts on users.

		Before the 1960s	1960 – 1970	1975 - 1980	1980 - Present	Possible future scenario (year 2035)
Irrigation	Anjar	Irrigation from the Anjar Spring by gravity and Arabic wells for lands not having access to the irrigation system	**1962:** Establishment of pumps on the Anjar Spring pond Irrigation of originally rain-fed area from the Anjar Spring by motor-pumps	Use of pumps to complement irrigation in the spring-based system in years of low rainfall Stop the use of irrigation by motor-pumps and drilling wells in the Cretaceous aquifer for the irrigation of originally rain-fed area	**1982:** Increase in the power of pumps on the Anjar Spring pond **2014:** Drilling of two wells in the Anjar Spring's vicinity Irrigation of the originally rain-fed area by wells drilled in the Cretaceous aquifer	Significant conjunctive use of groundwater as a result of the reallocation of the Anjar Spring for domestic use
	Kfarzabad	Small area irrigated from Chamsine Spring and Arabic wells for lands with no access to surface water	Start of drilling tube wells in the Cretaceous aquifer	Multiplication of tube wells in the Cretaceous aquifer	Irrigation of most of the Kfarzabad Plain by wells drilled in the Cretaceous aquifer	Irrigation from wells drilled in the Cretaceous aquifer
Domestic	Anjar	(To be completed)	From the Anjar Spring (but to be confirmed)	From the Anjar spring (but to be confirmed)	Drilling of municipal wells in the Cretaceous aquifer	Projected to be provided from the Anjar Spring as part of a larger public network to be supplied from the Anjar Spring (BWE Master Plan)
	Kfarzabad	(To be completed)	Public supply from the Chamsine Spring	Drilling of housing wells as a result of poor water supply from the public network	Multiplication of housing wells and illegal tapping from the Chamsine Spring to secure domestic water supply **2006-2014: Drilling of several state wells in the Chamsine Spring vicinity**	Wells drilled in the vicinity of the Chamsine Spring are projected to supply as an extension of the public network (on-going project)
Well depths (m b.g.l)		No wells	100 m	100-150 m	100-150 m	**Possibly 200 m and deeper**
Water levels (m b.g.l)			Data was not found	Data was not found	4 m in the winter Up to 70 m in the summer	**Significant decrease**
Impacts on users		Negative impact on Anjar farmers (starting in the 1960s) caused by the reduction in the flow of the Anjar Spring during summer. This is likely linked to the increase in groundwater abstraction from both the Cretaceous and the Eocene aquifers.		Groundwater allowed the irrigation of areas not having access to surface water throughout the irrigation season, and was an alternative for the irregular domestic supply from the Chamsine Spring. Wells still ensure irrigation requirements, but the reduction in water levels has resulted in increased pumping costs		If the Anjar Spring is reallocated for domestic use, there will be a significant increase of groundwater abstraction from the Cretaceous aquifer, which would impact in turn the spring discharges

4.6.4. Identification of competing users

Water allocation from the water resources included in this sub-area is of crucial importance as it impacts access to water of a large number of users, not only at the level of our study area but at the larger level of the ULRB as well.

Direct relations

1- Well users in Kfarzabad and Anjar have direct impacts on each other as they share the Cretaceous aquifer in this region, with Kfarzabad farmers being the largest groundwater consumers.
2- Although it is difficult to assess in which way and to what extent groundwater overexploitation in Anjar-Chamsine aquifer is impacting Anjar and Chamsine spring discharges in the absence of reliable spring measurements, it is likely that the experienced reduction in spring flows is linked to groundwater overexploitation in that aquifer. If this is the case, the Chamsine Spring users (the towns currently supplied with domestic water from the pumping station at Chamsine) as well as the Anjar Spring users (Anjar farmers and all the farmers using the Ghozayel River for irrigation) would be impacted by farmers using wells in the Anjar-Chamsine Aquifer.
3- The reallocation of the Anjar Spring by the BWE would substantially reduce surface water availability for farmers using Anjar and the Ghozayel rivers. Furthermore, it will result in increasing pressure on groundwater resources. In our study zone, the main impacted users would be Anjar and Barr Elias farmers.

Indirect relations

1- The reduction in water availability for irrigation in Anjar and Barr Elias would push farmers to rely on the Cretaceous aquifer, in the case of Anjar farmers, and on the Eocene aquifer, in the case of Barr Elias farmers. This would lead to further reduction in water levels in these aquifers, and not only impacting groundwater availability for farmers but also contributing to further reduction in spring flows.
2- This would in turn reduce the projected domestic supply from the springs.

Figure 20: Anjar new collective irrigation wells.

Notes: 1. Anjar Spring pond under rehabilitation in fall 2014. 2 and 3. Anjar new wells drilled in the Cretaceous aquifer in summer 2014 next to the spring. 4. Pipe connected to a well to supply water to the primary canal in the Anjar Irrigation System.

Figure 21: Illegal tapping from Chamsine public wells.

Notes: 1 and 2. Water vendor illegally pumping water from a public well drilled next to the Chamsine Spring in the Cretaceous aquifer. 3. Farmers washing their fresh vegetables downstream in the proximity of the pumping station at Chamsine.

4.7. Eocene sub-area

4.7.1. Evolution of water supply for irrigation

This sub-area is mainly composed of Terbol, Hoshmosh and the Faour regions. Until the 1960s, it used to be partly irrigated by '*the Nabeh Ras El Ain*' located at the level of Terbol (at its origin the spring of 'Naher El Faour' formed a tributary to the Ghozayel River) and other small springs sprouting from the Eocene aquifer. It started to rely on groundwater as an alternative of the drying-out of these springs. However, due to the different social histories of these three territories, the evolution of groundwater use differed substantially between Terbol, Hoshmosh and the Faour regions.

Terbol is a large agricultural village in the Central Bekaa, well known for its intensive cultivation of vegetable crops (Francis 2008; Saab 2009). Like most of the Bekaa's villages, it has a very rich history. Different civilizations have settled there over the centuries as evidenced by many vestiges, which still can be found in Terbol's mountain. The modern village of Terbol was established by two families who came from Mount-Lebanon and settled there in 1841, after they had been given lands by 'Amir Fakhreddine' as a reward of their support in 'Ain Dara's War' (Barrak Assi, 2012). Terbol's community mainly lived from agriculture and has grown in numbers, e.g., around 700 households and 10,000 residents.

Hoshmosh is an agricultural area located north of Terbol, commonly known as 'Hoshmosh Farm'. As shown on the map, it has administrative boundaries but it does not include a small residential area. It is formed by a group of large agricultural plots cultivated by farmers, mainly from Terbol and Ryak. These plots were traditionally owned by two of the affluent families ('notables'). They acquired large amounts of lands in the Bekaa through the land reforms conducted at the end of the nineteenth century by the Ottoman administration (Blanc 2006; Ghiotti and Riachi 2013). One of these families, still residing in the Bekaa, has conserved the ownership of the plots and continues to rent them on a yearly basis to farmers from Ryak and Terbol. The second family gradually sold most of their plots to large-scale farmers from Terbol and Ryak, notably in the period when agriculture was booming (1960s-1970).

Faour is a region located south-east of Terbol, where lives the tribe of 'Arab el Hrouk' known also as 'Arab El Faour'. The community is constituted of farmers and livestock raisers generally living in basic socioeconomic conditions and with poor access to public services. The tribe is, originally, a part of the many nomadic tribes who used to bring their herds for pasture during the summer in the fertile and water-rich lands of the Bekaa, and return to spend the winter in neighboring regions of Syria (Joseph 2013). Beginning of the twentieth century, the local farmers started to hire these tribesmen as agricultural laborers, but following Lebanese policies restricting nomadic migrations, they (the tribesmen) gradually settled in the southern part of Terbol's territory.[53] At present, the Faour community has rapidly expanded to reach around 10,000 residents, and most of them have obtained Lebanese citizenship.

Three main surface water sources were at the origin of the development of this sub-area. While Hala Yahfoufa River used to supply a substantial part of Hoshmosh as described earlier, the '*Nabeh Ras El Ain*' and '*Nabeh El Faour*' springs sprouting from the Eocene aquifer, allowed the early development of agriculture for Terbol and Faour communities, respectively.

The '*Nabeh Ras El Ain'* played a major role in the development of the Terbol Town. In the nineteenth century, it was used for the cultivation of fruit trees and vineyards that were established next to the spring. During the French mandate and English interventions[54] (in the first half of the twentieth century) it was a strategic water source that was harnessed to supply water to the French and English headquarters, which were located in the region. In the early 1940s, small dams were successively built by the French and English governments, in order to store and convey water to their military headquarters and hospitals in Ryak, Tel Amara and Ablah. Due to the abundant discharge of the spring in years of heavy rainfall, these dams collapsed and had to be rehabilitated several times (Barrak Assi 2012: P30).

However, irrigation infrastructures around '*Nabeh Ras El Ain'* were modest. According to the farmers interviewed in Terbol, prior to the development of wells in the Eocene aquifer, the spring used to irrigate only one-third of the Terbol's Plain. Initially, water used to be diverted by gravity from the spring reservoir and conveyed through ditches to plots located downstream. Starting in the 1950s, the use of motor-pumps allowed water to be conveyed to some plots located upstream, but the area irrigated by the spring remained limited.

The '*Nabeh El Faour*', located south-east of Terbol, was the main reason for the 'Hrouk Tribe' to settle in this region. Together with '*Nabeh Ras El Ain*' water, this spring used to feed the '*Naher El Faour*' River that used to irrigate the Barr Elias lands until the 1960s, as described earlier. At

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[53] They built their first houses on a *Mouchaa* (collective land) owned by Terbol's Municipality and expanded their residential areas, both by buying small plots from Terbol's residents and by informally appropriating plots belonging to many of the landlords who left the region during the war, as reported by several farmers in Terbol.

[54] Following the defeat of the Ottoman Empire at the end of World War I, Lebanon was under French Mandate (1920-1943). The state of Lebanon with its current boundaries was created in 1920 and obtained its independence in 1943.

the level of Faour region, water was also diverted through ditches and used to supply lands located downstream of the spring, in Terbol and Zahle Maallaqa.

The remaining lands in Terbol, Faour (and Zahle Maallaqa) used to be cultivated with rain-fed crops (cereals, lentils and watermelons) or irrigated by groundwater abstracted from the alluvial plain (Quaternary aquifer) through shallow dug wells. As described for the Ryak region (Hala Yahfoufa sub-area), until the early 1960s, most of these wells used to irrigate plots not exceeding 20-50 du. Some tubewells were also used at that time but their number was limited since shallow wells had the capacity to supply the same amounts of water (Table 4 and Table 5) (Baldy 1960).

The first irrigation wells drilled in the Eocene aquifer were established in the mid-1950s. According to the well owners interviewed, these wells had expanded rapidly in the early 1960s. This information is also confirmed by Baldy who describes many wells drilled in the Eocene aquifer in this area that he calls 'the region of Terbol's tube wells' (*la région des forages de Terbol*) (Baldy 1960: P33-34), and where he observes during his survey (summer 1959) many new wells being drilled (Baldy 1960: P59). Wells were drilled at the foot of the mountain range and water was conveyed at that time through earthen ditches to plots located in the plains of Terbol (they were later replaced by metallic and plastic underground pipes). Some wells were also supplying water to plots in Dalhamyeh, Zahle Maalaqa and even in Kfarzabad, as recalled by an old well owner from Terbol.

Pumping water from the Eocene aquifer soon had a very noticeable impact on the '*Nabeh Ras El Ain*' and '*Nabeh El Faour*' springs. As described by Baldy, their flow was already substantially reduced in summer 1959 due to water abstractions from these wells (Baldy 1960: P41). However, although these abstractions reduced the natural flow of the spring, they increased the overall volume of water exploited, which had a positive impact on the development of agriculture, as pointed out by Baldy (1960: P42). In fact, between the 1960s and the 1980s, the exploitation of wells in the Eocene aquifer led to a substantial increase in irrigated areas. As described, for the development of large vegetable farms in Barr Elias wells were established at the foot of *Jbaily*, and the the high yields of these wells (average of 50 LPS/well, sufficient to irrigate between 300-400 du) allowed the development of large vegetable farms in Terbol, Hoshmosh and Faour. In this case, given the length of the Eocene mountain in this sub-area, many more wells were drilled (estimated at around 60 wells). Today, the area irrigated by these wells is around 14,000 du.

At the level of Terbol Village, the ownership of plots at the foot of the mountain was a windfall for the respective owners. Our interviews showed that many small land owners that happened to own plots in this area were able to expand their agricultural areas. Furthermore, they bought large amounts of lands between the 1960s and the 1980s with the profits made from agriculture. During this period, the large-scale farms irrigated by these wells were directly cultivated by the respective well owners. Given the large size of their plots, well owners also used to propose sharecropping arrangements to other farmers of the region. They often had financial partners from Zahle who provided the capital for drilling the wells. However, starting in the 1990s, there was a drastic change in the ownership of wells and lands. With the general decline of agriculture and several political events causing sudden losses in agriculture, most of the second generation of farmers sold their plots and wells to a businessman from Terbol. After being mainly cultivated and irrigated directly by their users, most of the large plots and several of the Eocene wells are now owned by one large investor and rented to Terbol farmers. Table 13 summarizes the evolution of irrigated areas and land use during the period of farm expansion (1960s-1980s) for the five families, who established the largest farms in Terbol by means of exploitation of Eocene wells. Table 17 presents the shift of well and land use for the same families starting in the 1990s. These examples represent around half of Terbol's agricultural area.

Figure 22: Irrigation systems in the Eocene sub-area.

Notes: 1. The pond/reservoir of Terbol Ras-El-Ain Spring before drying out (photo provided by a farmer). 2. The pond now used as an agricultural field after the spring dried out (May 2014). 3 and 4. Large wells drilled in the Eocene aquifer at the feet of the Mountain range in Terbol.

Table 13: Establishment of large family farms irrigated by Eocene wells between the 1960s and 1980s in Terbol.

	Before Drilling Eocene wells		Date of Drilling the first Eocene well	After drilling Eocene wells (1960s-1980s)	
Family and farm size	Land ownership	Land and water use		Land and well ownership	Land and water use
Family T1 2,500 du	The father was the owner of a small amount of land in the plain, and a small plot in the Eocene aquifer. The total size of owned plots was 100 du.	100 du under direct occupation Irrigation from shallow wells and Ras El Ain.	Late 1950s	Gradual buying of plots until reaching 2,500 du Drilling five other wells in the Eocene aquifer	Irrigation of 6,000 du of lands in Terbol, Kfarzabad and Barr Elias by Eocene wells A substantial amount of land used to be rented from small-scale land owners. Part of the land was cultivated under direct occupation and the rest under share cropping, where access to wells was subjected to a rental.
Family T2 >1,000 du	The father was the owner of a large amount of land in the plain, and some small plots in the Eocene aquifer.	Land was under direct occupation and share cropping. Partial irrigation of plots by shallow wells.	1960	Gradual buying of large plots in Hoshmosh with a family from Ryak. Drilling two other wells in the Eocene aquifer.	Irrigation of most of the plots in Terbol and Hoshmosh was by Eocene wells. Part of the land was cultivated under direct occupation and the rest under share cropping, where access to wells was subjected to a rental.
Family T3 450 du	The father was the owner of a large amount of land in the plain and in the Eocene aquifer.	Land was under direct occupation and share cropping. Partial irrigation of plots by shallow wells	1950s	Retaining land ownership Drilling other wells in the Eocene aquifer.	Irrigation of most of their plots by was Eocene wells Part of the land was planted under direct occupation and the rest under share cropping where access to wells was subjected to a rental.
Family T4 500 du	The father bought a small amount of land from large land owners in Terbol. Part of the land used to be located in the Eocene aquifer.	Land was under direct occupation and share cropping. Partial irrigation of plots by shallow wells and Ras El Ain	1950s	Gradual buying of plots until reaching 500 du	Irrigation of all the plots by the Eocene wells Partnership with investors from Zahleh. Part of the land was planted under direct occupation and the rest under share cropping, where access to wells was subjected to a rental.
Family T5 300 du	The father was the owner of a large amount of land in the plain and in the Eocene aquifer.	Land was under direct occupation and share cropping. Partial irrigation of plots by shallow wells	1968	Retaining land ownership	Irrigation of all the plots by the Eocene wells. All plots are planted under direct occupation by owners

Source: Based on interviewed farmers. Families T1 to T5 are, respectively, farmers Nos. 58, 23, 44, 52 and 19 as listed in Annex 4.

In Hoshmosh, land owners also started to drill wells in the Eocene aquifer during the same period in order to irrigate the originally rain-fed lands, which had no access to the Hala Yahfoufa River. Unlike in Terbol, Hoshmosh land owners were not a community of farmers residing locally and practicing agriculture as a source of livelihood. The land was cultivated by farmers from the neighboring villages (Ryak, Terbol and other villages located north of Ryak such as Sarraine, Haret El Fikani, Ali El Nahri and Massa) through sharecropping arrangements, where access to land and wells was provided by the land owners. Until today, part of Hoshmosh is still owned by one of these families, while the second family gradually sold most of its plots to farmers from Ryak and Terbol, and more recently from Sarraine and Nassryeh. Table 14 presents the well and land use for eight farmers in Hoshmosh.

Table 14: The evolution of land and well use in Hoshmosh.

Farmer	Land and well ownership	Land and well use
Farmer H1 1,000 du	The land is still owned by one of the two traditional elite families.	The land and wells are under tenancy.
Farmer H2 500 du	The land is still owned by one of the two traditional elite families.	The land and wells are under tenancy.
Farmer H3 Farmer H4 1,100 du	The land was bought by two partners from Terbol and Ryak, from one of the two traditional elite families.	Part of the land and wells are now rented out to a large agricultural company.
Farmer H5 100 du	The land was bought from one of the two traditional elite families.	The land and well are under owner occupation.
Farmer H6	The land was bought from one of the traditional elite families by a businessman from Nassryeh.	The land and well are under tenancy.
Farmer H7	The land was bought from one of the two traditional elite families.	The land and well are under owner occupation.

Source: Based on interviewed farmers. Farmers H1, H3 and H7 are respectively Farmers Nos.20, 23 and 53 listed in Annex 4.

In the Faour-Zahle Maallaqa region, wells were also drilled in the Eocene aquifer by land owners from Terbol and Zahle Maallaqa and, that had led to the expansion of the irrigated area in this region. Farmers from the 'Arab El Hrouk' (living in Faour) were used to be hired not only as agricultural workers in these farms, but also in other areas of the region as well. After the beginning of the Lebanese War in 1975, most of Zahle Maallaqa land owners left agriculture, as described earlier for the sub-area of Litani-Maallaqa. Most plots continued to be cultivated by Faour farmers under tenancy, while some of them were informally appropriated. During the 1980s, several new wells were drilled in the Eocene aquifer in this region as reported in a 'Focus Group' organized with a group of farmers from Faour.[55] Some of these wells were originally established to be used primarily for domestic supply. However, given their high yields, they were later used for irrigation in order to replace shallow wells that dried out in the plain. They are still used today, either for individual domestic supply or to convey water to plots in Terbol and the eastern part of Zahle Maallaqa. These wells are generally owned either by Faour residents, or land owners from Zahle Maallaqa, and are used by Faour farmers. Land is generally rented from

[55] Farmer No. 32 to Farmer No. 43. The Focus Group took place at the BAU Center in Taanayel on January 23, 2014.

other owners. Table 15 presents the evolution of well and land use for seven farmers from the Faour community.

Table 15: Evolution of well and land use in Faour.

Farmers	Well ownership	Date of well drilling	Evolution of Land and water use
Farmer F1 300 du	The well is owned by a resident from the Faour community. The well was originally drilled for domestic use.	1978	The land and well (Eocene) are rented from different owners. The farmer started renting this well after his shallow well dried out. Only a small part of the land is owned by this farmer.
Farmer F2 80 du	Resident from the Faour community.	1985	Land and well (Eocene) are rented from different owners.
Farmer F3 140 du	The well is owned by a resident from the Faour community. The well was originally drilled for domestic use.	1986	Land and well (Eocene) are rented from the same owner.
Farmer F4 80 du	The well is owned by a resident from the Faour community. The well was originally drilled for domestic use.	1996	Land and well (Eocene) are rented from different owners He started renting this Eocene well after his shallow well dried out.
Farmer F5 100 du	The well owner is a large-scale owner from Zahle	1959	Land and well are rented from the same owner.
Farmer F6 100 du	The well is owned by a resident from the Faour community.	Un-known	He uses the Eocene well to irrigate a 40 don plot, which he rents from a different owner. He also rents another plot with access to a well in the Quaternary aquifer
Farmer F7	The well is owned by a resident from the Faour community.	1984	The well is owned by the farmer and the land is rented.

Source: Based on interviewed farmers. Farmers F1 to F7 are respectively Farmers Nos. 35, 36, 37, 42, 40 and 41 listed in Annex 4.

On the other hand, the Quaternary aquifer remained an important water source in this sub-area. Similarly to the previously described sub-areas, the distribution of wells drilled in this aquifer was found to be closely related to the types of land organization and land tenure. In Hoshmosh, wells drilled in the Quaternary aquifer were reported to be rare. Land is organized in large size plots, all irrigated by wells drilled in the Eocene aquifer. In Terbol and Faour-Zahle Maallaqa, where the land is divided in to a large number of plots and distributed among the different families, many owners continued using the Quaternary aquifer. As described for the Hala Yahfoufa sub-area, water levels remained accessible through shallow wells until the early 1970s and were subsequently replaced by tube wells. Until the 1990s, these wells In Terbol and Zahle Maallaqa had sufficient discharges to irrigate around 30-60 du. With the overexploitation of the Quaternary aquifer, well yields gradually decreased and pushed farmers to multiply their number of wells in order to sustain sufficient yields during the summer. Importantly, a number of farmers shifted from using wells in the Eocene to wells drilled in the Quaternary aquifer. The first reason for this shifting of wells, as described by several well owners, is the adoption of drip irrigation. The increased water efficiency associated with this technology allowed some farmers traditionally renting out access to Eocene wells to drill their own wells at the plot level in the Quaternary aquifer. Another noteworthy factor is the fragmentation of the large farms, which were originally irrigated by wells drilled in the Eocene aquifer. Following the division of some large plots that were supplied by these wells, several farmers of the second generation have established independent farms and drilled wells in the Quaternary aquifer. Table 16 illustrates the multiplication of wells in the Quaternary aquifer for eight farmers from Terbol. Currently, there are hundreds of wells in the Quaternary aquifer located in Terbol and Faour-Zahle Maallaqa. In the Eocene aquifer, there are about 60 wells, of which around 10 to 15 wells have stopped being used or are underused.

4.7.2. Evolution of domestic water supply

The first community well that supplied the Town of Terbol with domestic water was drilled in the Eocene aquifer in the 1950s. It was equipped with one pipe supplying water to a community fountain in the village. In the 1960s, a distribution network was built and connected to this well. It was used both for domestic and potable use, until the well became contaminated with a high level of nitrates. This prevented the use of water for drinking purposes and a new well was drilled. The distribution network remained connected to the first well and still ensures domestic water supply in houses. The second well provides clean water and is connected to collective taps in the village, from which most residents regularly fill up their water bottles. It was also reported that several individual house wells were also drilled in the Quaternary aquifer, which were mainly used to irrigate private gardens.

With the establishment of the first wells, the management of collective domestic wells has been provided by the Terbol Municipality. Wells and network were operated by staff from the municipality, and the costs were traditionally levied from the residents as part of the annual municipal taxes. A few years ago, the BWE made an official demand to take over the management of the domestic supply service, as stipulated by Law 221 (2000). After several months of negotiations, the Municipality of Terbol accepted to transfer the service to the BWE. As reported by the Mayor of Terbol,[56] their consent was mainly due to the fact that the municipality was indebted to the state (Electricité du Liban authority) with USD 500,000 of unpaid electricity bills[57], part of which the BWE accepted to settle. However, due to substantially higher fees requested by the BWE, the number of subscribers is still very limited and is not sufficient for the BWE to start providing the service. Thus, given that the present situation does not allow either the municipality or the BWE to operate the system, residents have elected a small committee to provide the required management. This committee collects the fees and pays the operation and maintenance costs of the domestic well, including electricity and the salary of an employee.

[56] Terbol Mayor was interviewed several times; on Novembe 10 and 15, 2014, and on January 14 and 21, 2015.

[57] The mayor reported that the bill accumulated during the war, when the municipality could not pay it. He also said that the Terbol Municipality considers that the bill also includes electricity costs not related to water supply service, such as the use of the same electrical line by the Syrian base that was set up in the region at that time.

Table 16: Multiplication of tube wells in the Quaternary aquifer in Terbol.

Farmer and farm size	Land and water use before drilling wells in the Quaternary	Date of well drilling	Land and water use after drilling wells in the Quaternary
Farmer T1 80 du	The plot was cultivated under owner occupation. Irrigation by one shallow well. After his shallow wells dried out, he used to rent access to a well in the Eocene for a short period, until he drilled his first tube well in the Quaternary aquifer	1975	The plot is still under owner occupation Gradual drilling of two other tube wells in the same plot due to reduction in well yields.
Farmer T2 100 du	400 du plot. Part of it was owned by the farmer and the rest was rented from other owners. Irrigation by one shallow well that used to give a sufficient yield for 400 don	1975	The cultivated area was decreased from 400 to 100 du. It is cultivated under direct occupation Gradual drilling of two other tube wells
Farmer T3 120 du	120 du cultivated under owner occupation. Irrigation by one shallow well.	1968	The plot was under owner occupation until recently. It is now being rented out with access to wells. Gradual drilling of several tube wells
Farmer T4 160 du	The father used to rent land and access to well from other owners. Him and his brothers bought 160 du of land in 1990 and drilled tube wells in the Quaternary aquifer.	1990	The plot is still under owner occupation. Gradual drilling of several tube wells.
Farmer T5 50 du	The plot used to be part of a large farm irrigated by an Eocene well. After the land was divided due to heritage, he established a vineyard and drilled a Quaternary well.	2008	The plot is still under direct occupation. Gradual drilling of several tube wells.
Farmer T6 200 du	This plot used to be part of the same large farm of Farmer 5 and was irrigated by an Eocene well. After the land was divided due to heritage, several wells were drilled on the plot to replace irrigation from the Eocene.	Late 1990s	The plot was under owner occupation until recently. It is now being rented out with access to wells. Gradual drilling of several tube wells.
Farmer T7 20 du	This plot was bought in 2004 and a tube well was drilled.	2004	The plot is under owner occupation. Irrigation by one tube well
Farmer T8 21 du	The plot was occupied by Syrian troops. The owner established a farm and drilled wells in the Quaternary aquifer after the departure of the troops.	2000	The plot is under tenancy. Irrigation by several tube wells.

Source: Based on interviewed farmers. Farmers T1 to T8 are respectively Farmers Nos. 47, 32, 18, 51, 15, 44, 22 and 17 listed in the Annex 4.

Table 17: Shift in the ownership of land and Eocene wells (starting in the 1990s) in Terbol.

Family	Land and water use until the 1980s	Reduction in land and well ownership	New owner(s)	Actual land and water use
Family T1	Cultivating 2,500 du of land under direct occupation and 3,500 under tenancy Irrigation by six wells in the EoceneEocene	1990s: Selling most of the plots (1,700 du) and Eocene wells Out of the 2,500 du and the six wells, only 250 du and one well were kept	The main owner is a businessman from Terbol working in Gulf countries	New owner rents out the lands with access to Eocene wells. Only one of the five sons is still a farmer in Terbol, planting the remaining plot The others either invested in agriculture in Romania or have other professions
Family T2	Cultivating more than 1,500 du under direct occupation Irrigation by three wells in the Eocene	1997: Selling large amount of lands	Same businessman from Terbol	New owner rents out lands with access to Eocene wells The remaining plots (1,000 du) are rented out to a large agricultural company
Family T3	Cultivating around 500 du under direct occupation Irrigation by two wells in the Eocene	1990s: Selling one well	Same businessman from Terbol	New owner rents out access to the well The remaining Eocene well is rented out with 150 du plot to the same large agricultural company 200 du are rented out with access to quaternaryQuaternary wells Only 50 du is planted under direct occupation
Family T4	Cultivating around 500 du under direct occupation Irrigation by one well in the Eocene	1990s: Selling most of the plots Only the well and one 60 du plot was kept	Businessman from Beirut working in the Gulf countries	The 60 du plot is planted under direct occupation by one of the sons He rents from the new owner the plots he bought from his family
Family T5	Cultivating around 500 du under direct occupation Irrigation by one well in the Eocene	1990s: Selling 300 du of land Well was kept	Same businessman from Terbol	The son who sold his plot, rents plots with access to QuaternaryQuaternary wells

Source: Based on interviewed farmers.

The Faour Town is not equipped with a domestic distribution network. Most of the houses are supplied by individual wells, or collective wells supplying small groups of houses. Faour residential areas being located at the foot of the mountain range, most of these wells are drilled in the Eocene aquifer. As described earlier, many of these wells started to be used for the irrigation of farms in Faour-Zahle Maallaqa following the drying-out of shallow wells dug in the Quaternary aquifer.

4.7.3. Impacts on users

Similarly to what has been found in other sub-areas, users of this area too, have been negatively impacted by the overexploitation of the aquifers. Following the development of wells in the Eocene aquifer, water levels gradually decreased and required deepening of wells. Wells that were first drilled at 60-90 m depth have been gradually deepened and are now between 150 and 250 m deep, incurring investments in drilling and higher pumping costs. Moreover, the drying-out of surface water resources that occurred as result of the Eocene aquifer overexploitation impacted downstream users in Barr Elias, who were traditionally using the '*Naher El Faour*'.

The multiplication of wells in the Quaternary aquifer also resulted in the overexploitation of this aquifer and led to the drying-out of shallow wells. Tube wells that replaced shallow wells gradually experienced further decrease in water levels and well yields during the summer. Similarly to the other sub-areas, wells found in the Quaternary aquifer could not be deepened due to the physical properties of the soil, which required drilling more wells in order to sustain the yields needed to cultivate a second season in the summer. Several factors led to further multiplication of wells in the Quaternary aquifer, such as the fragmentation of large farms traditionally supplied by the Eocene aquifer and the increased water efficiency provided by the drip technology. Unlike in Litani-Maallaqa and Litani-Barr Elias sub-areas, land tenure was not a constraint to the multiplication of wells in Terbol, where most of the plots irrigated by the Quaternary aquifer are cultivated by the land owners directly. However, being mostly tenants, Faour farmers were not able to replace their shallow wells by tube wells and had to rent access to wells drilled in the Eocene aquifer.

4.7.4. Evolution of the access to land and water

An important phenomenon was identified in these detailed interviews. It concerns the evolution of land and well ownership, and the impact it had on the cost of access to land and water. While land tenancy and sharecropping have always been prevailing for the Faour community, the majority of Terbol farms were cultivated under owner occupation until the 1990s. Wells drilled both in the Eocene and the Quaternary aquifers were all owned and used by local farmers, allowing the development of large family farms between the 1960s and the 1980s. On the other hand, wells drilled in the Quaternary aquifer allowed small land owners to ensure their access to water and resulted in the development of small and medium-sized farms, which were mostly cultivated under owner occupation. Furthermore, revenues from agriculture allowed some farmers from Ryak and Terbol to buy a substantial amount of land from the traditional elite families owning large plots in Hoshmosh. However, starting in the 1990s, decreasing revenues from agriculture and the general instability of the sector pushed many farmers in Terbol to sell their plots and wells to investors and to invest in other sectors. The ownership of land and water shifted from farmers to investors, which had a large impact on the cost of access to land and water. Today, most of the large farms and Eocene wells are owned by these investors. The cost of land rental is high and doubles when the farmer has to rent access to a well. When both the land and well are rented, the cost of access to land and water now constitutes between 20 and

25% of the production costs (not including the cost of irrigation and other input factors), which adds as a substantial burden on the farmers.

4.7.5. Identification of collective users

Direct relations

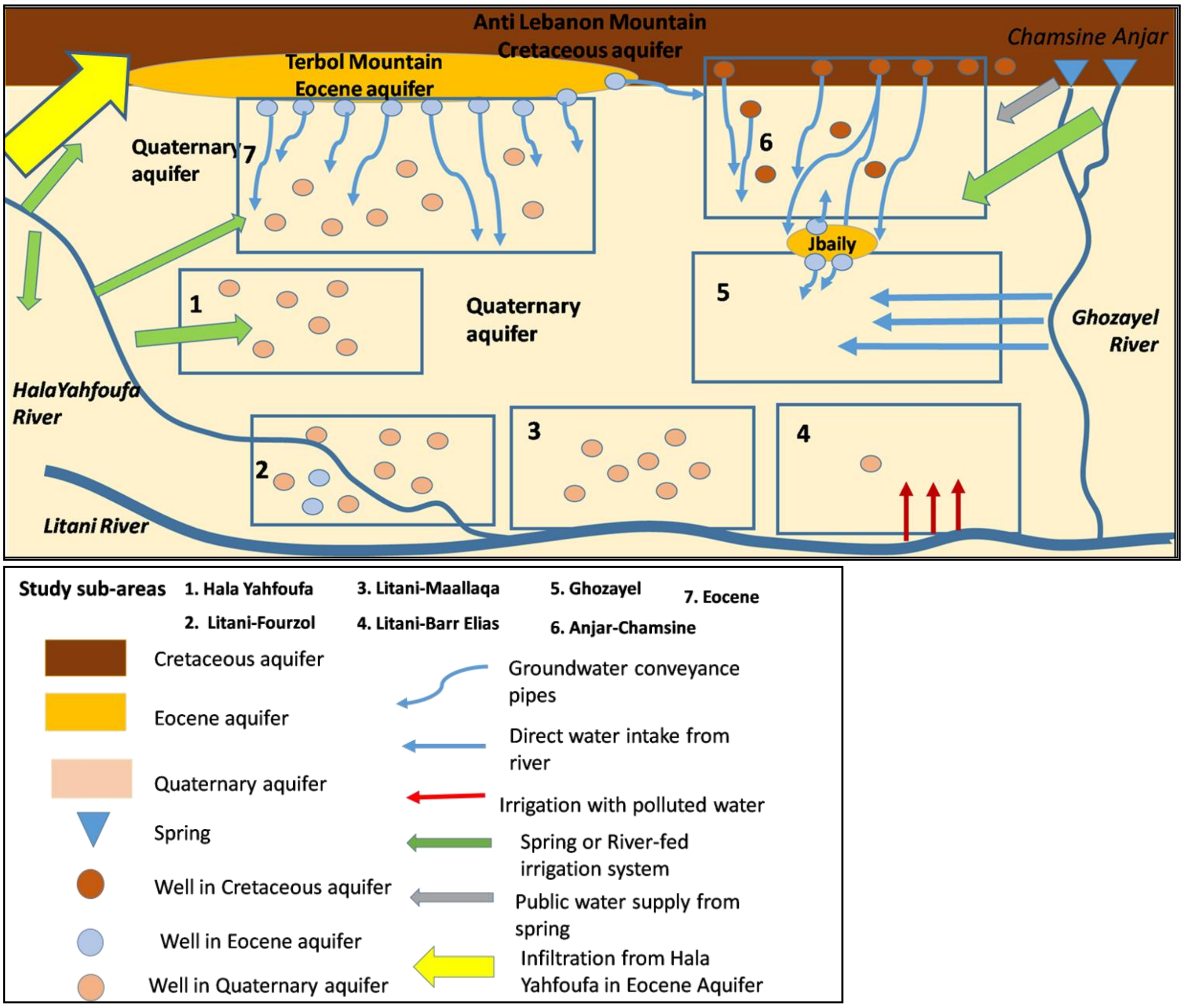
1- Well users of the Eocene aquifer in Terbol, Hoshmosh and Faour have direct impacts on each other as joint users of this aquifer in this region. Along with the other users of the Eocene aquifer in the region, they all contribute to groundwater overexploitation, with farmers being responsible for the largest share of water abstractions.
2- Their water abstractions have direct impacts on the users of the Eocene outcrop in Barr Elias *Jbaily*.
3- A direct impact was the drying-out of the Naher El Faour caused by the exploitation of the Eocene aquifer in Terbol. This had a negative impact on Barr Elias farmers and pushed them to rely on the Ghozayel River and on the Eocene outcrop in Barr Elias.
4- Well users of the Quaternary aquifer in this sub-area have direct impacts on each other and on the other users of the Quaternary aquifer of the sub-area.

Indirect relations

Since the Eocene aquifer has been demonstrated to be partly recharged by losses from the Hala Yahfoufa River, users of this aquifer are negatively impacted by water abstractions conducted by farmers and residents in Sarraine, Nassryeh and Ryak-Haouch Hala.

The following figure summarizes the present situation of groundwater and surface water use in the study area.

Figure 23: A conceptual figure of the actual state of water use in the study area



5. Unpacking the complexity of groundwater governance[58]

5.1. The difficulty of collective water management at the level of users

5.1.1. The individualistic nature of groundwater use and the lack of awareness of its collective dimension

As illustrated for each of the different sub-areas, most of groundwater abstraction for irrigation happens individually by farmers. Hundreds of irrigation wells are found in our study area and are mostly operated independently. The only irrigation wells used collectively are those that were recently drilled by the Anjar Irrigation Committee (in Anjar-Chamsine sub-area) to complement the supply to the collective irrigation system fed by the Anjar Spring. However, there are some other wells used collectively by farmers in Fourzol (in Fourzol-Litani sub-area), which are made use of to respond to water shortages during the summer. Other collective arrangements were found in other irrigation wells, but they are of a commercial nature and occur when well owners provide access to their wells (and often plots) to farmers at a cost. Thousands of domestic wells were also found to be used independently by individual houses in all the residential areas of the study area.

At the level of the study area there is no coordination between the numerous groundwater abstractions that take place in one same aquifer, which is shared among several sub-areas areas. Also, it is obvious that the complex recharge mechanisms of aquifers are unknown or unclear to the private users, and, as such, are not taken into account in the management of groundwater resources. Although farmers have good knowledge about groundwater availability within the aquifer they use, this knowledge remains limited to their area of activity (e.g., community or farming area). The structure of aquifers, their depth, superimposition and recharge mechanisms are largely unknown to farmers and residents. Capacity building in this field, although unlikely to resolve the problem of overexploitation, is to be considered as a tool to be used by decision-makers and development programs to improve users' awareness about the impacts their abstractions have on other users' resources. However, as described later, knowledge of the responsible water authorities in this field is also lacking.

5.1.2. Conflicts around surface water allocation and unclear water rights

Water allocation from the different water resources existing in our study area, was found not only to be subjected to conflicts in situations of water scarcity but also reveals the weak allocation mechanisms in place at the level of users. Concerning water allocation from the Hala Yahafoufa River, for instance, conflicts between Ryak-Haouch Hala farmers and upstream communities have been reported to date from the 1970s, without any attempt from farmers or the respective municipalities to secure and resolve these water allocation issues. Moreover, a conflict among farmers of the same town (Ryak-Haouch Hala) was also identified, where farmers using the Ryak Canal accused farmers using the Hoshmosh Canal of diverting most of the remaining flow. Water allocation conflicts were also observed for the use of the Litani River as described earlier, and also at the level of the Ghozayel River during the dry summer of 2014.[59] In the latter case, the Lebanese Army was reported to have intervened and played the role of mediator in this conflict. A meeting was held between some farmers from Anjar, Barr Elias and Marj (located downstream to Barr Elias) where allocation rules were agreed upon. However,

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[58] Part of this section (5.2) was written based on interviews conducted with Dr. Joelle Puig.

[59] One of the most severe droughts on record.

compliance with these rules was reported to have lasted for a few days only. As earlier described, water rights attached to surface water date back to the 1920s. Following the drastic evolution in water use since this period, they have turned out to be inadequate to the way water is currently abstracted and, as such, have become a source of conflicts rather than a regulatory framework helping users to organize collective water allocation.

5.1.3. The general absence of collective action

The difficulty to develop a collective water management system seems to be part of the general problem of ensuring and sustaining collective action. A revealing indicator is the absence of active agricultural cooperatives in our study area and at the scale of the ULRB. This could be explained by the difficulties of the agricultural sector and the prevalence of commercial relations, which result in a very competitive mentality and a lack of trust between farmers. In fact, when asked about their readiness to engage in collective arrangements to reduce groundwater abstraction or better allocate water resources, most of the farmers agreed to say that there is no possible collective action between farmers. Another factor explaining individualistic and competitive strategies rather than collective ones could be the weak rule enforcement on the part of water authorities, which may have resulted in a lack of trust of public institutions and a consequent loss of respect for the common good. This brings us to the management problems related to Water Authorities.

5.2. The difficulty of groundwater management at the level of the state

5.2.1. The unsuitability of groundwater regulations and administrative procedures

With regard to state institutions, factors causing the proliferation of unlicensed wells are linked to the existing status of groundwater regulations and their enforcement. The analysis of the evolution of groundwater levels shows that well depth limitations found in the legislation (wells with depth exceeding 150 m need an official license to operate) are not adapted to the objective of preventing groundwater overexploitation. In most aquifers found in the study area, the use of wells with depths less than 150 m has plainly led to a situation of overexploitation. In the Quaternary aquifer, where well depths rarely exceed 100 m, water levels have gradually dropped causing a dramatic decrease in well yields and water shortages in the summer season. In the Eocene aquifer, the use of wells not exceeding depths of 60-90 m have rapidly resulted in the drying-out of '*Nabeh Ras-El-Ain*' and '"*Nabeh El Faour*' springs, which originated with the inception of the Eocene aquifer exploitation in the 1960s. As for the condition related to water withdrawals (100 m^3/day), it is also beyond the average withdrawals from most wells. Similarly to water rights, these conditions were defined in 1926 (Decree No.320), and were retained in the last Decree (Decree No.14438) organizing private groundwater use issued in 1970, which still remains as the main reference for the MEW.

As for the last decision that was issued by the MEW in 2010 (Decision No.118) with the purpose of reorganizing the enforcement of groundwater regulations and increase well control through the modification of the administrative procedure to apply for well permits, it was found to have produced an effect contrary to what was expected by the authorities. According to the respective directors of both Departments of Groundwater and Hydrogeology and Water Rights and Expropriation, and other employees interviewed,[60] the recently modified administrative procedure led to a dramatic decrease in the numbers of permit applications submitted to the ministry. The main reason is the substantially higher fee (USD 935) that users have to pay to the

[60] The Director of the Department of Groundwater and Hydrogeology was interviewed on December 6, 2015 and January 20, 2016. The Director of Water Rights and Expropriation was interviewed on January 20, 2016.

private companies licensed by the Ministry for the handling of the technical aspects of permit applications. As a result, the number of applications (linked to well notifications) has fallen from 2,000 to 500 applications/year. Moreover, the administrative procedure to be followed by users was reported to be longer and complicated, another factor hindering the process of permit application by users.

It is to be noted that the officials interviewed all acknowledged the unsuitability of the conditions imposed by these regulations. Several texts proposing better adapted conditions have been submitted over the years, but have failed to obtain approval at the central level. Reasons for this state of affairs are unclear (resistance from some quarters, willingness not to impose costs on small farmers, preference for *status quo*, complex bureaucratic steps required for modifying legal texts, etc).

5.2.2. Weak enforcement of groundwater regulations

Aside from the difficulties associated with current groundwater regulation and the cost and complexity of the lately implemented administrative procedure, the lack of enforcement of present regulations has also been found to be a substantial obstacle to groundwater management. According to high-level officials within the MEW, there are several reasons hindering enforcement.

The first one is the substantial understaffing of this department. It was reported that around 100 employees are needed to conduct regular field visits across the country, but in reality there are no more than 10 employees currently working in the department.[61]

The second reason is the delay by the Ministry of Interior (MI) in taking action and approaching users when this is requested by the MEW. According to officials interviewed, although the employees in the respective departments can theoretically perform field visits without being accompanied by the Internal Security (IS), they prefer not to do so for safety reasons. The MEW officials complained about what they see as the limited action of the MoI in this regard. However, this must be put in persepective: lack of political will to enforce control over groundwater is very common across the world, and certainly across the Middle East and Northern Africa region (Closas and Molle, 2016). Understandingly, governments are reluctant to be strict about the control of a resource that is so essential to the economy in general and rural livelihoods in particular. And the nature of groundwater (hidden resource, with a stock that can be incrementally further depleted without, in the short term, glaring negative impact) is also known to work against motivating politicians or administrators to take unpopular measures.

The third reason, unfortunately a well-known one in Lebanon, is linked to corruption and the abuse of political power. This was reported by ministry officials and most of the users interviewed and is an open secret (Farajalla et al., 2015). Officials often accept bribes to turn a blind eye to infringements. This is also a commonplace situation worldwide, whereby the need to pay for authorizations gives value to an otherwise free resource and therefore invites corruption (Molle and Closas, 2017).

Concerning the role of municipalities in enforcement, all interviewed users reported that their action is limited to reporting infringements to the MoI or to the MEW. In fact, as explained by some mayors,[62] municipalities consider that they are not able to intervene because of their close

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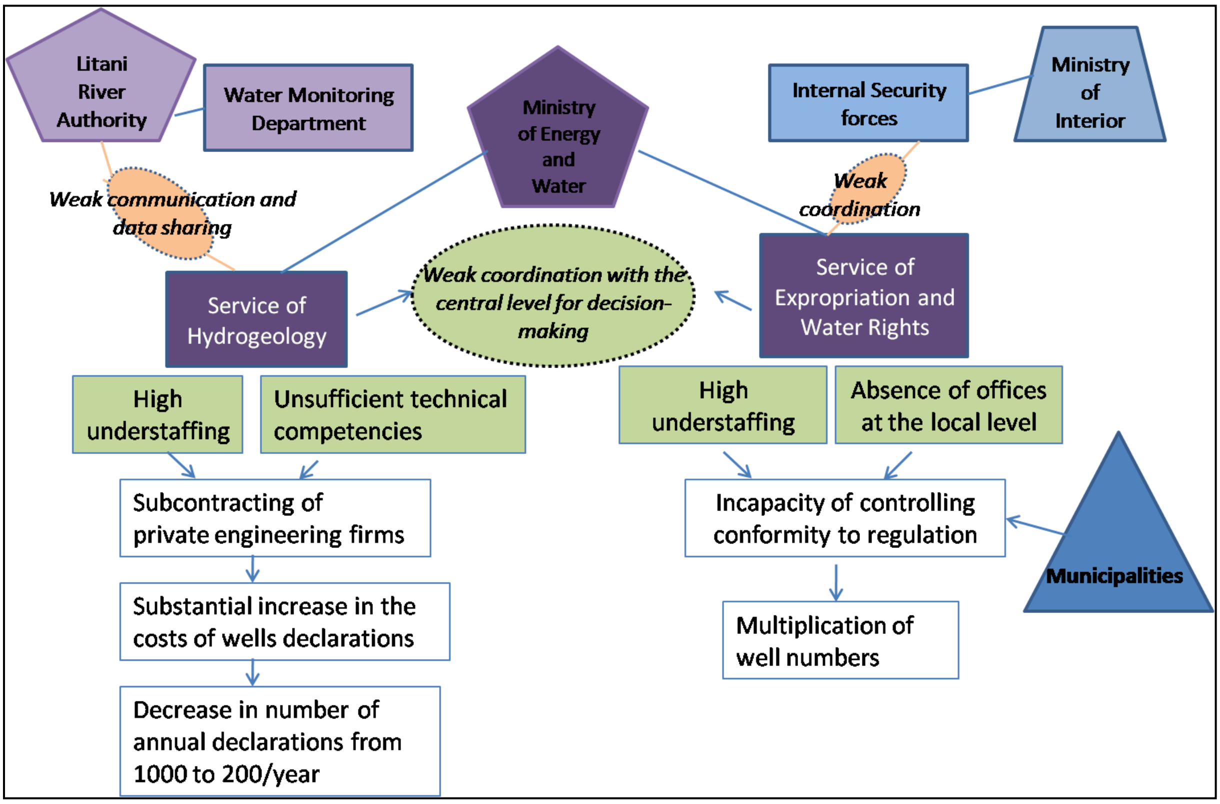
[61] It must be noted that this problem is common to the MEW Departments as well as to all other water authorities, and is linked to a government ban on recruitment by the public sector (USAID 2012e).

[62] The Mayors of Anjar, Terbol and Barr Elias were interviewed on September 9, 2014, November 10, 2014 and November 18, 2015, respectively.

social relationship with farmers and residents, which is necessitated by the nature of the work they do. The governance problems resulting in poor well control and enforcement are illustrated in Figure 24.

Figure 24: Governance problems of well control and enforcement.



Source: Author.

5.2.3. Weak knowledge of hydrogeology and actual state of surface and groundwater resources

Knowledge and research about the actual state of groundwater resources was found to be lacking at the level of the Department of Groundwater and Hydrogeology of the MEW. Main reasons being understaffing and having serious problems with technical capacities, in the face of a resource that is distributed in numerous, complex and interconnected aquifers. As reported by an interviewee, while a proper functioning of the department requires 49 positions including engineers, hydrogeologists and technicians, there are only 9 employees currently working for the department, none of whom is a hydrogeologist. The last one retired a couple of years ago and the MEW has not been able to recruit new employees. The alternative has been to entrust the task of revising the technical aspects of permit application to private consultancy firms, but this has not added any technical capacities to this department. The only technical deliverable provided by these firms to the department is the short technical reports concerning the application of well permits. Moreover, the intervention of these companies did not bring the expected support to the department in terms of technical expertise and labor time. It was reported that the technical reports issued by these companies are often not reliable and still need to be revised by the ministry employees.

Permit applications (including the latter technical reports) were reported to be revised based on the old hydrogeologic maps produced by the 1970 UNDP study. The recent National Groundwater Assessment conducted in cooperation with UNDP (2014) provided updated maps and current groundwater data, but it was only submitted recently to the Department of Groundwater and Hydrogeology (around 2 years after the end of the UNDP Project). This means that from 1970 to 2016 permits were issued based on outdated technical data. Furthermore, the evolution of groundwater levels, well yields and spring discharges have not been taken into account.

Concerning water monitoring, it must be also remembered that measurements of surface water flows and groundwater tables are the task of the LRA and not of the MEW. Data is archived and stored at the LRA, and is transmitted to this department only upon request. The MEW has only recently established a few groundwater monitoring wells through the last UNDP Project, of which only four are in the Bekaa (and none in our study area). As recommended by the UNDP, groundwater monitoring at the national level should be substantially developed for a better management of the resource. In the meantime, improving data sharing between LRA and the Department of Groundwater and Hydrogeology is also much needed.

5.2.4. Weak coordination of present and future water allocation

Aside from its role in regulating and controlling the access of users to groundwater, the MEW is responsible for the overall planning of water supply at the level of all the country's river basins. In the ULRB (except south of the Damascus Road, where it is theoretically under the purview of the LRA),[63] and since the implementation of Law 221 (issued in 2001) in 2005, the BWE is supposed to cooperate with the MEW and establish Master Plans for domestic and irrigation supply, as well as wastewater management. In this regard, understanding the current and projected availability of groundwater resources and their link to surface water, as well as how they are being managed by users is crucial in order to adequately allocate water resources to the different planned infrastructures.

Our study case showed a clear absence of past and present coordination between different water abstraction plans and strategies. In our study area, water from two existing rivers (Litani and Hala Yahfoufa) was over-exploited and, as such, the resource was not made available in the summer for downstream communities. Moreover, irrigation wells that expanded where surface water sources were inaccessible led to the drying-out of several springs (*Nabeh Ras El Ain* and *Nabeh El Faour* springs). Due to the unreliability of collective domestic water supply, not only private domestic wells but also municipal and state domestic wells, proliferated in an uncoordinated way and contributed to groundwater overexploitation and to the reduction in spring discharges (Anjar and Chamsine springs). In this context, the BWE is faced with major challenges both in regulating present water allocation and in defining future plans.

Importantly, when analyzing the planned water allocation defined by the recently published 'Water Supply and Wastewater Systems Master Plan' by the BWE in the light of the current allocation system and the already identified over-allocation problems, it was found that the future plan of reallocating water from spring systems do not take into account the current problems of both surface water and groundwater over-allocation and overexploitation:

- At the level of Hala Yahfoufa sub-area, it was found that water from the Hala Yahfoufa River was already over-allocated.
- At the level of the Anjar-Chamsine sub-area, it was found that: 1) Concerning the Chamsine Spring, the increased over-allocation from springs and nearby wells proved already to be insufficient for the planned service area; 2) Concerning the Anjar Spring, it was proved that the projected water discharge to be reallocated for domestic supply

[63] This separation is problematic to integrated planning of water allocations on the ULRB. However, this problem will not be addressed as part of this study.

would lead to a situation of over-allocation, where domestic supply would compete with existing irrigation needs. Aside from the problems that the BWE would face in terms of water rights abolition, the only alternative for farmers currently using the Anjar Spring would be to rely on the already overexploited water of the Cretaceous aquifer.

This competition will be particularly acute in the summer months of deficit years, when the Anjar Spring discharge drops to a few hundreds liter/second: a planned diversion for domestic water of 200 l/s means that the situation that occurred for the first time in 2014 (Anjar farmers having to drill wells to supply their irrigation scheme) will repeat itself frequently, with a cumulative negative impact on the stock of water in the Chamsine-Anjar system (and therefore on the water level).

This clearly shows that the BWE Master Plan must be revised, taking into account these actual and future situations of surface and groundwater overexploitation.

6. Conclusions

The evolution of groundwater use in each of the sub-areas included in our study case showed that groundwater levels and well yields have been decreasing in all aquifers, since the beginning of groundwater exploitation in the early 1960s. Depending on the physical characteristics of the aquifers, the specific geography of the area and the social and political evolution of each town, the study case revealed a diversity of situations of groundwater overexploitation and different impacts on water users' access to groundwater and coping strategies.

In general, it revealed a clear shift towards a conjunctive use of groundwater as a result of the reduction of surface water availability (mainly in the Litani and Hala Yahfoufa rivers). In these circumstances, water from the Quaternary aquifer was the main alternative for users located far from the other aquifers (Eocene and Cretaceous) in addition to water from the Ghozayel River, which has become insufficient in recent years. Only in one sub-area (Hala Yahfoufa), does the Quaternary aquifer still ensure a reliable alternative to the reduction of surface water availability from the Hala Yahfoufa River. As for the three other sub-areas, which were initially irrigated by the Litani (Litani-Fouzol; Litani-Maallaqa and Litani-Barr Elias), water from this aquifer has become insufficient for summer irrigation. While it was possible for Litani-Fourzol users to develop some adaptation strategies to cope with water shortage (switching to grapes, multiplying wells), most of Litani-Maallaqa and Litani-Barr Elias users were forced to reduce their cropping areas due to land use and financial factors constraining them from drilling more/deeper wells.

In the eastern part of the study area, the Eocene and Cretaceous aquifers offered a substantial resource for farmers who did not have access to surface water resources. The Eocene aquifer allowed a substantial development of agriculture in Hoshmosh, Terbol and Faour-Zahle Maallaqa. However, water levels have substantially decreased and led to increased pumping costs. Moreover, land fragmentation and financial limitations were found to be a constraint to a sustained use of this Eocene aquifer in Terbol and Faour-Zahle Maallaqa, which consequently increased the pressure on the Quaternary aquifer. The Cretaceous aquifer allowed a substantial development of irrigation in Kfarzabad, and also in the originally rain-fed lands of Anjar. There too, water levels have significantly decreased. Globally, users are still able to ensure their water needs from this aquifer, but their water availability is very likely to be impacted as a result of further groundwater abstraction for domestic supply, as planned by the BWE's recent Master Plan. Water reallocation would also substantially reduce water availability for farmers using the Anjar Spring and the Ghozayel River, and would force them to rely on groundwater as an alternative.

Analyzing the drivers and impacts of groundwater overexploitation in each of the seven sub-areas revealed clear interrelations, both between the users of the same sub-area (using the same aquifer and all contributing to its overexploitation) and between users of the different sub-areas. For example, groundwater overexploitation in a certain sub-area is often a result of surface water and/or groundwater use and abstraction in another (upstream) sub-area, which in turn can impact water availability in a third (downstream) hydraulically interconnected sub-area. This creates a complex system of interrelated water uses, where reducing groundwater overexploitation and balancing its negative impacts among the different users requires the integrated understanding and management of surface and groundwater resources.

Analysing the management strategies developed by users on the one hand, and by the different water authorities on the other, reveals many obstacles to establishing and enforcing appropriate and coordinated allocations from both surface and groundwater resources. At the level of users, the obstacles to collective groundwater management are linked to the individualistic nature of groundwater use and the lack of clarity of water rights, and are reinforced by the general absence of collective action among users of the same community, or between the different user communities. This reveals that substantial challenges pertaining to water planning are to be faced by the state in the upcoming years. However, the analysis of the actions of the different responsible water authorities showed that many problems hinder the needed integrated planning and coordination of abstractions. These obstacles include inadequate groundwater regulations adopted by the MEW; a weak enforcement on the part of the MEW and the MI; limited groundwater monitoring by LRA and hydrologic knowledge which prevent sound planning; and, most importantly, the current incapacity of the BWE to coordinate water abstractions at the level of its territory. The underlying problems are linked to structural problems of the water sector's institutional framework (dilution of responsibilities and absence of coordination mechanisms) in addition to the general lack of human, technical and financial capacities of water authorities.

In conclusion, analyzing the historical drivers of groundwater overexploitation and its governance framework showed that the problem of groundwater management is broader than a problem of inadequacy of groundwater legislation and of its enforcement, and must be looked at as a result of a wider problem of water supply and uncoordinated water abstractions.

A number of general recommendations can be drawn from this study and add to those commonly issued by studies and research addressing water management problems in Lebanon. They include the strengthening of public institutions in terms of human resources and technical capacities, defining clearer responsibilities and removing overlaps and duplication, improving coordination between authorities, updating obsolete legal texts, etc. In the short term, two main points must be addressed by decision-makers and discussed with water user representatives during the upcoming 'dialogue'. The first concerns the importance of reviewing the future water allocation projects planned as part of the BWE Master Plan, in the light of the revealed situations of surface water over allocation and groundwater overexploitation. The second is to make use of these concrete examples of groundwater exploitation to reflect on more constraining and better adapted conditions for the provision of permits.

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8. Annexes

8.1. Annex 1: Interviewed mayors and municipality officials (names withheld).

Town	***Position***	***Date of interview***	***Comments***
Barr Elias	Employee	June 25, 2013	Key Informant Survey with BAU
Barr Elias	Secretary	June 23, 2013	Key Informant Survey with BAU
Qab Elias	Mayor	June 26, 2013	Key Informant Survey with BAU
Baalbeck	Vice Mayor	August 22, 2013	Key Informant Survey with BAU
Kfarzabad	Former Mayor President of Eastern Zahle Union of Municipalities	September 18, 2013	Key Informant Survey with BAU
Zahle	Vice Mayor	October 9, 2013	Key Informant Survey with BAU
Kamed El Lawz	Mayor	October 10, 2013	Key Informant Survey with BAU
El Marj	Mayor	November 10, 2013	Key Informant Survey with BAU
Machghara	Mayor	November 12, 2013	Key Informant Survey with BAU
Lala	Mayor	November 23, 2013	Key Informant Survey with BAU
Karaoun	Mayor	November 27, 2013	Key Informant Survey with BAU
Aita El Fokhar	Vice Mayor	November 27, 2013	Key Informant Survey with BAU
Saadnayel	Member in the Municipal Council	December 9, 2013	Key Informant Survey with BAU
Temnine El Tahta	Mayor	June 2014	Walk-through Survey
Anjar	Mayor	September 9, 2014	Walk-through Survey with BAU
Jdita	Mayor	September 15,2013	Walk-through Survey with BAU
Terbol	Mayor	November 10, 2014 November 15, 2014 November 10, 2014 January 14, 2015 January 21, 2015	
Terbol	Secretary	November 10, 2014	
Ryak	Mayor	March 17, 2015	
Jenta	Mayor	March 23, 2015	
Barr Elias	Mayor	November 18, 2015	

8.2. Annex 2: Interviewed officials in state institutions (names withheld).

No.	Position	Date of interview
1	Director of the Groundwater and Hydrogeology Service at MEW	December 6, 2014 January 20, 2015
2	Engineer in Groundwater and Hydrogeology Service at MEW	December 6, 2014
3	Employee at the Water Monitoring Service of the LRA	January 13, 2015
4	Director of Chamsine Pumping Station	January 14, 2015
5	Secretary of the BWE	January 16, 2015
6	Director of the Expropriation and Water Right's Service	January 20, 2015
7	Head of the Water Rights' Bureau (Under the Service of Expropriation and Water Rights' Service)	January 20, 2015
8	General Director of Directorate of Hydraulic Resources	January 20, 2015
9	Director of Tutelage at the MEW	January 20, 2015
10	Director of Rural Engineering Service at the MoA	February 17, 2015
11	Director General of the BWE	April 1, 2015

8.3. Annex 3: Other informants interviewed.

No.	Position	Date of interview	Comments
1	Director of the Cooperative of Sugar Beets	August 6, 2013	Key Informant Survey with BAU
2	Well Driller	July 3, 2014	Walk-through Survey
3	Supervisor at the ICARDA	November 12, 2014	Individual interview
4	Researcher at the ICARDA	November 12, 2014	Individual interview
5	Water vendor in the Kfarzabad region	December 15, 2014	Individual interview
6	Author of a book about Terbol's history	January 16, 2015	Individual interview
7	Professor of Hydrology in the Faculty of Geography at the Lebanese University	March 20, 2015	Individual interview
8	Consultant with Programme Solidarité Eau Association	November 11, 2015	Individual interview
9	Employee of the Anjar Irrigation Committee	November 27, 2015	Individual interview

8.4. Annex 4: Interviewed farmers (names withheld).

No.	*Town of origin*	*Plot location*	*Area (du)*	*Water Source/ Aquifer*	*Date of interview*	*Comments*
1	Saadnayel	Saadnayel		Berdaouni	September 12, 2013	Key Informant Survey with BAU
2	Barr Elias	Barr Elias	100	Litani and Quaternary aquifers	June 23, 2014; November 27, 2015	Walk-through Survey and Individual interview
3	Faour	Barr Elias	500	Litani	June 23, 2014	Walk-through Survey
4	Maallaqa	Maallaqa	80	Litani	June 25, 2014	Walk-through Survey
5	Maallaqa	Maallaqa		Quaternary	June 25, 2014; November 26, 2015	Walk-through Survey and individual interview
6	Fourzol	Fourzol		Quaternary	June 26, 2014	Walk-through Survey
7	Fourzol	Fourzol	7	Quaternary	June 26, 2014; November 27, 2015	Walk-through Survey and individual interview
8	Hizzine			Neogene	July 1, 2014	Walk-through Survey
9	Saideh	Saideh		Not clear	July 1, 2014	Walk-through Survey
10	Makseh	Haouch El Oumara	70	Berdaouni Quaternary	July 3, 2014	Walk-through Survey
11	Marj	Marj		Litani Ghozayel	July 3, 2014	Walk-through Survey
12	Qabb Elias	Nassryeh Tal El Akhdar		Jair River Jurassic	July 3, 2014	Walk-through Survey
13	Mreijat	Tal Dnoub		Eocene	July 4, 2014	Walk-though Survey
14	Marj	Waqf	1,470	Ghozayel Jurassic	September 2, 2014	Walk-through Survey
15	Terbol	Terbol	50	Eocene and Quaternary	November 5, 2014; January 22, 2015	Individual interview and Focus Group
16	Dalhamyeh	Dalhamyeh	70	Quaternary	November 10, 2014	Individual interview
17	Syria	Terbol	21	Quaternary	November 10, 2014	Individual interview
18	Terbol	Terbol	140	Quaternary	November 11, 2014	Individual interview
19	Terbol	Terbol	600	Eocene	November 12, 2014	Individual interview
20	Terbol	Hoshmosh and Majdel Anjar	950	Eocene Quaternary	November 18, 2014	Individual interview

21	Beirut	Terbol and Hoshmosh	1,500	Eocene	November 19, 2014	Individual interview
22	Terbol	Terbol	Area	Quaternary	November 19, 2014	Individual interview
23	Terbol	Terbol and Hoshmosh	1,000-1,500	Eocene	November 28, 2014 January 22, 2015	Individual interview and Focus Group
24	Faour	Kfarzabad		Cretaceous	December 11, 2014	Individual interview
25	Kfarzabad	Kfarzabad		Cretaceous	December 11, 2014	Individual interview
26	Kfarzabad	Kfarzabad		Cretaceous	December 11, 2014	Individual interview
27	Kfarzabad	Kfarzabad		Cretaceous	December 11, 2014	Individual interview
28	Kfarzabad	Kfarzabad		Cretaceous	December 15, 2014	Individual interview
29	Kfarzabad	Kfarzabad		Cretaceous	December 15, 2014	Individual interview
30	Ain Kfarzabad	Ain Kfarzabad		Other units	December 15, 2014	Individual interview
31	Kfarzabad	Kfarzabad		Cretaceous	December 15, 2014	Individual interview
32	Terbol	Dalhamyeh	40	Quaternary	January 22, 2015	Focus Group
33	Barr Elias	Barr Elias	1,500	Ghozayel River and Eocene Aquifer	January 23, 2015; November 18, 2015	Individual interview and Focus Group
34	Faour	Barr Elias	50	Eocene	January 23, 2015	Focus Group
35	Faour	Terbol	300	Eocene	January 23, 2015	Focus Group
36	Faour	Terbol	80	Eocene	January 23, 2015	Focus Group
37 38	Faour	Terbol	140	Eocene	January 23, 2015	Focus Group
39	Faour	Terbol	150	Quaternary	January 23, 2015	Focus Group
40	Faour	Terbol	170	Eocene	January 23, 2015	Focus Group
41	Faour	Terbol	100	Quaternary and Eocene	January 23, 2015	Focus Group
42	Faour	Terbol and Dalhamyeh	80	Quaternary and Eocene	January 23, 2015	Focus Group
43	Faour	Terbol		Eocene	January 23, 2015	Focus Group
44	Terbol	Terbol and Kaa	1,050	Eocene and Quaternary	December 3, 2014	Individual interview
45	Faour	Terbol and Barr Elias	20	Quaternary	December 10, 2014	Individual interview

46	Terbol	Terbol	20	Quaternary	December 10, 2014	Individual interview
47	Terbol	Terbol	40	Quaternary and Eocene	January 22, 2015	Focus Group
48	Ryak	Ryak		Quaternary	March 7, 2015	Individual interview
49	Ryak	Ryak		Quaternary	March 17, 2015	Individual intrerview
50	Ryak	Ryak	70	Quaternary	April 1, 2015	Individual interview
51	Terbol	Terbol	160	Quaternary and Eocene	May 20, 2015	Individual interview
52	Zahlé	Terbol	200	Eocene	May 21, 2015	Individual interview
53	Nassryeh	Hoshmosh	200	Eocene	May 23, 2015	Individual interview
54	Terbol	Terbol	200	Eocene and Quaternary	May 28, 2015	Individual interview
55	Faour	Terbol	40	Eocene	May 29, 2015	Individual interview
56	Terbol	Terbol	200	Eocene and Quaternary	June 3, 2015	Individual interview
57	Terbol	Terbol	120	Eocene and Quaternary		Individual interview
58	Terbol	Terbol	200	Eocene and Quaternary	July 2, 2015	Individual interview

8.5. Annex 5: Production cycles, irrigation calendars and production costs for the main cultivated crops.

	Wheat	Potato (Local)	Potato (Imported)	Onion	Garlic	Cabbage	Cauliflower	Parsley	Mint
Duration of production cycle	8 months	6 months or 5 months		6 months	6 months	70 days	70 days	5 months	Up to 4 years
Period	November-June	February-November		October-March	October-March	Starting March until October	Starting March until October	Starting February until October 1,	All year long
Maximum number of cycles/year	1	2		1	1	2	2	but harvested five times per year	Harvested up to six times
Production costs (USD/du) without the cost of access to land and water									
Land preparation	30	30	30	30	30	20	20	20	20
Seeds/Seedlings	9	120	183	45	70	45	45	20	30
Fertilizers	37	125	125	200	200	15	15	40	60
Phytosanitary	25	25	25	150	150	50	50	30	40
Labor	10	27	27	150	150	50	50	30	35
Irrigation (Energy)	20	150	150	150	150	87	87	60	80
Total cost	131	477	540	725	750	267	267	200	265
Selling price in 2014	200	1,600	1,600	2,000	2,000	500	500	265	400
Selling price in 2015	95	1,350	1,350	1,600	2,000	500	500	133	350
	Radish	Roman Lettuce	Iceberg Lettuce	Tomatoes	Green Peas	Faba Beans	Broccoli		
Duration of production cycle	1 month	70 days	80 days	4 months	5 months	5 months	6 months		
Period	March-November	March-December	March-December	April-September	November-April	November-April	March-December		
Maximum number	6	6	4	2	1	1	2		

of cycles/year							
Production costs (USD/du) without the cost of access to land and water							
Land preparation	20	20	20	30	30	30	30
Seeds/Seedlings	15	50	180	50	35	20	90
Fertilizers	15	40	60	30	25	25	50
Phytosanitary	30	60	200	80	20	20	90
Labor	10	40	200	120	100	120	150
Irrigation (Energy)	40	95	80	160	70	70	160
Total cost	130	305	740	470	280	285	570
Selling price in 2014	450	500	1,600	600	500	450	700
Selling price in 2015	350	650	1,200	560	600	500	800
	Almond	Cherry	Peach	Persimmon	Pear	Apple	
Production costs (USD/du) without the cost of access to land and water							
Land preparation	20	20	20	20	20	20	
Seeds/Seedlings	5	3	7	6	5	7	
Fertilizers	150	150	150	150	150	150	
Phytosanitary	170	170	170	170	170	170	
Labor	200	200	200	200	200	200	
Irrigation (Energy)	100	100	100	100	100	100	
Total cost	645	643	647	646	645	647	
Selling price in 2014	700	800	1,000	1,200	900	850	
Selling price in 2015	400	600	300	499	500	400	

8.6. Annex 6: Compilation of well data found for the different sub-areas.

Town	Aquifer	Type of use	Year of install-ation	Depth (m)	Water level (m BG)	Dis-charge (LPS)	Irrigated areas and crop types (du)	Irrigation technique	Pump type	Energy supply	Convey system	Northing Easting	Easting	Elevation	Source of data	Measurement date (if conducted)
Hoshmosh	Eocene	Domestic Municipal well for Ryak	2003	292					125 HP					952	LWWSS	
Hoshmosh	Eocene	Irrigation			50-70 m in the summer										Interview	
Terbol	Eocene	Monitoring		99	30							33.80583°	35.99187°		LRBMS 2013 (expansion)	09-03-2012
Terbol	Eocene	Domestic (Municipal wells)	1985	96					10 HP					895	LWWSS 2014a	
			2000	208										927		
Terbol	Eocene	Irrigation	1980	225	9,66				Axial pump			33,8138	35,985933	891	LRBMS	5-6-2011
					2,33											2010
Terbol	Eocene	Irrigation	1973	140	20,25				Electrical submersible pump Ø 2 1/2"			33,83485	35,9849	904	LRBMS	6-6-2011
					7,77											2010
Terbol	Eocene	Irrigation	1973	150	54,8				Unequipped			33,806683	35,9931	899	LRBMS	6-6-2011
					23,36											2010
Terbol	Eocene	Irrigation		55					Submersible pump						LRBMS	5-6-2011
Terbol	Eocene	Irrigation	1968	150											Interview	

	Quaternary	Irrigation	2008	80	7 m in the winter		50 Table grapes								Interview	**5-11-2014**
		Irrigation (three wells)	First in 1975	50			80 Vegetables								Interview	
		Irrigation (four wells)	First in 1975	60			Vegetables								Interview	
		Irrigation	1968	100			120								Interview	11-11-2014
		Irrigation (many)	First in 1990	80			Vegetables								Interview	
		Irrigation	2004	60	30 m in the summer		20 Vegetables								Interview	
		Irrigation (two wells)		50	25-30 in the summer										Interview	
		Irrigation (three wells)	2000	70-90	40 m in the summer		21 Vegetables and fruit trees								Interview	
	Eocene	Irrigation	1978	180			300 Vegetables	Sprinklers /drip							Focus Group	
		Irrigation	1985	150			80 Vegetables	Sprinklers /drip							Focus Group	
		Irrigation	1986	150			140 Vegetables	Sprinklers /drip							Focus Group	
		Irrigation		170			150 Vegetables	Sprinklers /drip							Focus Group	
		Irrigation	1959	250			170 Vegetables	Sprinklers /drip							Focus Group	
		Irrigation		140			100 Vegetables	Sprinklers /drip							Focus Group	

		Irrigation	1986				80 Vegetables	Sprinklers /drip							Focus Group	
Kfarzabad	Cretaceous		2009	80	60,19 69,7				¾ " pump unequipped			33,769117	35,982283	973	LRBMS	2010 06-06-2011
		Irrigation	2005	140	98 57,95							33,766983	35,983283	993	LRBMS	06-06-2011
				100	23,07 19,97				Electrical submersible pump ∅ 1 ¼ " unequipped			33,7584	35,96485	893	LRBMS	2010 06-06-2011
		Irrigation	2008	125	42,66				Electrical submersible pump ∅ 4 "			33,7507	35,963133	910	LRBMS	2010
		Irrigation			10,25							33,750367	35,958117	874	LRBMS	2010
		Irrigation			40,46							33,75034	35,9634	917	LRBMS	06-06-2011
		Irrigation			10,12				Axial pump			33,75127	35,95897	885	LRBMS	06-06-2011
		Irrigation		100											BAU	
		Irrigation		100											BAU	
		Irrigation		120											BAU	
		Irrigation		120											BAU	
		Irrigation		100											BAU	
		Irrigation		140											BAU	
		Irrigation		150											BAU	
		Irrigation		170											BAU	
		Irrigation		100											BAU	

		Irrigation		150	40		3 du apple 4 du apple	Drip	Submersible 1" 3HP	Diesel generator					Interview	15-12-2015
Anjar	Cretaceous	Monitoring		84,1	0,1							33.73372°	35.94691°		LRBMS 2013	20-8-2013
		Irrigation used to complement irrigation in spring based system	2014	75	4,5	83	Used collectively in the irrigation system		Submersible			35.944633	33.732783	882	SPNL	10-6-2014
			2014	65		Giving 83LPS together			Submersible			35.944633	33.732783	882		
		Domestic (Municipal wells)		131		36,1			30 HP					925	LWWSS 2014a	
		Irrigation		125		40,3			180 HP					887		
Barr Elias	Quaternary	Irrigation		12											BAU	
		Irrigation		90											BAU	
		Irrigation		100											BAU	
		Irrigation		110											BAU	
		Irrigation		105											BAU	
		Irrigation		90											BAU	
		Irrigation		105											BAU	
		Irrigation		100											BAU	
Ryak	Quaternary	Monitoring		50	8							33.857800	35.987430		LRBMS 2013	10-6-2013
		Irrigation	1981	130	27,5 16	0,13			Electrical submersible pump			33,846067	35,995333	920	LRBMS	2010 22-06-2011
		Domestic	1999	125	36,53 23,89	0,11			Electrical submersible pump			33,853217	36,012233	930	LRBMS	2010 22-06-2011
		Irrigation	1997	110	20 m in the	7,5	54 du of Almond	Drip for fruit trees	Electrical submersible	Public electricity	Plastic pipes				Interview with the	1-4-2015

					summer 13-15 in the winter		Nectarine Kaki 26 du of vegetables	Sprinklers for vegetables	pump 10.5HP	network	Wells are connected to the same irrigation system				same farmer	
		Irrigation	1997	55		7,5			Electrical submersible pump 5.5 HP	Public electricity network						
		Irrigation	1980				24								Interview	7-3-2015
Fourzol	**Quaternary**	Irrigation		70	2,87										LRBMS	5-6-2011
		Irrigation							Submersible pump						LRBMS	23-6-2011
		Irrigation					Grapes (newly planted) Same plot	Elevated drip system	Axial shaft pump	Diesel generator					Walk-thtough Survey	Rudy Saydeh
		Irrigation							Axial pump	Diesel generator					Walk-through Survey	Rudy Saydeh
		Irrigation							Submersible pump	Diesel generator					Walk-through Survey	Rudy Saydeh
		Irrigation					Harvested wheat	Sprinklers	Submersible pump	Public electricity network					Walk-thtough Survey	
		Irrigation					Tomato under greenhouse	Drip	Submersible Pump	Diesel generator	Water is pumped to a common concrete reservoir and then to the system				Walk-through Survey	Georges Assaf
		Irrigation					Grapes	Elevated drip system	Submersible pump	Diesel generator					Walk-through Survey	
		Irrigation													Walk-thtough Survey	

		Irrigation					Grapes (newly planted)	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Fruit trees	Drip	Submersible pump	Public electricity network					Walk-thtough Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-thtough Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Grapes	Drip	Submersible pump	Public electricity network					Walk-through Survey	
		Irrigation					Grapes	Drip	Centrifugal pump 7HP	Public electricity networkl					Interview	
Damhamyeh		Irrigation	1970	50	22,85				Axial pump						LRBMS	2010
					3,85											5-6-2011
		Irrigation	1980	50	25,75				Two Eeectrical submersible pump ∅ 2 " inch						LRBMS	2010
					1,65											5-6-2011
		Irrigation	1970	45	19,6				Axial pump						LRBMS	2010
					1,95											5-6-2011
		Irrigation		90	1,44										LRBMS	5-6-2011
		Irrigation		70					Axial pump	Diesel generator					Walk-through Survey	

		Irrigation							Submersible pump	Diesel generator					Walk-through Survey	
		Irrigation							Submersible pump	Diesel generator					Walk-through Survey	
		Irrigation							Submersible pump	Diesel generator					Walk-through Survey	
Zahle Maalaqa		Irrigation	1973	215	24,5		107 du of fruit trees and vegetables	Drip for fruit trees Sprinkler for vegetables	Axial pump	Diesel generator					LRBMS	2010
			1982						Axial pump	Diesel generator					Interview with farmer	
		Irrigation				10	150 du wheat and vegetables		Axial pum	Diesel generator		33°48'45.00	35°56'25.00		Walk-through Survey	
		Irrigation							Submersible pump	Diesel generator		33°48'40.00	35°56'17.00		Walk-through Survey	
		Irrigation					50					33°49'5.55	35°56'37.37		Walk-through Survey	
		Irrigation					35 for the four wells	Potato, raddish, sugarbeet	Submersible pump	Diesel generator		33°49'6.00	35°56'38.00		Walk-through Survey	
		Irrigation							Submersible pump	Diesel generator		33°49'10.00	35°56'39.00		Walk-through Survey	
		Irrigation							Submersible Pump	Diesel generator		33°49'12.00	35°56'49.00		Walk-through Survey	
		Irrigation							Submersible pump	Diesel generator		33°49'5.53	35°56'37.36		Walk-through Survey	
								Alfalfa and zuchini	Submersible pump	Electricity network		33°49'21.00	35°56'44.00		Walk-through Survey	
									Submersible pump	Electricity network		33°49'12.00	35°56'44.00		Walk-through	

															Survey	
									Submersible pump	Electricity network		33°49'28.00	35°56'58.34		Walk-through Survey	
									Submersible pump	Electricity network		33°49'28.00	35°56'49.00		Walk-through Survey	
								Zuchini, lettuce, garlic	Submersible pump	Diesel generator		33°49'6.84	35°56'58.34		Walk-through Survey	
									Axial pump	Diesel generator inside building		33°49'41.00	35°56'54.00		Walk-through Survey	
									Axial pump	Diesel generator		33°49'48.00	35°57'4.00		Walk-through Survey	

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www.iwmi.org

127, Sunil Mawatha, Pelawatte, Battaramulla, Colombo, Sri Lanka
Mailing Address: P.O. Box 2075, Colombo, Sri Lanka
Tel: +94-11 2880000 Fax: +94-11 2786854 E-mail: iwmi@cgiar.org Web: www.iwmi.org

International Water Management Institute