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LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

HYDROGEOLOGIC REFERENCE REPORT (APRIL 2012)

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This report was produced for review by the United States Agency for International Development (USAID). It was prepared by International Resources Group (IRG) under Contract EPP-I-00-04-00024-00 order no 7.

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The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government

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ACRONYMS

AUB	American University of Beirut
CS	Council for the South
DAI	Development Alternatives, Inc.
ET	Evapotranspiration
ICARDA	International Center for Agricultural Research in the Dry Areas
IRG	International Resources Group
IQC	Indefinite Quantity Contract
IWRM	Integrated Water Resources Management
LRA	Litani River Authority
LRBMS	Litani River Basin Management Support Program
MEW	Ministry of Energy and Water
RBMP	River Basin Management Plan
ULRB	Upper Litani River Basin
UNDP	United Nations Development Program
USAID	United States Agency for International Development

FOREWORD

This Hydrogeologic Reference Report was prepared by UHL & Associates, Inc., under subcontract with International Resources Group (IRG), the main contractor under the Litani River Basin Management Support (LRBMS) Program, a USAID-funded program in Lebanon (Contract EPP-I-00-04-00024-00 Task Order No.7) under the Integrated Water and Coastal Resources Management Indefinite Quantity Contract (IQC) II.

EXECUTIVE SUMMARY

PROGRAM BACKGROUND

The LRMBS Program is a four-year program to improve water management in the Litani River Basin in the Bekaa. It is undertaken by IRG, in cooperation with LRA, and is funded by USAID. The program began in October 2009 and has four components: Building Institutional Capacity, Water Monitoring, Irrigation Management and Risk Management.

The Hydrogeologic Reference Report was developed to provide an overview and understanding of groundwater conditions in the Upper Litani River Basin (ULRB) for the principal aquifer units and to set the framework for the application of a numerical groundwater model for simulating water-level impacts from present and future groundwater withdrawals.

The Upper Litani River Basin reaches from the surface-water divide between the Litani and Orontes Rivers near Baalbek in the northeast, to Lake Qaraoun in the southwest. The Upper Litani Basin is characterized by the Bekaa Valley which is approximately 10+ kilometers wide near the basin divide close to Baalbek and thins to a width of a few kilometers in the southwest near Lake Qaraoun.

PRINCIPAL AQUIFERS

The Upper Basin is underlain by five principal geologic and hydrogeologic units or aquifer systems (**Figure 2**).

Quaternary Aquifer: The unconsolidated Quaternary deposits (fine grained silts and clays interspersed with thin sand and gravel lenses) are found in the central part of the Upper Litani Basin and outcrop over much of the Valley north of Joub Jannine. These deposits can be 200 meters thick and greater.

Neogene Aquifer: The Neogene is comprised of older alluvial deposits and conglomerate and its outcrop area is less extensive than the Quaternary. The Neogene can be up to 300 meters thick and greater.

Eocene Aquifer: The Eocene Formation outcrops in thin bands (generally 1 Km and less) on both the east and west sides of the Bekaa Valley, and in a broader area in the southern part of the Valley. The formation is up to 250 meters thick.

Cretaceous C4 Aquifer: The C4 Formation 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 just north of Lake Qaraoun. This formation is up to 600 meters thick and the most extensive and prolific aquifer in the Upper Basin.

Jurassic Aquifer: The Jurassic Formation outcrops in the western part of the Upper Basin from Chtaura down to Lake Qaraoun and comprises a prolific aquifer.

SPRINGS

Several high capacity springs issue from the carbonate rock aquifer units (Eocene, Cretaceous and Jurassic) that bound the Bekaa Valley on both the east and west sides (**Figure 3)**. The principal springs on the eastern side of the valley (Anjar and Chamsine) issue at the contact between the lower permeability Quaternary unit and the more permeable Cretaceous aquifer unit. Three springs that historically issued from the Eocene Aquifer area with a possible and likely contribution from the Cretaceous Aquifer (Ras el Ain, El Faouar, and Ain el Beida Springs) no longer flow due to the heavy irrigation pumpage from the Eocene and Cretaceous Aquifers in the area surrounding these springs.

On the western side of the Basin, one of the principal springs (Berdouni) is structurally controlled and issues from along the Yammoune Fault area. Other important springs on the western side of the valley include the Chtaura, Kab Elias, and Ammiq Springs. Spring flow rates measured during the UNDP study are provided in **Table 2**. Present efforts at spring flow measurements are reportedly very limited.

Spring flow is the main component of groundwater discharge in the Upper Litani Basin and in the past, spring discharge provided over 90% of the baseflow to the Litani River. It has mainly been the capture of this spring discharge for irrigation, industrial and municipal uses that has caused the reduction in baseflow and the drying up of the Litani River during the warmer dry season months.

GROUNDWATER SYSTEM ELEMENTS

Historical Groundwater Level Conditions and History: Historical data are available for a number of wells completed in the Quaternary and Neogene Aquifers in the 1950's to the early 1970's timeframe. The next period during which water-level data are available is from 1990 to around 2002 when many municipal drinking water wells were installed – principally in the three carbonate rock aquifers.

Water Level Declines have been noted (measured) in several of the aquifer units and appear most marked along the edges of the valley for wells completed in the Eocene and Cretaceous Aquifers and to

an extent in the Neogene Aquifer in northeast basin areas. The impacts from the lowering of water levels include: a. reduction in spring flows; b. the drying up of certain springs, and c. a reduction of well yields.

Groundwater Flow Conditions: The first effort at developing an understanding and quantifying of groundwater flow conditions in the ULRB was during this work effort under the LRBMS. Two carefully planned synoptic water level measurement events were carried out where water levels were measured in over 120 wells. The collected water level data were then utilized to construct the two water-level contour or potentiometric surface maps for the ULRB – one for dry season (2010) and one for wet season conditions (2011).

Aquifer Hydraulic Characteristics: Pumping test results were compiled from various sources and summarized in **Table 3** and **Figure 8** for 66 tests. There is a wide range of up to three to four orders of magnitude for the aquifer hydraulic characteristic values (Transmissivity and Specific Capacity) for the individual aquifer units. For the five aquifer units, there is a range up to four to five orders of magnitude for the values.

Aquifer Recharge: Aquifer recharge estimates were developed on the basis of historical spring flows (UNDP 1970); historical baseflow evaluation (LRBMS); and an analysis of precipitation inputs to the five aquifer systems **(Table 5).** A practical range of groundwater recharge in the ULRB is in the range of 200 to 220 MCM/Yr. The bulk of the recharge (82%) is to the carbonate rock aquifer units and as such serious consideration needs to be given to Planning and Land Use practices in these critical aquifer recharge areas if spring flows and quality are to be maintained.

Static Groundwater Reserves: Static Groundwater Reserve estimates are conservatively in the range of 15,000 MCM and greater. To put the static reserve calculations into perspective, groundwater storage of 15,000 MCM is equivalent to 90 years of pumping at a gross withdrawal rate of 160 MCM/Yr. without recharge. In the context of water-resources planning, groundwater systems with large storage reserves have a significant drought buffer and this allows for greater planning flexibility for evaluating alternative supplies than for groundwater systems with very small or low storage reserves with say only a few years of drought-buffer storage.

Groundwater Use: There has been no inventory of groundwater and spring withdrawals quantities for municipal, industrial and irrigation uses in the ULRB. As such, we have used indirect sources of information and data to come up with some preliminary estimates of groundwater abstractions for irrigation, municipal and industrial uses for initial modeling purposes.

GROUNDWATER NUMERICAL MODELING

The modeling process will be incremental and with a long term vision – it can be viewed as a management tool that will be updated from time to time as more data and information are made available and analyzed. It is very clear that we will enter the initial modeling phase with clear and sufficient data in some areas and insufficient data in others. So for the purpose of getting started, we will need to rely on historical data to an extent and estimates in areas such as groundwater pumpage by aquifer unit, current and historical spring flows, etc.

Modeling Objectives: The principal Modeling Objectives include the following general areas:

- The development of a representative groundwater model for the Upper Litani Basin Groundwater Aquifers that can be used for:
    - Future predictions of groundwater surface elevations under a range of development scenarios.
    - Evaluation of groundwater – surface water interaction.
    - Troubleshooting and problem solving for focused problem areas.

- The application of the model for problem solving in areas such as:
    - The development of **"Spring Protection Zones"** to preserve/maintain spring flows. Specific areas that might be addressed include:
        - Set back distances from springs for production wells;
        - Spring contribution area protection programs.
    - Municipal well protection zones – set back distances from Municipal Wells for irrigation wells.
    - Potential future expansion of Canal 900 where part of the Canal 900 water will come from five installed production wells.
    - Increased Jurassic Aquifer Development in the west-southwest basin areas
    - Evaluation of the basin area near and around Lake Qaraoun to assess:
        - Input to the underlying aquifer system(s) from the Lake and
        - Flux out of the southern part of the basin (model area)

Model Boundary Conditions: The modeled area will be the same as the surface drainage basin area for the Upper Litani Basin. The basin boundaries will be no flow boundaries except for the southern basin model boundary where there is a flux out of the Upper Basin to the south of Lake Qaraoun.

Groundwater Management/Policy: There are a number of groundwater management and policy areas that can be investigated in a preliminary way through numerical modeling approaches. These include:

- Encourage the development of the Quaternary and Neogene Aquifers for irrigation use with the goal of reducing pumpage from the bounding Carbonate rock aquifer units for irrigation use (Eocene, Cretaceous and Jurassic Aquifers). This type of a management initiative will help restore spring flows at springs that have dried up or experienced reduced flow; protect future spring flows; and assist in the restoration of baseflow (dry weather flow) to the Litani and its tributaries.

- Manage the allocations from spring flow for irrigation use with the goal of reserving a percentage of spring flow for Litani baseflow maintenance to restore "Ecological Water Needs".

- Preserve the carbonate aquifer units for drinking water use (already a government goal/policy).

Planning: What the groundwater recharge analysis clearly signals is that land use considerations and planning are critical and needed in the upland carbonate rock aquifer areas if the quantity and quality of groundwater recharge (and by association Spring Discharge) is to be maintained. There are a number of detrimental land uses in the carbonate rock areas (e.g. large quarries) that impact groundwater recharge and by association springs discharge water quantity and quality.

Pre- Modeling Recommended Studies/Data Gathering: There are a number of areas where additional data collection and field work will provide a firmer and more realistic modeling basis and include the following evaluations:

- A rapid assessment of the Eocene/Cretaceous area in the east central part of basin (Terbol to Chamsine Spring) in regard to irrigation pumpage; water levels and local recharge analysis/water balance.

- An evaluation of the area around Lake Qaraoun and to the south to assess potential contribution from the Lake to the underlying carbonate rock aquifers (Eocene and Cretaceous) and the magnitude of the groundwater flux out of the Model Domain to the south (critical boundary condition).
- An assessment of the Berdouni Spring area which is a hot topic area vis a vis competing uses; water scarcity in the dry season; and the critical need for Ecological Stream Flow through Zahle.
- Interaction with the UNDP countrywide Hydrogeologic Study Team to evaluate findings and data that would assist in the ULRB modeling work.

Additional Recommended Pre-Modeling Activities Include:

- The implementation of late dry season spring flow measurements which could be a pre-cursor to a more systematic spring flow measurement program for the LRA.
- Consultation with the MEW and local well drillers to explore if additional pumping test data are available for incorporation into the modeling effort.
- Controlled Aquifer Pumping Tests: The scarcity of controlled aquifer pumping tests in all of the five principal Aquifer units is a significant data gap. The results from controlled aquifer tests provide the real underpinning for numerical models and will provide real value down the road for the LRA. What is involved here is looking at opportunities where there are existing production wells and nearby wells that could be used for observation wells. This would save the cost of drilling new pumping and observation wells. Some immediate opportunities for conducting controlled aquifer pumping tests are outlined in the report section 4.3

Rapid assessment of irrigation pumpage for selected areas such as Jurassic area to the southeast from Kab Elias down to Mansoura.

1. INTRODUCTION

1.1. AUTHORIZATION

International Resources Group (IRG) was contracted by USAID/Lebanon (Contract EPP-I-00-04-00024-00 Task Order No. 7) under the Integrated Water and Coastal Resources Management Indefinite Quantity Contract (IQC) II to implement the Litani River Basin Management Support (LRBMS) Program. The period for performance of the contract is September 29, 2009 to September 30, 2012.

1.2. PROGRAM OBJECTIVES

The purpose of the LRBMS Program is to set the ground for improved, more efficient and sustainable basin management at the Litani River Basin through provision of technical support to the Litani River Authority and implementation of limited small scale infrastructure activities.

The LRBMS program is part of USAID's increasing support for the water sector in Lebanon. The Litani River Basin suffers the fate of many river basins around the world: increasing demands compete for limited natural resources. Groundwater over-exploitation, deforestation and overgrazing, unplanned urban sprawl, untreated wastewater effluents, and unsustainable agricultural practices contribute to environmental degradation in the form of declining water and soil quality.

Solutions do exist to reverse these trends and establish sustainable management practices. The key to successfully implement such solutions requires applying the principles of Integrated Water Resources Management (IWRM) through a single river basin authority rather than multiple agencies responsible for different aspects of water management as is the case in many countries. Fortunately, the existence of the Litani River Authority (LRA) provides a unique platform to become such an IWRM river basin authority that will mobilize stakeholders in the river basin and address these challenges in an integrated manner.

Successful implementation of LRBMS will prepare the LRA to assume the role of an integrated river basin authority upon the removal of the present legal constraints.

1.3. PROGRAM COMPONENTS

LRBMS works with national and regional institutions and stakeholders to set the ground for improved, more efficient and sustainable basin management at the Litani River Basin. The LRBMS technical assistance team provides technical services and related resources to LRA in order to improve their

planning and operational performance and equip them with the necessary resources for improved river basin management.

To achieve the program objectives, LRBMS undertakes activities grouped under the following four components:

1) Building Capacity of LRA towards Integrated River Basin Management

2) Long Term Water Monitoring of the Litani River

3) Integrated Irrigation Management which will be implemented under two sub-components:

   a. Participatory Agriculture Extension Program: implemented under a Pilot Area: West Bekaa Irrigation Management Project

   b. Machghara Plain Irrigation Plan

4) Risk Management which will be implemented under two sub-components:

   a. Qaraoun Dam Monitoring System

   b. Litani River Flood Management Model

1.4. PURPOSE OF THE HYDROGEOLOGIC REPORT

Over the past one and half years, the Litani River Basin Management Support (LRBMS) Program has had a groundwater component that, as one its activities, focused on the development of a physical framework for the hydrogeologic (groundwater) system in the Upper Litani Basin. The report serves to:

- Provide an overview and understanding of groundwater conditions in the Upper Litani River Basin (ULRB) for the principal aquifer units (areal extent; thickness, water levels, and aquifer hydraulic characteristics).
- Summarize pertinent technical information from previous hydrogeologic studies and investigations in the basin.
- Develop the framework for the application of a numerical groundwater model for simulating impacts from present and future groundwater withdrawals. The groundwater model can be used as a management and planning tool for aquifer management and to assess impacts to the groundwater and surface water (springs) systems from a variety of development scenarios. The Key modeling data needs include:
    - Potentiometric surface maps as a basis for model calibration: Two maps were developed, one for the dry (2010) and one for the wet season (2011) periods.
    - An analysis of groundwater flow conditions for the definition of groundwater basin boundary conditions as there has been postulation of an out-of-basin groundwater flow component to the southeast into the Hasbani Basin.
    - An evaluation of groundwater recharge from precipitation.
    - An analysis of spring flow conditions from previous work by the UNDP and evaluation of selected springs.

- An overview of aquifer hydraulic characteristics (transmissivity, specific capacity, and storativity) for the 5 principal aquifer systems.

- The outline of modeling objectives, strategies and goals and the development of a practical range of model simulations for present and future groundwater management purposes.

Figure 1 is a project area location map that shows the boundaries of the ULRB to Lake Qaraoun**.**

2. OVERVIEW OF PREVIOUS HYDROGEOLOGIC INVESTIGATIONS

UNDP (1970): The 1970 UNDP groundwater study was the first comprehensive nationwide evaluation of groundwater resources. In the Upper Litani Basin, valuable baseline data were collected, specifically in regard to spring flows, which was and continues to be the main component of groundwater discharge in the Upper Litani Basin. Ten (10) principal springs were identified (**Table 2)** and at least three of these springs do not flow today.

The estimated seasonal discharge from these 10 springs in the late 1960's and 1970's timeframe was 205 million cubic meters per year (MCM/Yr.). Small to medium size springs in the upper basin (of which there are many) probably account for at least another 10 to 20 MCM/Yr. These would include Yafoufaa, Krazet and others (**Figure 3**). So groundwater discharge from the carbonate rock aquifer systems was likely in the range of 215 to 225 MCM/Yr. in the timeframe of the UNDP study. The UNDP work also involved the installation of test wells proximate to a number of springs in the Valley and the performance of aquifer tests to determine aquifer hydraulic conditions (Report Section 4.3)

DAI - Groundwater Vulnerability Mapping (BAMAS- 2003 & 2005): The main objective of the Litani Water Quality Management Basin Advisory Services (BAMAS) Project was to identify and assess management and investment options and scenarios for water quality improvement and pollution remediation for the ULRB and Lake Qaraoun and develop an environmental management plan for their implementation.

The BAMAS project also conducted groundwater modeling to assess the vulnerability of the principal aquifer systems to land use practices and contamination sources in the basin. The modeling was conceptual in nature in that field-derived groundwater levels and aquifer hydraulic characteristics were not used to develop and calibrate the model. DAI/BAMAS extended the model domain outside or beyond the physical basin boundaries to the east-southeast where it was opined that there was an out-of-basin groundwater flow component into the Hasbani Basin. In the LRBMS work, we have shown through the development of potentiometric surface maps, constructed from field derived water-level measurements, that this is not the case and that the groundwater system boundaries in the ULRB are

conterminous with the surface water system divides. This is discussed in more detail in Report Section 4.2.

The DAI (2003) groundwater recharge estimate of 388 Million Cubic Meters per year (MCM/Yr.) appears overestimated given the physical area of the ULRB (approximately 1,500 Km^2); the 1100 MCM/Yr. of precipitation falling on the basin; and the 60% evapotranspiration (ET) estimate. If ET is taken at 660 MCM/Yr. and groundwater recharge at 388 MCM/Yr. then there is basically very little water available for runoff on the basis of DAI's estimates.

JICA (2003): JICA developed a water balance for the upper basin and estimated groundwater recharge to be 484 MCM/Yr. This estimate is overestimated given average precipitation and ET.

3. GROUNDWATER SYSTEM FUNCTIONING/HYDROGEOLOGIC OVERVIEW

The Upper Litani River Basin reaches from the surface-water divide between the Litani and Orontes Rivers near Baalbek in the northeast, to Lake Qaraoun in the southwest. The Upper Litani Basin is characterized by the Bekaa Valley which is approximately 10+ kilometers wide near the basin divide close to Baalbek and thins to a width of a few kilometers in the southwest near Lake Qaraoun.

The valley floor (Bekaa Plain) is bounded by hilly mountainous terrain comprised of carbonate bedrock aquifer systems on both the western and eastern sides. The valley floor is heavily cultivated and the upland areas bounding the valley floor are also cultivated in places. The Upper Basin is underlain by five principal geologic and hydrogeologic units (aquifer systems). These are shown on **Figure 2,** a geologic map for the Upper Basin, and include the following principal aquifer units:

- Quaternary – Alluvium, colluvium
- Neogene – Conglomerate, alluvium, colluvium
- Eocene – Carbonate aquifer
- Cretaceous – Carbonate aquifer
- Jurassic – Carbonate aquifer

Table 1: Summary of Principal Aquifer Units

Name	Description and location	Overview
Quaternary:	Unconsolidated alluvial deposits found in the valley north of Joub Jennine. These deposits can be > 200 meters thick.	Well yields range from <5 to reportedly as much as 30 LPs. No significant water level declines noted. However there has had to be some decline in the northern part of the basin as the source spring for the Litani River (Ain Assaouda) reportedly no longer flows. There are many low to medium capacity irrigation wells completed in this aquifer unit
Neogene:	Older alluvial deposits and conglomerate which underlie the Quaternary in places and outcrop on the west side near the foothills from Chtaura to Chmistar and over a large area from northeast of Rayak to Baalbek. There is also a small Neogene outcrop area in the southwest basin area.	Well yields range from <5 to reportedly as much as 30 LPs. Localized water level declines in the east-northeast part of the basin where there are many irrigation wells.
Eocene:	Carbonate Rock Aquifer system that outcrops in thin bands on the east side of the basin from Baalbek to Terbol and on the west side in a thin band from Zahle to Chmistar. The formation outcrops in a broad area around Joub Jannine and Kamed El Laouz down to and south of Lake Qaraoun. The formation is up to 250 meters thick.	Well Yields up to 50 LPs and greater. Localized water level declines in the eastern part of the basin near Terbol and north of Anjar and in the Baalbek area. 3 springs have dried up in the Terbol area.
Cretaceous:	Carbonate Rock Aquifer system that outcrops extensively on both sides of the valley as the main constituent of both mountain ranges.	Well Yields up to 150 LPs. Irrigation wells north of Anjar on the east side of the Upper Basin and in the southern part of the Upper Basin just north of Lake Qaraoun. A large number of municipal wells are completed in this aquifer unit on both sides of the valley.
Jurassic:	Carbonate Rock Aquifer system that outcrops in the west side of the basin from Chtaura to south of Lake Qaraoun.	Well Yields up to 130 LPs. Irrigation wells from the area south of Kab Elias down to the Lake on the west side of the Valley. Municipal wells from Chtaura to the Lake Qaraoun area.

The younger Quaternary and Neogene units are present/outcrop over large areas (approximately 600 Km^2) in the Valley, as outlined on **Figure 2**, and also on the two geologic cross sections oriented across the valley in a west-to-east direction provided in **Appendix A.** The carbonate rock aquifer units bound the Valley on its western and eastern sides and underlie the younger Quaternary and Neogene units at depth (from a few meters near the edges of the valley floor to > 300 m) in the central valley floor area. The aquifer systems are hydraulically interconnected and before significant groundwater development/abstraction, groundwater flow was from areas of groundwater recharge (principally higher

elevation carbonate rock aquifer systems - Eocene, Cretaceous and Jurassic Aquifers) to areas of groundwater discharge (springs, wetlands, and baseflow to the Litani River).

Springs: Several high capacity springs issue from the carbonate rock aquifer units that bound the Bekaa Valley on both the east and west sides (**Figure 3)**. The principal springs on the eastern side of the valley (Anjar and Chamsine) issue at the contact between the lower permeability Quaternary aquifer unit and the more permeable Cretaceous aquifer unit. The Yahfoufa Spring (also called El Ghaida) in the northeast part of the basin issues from the Cretaceous Aquifer. Three springs, that historically issued from the Eocene Aquifer area with a possible and likely contribution from the Cretaceous Aquifer, (Ras el Ain, El Faouar, and Ain el Beida Springs) no longer flow due to the heavy irrigation pumpage from the Eocene and Cretaceous Aquifers in the area surrounding these springs.

On the western side of the Basin, one of the principal springs (Berdouni) is structurally controlled and issues from along the Yammoune Fault area. The Berdouni spring flows during the drier summer and early fall months has been reduced to the extent that only wastewater discharge flows provide baseflow to the Berdouni stream through Zahle. Other important springs on the western side of the valley include the Chtaura, Kab Elias, and Ammiq Springs. The Ammiq spring issues near the contact of the permeable Jurassic Rock Aquifer system and the lower permeability Quaternary Aquifer deposits. Spring flow rates measured during the UNDP study are provided below in **Table 2**

Table 2: Representative Spring Flow Rates (UNDP, 1970)

West Side Springs	MCM/Yr.	East Side Springs	MCM/Yr.
Berdouni	44.51	Yahfoufa	Not measured
Chtaura	14.5	Chamsine	14.5
Jdita	4.14	Anjar	63.5
Ammiq	22.44	Ras el Ain	7.04 (presently dry)
Kab Elias	21.51	Faonar	3.64 (presently dry)
		Ain el Bado	8.21 (presently dry)

Present efforts at spring flow measurements are reportedly very limited.

In the past, the spring discharge provided over 90% of the baseflow to the Litani River. It has mainly been the capture of this spring discharge for irrigation, industrial and municipal uses that has caused the drying up of the Litani River during the warmer dry season months. In addition smaller springs like Ras

el Ain (near the ICARDA farm in Terbol), Faonar and Ain el Bado Springs have dried up due to the lowering of water levels and the capture of spring flows from irrigation pumpage. These three springs issued from the base of the Eocene Formation on the east side of the Basin and likely had contribution from the Cretaceous Aquifer as well. The loss of baseflow, often referred to as "Ecological Flow", has impacted ecosystems such as wetlands as well as riparian vegetation and fauna.

Quaternary: The unconsolidated Quaternary deposits are found in the central part of the Upper Litani Basin and outcrop over much of the Valley north of Joub Jannine. These deposits can be 200 meters thick or greater. The lithology is mainly comprised of low permeability fine grained silts and clays interspersed with thin sand and gravel lenses. Reported well yields are in the range of less than 5 up to as much as 30 liters per second (LPs). Most well yields are reportedly in the few LPs to 10 LPs range.

Neogene: The Neogene and Quaternary deposits are somewhat interrelated as they both outcrop in the central part of the Upper Basin and the Neogene underlies the Quaternary unit in places. The outcrop area of the Neogene Formation is less extensive than the Quaternary and the Neogene deposits can be up to 300 meters thick and greater in the Upper 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 in the southwest basin area. The principal water bearing units in the Neogene are conglomerate deposits. There are many hundreds of irrigation wells completed in this unit and it serves as an important aquifer system for irrigation purposes. Well yields are reportedly in the range of less than 10 to as much as 30 LPs.

Eocene: The Eocene Formation outcrops in thin bands (generally 1 Km and less in width) 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 Joub Jannine and Kamed El Laouz areas down to and south of Lake Qaraoun. The formation is up to 250 meters thick. On the east side of the Upper Basin, the Eocene outcrops from the Terbol area to the north up to Baalbek (where it is an important aquifer) and on the west side from Zahle up to Chmistar

There appear to be many hundreds of wells completed in this formation for irrigation purposes and development is significant on the east side of the Upper Basin from Baalbek down to the Kamed El Laouz area. Well yields can range up to 50 LPs and higher.

Cretaceous C4: The C4 Formation 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 just north of Lake Qaraoun. This formation is up to 600 meters thick. It is heavily developed just north of

the Aanjar area on the east side of the Upper Basin. There are also many irrigation wells in the southern part of the Upper Basin just north of Lake Qaraoun. Well yields up to 150 LPs and greater are possible. Many municipal supply wells are completed in this unit.

Jurassic Formation: The Jurassic Formation outcrops in the western part of the Upper Basin from Chtaura down to Lake Qaraoun. There are many irrigation and municipal wells completed in this unit from the area south of Chtaura down to the Lake. Well yields up to 130 LPs and greater are possible.

Pre-development (circa 1960's) groundwater conceptual model: Prior to extensive groundwater development in the Upper Litani River Basin, the lower elevation reaches of the basin (valley floor) were characterized by very shallow water levels and extensive wetlands. Groundwater flow was from the higher elevation carbonate aquifer systems to the Quaternary and Neogene aquifer systems contained within the Bekaa Valley. Groundwater flow and spring discharge was directed to the Litani River and wetlands which served as groundwater discharge areas for the groundwater system. The groundwater recharge in the Upper Basin, at large, equaled the spring discharges and Litani River baseflow under equilibrium conditions.

4. GROUNDWATER SYSTEM ELEMENTS

4.1. GROUNDWATER LEVEL CONDITIONS AND HISTORY

Considerable data are available from well survey records of the Ministry of Water and Power from the 1950s through the early 1970s for shallow wells completed in the Quaternary and Neogene Aquifers in the ULRB. **Figure 4** shows the locations of wells inventoried in that timeframe and groundwater level elevations.

Between 1990 and 2002, many village and town drinking water wells were installed by the CDR; CS (Council for the South); and MEW (Ministry of Energy & Water) in the ULRB and technical data were collected and assembled for these wells. **Figure 5** shows the locations of these wells and measured groundwater level elevations. The data base for the historical well data is provided in **Appendix D.**

In the late August and early September 2010 field survey under the LRBMS, several areas in the Upper Basin were visited, water-level measurements were obtained, and drillers were interviewed to develop a preliminary assessment of present water-level conditions in the Quaternary, Neogene and Eocene Aquifer systems. A brief summary of the findings from this initial survey is provided below.

- In the northern part of the basin (Quaternary Formation), water levels in 2 wells ranged from 7 to 14 meters below ground surface (m, bgs). Overall, it was indicated from well drillers and well owners that well yields are relatively low for wells completed in this unit throughout the Upper Basin and that water levels had not declined significantly.
- The American University of Beirut (AUB) Farm located near Talia has 9 production wells, 3 of which are in use. Historical water levels in this area were reportedly on the order of a few meters below ground surface. The September 2010 measurements in 2 wells at the farm were 21 and 26 m, bgs indicating a decrease in water levels of 20+ meters in this area over the past several decades. A local driller indicated that in the Neogene Formation in this area northeast of Rayak, water-level declines of up to 50 meters have been experienced since the mid-1980s.
- There has been significant development in the Eocene and Cretaceous Aquifers from the Baalbek area down to the International Center for Agricultural Research in the Dry Areas (ICARDA) farm in the Terbol area and south to Aanjar. There are hundreds of wells on the east side of the Upper Basin in this area. At the ICARDA Farm irrigation well, a 30+ meter decline in water level has been noted in the past 10 years from a production well that was flowing artesian when first installed. In this timeframe, the Ras el Ain Spring has dried up and wetlands

at the base of the foothills at the ICARDA farm have disappeared. Two other nearby springs (Faouar and Ain el Baida) have also dried up.

- The central part of the basin, underlain by the Quaternary Formation, is characterized by lower yielding wells and water levels are reportedly shallow.
- The southern part of valley between the village of Joub Jannine and Lake Qaraoun is underlain by the Eocene and Cretaceous Aquifers. This area is irrigated from the 900 Canal and from wells. A well within a few kilometers of the Lake was measured, and the water level was 33 m, bgs and at a similar elevation as the Lake. From our interviews with several well owners in the lower part of the valley, it does not appear that groundwater levels have been impacted, and several farmers indicated that they no longer use their wells because of the availability of surface water from the 900 Canal.
- The southwest side of the Valley is underlain by the Jurassic age carbonate rock aquifer system as well as the Neogene and Cretaceous Formations. There are many wells along the fringe of the Valley in this area completed in the carbonate rock aquifers. One farmer in this area operates about 20 wells that are 100 to 120 m deep and reportedly have water levels in the 50 to 60 meter, bgs range. This will be followed up in additional study.

4.2. GROUNDWATER FLOW CONDITIONS

In order to develop an understanding of groundwater flow conditions in the Upper Litani Basin, two synoptic water-level measurement events were conducted: the first in October/November 2010 and the second in June 2011. This was the first effort undertaken in the ULRB to develop an understanding of groundwater flow conditions in the basin at large. The October/November 2010 event was towards the end of the dry season and the June 2011 event at the end of the rainy season. Potentiometric surface maps were developed for both of these water-level measurement events and they are provided in **Figures 6 and 7.**

Fall 2010 Potentiometric Surface Map:

The fall 2010 "Potentiometric Surface Map" **(Figure 6)** was developed from water-level measurements made in 125 wells in October & November 2010. The surveyed wells are completed in the five principal aquifer systems. **Appendix B** provides the water level data base for both the 2010 and 2011 water-level measurement events.

Several "Pumping Cones of Depression" are indicated on the Potentiometric Surface Map (**Figure 6)** and are principally evident in the Neogene, Eocene and Cretaceous Aquifers. A groundwater divide has been delineated just southwest of Baalbek and is close to the surface water divide between the Litani and Orontes Rivers. South of the divide, there are groundwater flow contributions from both the east and west higher elevation sides of the Valley from the bounding carbonate rock aquifer systems (Cretaceous and Jurassic) to the valley center which is underlain by the Quaternary and Neogene Aquifer systems. Within the Bekaa Valley, groundwater flow is down-valley.

Several pumping cones-of-depression are evident in the Neogene Aquifer in the region just north of Rayak up to Baalbek. A finer grid of water-level monitoring in this unit would likely delineate a more concise picture of water level conditions and pumping cones-of-depression. Along the eastern valley boundary, there are pumping cones-of-depression evident in the Eocene and Cretaceous aquifers near Terbol; north of the Chamsine Spring; and south of Aanjar. On the southwest side of the valley, in the Jurassic Aquifer, the water level network is sparse and areas where there are likely pumping influences have not been delineated as yet.

May-June 2011 Potentiometric Surface Map:

The late spring 2011 potentiometric surface map was developed from water-level measurements made on approximately 188 wells in June 2011 (**Attachment B)**. The seasonal differences in water levels from the dry (Fall 2010) to wet (Spring 2011) seasons was in the range of from a few meters to as much as a few tens of meters.

The potentiometric surface contour configuration between the two maps is reasonably similar with a small shift in a given contour down-valley to account for the rise in water levels between the 2 events (dry to wet season). There are fewer pumping cones-of-depression in this timeframe which is reflective of lower rates of irrigation pumpage in late May and June.

For this event, there was a specific focus to assess if there is an out-of-basin groundwater flow component to the southeast from the Litani Basin into the Hasbani Basin as had been postulated by DAI (2005) in their modeling work. This was evaluated by expanding the groundwater level monitoring network in southeast basin areas and into the Hasbani Basin. The water-level data for wells 128, 130, and 156 on **Figure 7**, which are located near the southeast surface water divide, are higher in elevation than water levels in wells just to the west indicating that there is no out-of-basin groundwater flow component. Overall, it can be stated with a reasonable degree of scientific certainty that the

groundwater system boundaries conform to the surface water system boundaries. This is a very important finding for groundwater modeling purposes.

Seasonal water-level changes for the five aquifer systems (summarized below) were developed through a comparison of end of dry season (October – November 2010) and end of wet season water levels (June 2011). The largest seasonal water-level changes were for the Cretaceous and Eocene Aquifers.

Aquifer Unit	Maximum Water-Level Change (meters)	Minimum Water-Level Change (meters)	Average Water-Level Change (meters)
Quaternary	24.10	0.24	9.59
Neogene	23.60	1.72	8.89
Eocene	11.94	11.45	11.68
Cretaceous	35.13	14.68	25.68
Jurassic	13.78	4.31	8.40

1970 Water Level Data

The available well records in the 1970's timeframe are principally for shallow wells completed in the Quaternary and Neogene Aquifers in the northern part of the upper basin. In this timeframe, there are also records for several wells on both the east and west sides of the Valley completed in the Eocene, Cretaceous and Jurassic Aquifers. The spatial distribution of the wells does not allow for the development of a water-level contour map in this timeframe.

1990/2002 Water Level Data

The well records that are available in this timeframe are principally for drinking water wells installed by CDR; CS; and MEW. The spatial distribution of wells drilled in this timeframe is largely on the east and west sides of the valley with completions primarily in the Eocene, Cretaceous and Jurassic Aquifer Units. The wells were installed in some of the larger towns in the Valley as well as in villages in and on the fringes of the Valley. For a number of wells there is pumping test documentation including well yield, water-level drawdown and calculated aquifer hydraulic characteristics (specific capacity and transmissivity). It was possible to develop a water-level contour map **(Figure 5)** for the west and east sides of the valley for the bedrock aquifer units (Eocene, Cretaceous and Jurassic Aquifer Units).

4.3. AQUIFER HYDRAULIC CHARACTERISTICS

A number of pumping tests have been conducted on test and production wells installed in the five principal aquifer units. In the UNDP timeframe, test wells were installed in the Carbonate Rock Aquifers (Cretaceous and Jurassic) proximate to the Aanjar, Chamsine, and Ammiq Springs and pumping tests were conducted to evaluate the interconnection between the carbonate rock aquifer systems and these three major springs. Additional pumping tests were conducted on production wells completed in the Neogene, Jurassic, and Cretaceous aquifer in this timeframe.

From the 1990s to early 2000s, a number of public supply wells were installed by CDR; CS; and MEW in the Eocene, Cretaceous and Jurassic Aquifer systems and the results for these pumping have been included in the data base in **Table 3**. **Table 4** provides a summary of aquifer characteristics for the 5 principal aquifer systems and **Figure 8** shows the locations of wells that have been pump tested.

Quaternary: Four were tested at very low flow rates (2 to 6.3 LPs). Two of these wells are monitoring wells installed in 2011/12 under this program as part of the Litani River Authority (LRA) groundwater level monitoring network **(Figure 10)**. Specific capacities ranged from 0.07 to 0.12 lps/m. Additional aquifer hydraulic characteristic data for the Quaternary Aquifer will be available in 2012 from the monitoring well to be installed at the ARIC Research farm facility and possibly from additional data collection as part of the UNDP countrywide Hydrogeologic Study.

Neogene: Records were found for five wells tested in the Neogene Aquifer. Pumping rates ranged from 1 to 14 LPs and for one test an aquifer transmissivity of 1.3×10^{-6} m^2/s was determined. This is a very low transmissivity. Specific capacities ranged from 0.008 to 0.81 lps/m. Additional effort should be made as part of the pre-modeling work to obtain pumping test records for this aquifer unit which is heavily developed in the northeast part of the upper basin.

Eocene: Records were available for 18 wells pump tested in the Eocene Aquifer. Pumping rates ranged from 1.3 to 35 LPs and the calculated aquifer transmissivities ranged from a low of 3.9×10^{-6} to as high as 5.1×10^{-3} m^2/s. Specific capacities ranged from 0.01 to 5.7 lps/m.

Cretaceous: Records were reviewed for 25 pumping test for wells completed in the Cretaceous Aquifer. Pumping rates ranged from 2 to 111 LPs and calculated aquifer transmissivity ranged from a low of 3×10^{-4} to 9.1×10^{-3} m^2/s. Specific capacities ranged from 0.028 to 222 lps/m.

Jurassic: Pumping test results were available for 14 wells completed in the Jurassic Aquifer unit. Pumping rates ranged from 11.9 to 120 LPs and aquifer transmissivity was within a range of from

$2.3x10^{-4}$ to $1.6x10^{-1}$ m^2/s (the highest calculated transmissivity in the valley). Specific capacities ranged from 0.39 to 24.3 lps/m.

Table 4: Summary of Aquifer Hydraulic Characteristics

Aquifer Unit	No. of Tests	Range of Tested Well Yields (lps)	Range of Specific Capacity (lps/m)	Range of Aquifer Transmissivity (m^2/s)
Quaternary	4	2 to 6.3	0.071 to 0.12	
Neogene	5	1 to 14	0.008 to 0.81	$1.3x10^{-6}$
Eocene	18	1.3 to 35	0.010 to 5.7	$3.9x10^{-6}$ to $2.9x10^{-3}$
Cretaceous	25	2 to 111	0.028 to 222	$3.0.5x10^{-4}$ to $9.15x10^{-3}$
Jurassic	14	11.9 to 120	0.39 to 24.3	$2.35x10^{-4}$ to $1.6x10^{-1}$

There is a wide range of up to 3 to 4 orders of magnitude for the aquifer hydraulic characteristic values (Transmissivity and Specific Capacity) for the individual aquifer units. For the 5 aquifer units, there is a range up to 4 to 5 orders of magnitude for the values.

Recommendation: As a precursor to the groundwater numerical modeling effort, additional sources (e.g. MEW and local well drillers) should be consulted to explore if additional pumping test data and results are available for the modeling effort. The UNDP country wide hydrogeologic project should also be consulted with in this regard.

The scarcity of controlled aquifer tests in all five principal Aquifer units is a significant gap. The results from controlled aquifer tests provide the real underpinning for numerical models and will provide real value down the road for the LRA. What is involved here is looking at opportunities where there are existing production wells and nearby wells that could be used for observation monitoring purposes. This would save the cost of drilling new pumping and observation wells. Some immediate opportunities for conducting controlled aquifer pumping tests include: **1.** The AUB Farm wells in the Neogene Aquifer near Talia; **2.** The ICARDA well completed in the Eocene Aquifer near Terbol; **3**. The LRA wellfield in the Kamed el Laouz area in the Eocene Aquifer; and **4.** A group of irrigation wells in the southwest basin area completed in the Jurassic Aquifer.

4.4. AQUIFER RECHARGE MECHANISMS AND DETERMINATIONS

Groundwater recharge estimates are approached on a number of levels depending on data availability. One methodology for a groundwater system that is in a state of **equilibrium** (minimal development) is to assume that groundwater recharge (input to the groundwater system) is equivalent or equal to baseflow (output from the groundwater system). A second methodology is to assume that groundwater recharge is a **percentage of annual precipitation**. A third methodology that could be applied to the Quaternary and Neogene Aquifers was to evaluate **seasonal changes in water levels** and utilize that information to estimate groundwater recharge.

Pre-Development – System Equilibrium: Groundwater recharge was estimated for periods before significant groundwater pumping occurred by the UNDP (1970) at 200 Million Cubic Meters (MCM)/year for the Upper Litani River Basin. This estimate is equivalent to baseflow estimates for the same period of 5 m^3/sec (160 MCM/Yr.) during dry months and 7 m^3/sec (220 MCM/Yr.) during the winter season or wet months. It is reasonable to assume that the bulk of baseflow to the Litani River in this timeframe was from spring flow discharge.

Percentage of Annual Precipitation: This approach assumes that groundwater recharge is a percentage of annual precipitation. This percentage can range from less that 1% in very arid areas to upwards of 25% or more in humid areas underlain by permeable aquifers. The UNDP estimate of 200 MCM/Yr. is equivalent to 20% of precipitation in the Upper Basin on the basis of annual precipitation at 1000 MCM/Yr. This is on the high end of the percent of recharge from precipitation, but certainly within a practical range, given that the principal aquifer systems on the edges and upland areas of the basin are high permeability carbonate rock systems.

A precipitation distribution map for the Upper Litani Basin developed by LRBMS was superimposed on the geologic map for the Upper Litani Basin and an analysis made of precipitation distribution over the principal geologic/aquifer units. The Upper Litani Basin was divided into the east and west sides for analysis purposes as outlined on **Figure 9.** The next step in the analysis was to determine the area of

each geologic unit within a specific precipitation interval which is outlined on **Appendix C and Table 5** and summarized below**.**

West Side of Basin: The carbonate aquifer units outcrop over 435 square kilometers (Km^2) and the Quaternary and Neogene units over 304 Km^2. The total precipitation falling on this part of the basin is 708 MCM/Yr.

Groundwater recharge is estimated at 120 MCM/Yr. with 99 MCM/Yr. recharging the carbonate rock aquifer units that outcrop on the western edges of the valley and in the upland areas that receive higher precipitation and 21 MCM/Yr. recharging the unconsolidated Quaternary and Neogene aquifer units that outcrop in the valley.

Precipitation falling on the carbonate rock aquifer units is 495 MCM/Yr. and it was assumed that 20% of the annual precipitation will recharge the underlying aquifer units which translates to 99 MCM/Yr.

Precipitation falling on the unconsolidated Quaternary and Neogene aquifer units 212 MCM/Yr. and it was assumed that 10% of the annual precipitation will recharge the underlying aquifer units which translates to 21 MCM/Yr.

East Side of Basin: The carbonate rock aquifer units outcrop over 604 Km^2 and the Quaternary and Neogene units over 292 Km^2. The total precipitation falling on this part of the basin is 527 MCM/Yr.

Groundwater recharge is estimated at 90 MCM/Yr. with 74 MCM/Yr. recharging the carbonate rock aquifer units that outcrop on the eastern edges of the valley and in the upland areas that receive slightly higher precipitation and 16 MCM/Yr. recharging the unconsolidated Quaternary and Neogene aquifer units that outcrop in the valley.

Precipitation falling on the carbonate rock aquifer units is 370 MCM/Yr. and it was assumed that 20% of the annual precipitation will recharge the underlying aquifer units which translates to 74 MCM/Yr.

Precipitation falling on the unconsolidated Quaternary and Neogene aquifer units is 157 MCM/Yr. and it was assumed that 10% of the annual precipitation will recharge the underlying aquifer units which translates to 16 MCM/Yr.

Precipitation Recharge Summary: Groundwater recharge to the Upper Litani Basin is estimated at 210 MCM/Yr. on the basis of this precipitation-recharge analysis. 47% or almost half of the annual recharge is attributable to input from the western upland and mountainous areas that are underlain by permeable carbonate rock aquifer systems that receive the highest rates of precipitation annually. The

eastern basin areas that are underlain by carbonate rock aquifer systems receive 35% of the total recharge to the basin and thus the carbonate rock aquifer units account for 82% of the total recharge of 210 MCM/Yr. to the Upper Litani Basin. A more detailed breakdown of precipitation input to the specific geologic units on the east and west sides of the Valley is provided in **Appendix C**.

Table 5: Aquifer Recharge Calculations as a Percentage of Precipitation by Geologic Unit

WEST		Area (Km^2)	Precipitation (MCM/Yr.)	% Infiltration	Recharge (MCM/Yr.)
	Carbonate Aquifers	435	495	20	99
	Quaternary/Neogene	304	212	10	21
EAST					
	Carbonate Aquifers	604	370	20	74
	Quaternary/Neogene	292	157	10	16
	TOTALS	**1,635**	**1,234**		**210**

Seasonal Changes in Water Levels: This analysis is based on the seasonal change in water levels between the end of dry season 2010 and end of wet season 2011 measurements made on the well network under this project (**Appendix B**). Only the Quaternary and Neogene Aquifers had a representative distribution of wells over their aquifer areas for the application of this technique and, as such, the analysis was applied to these two aquifer systems only. The average seasonal water-level change for these two aquifers was 9.59 meters for the Quaternary and 8.89 meters for the Neogene. The recharge estimate for a specific aquifer unit is developed by multiplying the area of aquifer outcrop by the seasonal water level change and an estimated aquifer specific yield:

Aquifer Area (m^2) x Water Level Change (m) x Specific Yield = Estimated Recharge (m^3)

Using a specific yield of 0.01 or 1% for both aquifer systems; the recharge estimates are 39 MCM/Yr. for the Quaternary Aquifer and 16 MCM/Yr. for the Neogene aquifer for a total recharge of 54 MCM/Yr. for both systems. The precipitation recharge analysis arrived at an estimate of 37 MCM/Yr. for both aquifer systems (**Table 5** above).

Recharge Estimate Summary: The 1970 UNDP study had estimated a 200 MCM/Yr. recharge contribution for the Upper Litani Basin which is comparable to the 210 MCM/Yr. estimate derived from the precipitation analysis. A groundwater recharge estimate in the range of 200 to 220 MCM/Yr. is reasonable given the hydrogeologic framework in the Upper Basin.

The DAI (2003) and JICA (2003) groundwater recharge estimates of 388 MCM/Yr. and 484 MCM/Yr. are overestimated given the physical area of the Upper Litani River Basin (approximately 1,500 Km^2) and 1100 MCM/Yr. precipitation falling on the basin.

What this analysis signals is that land use considerations and planning are critical in the upland carbonate rock aquifer areas if the quantity and quality of groundwater recharge (and by association Spring Discharge) is to be maintained. There are a number of detrimental land uses in the carbonate rock areas (e.g. large quarries) that impact groundwater recharge and by association springs discharge water quantity and quality.

4.5. ESTIMATES OF STATIC AND DYNAMIC GROUNDWATER RESERVES

A preliminary estimate of static groundwater reserves is provided in **Table 6**. For each of the aquifer units, the static reserve (groundwater storage) calculations were made on the basis of 100 meter aquifer thickness and specific yields (effective porosity) of 5% and 10%. These estimates of 8,065 MCM to 16,130 MCM are conservative in that all of the aquifer systems are greater than 100 meters in thickness. If a 200 meter aquifer thickness is assumed, the estimate of the Static Reserve would be from 16,000 to 32,000 MCM. To put the static reserve calculations into perspective, groundwater storage of 10,000 MCM is equivalent to 60 years of pumping at a annual withdrawal rate of 160 MCM/Yr.

Table 6: Estimates of Static Groundwater Reserves By Aquifer

Unit	Age	Area (Km^2)	Groundwater Storage	
			Specific Yield (SY = 5%)	Specific Yield (SY = 10%)
1	Quaternary	408	2,040	4,080
2	Neogene	187	935	1,870
3	Eocene	134	670	1,340
4	Cretaceous	738	3,690	7,380
5	Jurassic	146	730	1,460
	Totals	**1,613**	**8,065**	**16,130**

The comparison of the static reserve (groundwater storage) to the dynamic reserve (annual groundwater recharge) provides for an understanding of the drought buffer of an aquifer system or the combination of several aquifer systems in a river basin. The ratio of the Static Reserve to the Dynamic Reserve is referred to as the "Drought Resiliency Quotient ™".

For the Upper Litani River Basin, if we take a Static Reserve at say 20,000 MCM and the Dynamic Reserve at 200 MCM/Yr., the Drought Resiliency Quotient ™ is 100. If the Static Reserve is estimated at 10,000 MCM and the Dynamic Reserve at 200 MCM/Yr. the Drought Resiliency Quotient ™ would be 50. The higher the Quotient, the more resiliency the aquifer system(s) has to droughts and large variations in precipitation. Drought Resiliency Quotients ™ that are in the 1 to 10 range are common for marginally productive bedrock aquifer systems; 10 to 100 for aquifer systems with moderate volumes of groundwater in storage and >100 for productive aquifer systems with deep depths of fresh groundwater circulation and large volumes of groundwater in storage.

In the context of water-resources planning, groundwater systems with large storage reserves have a significant drought buffer and this allows for greater planning flexibility for evaluating alternative supplies than for groundwater systems with very small or low storage reserves with say only a few years of drought-buffer storage.

5. GROUNDWATER USE

There has been no inventory of groundwater and spring withdrawals for municipal, industrial and irrigation uses in the Upper Litani Basin. As such, we have used available sources of information, reports, and data to come up with some preliminary estimates of water use.

Irrigation: The Litani River Basin Management Support (LRBMS) Program has estimated that the irrigated land in the Upper Litani Basin is around 15,000 hectares for irrigated crops (vegetables, potatoes, tomatoes) and 20,000 hectares for perennial crops (fruit and olive orchards and vineyards) (LRBMS Water Balance Report, August 2011). This report estimates water consumptive use for irrigation at 200Mm^3/yr. for the ULRB.

The "Atlas Agricole du Liban" (2005) has estimated that 35% of the irrigation use in the Litani is from surface water and 65% from groundwater which translates to 130 Mm^3/yr from groundwater and 70 Mm^3/yr. from surface water sources which also includes spring use.

Spring use is significant in the east-central part of the basin from Anjar and Chamsine Springs. The Chamsine Spring is also taped for drinking water use as well which is piped to southern areas in the basin. There is also spring capture for irrigation use from the Berdouni, Chtaura, Jdita, and Kab Elias Springs. The largest spring in the west side of the Basin (the Berdouni Spring) has competing uses for bottled water and industrial use and for Zahle drinking water supply from proximate wells.

Drinking Water: The current population in the Upper Litani is estimated at 380,000 and with a water use of 150 l/p/day; this translates to 21 MCM/Yr. usage (RBMP).

Industrial: Industrial use is estimated at 5 MCM/Yr. (RBMP).

Growth rates are assumed to be 2 percent per year for all three water usage categories. **Table 7** provides an estimate of groundwater withdrawals use for irrigation, drinking water, and industrial uses for wells completed in the unconsolidated aquifers (Quaternary and Neogene) and carbonate aquifers (Eocene, Cretaceous and Jurassic) in 2012. Projected demands are provided for 2020 and 2030.

Table 7: Estimated Groundwater Withdrawals by Aquifer Unit

Estimated Pumpage	2012 (MCM/YR)		2020 (MCM/YR)		2030 (MCM/YR)	
	Irrigation	Drinking/ Industrial	Irrigation	Drinking/ Industrial	Irrigation	Drinking/ Industrial
Aquifer Type						
Unconsolidated Aquifers (Quaternary/Neogene)	40	1				
Carbonate Aquifers (Eocene, Cretaceous, Jurassic)	90	25				
Totals	**130**	**26**	**153**	**30**	**185**	**36**

The areas of concentrated groundwater (well) pumpage include:

Northern Basin Areas that are irrigated by groundwater (wells) are located north of areas irrigated by the west side springs (Berdouni; Chtaura and Jdita) and east side springs (Anjar and Chamsine). These include broad areas to the north of Bar Elias outlined below:

- The Cretaceous and Eocene aquifers north of Anjar Springs up to Baalbek.
- The Neogene area in the northeast from north of Rayak up to Baalbek.
- The Quaternary area north of Bar Elias up to the Litani basin divide near the Litani source spring.

Southern Basin Areas:

- The Eocene area in the southeast – Kamed de Laouz and Joub Janine Areas.
- Jurassic areas on the west side of the basin from Chtaura to Mansoura.

Pre-Modeling Data Collection Recommendations:

The pre-modeling data collection should include a rapid assessment of irrigation wells in key selected areas such as:

- The Eocene/Cretaceous area in the mid east central part of basin (Terbol to Chamsine Spring).
- Southern part of the basin near from Joub Jannine to the Lake.
- Berdouni Spring area, which is a hot topic area.
- Jurassic area to the southeast from Kab Elias down to Mansoura.

6. NUMERICAL MODELING FRAMEWORK

The modeling process will be incremental and with a long-term vision – it can be viewed as a management tool that will be updated from time to time as more data and information are made available and analyzed. It is very clear that we will enter the initial modeling phase with clear and sufficient data in some areas and insufficient data in others such as:

- Current groundwater pumpage/abstraction rates and distribution by aquifer unit.
- Recent and current spring flow data and spring flow abstraction for irrigation and other uses.
- Projections of future groundwater withdrawals.
- Aquifer hydraulic characteristic information particularly for the Quaternary and Neogene Aquifers.

So for the purpose of getting started, we will need to rely on historical data to an extent and estimates in areas such as groundwater pumpage by aquifer unit, current and historical spring flows.

As for pre-modeling work components, there are a few areas that are recommended to fill in some of these data gaps and uncertainties, and these include:

- A "Rapid Assessment" of irrigation wells in selected areas discussed in report section 5.0 above.
- An evaluation of southern model boundary conditions to evaluate groundwater flux to the south out of the model area.
- Spring flow measurements if possible.

Coordination with the on-going UNDP Hydrogeologic Project to assess if additional relevant data and information have been gathered.

6.1. MODELING OBJECTIVES AND APPLICATIONS

The principal Modeling Objective is the development of a representative groundwater model for the Upper Litani Basin Groundwater Aquifers that can be used for:

- Future predictions of groundwater surface elevations under a range of development (abstraction) scenarios.
- Evaluation of groundwater – surface water interaction.
- Troubleshooting and problem solving for focused problem areas such as:
  - The development of **"Spring Protection Zones"** to preserve/maintain spring flows. Specific areas that could be addressed include spring contribution area protection programs with an initial focus on:
    - Ammiq Spring in the southwest given the many irrigation wells nearby.
    - Anjar and Chamsine Springs in the east central part of the basin again given the many irrigation wells proximate to the spring.
    - Berdouni Spring given the complex competing uses and baseflow considerations (ecological flows) in the summer months for Zahle.
  - Set back distances from springs for production wells;
- Municipal well protection zones – set back distances from Municipal Wells for irrigation wells.
- Potential future expansion of Canal 900 where part of the Canal 900 water will come from five installed production wells.
- Increased Jurassic Aquifer Development in the west-southwest basin areas.
- Evaluation of the Basin area near and around Lake Qaraoun to assess:
  - Input to the underlying aquifer system(s) from the Lake and
  - Flux out of the southern part of the basin (model area)

Calibration considerations include:

- Pre-development water levels and conditions (circa 1970 – **Figure 4** and 1990s to 2000 timeframe – **Figure 5)**.
- 2010 and 2011 potentiometric surface maps for dry and wet seasons (**Figures 6 & 7**).
- Additional water level and groundwater flow assessments in the southern part of the Upper Litani Basin.

6.2. MODELING BOUNDARY CONDITIONS

The modeled area will be the same as the surface drainage basin for the Upper Litani Basin. The basin boundaries will be no flow boundaries except for the southern basin area where there is a flux out of the Upper Basin to the south of Lake Qaraoun.

Additional field work is recommended to evaluate water-level conditions and groundwater flow in the area around and downstream of Lake Qaraoun to determine the flux out of the model area/domain.

6.3. MODEL INPUTS

Precipitation/Recharge: Report **Figure 9** and **Table 5** provide a summary of precipitation input over the ULRB and recharge estimates for the principal aquifer units.

Spring Flows: Spring flow data are sparse and the modeling effort will need to rely on UNDP study timeframe data as well as more recent data for the Berdouni Spring. A pre-modeling effort will be made to:

- Research in more depth about historical spring flow data availability; and
- Visit each spring in a dry season and evaluate flow conditions.

River Flow (historical and present): River flow data are available for the gauging station north of Lake Qaraoun near Joub Jannine and baseflow estimates can be made from the dry season flow data.

Baseline and Present Water Levels: 1970s timeframe water levels are provided on **Figure 4** and 1990 – 2002 water levels on **Figure 5**. Two water level measurement events were conducted for the LRBMS Program; the first in October/November 2010 (after the dry season) and the second in June 2011 (after the wet season). The first Potentiometric Surface maps for the ULRB were developed from these 2 comprehensive measurement events (**Figure 6 & 7**). **Appendix B** contains the well and water-level data base for these two measurement events.

Aquifer Hydraulic Characteristics: Report Section 4.3 provides a summary of pumping test results for the five principal aquifer units. **Table 3** provides as summary of the data that we were able to find and compile and **Figure 8** is a location map showing the well locations for the wells tested. A pre-modeling effort will be directed towards assessing from MEW and local drillers as to the availability of additional pumping test data for the ULRB.

Hydraulic Gradients: These can be derived from the potentiometric surface maps.

Groundwater Use: Report Section 5.0 provides a very general framework in regards to groundwater use. This is an area that can be strengthened for selected areas where the modeling will initially focus.

6.4. MODELING CALIBRATION APPROACHES

The groundwater model calibration will utilize the following data and information in the calibration process:

- Pre-development water levels and conditions (circa 1970 – **Figure 4** and circa 1990s to 2000 on **Figure 5.**
- The 2010 and 2011 potentiometric surface maps for dry and wet seasons (**Figures 6 & 7**) which provide an understanding and overview of current groundwater flow conditions.
- The water level data base in **Appendix B**.
- Best approximations of Spring Flow given the scarcity of data for this important model component.
- The available aquifer hydraulic data and information in **Table 3** and **Figure 8.**

- Basin precipitation data and overview (**Figure 9).**
- Aquifer recharge estimates (**Table 5).**
- Model Domain (**Figure 1)** which will comprise the Upper Litani Basin from the basin divide down to Lake Qaraoun. The groundwater system boundaries conform to the surface water drainage system boundaries and there is no out-of-basin groundwater flow component into the Hasbani Basin to the southeast.
- Any additional water level and groundwater flow assessments in the southern part of the Upper Litani Basin.

Calibration efforts will be to existing water-level conditions and spring flow estimates on the basis of dry and wet season Potentiometric Surface Maps.

6.5. POTENTIAL MODEL SIMULATIONS

In addition to what has been outlined in Section 6.1, the modeling will explore development options starting with best estimate of present day development/pumpage for:

- Municipal Use
- Industrial Use
- Irrigation Use

and progress through in 5-year increments to assess development scenarios and impacts.

Modeling could potentially be used to develop simulations that take into account current and future water use requirements for Municipal, Industrial and Irrigation uses with the following restrictions:

- Restrict the bounding carbonate aquifers (Eocene, Cretaceous and Jurassic) for drinking water use only.
- Only allow industrial and irrigation development/pumpage from the less productive Quaternary and Neogene Aquifers.
- The exploration of mitigation options to restore spring flows in certain areas is an area that will be considered as well.

7. REFERENCES

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www.usaid.gov

TABLES

TABLE 3: SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS

Map ID	Well ID	Well Depth (m, bgs)	Elevation (m, amsl)	Date Tested	Static Water-Level (m, bmp)	Pumping Water-Level (m, bmp)	Drawdown s, (meters)	Pumping Rate (lps)	Specific Capacity (lps/m)	Transmissivity (m^2/s)
Quaternary Formation										
AT-1	LRB MW	31		2012			16.50	2.00	0.12	
AT-2	LRB MW	71		2012			42.00	5.00	0.12	
AT-3	Majdalune	115	1030	21/4/1983	30.00		70.00	5.00	0.07	
AT-4	Karak			6/9/97	29.00	89.35	60.35	6.33	0.10	
Neogene Formation										
AT-5	Rayak ARIC Center	144.85	915	UNDP Timeframe	106.00	115.00	9.00	7.30	0.810	
AT-6	Al Kafrak	200	915	25/11/1999	55.30		75.70	14.00	0.184	
AT-7	Ash Shahima-Zahleh	200	945	28/4/1995	6.00		144.00	1.20	0.008	
AT-8	Niha	550	1100	22/2/1991	0.50		481.71	2.70	0.005	1.3x10-6
AT-9	Timnine at Tahta	450	990	5/11/93	325.00		100.00	1.00	0.010	
Eocene Formation										
AT-10	Ghazzeh	185	867	UNDP Timeframe	21.80	27.90	6.10	34.80	5.70	
AT-11	Baalbek (Basatine)	152	1110	6/9/78	24.00		6.31	35.00	5.54	2.9X10-3
AT-12	Baalbek (Sharawneh)	152.5	1120	29/8/1978	42.65		20.50	23.00	1.12	
AT-13	Baalbek (Artificial Recharge-1)	225	1080	14/5/2002	131.82		72.54	7.00	0.09	7.3x10-5
AT-14	Baalbek (Artificial Recharge-2)	225	1080	21/5/2002	84.85		120.90	1.30	0.01	3.9x10-6
AT-15	Duriss	500	1110		137.12		72.73	12.00	0.16	1.1x10-4
AT-16	Seriine Al Faouka	500	1060	5/7/94	176.00		4.00	10.00	2.50	
AT-17	Timnine At Tahta	176	1050	28/12/1984	13.70		11.30	14.00	1.23	
AT-18	Yahfufa -Janta	250	1000	8/9/94	95.00		32.00	22.00	0.68	
AT-19	Dakwa-West Bekaa	230	900		74.00		3.61	3.70	0.09	1.2x10-3
AT-20	Mansura-West Bekaa	150	863	8/5/93			59.10	9.16	0.013	3.4x10-3
AT-21	Sohmor - West Bekaa	320	845		129.22		135.00	6.00	0.044	8.3x10-6
AT-22	Yohmor - West Bekaa	407	890	1/8/96	120.36		180.00	12.00	0.066	
AT-23	Zellaya - West Bekaa	410	710	6/9/00	92.50		166.00	11.40	0.068	3.95x10-5
AT-24	Alkhodr	335	1172	27/11/97	84.80		105.70	35.00	0.33	
AT-25	Seri'ine	350	1040	11/12/97	170.70		35.80	32.00	0.89	
AT-26	Zahleh - Ksarnaba Well	395	1180	21/12/2011	161.98		2.96	13.50	4.56	5.13x10-3
AT-27	Hechmech			27/9/1999	111.00	213.36	102.36	15.20	0.148	

TABLE 3: SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS

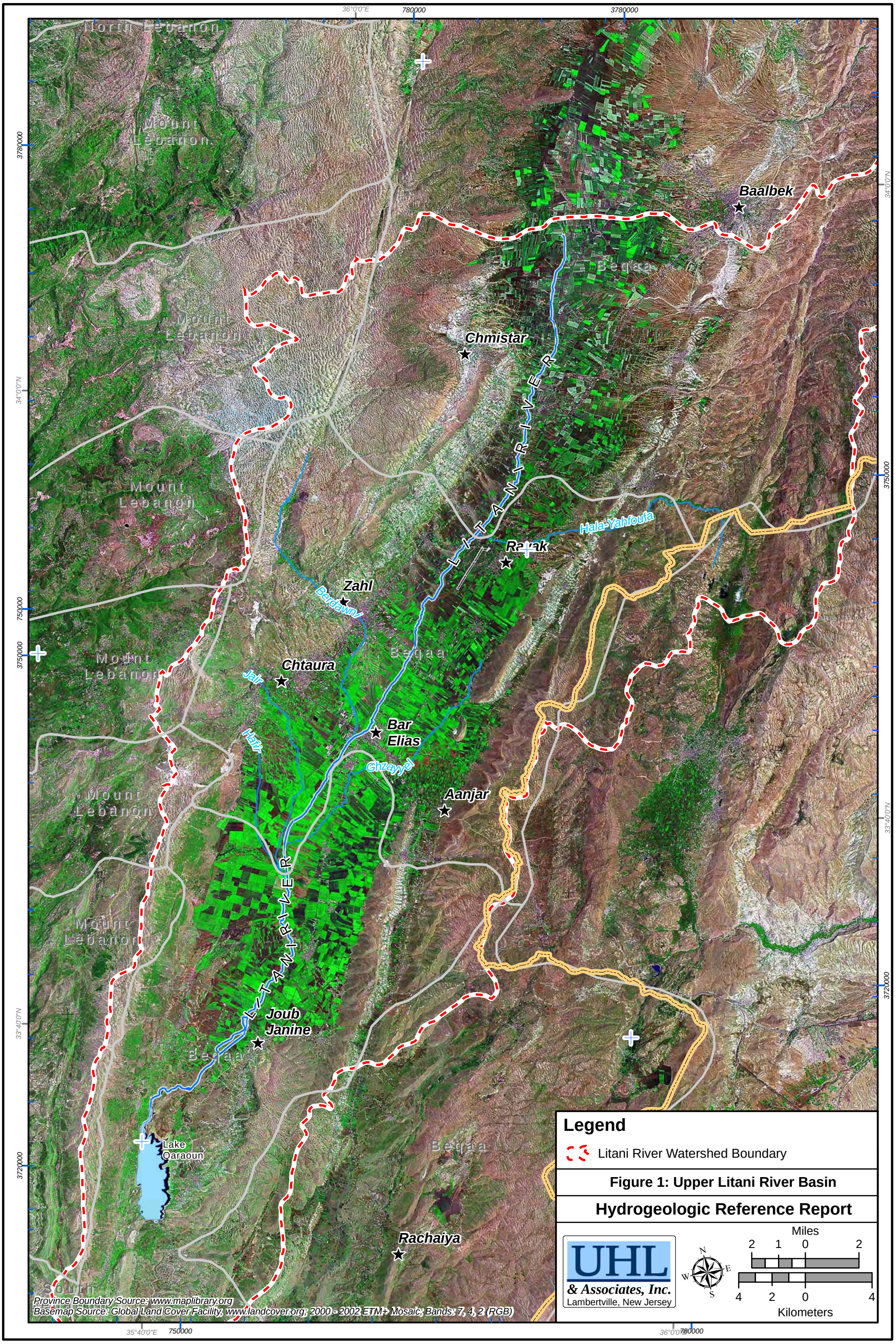
Map ID	Well ID	Well Depth (m, bgs)	Elevation (m, amsl)	Date Tested	Static Water-Level (m, bmp)	Pumping Water-Level (m, bmp)	Drawdown s, (meters)	Pumping Rate (lps)	Specific Capacity (lps/m)	Transmissivity (m^2/s)
Cretaceous Formation										
AT-28	Anjar No. 120/20A	62	922	UNDP Timeframe	41.81		1.19	31.60	26.66	
AT-29	Shamsine No. 8/20C	151.1	870	UNDP Timeframe	0.90		0.50	111.00	222.00	
AT-30	Anjar No. 7/20C	149.7	883	UNDP Timeframe	2.30		6.31	97.00	15.37	
AT-31	Anjar No. 6/20C	135	876	UNDP Timeframe	5.20		10.00	57.30	5.73	
AT-32	Anjar No. 5/20C	169.7	873	UNDP Timeframe	0.00		4.35	104.00	23.90	
AT-33	As Safra	475	1210	28/8/1994	405.00		70.00	2.00	0.028	
AT-34	Al Manara	395	1140	4/11/97	239.50		19.60	15.90	0.812	3.05x10-4
AT-35	Kherbet Ruha	300	1090	7/1/98	150.00		51.00	19.20	0.377	9.15x10-3
AT-36	Swary	335	1012	31/10/1998	124.00		9.66	13.75	1.42	2.5x10-3
AT-37	Britel 1	400	1212	30/11/97	105.50		130.40	19.00	0.145	
AT-38	Britel 2	345	1196	6/8/98	75.70		113.10	30.00	0.265	
AT-39	Baalbek 9	311	1360	18/6/1998	28.20		141.20	20.00	0.141	
AT-40	Baalbek 10	312	1385	14/5/1998			90.30	42.00	0.465	
AT-41	Baalbed 12	302	1361	21/8/1998	99.10		5.80	42.00	7.24	
AT-42	Baalbek 14	420	1460	29/10/1998	66.00		241.00	20.00	0.082	
AT-43	Baalbek 16	500	1385	16/7/1998	121.50		204.10	11.00	0.053	
AT-44	Baalbek 17	328	1379	2/7/98	65.60		74.10	55.00	0.742	
AT-45	Baalbek 18	335	1363	2/5/98	94.10		24.10	68.00	2.82	
AT-46	Nabi Shit 12	450	1281	2/6/98	266.50		2.80	36.00	12.85	
AT-47	Nabi Shit 13	350	1215	11/9/98	179.60		1.30	57.00	55.70	
AT-48	Nabi Shit 14	450	1274	6/2/98	263.00		1.40	36.00	25.74	
AT-49	Tayeh 1	350	1273	6/11/98	117.50		167.50	66.60	0.396	
AT-50	Wadi Mcheik			16/7/99	333.00	413.09	80.09	4.10	0.051	
AT-51	Anjar			4/10/99	39.15	40.74	1.59	23.10	14.53	
AT-52	Jdita			26/6/99	26.65	28.08	1.43	45.00	31.47	
Jurassic Formation										
AT-53	Kab Elias No. 88/15B	150	898	UNDP Timeframe	36.82	45.68	8.86	16.75	1.89	
AT-54	Kab Elias No. 89/15B	150	882	UNDP Timeframe	23.79			13.30		
AT-55	Kabb Elias93/15 (B)		878	UNDP Timeframe				120.00		3.6x10-2
AT-56	Haush Kaysar 90/15B	150	880	UNDP Timeframe	21.38		14.42	32.40	2.24	
AT-57	Ammiq No. 112/20A	150	867	UNDP Timeframe	2.39		18.50	15.94	0.86	
AT-58	Ammiq No. 112/20A	150	867	UNDP Timeframe	2.82		2.98	61.20	20.53	
AT-59	Tell Ed Deir No. 96/20B	275	878	UNDP Timeframe			1.39	33.80	24.31	
AT-60	Aiin Et Tineh	254	1000	8/7/81	138.00		13.50	12.50	0.925	

TABLE 3: SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS

Map ID	Well ID	Well Depth (m, bgs)	Elevation (m, amsl)	Date Tested	Static Water-Level (m, bmp)	Pumping Water-Level (m, bmp)	Drawdown s, (meters)	Pumping Rate (lps)	Specific Capacity (lps/m)	Transmissivity (m^2/s)
AT-61	Jdita	150	1040	2/5/95	20.35		2.20	44.00	20	1.6x10-1
AT-62	Aiin Zebda	238	1270	23/6/2000	59.80		9.66	17.12	1.8	
AT-63	Aytanite	212	1100	30/12/98	52.75		30.00	11.90	0.396	2.35x10-4
AT-64	Kefraya	301	1055	15/6/97	149.50		2.03	21.50	10.59	4.8x10-3
AT-65	Saghbine	293	1110	27/12/97	75.00		42.00	21.27	0.506	$5.19x10^{-4}$
AT-66	Meydune	200	970	6/9/95	76.00		12.65	12.50	0.988	$3.33x10^{-3}$

m, bgs: meters below ground surface
m, bmp: meters below measuring point
lps: liters per second
lps/m: liters per second per meter
m^2/s: meters sq. per second

FIGURES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3720000
35°40'0"E
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Mount Lebanon
Mount Lebanon
Mount Lebanon
South
Bequaa
Bequaa
Bequaa
Bequaa
Baalbek
Chmistar
LITANI RIVER
Hala-Yahfoufa
Rayak
Zahl
Berdawni
Chtaura
Jair
Hafir
Bar Elias
Ghzayyé
Aanjar
Joub Janine
Lake Qaraoun
Rachaiya
Province Boundary Source: www.maplibrary.org
Basemap Source: Global Land Cover Facility, www.landcover.org; 2000 - 2002 ETM+ Mosaic; Bands: 7, 4, 2 (RGB)
Legend
Litani River Watershed Boundary
Figure 1: Upper Litani River Basin
Hydrogeologic Reference Report
UHL
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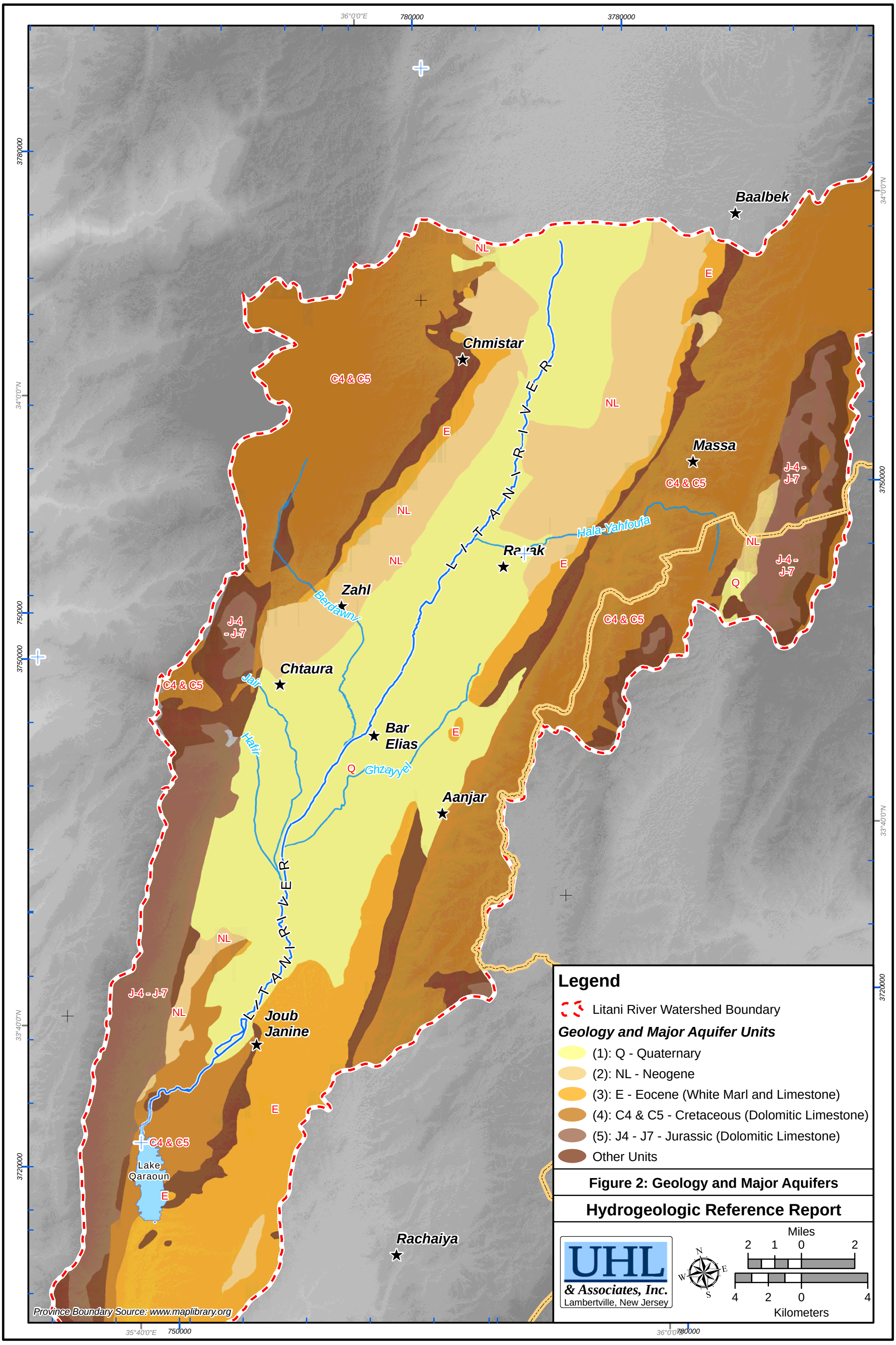
Kilometers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Baalbek
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Rayak
Zahl
Chtaura
Bar Elias
Aanjar
Joub Janine
Rachaiya
Lake Qaraoun
L I T A N I R I V E R
Hala-Yahfoufa
Berdawni
Jair
Hafir
Ghzayyel
NL
E
Q
C4 & C5
J-4 - J-7
Legend
Litani River Watershed Boundary
Geology and Major Aquifer Units
(1): Q - Quaternary
(2): NL - Neogene
(3): E - Eocene (White Marl and Limestone)
(4): C4 & C5 - Cretaceous (Dolomitic Limestone)
(5): J4 - J7 - Jurassic (Dolomitic Limestone)
Other Units
Figure 2: Geology and Major Aquifers
Hydrogeologic Reference Report
UHL & Associates, Inc.
Lambertville, New Jersey
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S
E
W
Miles
2 1 0 2
4 2 0 4
Kilometers
Province Boundary Source: www.maplibrary.org

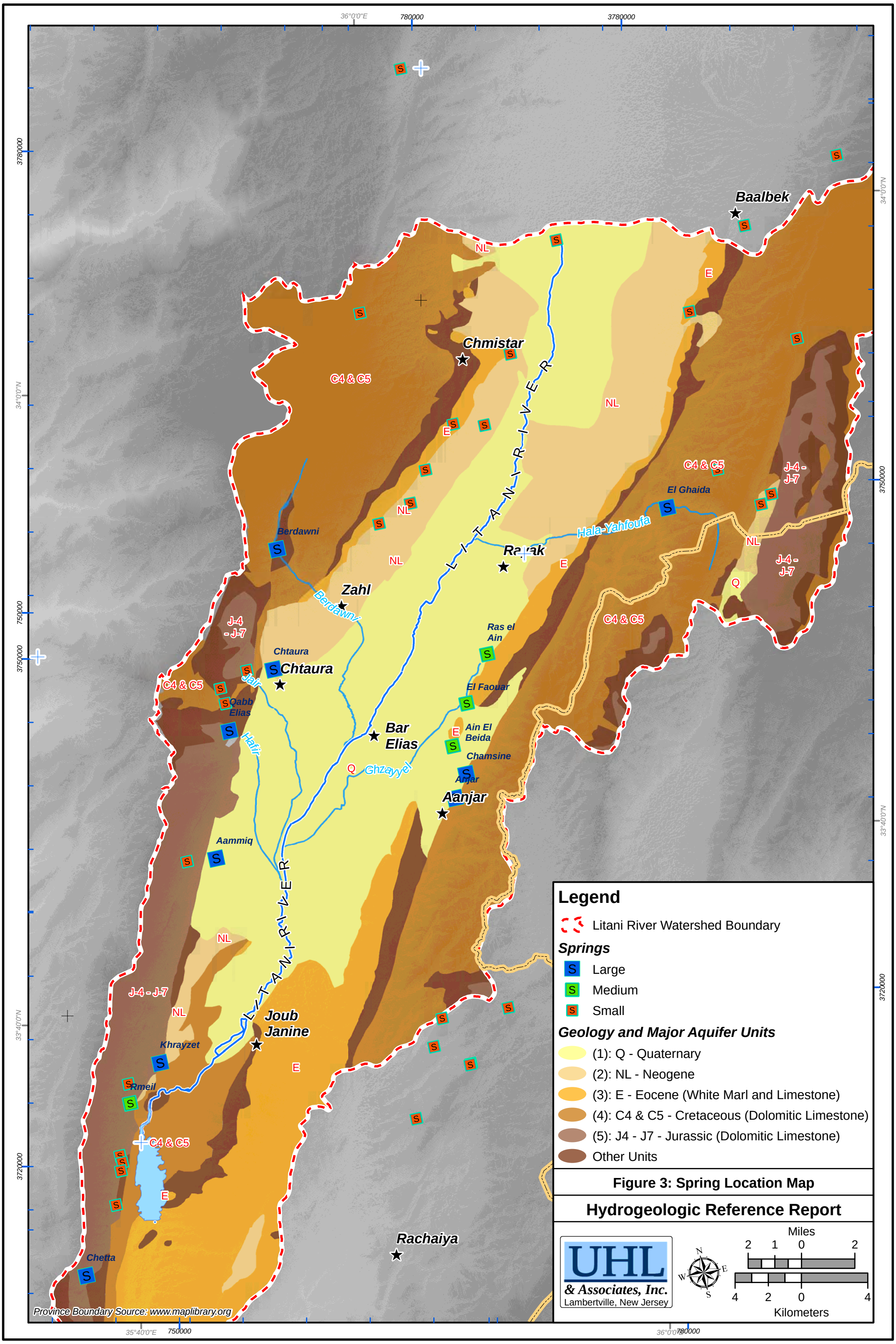


Figure 3: Spring Location Map

Hydrogeologic Reference Report

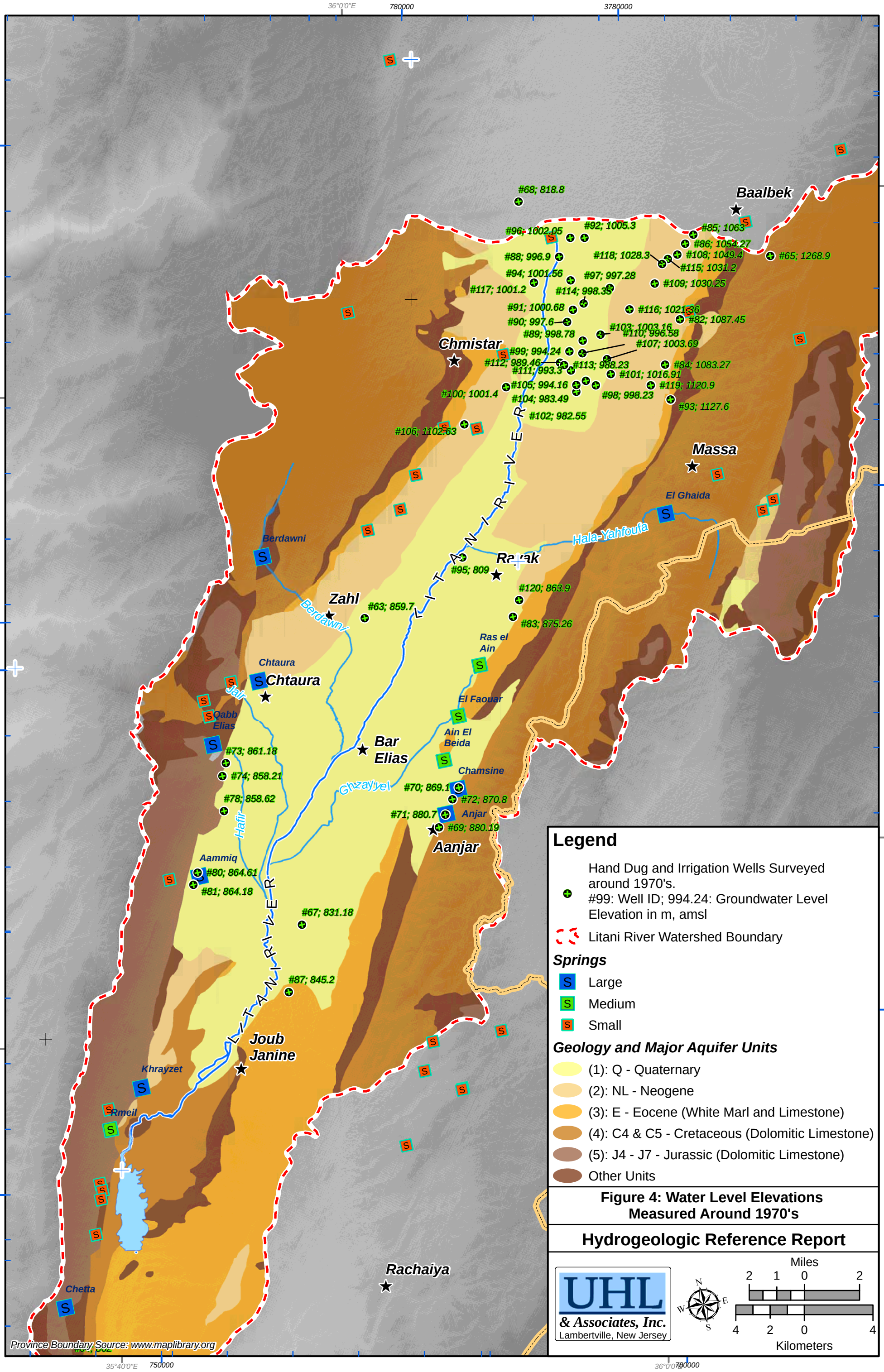


Figure 4: Water Level Elevations Measured Around 1970's

Hydrogeologic Reference Report

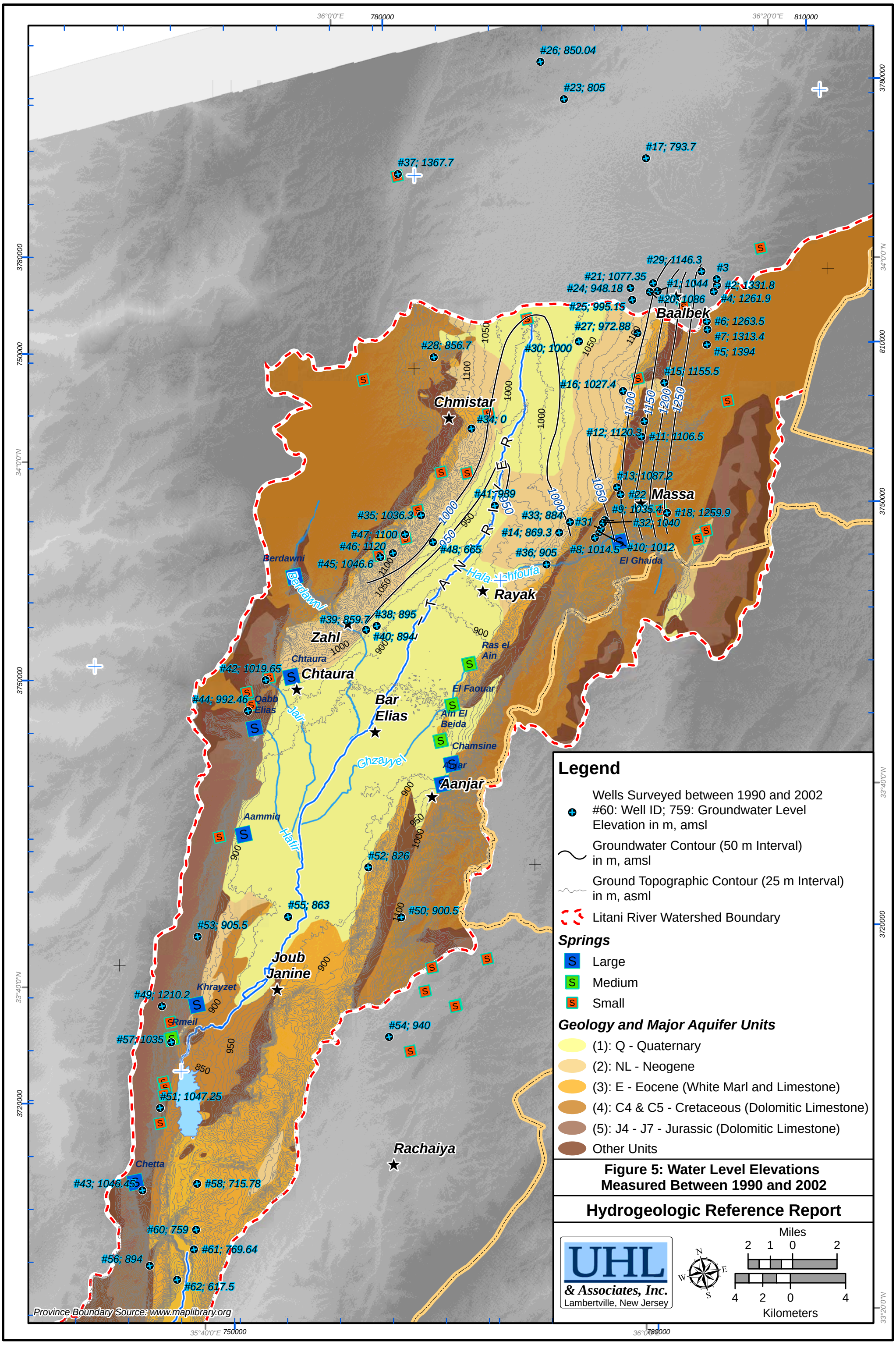


Figure 5: Water Level Elevations Measured Between 1990 and 2002

Hydrogeologic Reference Report

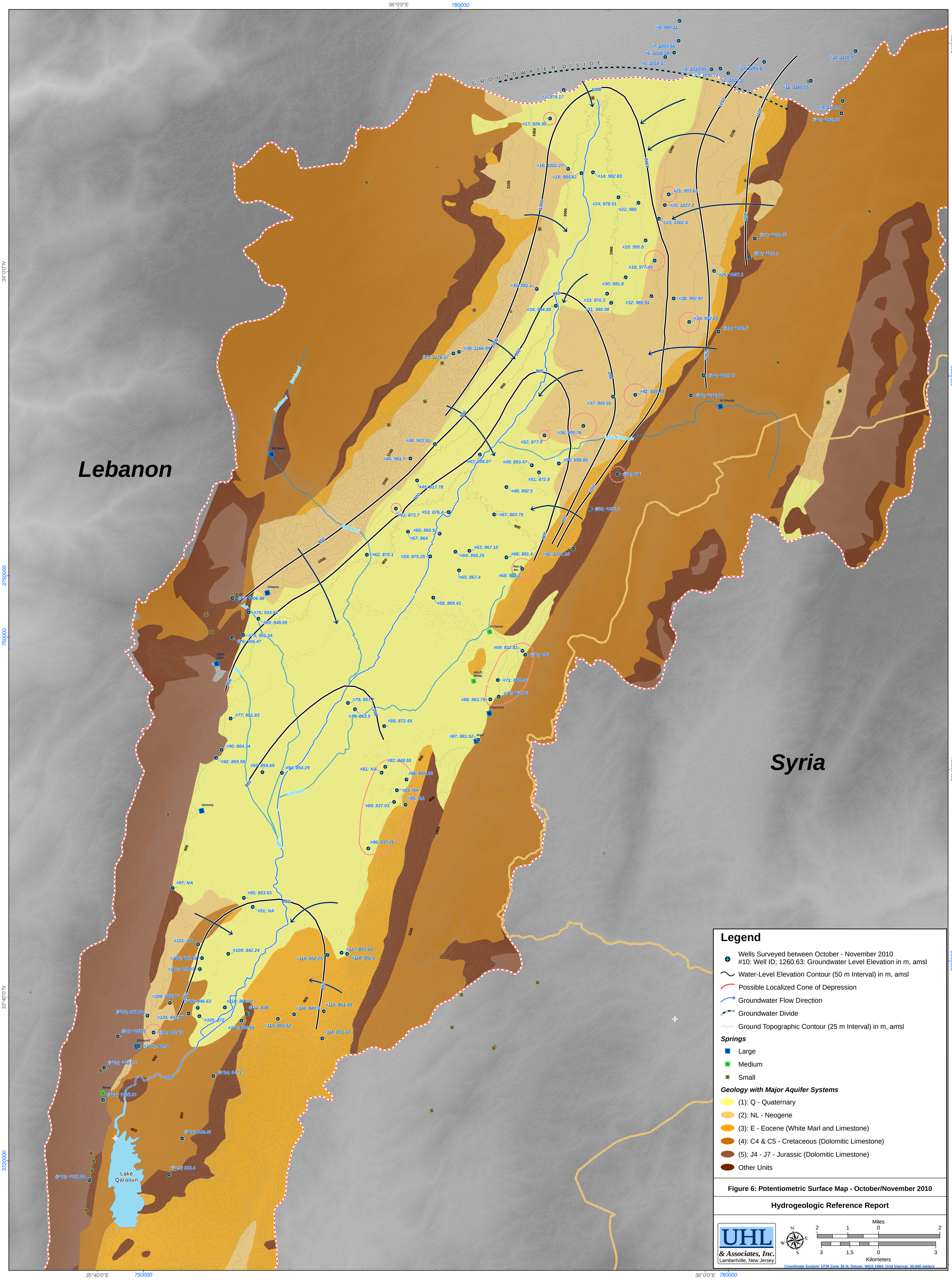


Figure 6: Potentiometric Surface Map - October/November 2010

Hydrogeologic Reference Report

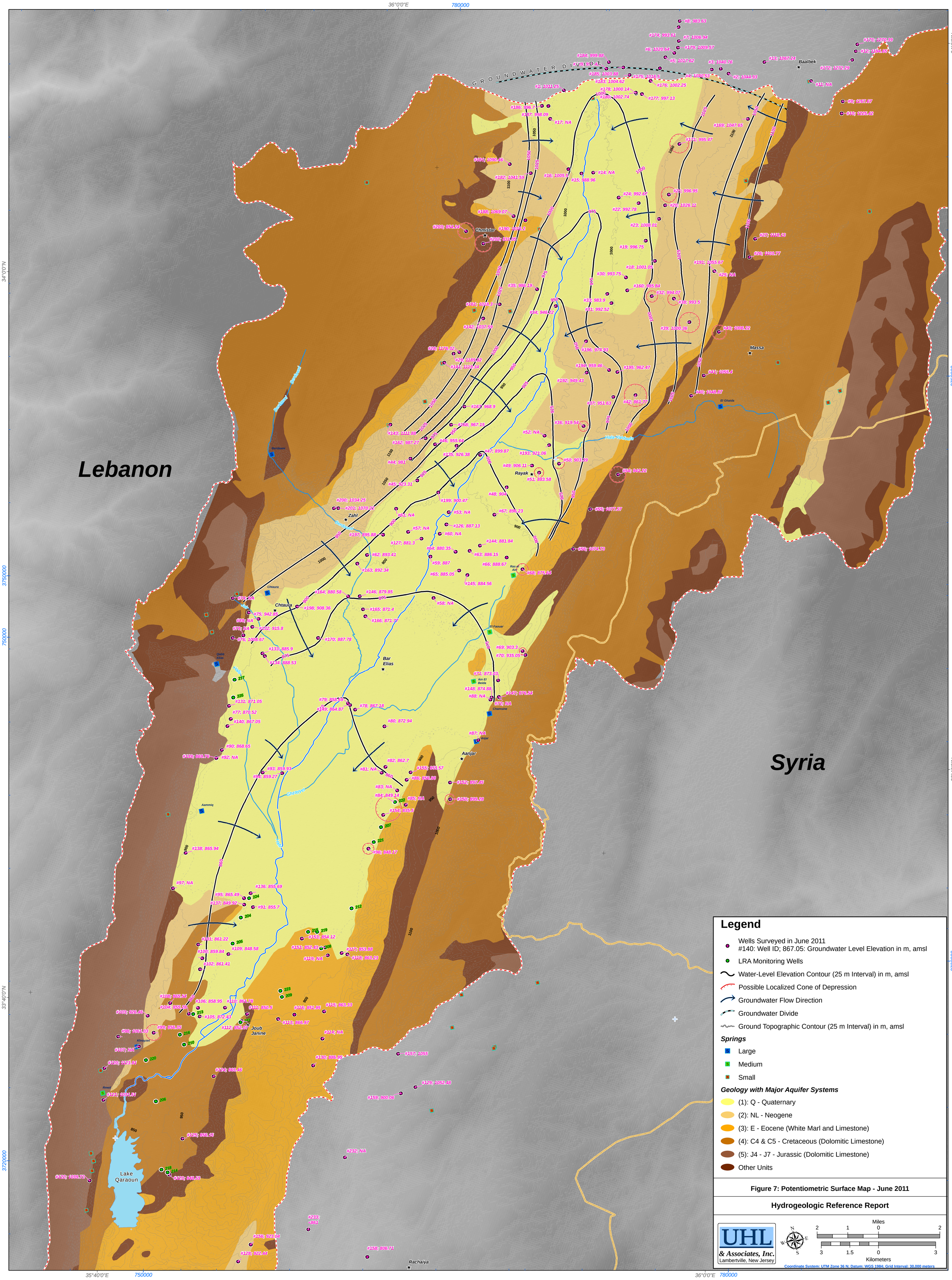


Figure 7: Potentiometric Surface Map - June 2011

Hydrogeologic Reference Report

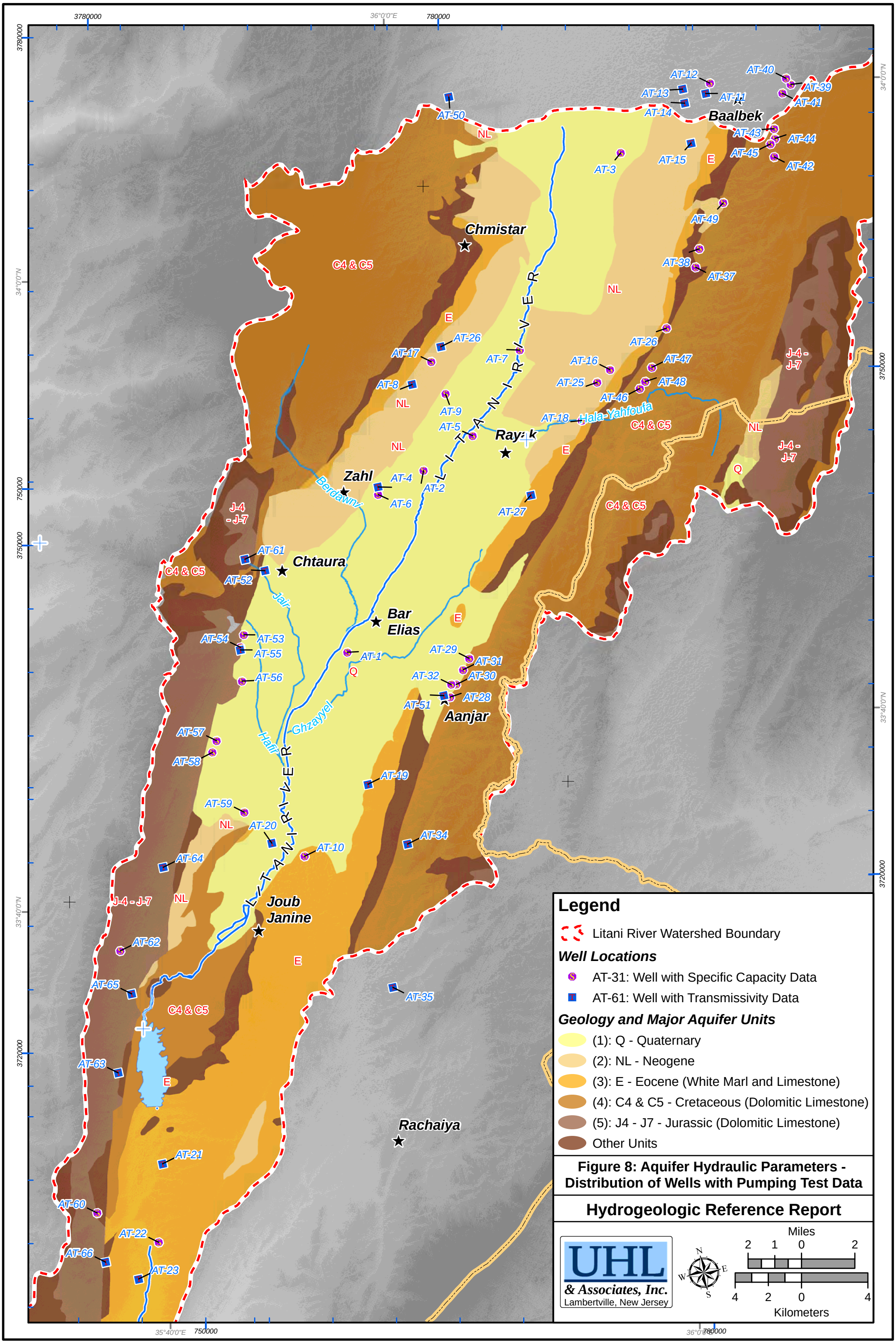


Figure 8: Aquifer Hydraulic Parameters - Distribution of Wells with Pumping Test Data

Hydrogeologic Reference Report

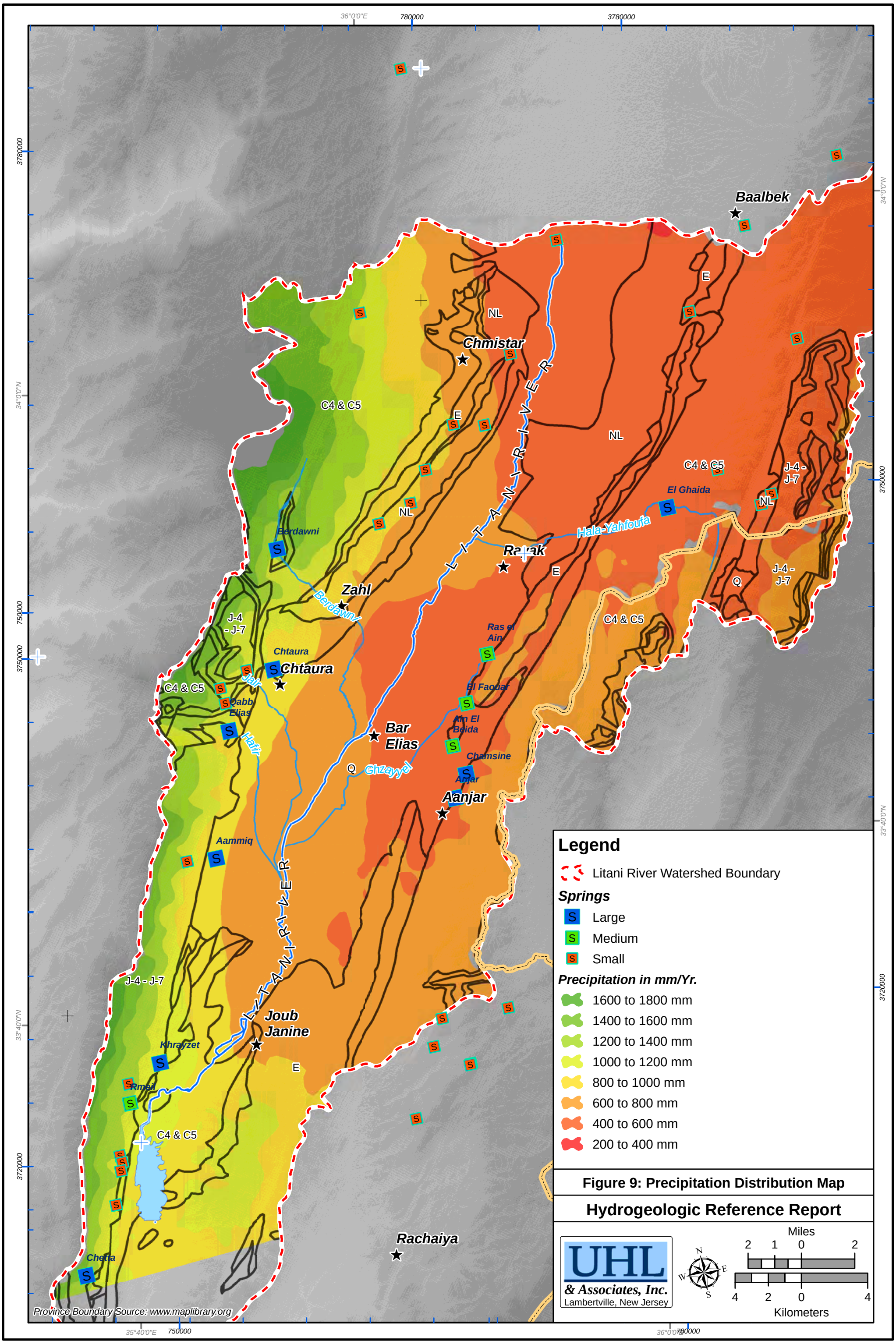


Figure 9: Precipitation Distribution Map

Hydrogeologic Reference Report

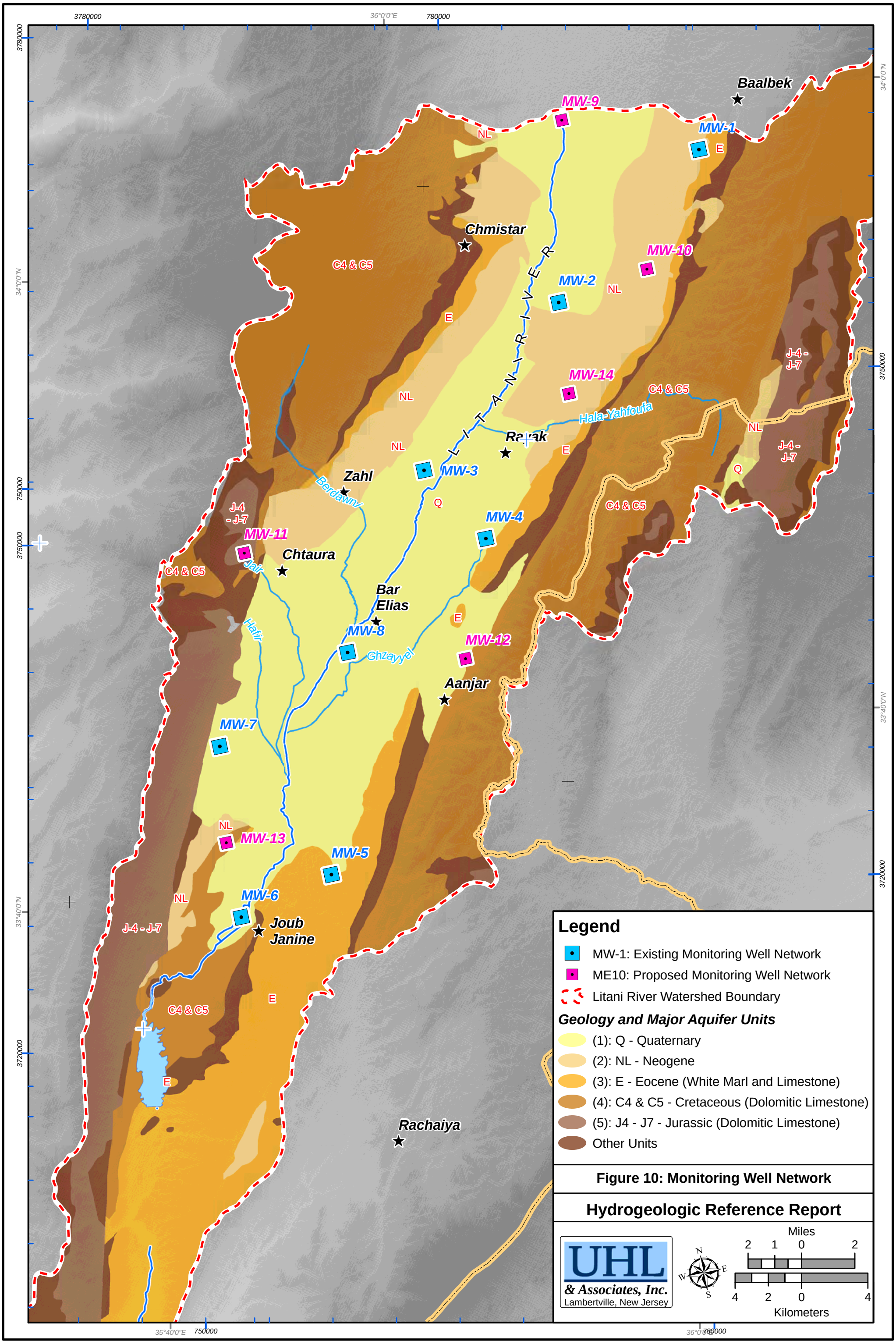


Figure 10: Monitoring Well Network

Hydrogeologic Reference Report

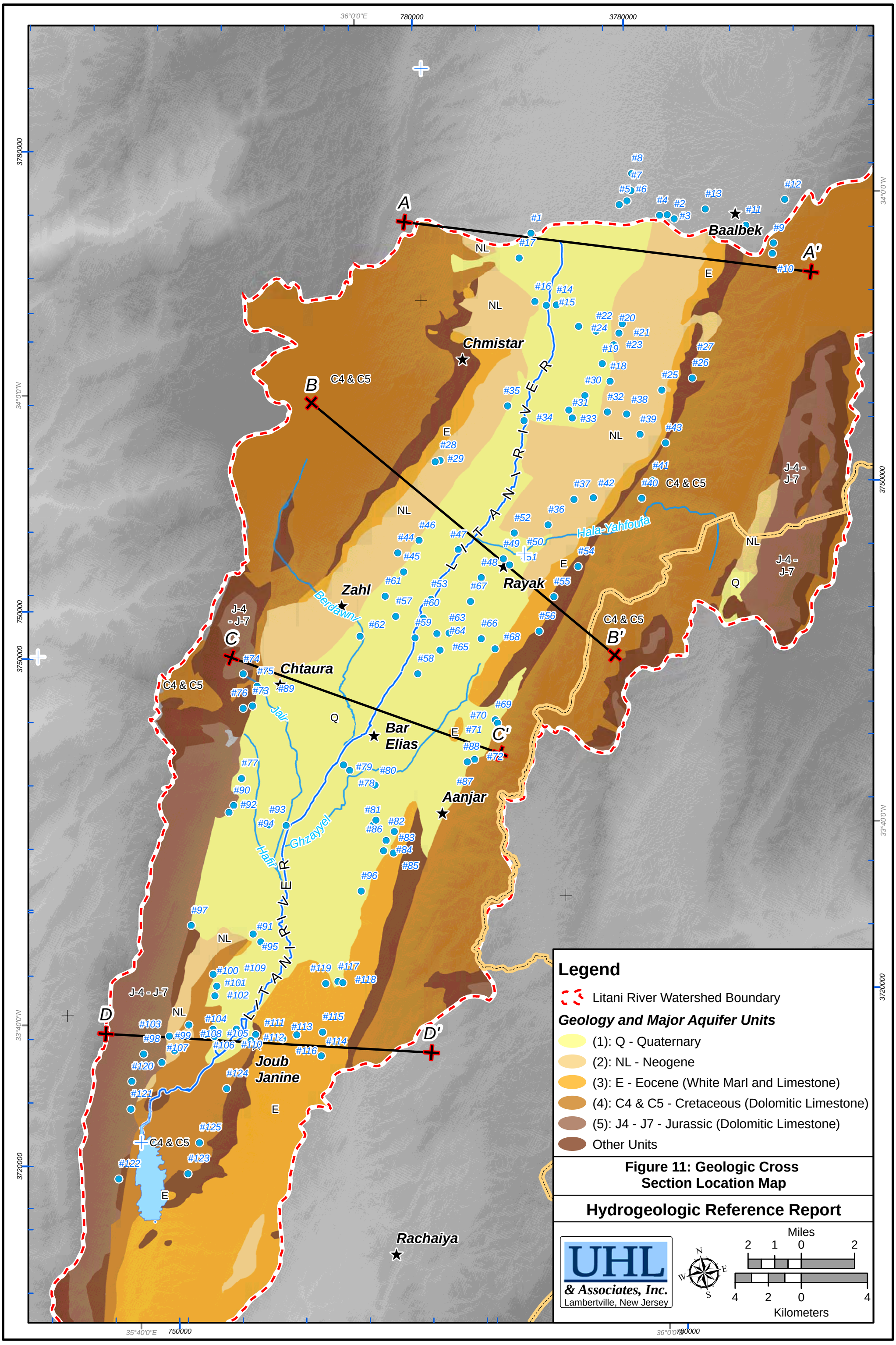
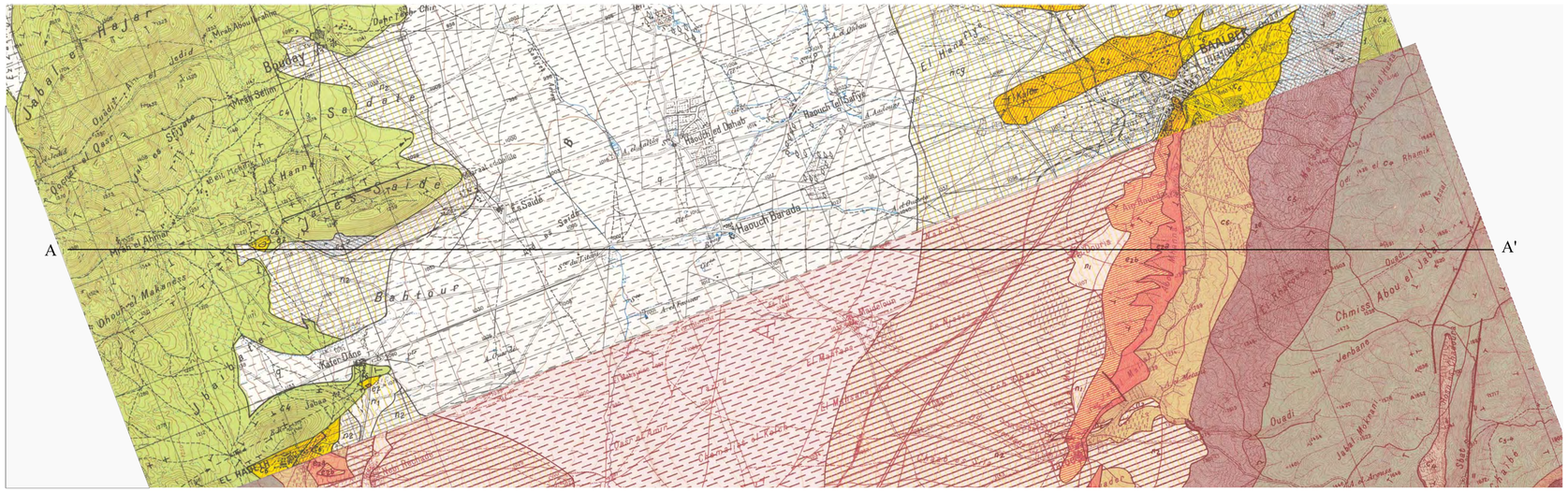


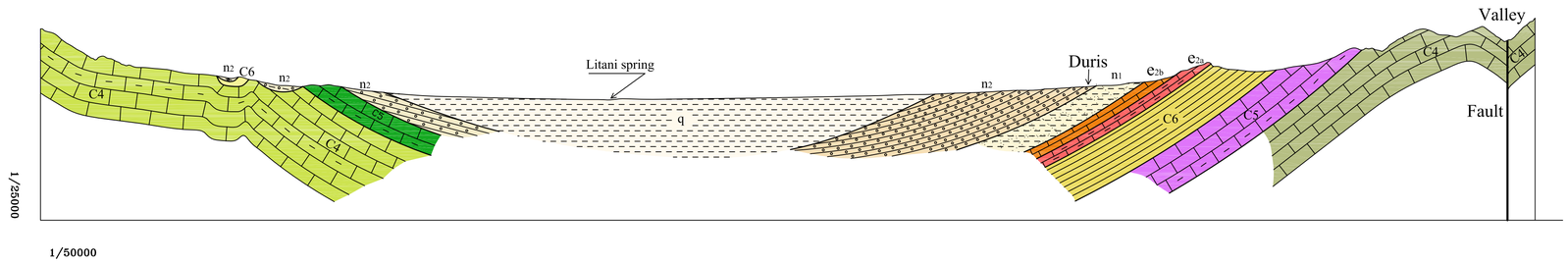
Figure 11: Geologic Cross Section Location Map

Hydrogeologic Reference Report

Baalback-Rayak Geological Cross Section A-A'



Extracted from Baalbeck - Rayak Geological map 1/50000



Legend — Baalbeck sheet

- q - Cultivated soil (Quaternary)
- n_2 - Lacustrine marl of Zahleh, pouding, conglomerates (Neogene)
- C6 - White marl (Senonian)
- C5 - Alternation of marly limestone & Limestone (Turonian)
- C4 - Sannine limestone, alternation of limestone & marly limestone (Cenomanian)

Legend — Rayak sheet

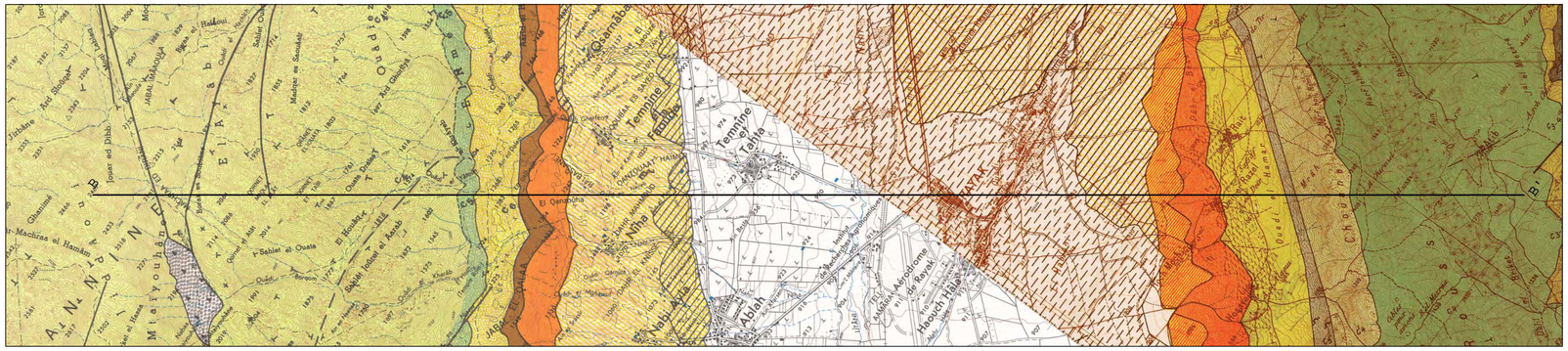
- q - Cultivated soil (Quaternary)
- n_1 - Lacustrine marl of Zahleh (Neogene)
- n_2 - Pouding conglomerates (Neogene)
- e_{2b} - Nummulitic limestone, upper Lutetian (Eocene)
- e_{2a} - Nummulitic marlylimestone, Lower Lutetian (Eocene)
- C6 - White marl (Senonian)
- C5 - Marly limestone & limestone (Turonian)
- C4 - Sannine bedded limestone (Cenomanian)

Litani River Basin
Management support (LRBMS)
Upper Litani River Basin

Geological Cross Section

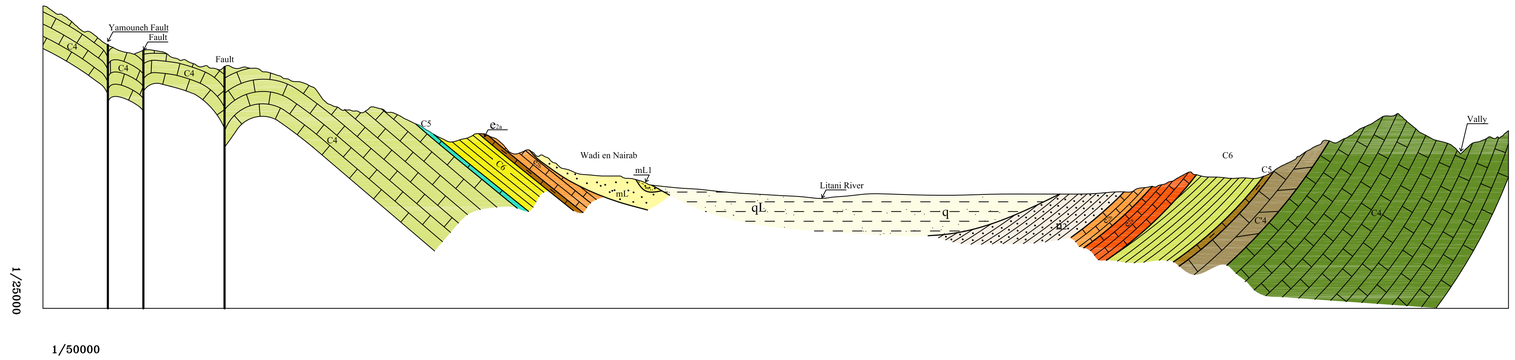
Scale	Baalbeck –Rayak Geological Sheet 1/50000	
H. 1/50000	IRG USAID Contractor	Cross Section A – A'
V. 1/25000	Performed by : K Mansour	Beirut 05/03/2012

Zahleh-Rayak Geological Cross Section B-B'



Cross section view side

Extracted from Zahle - Rayak Geological map 1/50000



Legend : Zahleh Sheet

- qL - Limon deposits (Quaternary)
- mL1 - Lacustrine marl of Zahleh (Continental miocene)
- mL - Zahleh poudings, Conglomerates (Continental miocene)
- e_{2b} - Jabal Ad Dher limestone, Subrecifal white limestone, upper Lutetian (Eocene)
- e_{2a} - Majdel Anjar marly limestone, lower Lutetian (Eocene)
- C6 - White marl (Senonian)
- C5 - Limestone (Turonian)
- C4 - Sannine limestone, alternation of limestone & marly limestone, slightly bedded (Cenomanian)

Legend Rayak Sheet

- q - Cultivated soil (Quaternary)
- n_2 - Pouding conglomerates (Neogene)
- e_{2b} - Nummulitic limestone, upper Lutetian (Eocene)
- e_{2a} - Nummulitic marlylimestone, Lower Lutetian (Eocene)
- C6 - White marl, upper creatceous (Senonian)
- C5 - Marly limestone & limestone (Turonian)
- C'4 - Dolometic limestone, dark gray (Terminal Cenomanian)
- C4 - Sannine bedded limestone (Cenomanian)

Litani River Basin
Management support (LRBMS)
Upper Litani River Basin

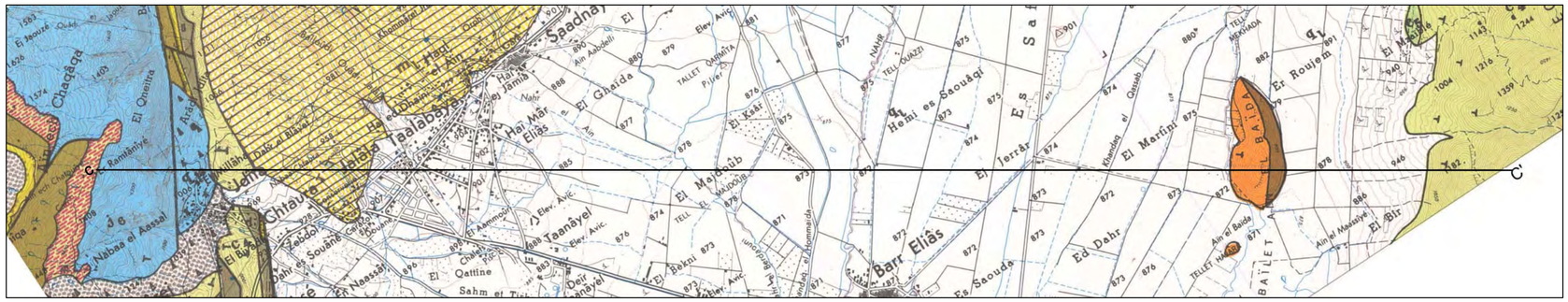
USAID FROM THE AMERICAN PEOPLE

LITANI River Authority

Geological Cross Section

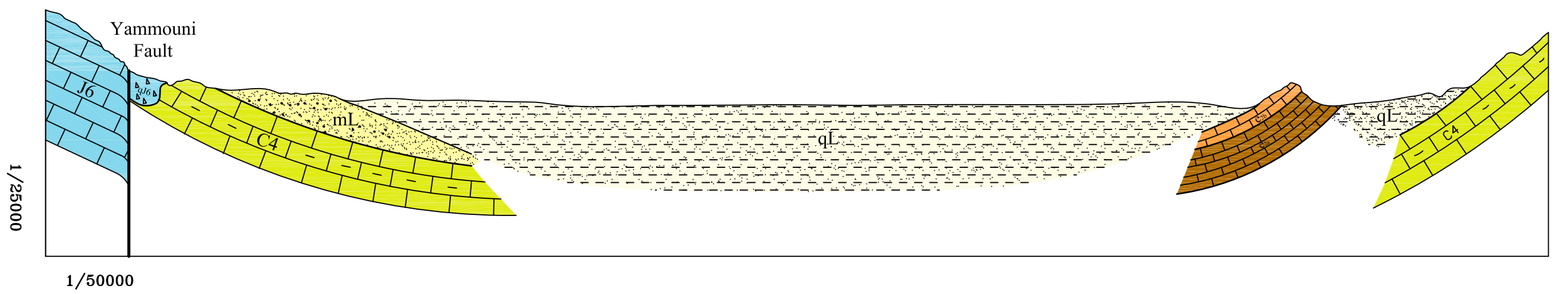
Scale	Zahleh –Rayak Geological Sheet 1/50000	
H. 1/50000	IRG USAID Contractor	Cross Section B – B'
V. 1/25000	Performed by : K Mansour	Beirut 05/03/2012

Zahleh Geological Cross Section C-C'



Cross section view side

Extracted from Zahle Geological map 1/50000



Legend

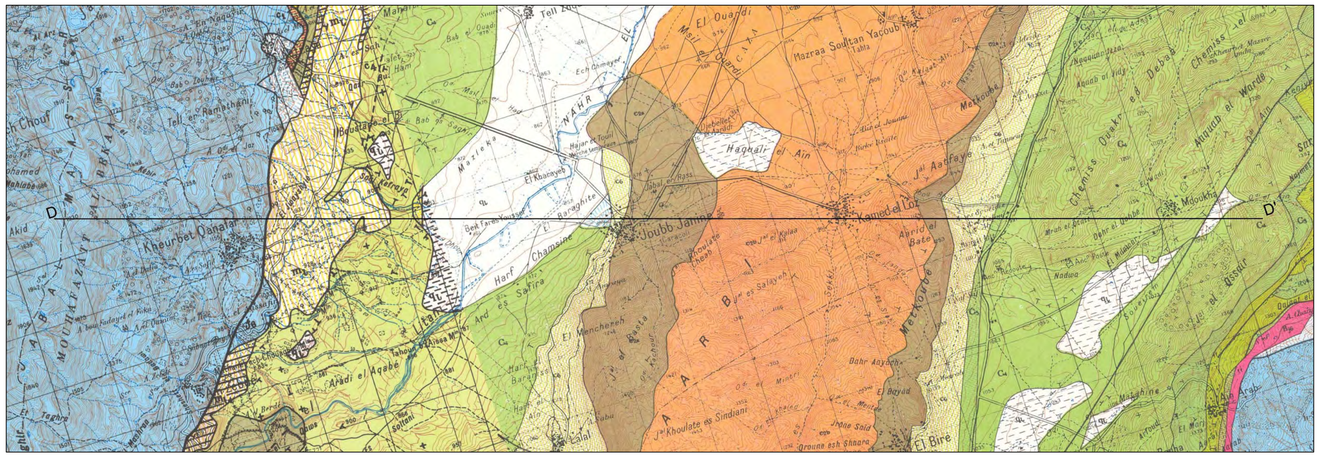
- qL - Limon deposits (Quaternary)
- mL - Zahleh poudings, Conglomerates (Continental miocene)
- e_{2b} - Jabal Ad Dher limestone, Subrecifal white limestone, upper Lutetian (Eocene)
- e_{2a} - Majdel Anjar marly limestone, lower Lutetian (Eocene)
- C4 - Sannine limestone, alternation of limestone & marly limestone, slightly bedded (Cenomanian)
- qJ6 - Jurassic eboulis (Jurassic)
- J6 - Blueish massif limestone Jurassic (Jurassic)

Litani River Basin
Management support (LRBMS)
Upper Litani River Basin

Geological Cross Section

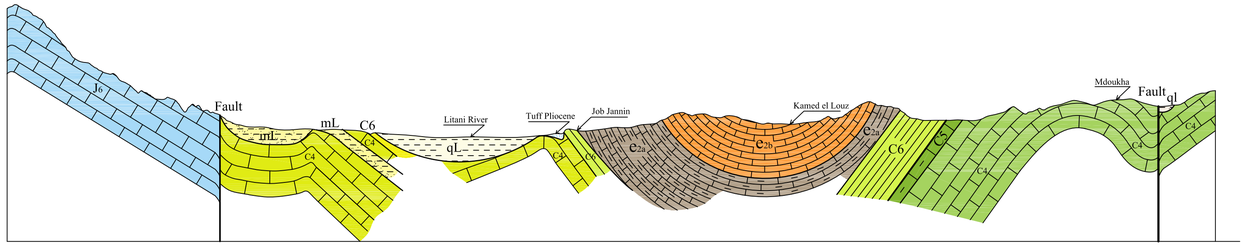
Scale	Zahleh Geological Sheet 1/50000	
H. 1/50000	IRG USAID Contractor	Cross Section C – C'
V. 1/25000	Performed by : K Mansour	Beirut 05/03/2012

Jezzine-Rashaya North Geological Cross Section D-D'



Extracted from Jezzine-Rashaya North Geological map 1/50000

Cross section view side



Legend Jezzine sheet

- qL - Limon (Quaternary)
- mL - Lacustrine marl (Continental- Miocene)
- C6 - Marley limestone and white marl (Senonian)
- C4 - Sannine limestone, alternation of limestone and marly limestone, slightly bedded (Cenomanian)
- J_6 - Kesserwane limstone, massive blueish limestone, Sequnian - kummeridgian (Jurassic)

Legend Rashaya North Sheet

- ql - Cultivated soil (Quaternary)
- T - Tuff - (Pliocene)
- e_{2b} - Limestone of jabal ed Dahr, white subrescifal numilitic limestone, upper Lutetian (Eocene)
- e_{2a} - Marly limestone of Majdal Anjar ,ummulitic marlylimestone, Lower Lutetian (Eocene)
- C6 - Chalky white marl (Senonian)
- C5 - Marly limestone, Ammonites and Hippurites limestone (Turonian)
- C4 - Sannine limestone slightly bedded (Cenomanian)

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LITANI River Authority

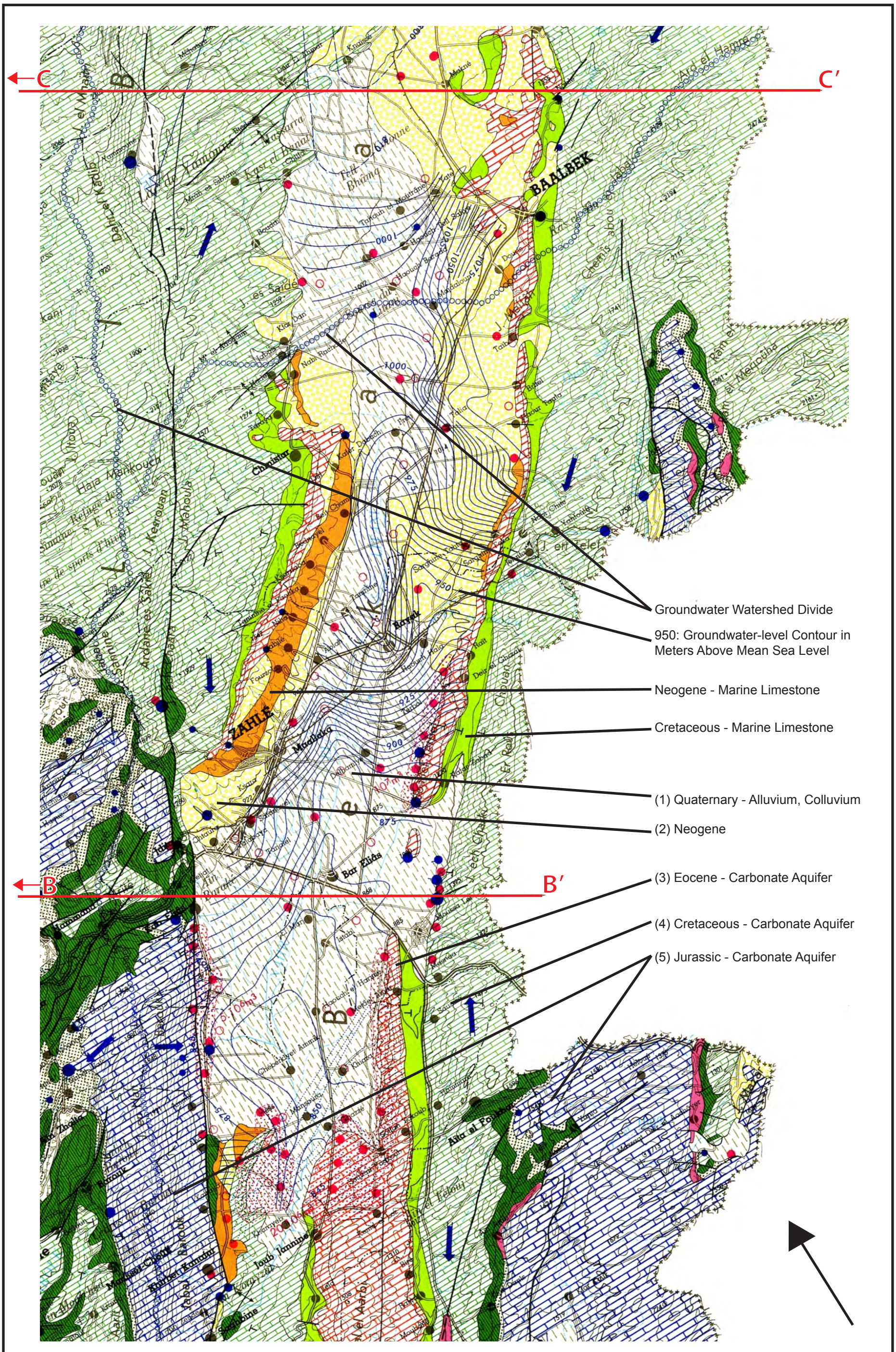
Geological Cross Section

Scale	Jezzine- Rashaya Sheet 1/50000	
H. 1/50000	IRG USAID Contractor	Cross Section D – D'
V. 1/25000	Performed by : K Mansour	Beirut 05/03/2012

APPENDICES

APPENDIX A

UNDP (1970) Hydrogeologic Map
And Cross Sections



Hydrogeologic Map of Project Area

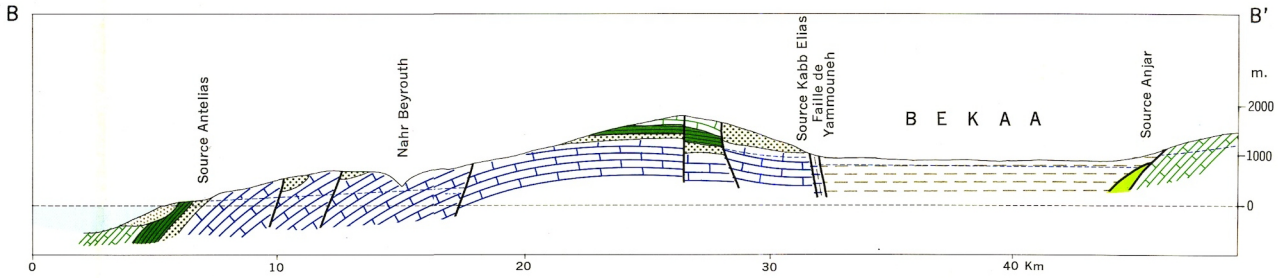
Hydrogeologic Reference Report

UHL & Associates, Inc.
Lambertville, New Jersey

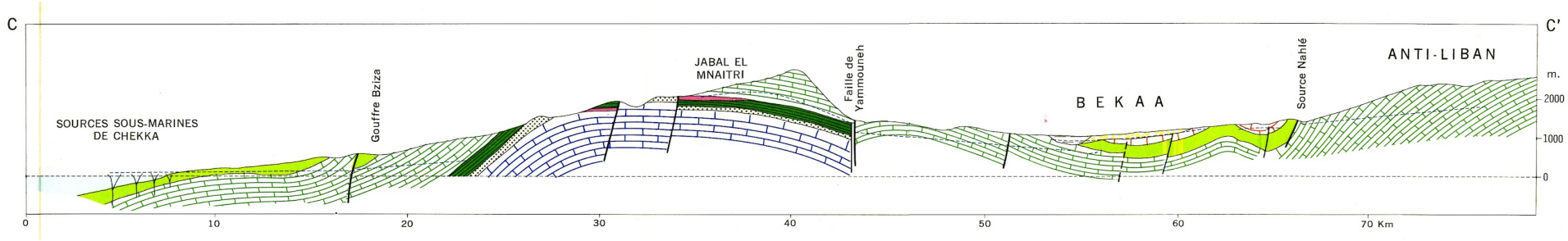
APPENDIX

A1

Cross Section B-B'



Cross Section C-C'



Cross Secion B-B' and C-C'

Hydrogeologic Reference Report

UHL & Associates, Inc.
Lambertville, New Jersey

APPENDIX

A2

APPENDIX B

Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

No.	Well ID	N	E	Elevation (m a.s.l)	Nature	Year of Installation	Depth (m BG)	BH Diameter (inch)	Usage	Town	Owner	Description	Date
1	A1-1	34.021917	36.080133	1013	Borehole				Irrigation	Saaide	Mehdi Zaiter	500 m away from saaideh road bifurcation	18-06-2011
2	A2-1	34.011083	36.173167	1080	Borehole		150		Domestic	Baalback	Saleh Saleh Taha	Al Abassyeh Area	20-06-2011
3	A2-2	34.0141	36.169433	1066	Borehole		100			Baalback	Abu riad mehdi Jaafar	Adduss Area	20-06-2011
4	A2-3	34.014817	36.164433	1061	Borehole	1997	80	14	domestic	Baalback	Saad ed din Al jobb	Adduss Area	20-06-2011
5	A2-4	34.025683	36.140567	1021	Borehole	2003	130	14	Mosque use	Haouch tall safiye	Mosque property		18-06-2011
6	A2-5	34.02664	36.14605	1023	Borehole	2003				Haouch tall safiye		Haouch tall safiye - Taat road - near cow's farm	18-06-2011
7	A2-6	34.0316	36.15015	1022	Borehole				Irrigation	Iaat	Wissam Zeidan	Haouch tall safiye - Taat road	18-06-2011
8	A2-7	34.040633	36.153333	1010	Borehole		100		Irrigation	Iaat	Ali Asaad El zein	Haouch tall safiye - Taat road	18-06-2011
9	A3-1	33.98542	36.23233	1380	Borehole	1998	500		drinking & domestic	Baalback	Bekaa Water Authority	Aamichki 16	18-06-2011
10	A3-2	33.98	36.230033	1380	Borehole	1998	328		drinking & domestic	Baalback	Bekaa Water Authority	Aamichki 17	11-06-2011
12	A3-4	34.006967	36.246283	1354	Borehole	1998	311		drinking & domestic	Baalback	Bekaa Water Authority	Al Aasayra 9	19-06-2011
13	A3-5	34.0123	36.19445	1106	Borehole	1978	152	14		Baalback	Bekaa Water Authority	Al Basatine Well	15-06-2011
14	B1-1	33.980833	36.0852	990	Borehole				Irrigation	Hizzine	Abbas Zaiter		
15	B1-2	33.981783	36.078717	993	Borehole	1993	40		Irrigation	Tarayya	Haddar Zaiter	Hizzine - Nabi rachade road	19-06-2011
16	B1-3	33.98525	36.072017	1008	Well				Irrigation	Hadath	Ali berro	Hizzine - Nabi rachade road	19-06-2011
17	B1-4	34.010367	36.0688	1024	Borehole								
18	B2-1	33.933383	36.107317	1040	Borehole	2004	600		drinking & domestic	Talia	Bekaa Water Authority	Near water tank	13-06-2011
19	B2-2	33.943683	36.105083	1035	Borehole	1999	70		Domestic	Talia	Abbas Ismail	Near highway - in front of trading bldg	15-06-2011
20	B2-3	33.957767	36.1204	1055	Borehole	1998	80		Irrigation	Britel	mohamad Hussein el Afi	on the main road to baalbak	16-06-2011
21	B2-4	33.962233	36.123983	1054	Borehole	1970	80		Car washing	Taibe	mohamad Zaytoun	on the main road to baalbak	15-06-2011
22	B2-5	33.961733	36.106167	1020	Borehole	1970	80		Domestic	Britel	Hajj Kamel harmush	Britel - Hizzine road	19-06-2011
23	B2-6	33.9522	36.115333	1045	Borehole	2005	60		Yard Irrigation	Britel	Municipality	In the munivipality yard	15-06-2011
23	B2-6	33.9522	36.115333	1045	Borehole	2005	60		Yard Irrigation	Britel	Municipality	In the munivipality yard	21-06-2011
24	B2-7	33.966517	36.095917	998	Borehole	2000	95		Irrigation	Hizzine	mohamad Salman El Dika	Al bustan area	19-06-2011
25	B3-1	33.922017	36.138667	1137	Borehole	1980	100		Domestic	Haour Taala	Mohamad Ali El Masri (Abu Abdallah)		
26	B3-2	33.924483	36.159883	1207	Borehole	1997	400		drinking & domestic	Britel	Bekaa Water Authority	Britel 1	16-06-2011
27	B3-3	33.9323	36.165467	1195	Borehole	1998	345		drinking & domestic	Britel	Bekaa Water Authority	Britel 2	16-06-2011
28	C1-1	33.9134	35.987367	1181	Borehole	2009				Qsarnaba	MEA-Abandoned well		02-06-2011
29	C1-2	33.913333	35.984067	1229	Borehole				Domestic	Qsarnaba	Ali Hussein Dirani		02-06-2011
30	C2-1	33.929017	36.08915	1014	Borehole	2005	120		Domestic	Haouch Sneid	Mohamad mahmoud	In front of Zahraa School	30-05-2011
31	C2-2	33.918933	36.077683	1006	Borehole	1960	60		Domestic	Sifri	Ibrahim Al Ali		13-06-2011
32	C2-3	33.917517	36.10085	1046	Borehole	1999	90		Irrigation	Sifri	Hajj Ahmad Awdeh		13-06-2011
33	C2-4	33.92355	36.076717	995	Borehole	1970	55		Irrigation	Sifri	AREC		14-06-2011
34	C2-5	33.92375	36.046767	952	Well		10		Domestic	Haouch er Rafqa			13-06-2011
35	C2-6	33.9336	36.0386	995	Borehole	1999	70		Domestic	Al Akidiyya - Beit Chama	Hanzal Hamieh		13-06-2011
36	C3-1	33.865517	36.04585	975	Borehole		300		Irrigation	Ali en Nahri	Adnan Mousawi	200m off ali nahri-siriine road	21-06-2011
37	C3-2	33.875633	36.066133	982	Borehole				Irrigation	Siriine el tahta	Mario Mhanna		22-06-2011
38	C3-3	33.913917	36.112717	1069	Borehole	1990	150		Domestic	El Khodr	hussein Awdeh		21-06-2011
39	C3-4	33.901433	36.118083	1112	Borehole				Domestic	El Khodr	Ali Abbas Hamzeh		21-06-2011
40	C3-5	33.867433	36.109167	1275	Borehole	1998	450		drinking & domestic	Nabi Chit	Bekaa Water Authority	Station 14	16-06-2011
41	C3-6	33.875283	36.118783	1224	Borehole	1998	350		drinking & domestic	Nabi Chit	Bekaa Water Authority	Station 13	16-06-2011
42	C3-7	33.874	36.07865	1035	Borehole	1997	350		drinking & domestic	Siriine el tahta	Bekaa Water Authority		16-06-2011
43	C3-8	33.893667	36.13295	1175	Borehole	1997	335		drinking & domestic	El Khodr	Bekaa Water Authority		16-06-2011
44	D1-1	33.8699	35.946283	990	Well		25		Domestic	Fourzol	Elie Fedaa		04-06-2011
45	D1-2	33.859117	35.9471	933	Borehole	1974	120		Domestic	Fourzol	Ibrahim Georges	Access between star optic and fourzol pharmacy	11-06-2011
46	D1-3	33.873783	35.961733	965	Borehole	1985	50		Domestic & yard irrigation	Ablah	Joseph kallas		13-06-2011
47	D2-1	33.863917	35.9851	903	Well	1960	25		Domestic	Ablah	Mohsen Es sayed	in front of antonin university	28-05-2011
48	D2-2	33.846067	35.995333	920	Borehole	1981	130		Irrigation	Haouch Hala	mahmoud Ibrahim		22-06-2011
49	D2-3	33.853217	36.012233	930	Borehole	1999	125		Domestic	Rayyak	Hamad Zaiter	Near al mustakbal school	22-06-2011

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

No.	Well ID	Water Level (m BG) (2011)	Water Level Altitude (m a.s.l) (2011)	T (˚C)	TDS (ppt)	pH	Air T (°C)	Water Level (m BG) (2010)	Water Level Altitude (m a.s.l) (2010)	T (˚C)	TDS (ppt)	pH	Air T (°C)	Casing Depth (m BG)	Casing Diameter (inch)	Screen Intervals	Surface Formation
1	A1-1	1.75	1011.25					33.83	979.17						10		Quaternary - Neogene
2	A2-1	35.07	1044.93					55.7	1024.3						14		Neogene
3	A2-2	25.24	1040.76					30.28	1035.72						14		Neogene
4	A2-3	20.47	1040.53					41.05	1059.95	16.8	0.28	7.95	17.2	78	10		Neogene
5	A2-4	3.38	1017.62					6.9	1014.1					130	12		Quaternary - Neogene
6	A2-5	2.36	1020.64					4.82	1019.18								Quaternary - Neogene
7	A2-6	15.06	1006.94					17.44	1004.56						12		Quaternary - Neogene
8	A2-7	26.37	983.63					25.89	984.11					100	12		Quaternary - Neogene
9	A3-1	112.33	1267.67					143.2	1236.8		0.142	7.47		350	12		C4
10	A3-2	154.58	1225.42					119.37	1260.63		0.124	7.47		328	12		C4
12	A3-4	159.35	1194.65					183.6	1170.4		0.17	7.8		311	12		C4
13	A3-5	38.76	1067.24					50.4	1055.6					152	12	25-150	Eocene
14	B1-1							7.17	982.83						10		Quaternary - Neogene
15	B1-2	4.04	988.96					8.38	989.23					12	12		Quaternary
16	B1-3	2.5	1005.5					5.73	1002.27								Quaternary
17	B1-4							97.05	926.95								Quaternary
18	B2-1	38.95	1001.05					62.55	977.45	27.1	0.23	8.24	25	600		200-600	Neogene
19	B2-2	38.25	996.75	19	0.34	9.55	17.1	39.2	995.8	18.8	0.36	9.18	17.7	70			Quaternary
20	B2-3	28.89	1026.11					27.8	1027.2	23.1	0.2	8.46	20.1	80			Neogene
21	B2-4	57.05	996.95					60.38	993.62	23.7	0.2	8.3	21	80			Neogene
22	B2-5	27.22	992.78	25.5	0.27	8.45	20	40	980	28.3	0.21	8.32	26	80			Quaternary
23	B2-6	42.97	1002.03	16.9	0.23	9.81	16.1	42.6	1002.4	23.5	0.24	8.69	23.2				Neogene
23	B2-6	36.99	1008.01					42.6	1002.4	23.5	0.24	8.69	23.2				Neogene
24	B2-7	5.33	992.67					19.99	978.01					95			Quaternary
25	B3-1							39.8	1097.2	17	0.25	8.59	16.5	100			Neogene
26	B3-2	103.23	1103.77					103.8	1103.2					349	12	100	C4
27	B3-3	76.87	1118.13					91.55	1103.45		0.211	7.38		290	12		C4
28	C1-1	4.68	1176.32					14.01	1166.99						14		Neogene - Miocene
29	C1-2	39.18	1189.82					52.83	1176.17						12		Neogene - Miocene
30	C2-1	20.25	993.75					32.2	981.8	20.9	0.25	8.59	20	120		60-120	Quaternary - Neogene
31	C2-2	13.48	992.52					25.02	1004.8	18.4	0.37	8.8	18.7	60			Quaternary - Neogene
32	C2-3	51.93	994.07					60.09	985.91	18.6	0.31	8.23	19.2	90			Neogene
33	C2-4	11.1	983.9					24.7	970.3	20	0.3	8.28	21.2	55			Quaternary
34	C2-5	5.78	946.22					7.15	944.85	24.8	0.46	7.84	25				Quaternary
35	C2-6	8.81	986.19					13.9	981.1	21	0.31	8.07	21.9	70			Neogene
36	C3-1	55.46	919.54				31	75.24	899.76					300	14		Neogene
37	C3-2	30.37	951.63					32.09	949.91								Neogene
38	C3-3	75.5	993.5				27	76.03	992.97	17.3	0.3	7.77	17.5				Neogene
39	C3-4	111.64	1000.46				27	119.97	992.03	17.3	0.3	7.77	17.5				Neogene
40	C3-5	226.13	1048.87					258.16	1016.84		0.173	7.7		400	12		C4
41	C3-6	168.6	1055.4					203.73	1020.27		0.173	7.7		282	12		C4
42	C3-7	173.23	861.77					198.57	836.43		0.21	7.6		253	12		Neogene
43	C3-8	168.78	1006.22					172.5	1002.53		174	7.7		333	12		C4-C5
44	D1-1	9	981					8.3	981.7	24.7	0.13	9.2	24.8				Neogene
45	D1-2	9.69	923.31				29.2	15.22	917.78	24.1	0.28	8.07	25.2	120			Quaternary - Neogene
46	D1-3	9.36	955.64					21.09	943.91	28.2	0.32	8.33	28.4	50			Quaternary - Neogene
47	D2-1	3.13	899.87					4.93	898.07	22.5	0.52	7.88	20.5			10-50	Quaternary
48	D2-2	16	904				32	27.5	892.5	22.1	0.36	8.25	22.9	130		60-130	Quaternary
49	D2-3	23.89	906.11				32	36.53	893.47	23.7	0.27	8.7	24.5	125		45-125	Quaternary

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

No.	Well ID	Aquifer	Pump Type	Discharge (m^3/h)	Pump Power	Pumping Duration (h/day)	Riser pipe Diameter (inch)	Remarks
1	A1-1	Quaternary - Neogene	electrical submersible pump Ø 3"					
2	A2-1	Neogene	electrical submersible pump Ø 1 1/4"					
3	A2-2	Neogene						Unequipped
4	A2-3	Neogene	electrical submersible pump Ø 1 1/4"					
5	A2-4	Quaternary - Neogene	2 electrical submersible pump Ø 1 1/4" and 2"					
6	A2-5	Quaternary - Neogene						Unequipped
7	A2-6	Quaternary - Neogene	Electrical submersible pump Ø 2"					
8	A2-7	Quaternary - Neogene	Electrical submersible pump Ø 3"					
9	A3-1	Cenomanian	Electrical submersible pump Ø 6"	39.6		24	5	
10	A3-2	Cenomanian	Electrical submersible pump Ø 8"			24		
12	A3-4	Cenomanian	Electrical submersible pump Ø 4"	43.2		24		
13	A3-5	Eocene	Electrical submersible pump Ø 6"					
14	B1-1	Quaternary - Neogene	electrical submersible pump Ø 1 1/4"					Unable to access due to muddy and wet soil
15	B1-2	Quaternary	Electrical submersible pump Ø 1"			24		
16	B1-3	Quaternary	Electrical submersible pump Ø 2"					
17	B1-4	Quaternary - Neogene						
18	B2-1	Eocene	Electrical submersible pump Ø 4"	50		24		
19	B2-2	Quaternary - Neogene	Electrical submersible pump Ø 2"	10		4		
20	B2-3	Neogene	electrical submersible pump Ø 1 1/4"	10		8		
21	B2-4	Neogene	electrical submersible pump Ø 1 1/2"	10		5		
22	B2-5	Quaternary	electrical submersible pump Ø 1 1/2"	10		3		
23	B2-6	Neogene	electrical submersible pump Ø 1 1/4"	6		6		
23	B2-6	Neogene	electrical submersible pump Ø 1 1/4"	6		6		
24	B2-7	Quaternary	electrical submersible pump Ø 2"			10		
25	B3-1	Neogene	electrical submersible pump Ø 1 1/4"	5		1		could not be measured / Get dry within 1h pumping
26	B3-2	Cenomanian				24		
27	B3-3	Cenomanian	electrical submersible pump Ø 6"			24		
28	C1-1	Neogene - Miocene	electrical submersible pump Ø 1 1/4"					B.H. Drilled for MEA not completed. Another B.H is being Drilled at almost 4m
29	C1-2	Neogene - Miocene	electrical submersible pump Ø 1 1/4"					
30	C2-1	Quaternary - Neogene	Axial Shaft pump	12		3		
31	C2-2	Quaternary - Neogene	electrical submersible pump Ø 1 1/4"	25		5		
32	C2-3	Neogene	electrical submersible pump Ø 1 1/4"	20		8		
33	C2-4	Quaternary		25		6		
34	C2-5	Quaternary	Centrifuged electrical pump					
35	C2-6	Neogene	electrical submersible pump Ø 1"	12		5		
36	C3-1	Eocene	electrical submersible pump Ø 5"					
37	C3-2	Neogene	electrical submersible pump Ø 2"			4		after 4 hours they stop pumping and wait for recovery
38	C3-3	Neogene	electrical submersible pump Ø 1"					
39	C3-4	Neogene	electrical submersible pump Ø 1 1/2"					
40	C3-5	Cenomanian	electrical submersible pump Ø 8"	169.14		24		
41	C3-6	Cenomanian	electrical submersible pump Ø 8"	168.92		24		
42	C3-7	Eocene	electrical submersible pump Ø 8"	110		12		
43	C3-8	C4-C5	electrical submersible pump Ø 6"	50-60		12		
44	D1-1	Neogene	Axial Shaft pump	0.2		3		
45	D1-2	Quaternary - Neogene	electrical submersible pump Ø 1"	0.5		4		
46	D1-3	Quaternary - Neogene	electrical submersible pump Ø 1"	0.25		3		
47	D2-1	Quaternary	electrical submersible pump	0.125				
48	D2-2	Quaternary	electrical submersible pump	0.5		12		
49	D2-3	Quaternary	electrical submersible pump	0.42		5		

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

50	D2-4	33.85105	36.02735	952	Borehole	1983	140		Domestic	Hayy el Fikani	Habib Ayyub	Near Dallal station and Ar rayyan sweets	22-06-2011
51	D2-5	33.849167	36.015233	935	Borehole	1998	130		Domestic	Ali en Nahri	Abbas Sindiane		22-06-2011
52	D2-6	33.865483	36.023133	950	Borehole	2009	230		Domestic	Ali en Nahri	Ibrahim Jomaa		
53	D2-7	33.84105	35.960183	887	Borehole	1970	85		Irrigation	Fourzol	Georges Sayida		
54	D3-1	33.839517	36.058333	1036	Borehole	1980	195		Irrigation	Raite	Youssef Shahade		22-06-2011
55	D3-2	33.826683	36.038383	1084	Borehole				Rock sawing industry needs	Deir el ghazal	Mkhayel Ed Debs		22-06-2011
56	D3-3	33.8103	36.023733	1089	Borehole		30		Domestic	kousaya	Naimeh Family		22-6-2011
57	E1-1	33.836533	35.935233	893	Borehole	1980	125		Irrigation	Zahle	Jean el Mansab		
58	E1-2	33.803417	35.940333	876	Borehole	1965	80		Domestic & irrigation	Zahle	Mohamad el Hajj		
59	E1-3	33.822717	35.944167	890	Borehole	1970	65		Domestic & irrigation	Zahle	Imad Salhab		05-06-2011
60	E1-4	33.83215	35.952367	885	Borehole	1973	215		Irrigation	Maalaqa	Michel Hjayje		
61	E1-5	33.848533	35.93165	924	Borehole	2009	180		Domestic	El Karak	Ali Hamze		
62	E1-6	33.830567	35.909533	912	Borehole	1983	125		drinking & domestic	Zahle	Bekaa Water Authority	Haoush el Omara Station 2	26-05-2011
63	E2-1	33.820967	35.96645	890	Borehole	1970	50		Irrigation	Dalhamiye	Hatem Saad		05-06-2011
64	E2-2	33.822083	35.958633	882	Borehole	1980	50		Irrigation	Dalhamiye	Ahmad Al Ali	Near plastic factory	05-06-2011
65	E2-3	33.8131	35.958117	887	Borehole	1970	45		Irrigation	Dalhamiye	Nemer Saad		05-06-2011
66	E2-4	33.8138	35.985933	891	Borehole	1980	225		Irrigation	Terbol	Toni Nassar		05-06-2011
67	E2-5	33.83485	35.9849	904	Borehole	1973	140		Irrigation	Terbol	Georges Abu khater		06-06-2011
68	E2-6	33.806683	35.9931	899	Borehole	1973	150			Terbol	Lebanese Agriculture Institute		06-06-2011
69	E3-1	33.769117	35.982283	973	Borehole	2009	80	16		Kfarzabad	Ghassan El Khatib		06-06-2011
70	E3-2	33.766983	35.983283	993	Borehole	2005	140	16	Irrigation	Kfarzabad	Ahmad el Khatib		06-06-2011
71	E3-3	33.7584	35.96485	893	Borehole		100	14		Kfarzabad	Georges Skaff		06-06-2011
72	E3-4	33.7507	35.963133	910	Borehole	2008	125		Irrigation	Kfarzabad	Omar		
74	F1-2	33.825567	35.829867	1040	Borehole				drinking & domestic	Jdita	Bekaa Water Authority		26-05-2011
75	F1-3	33.817233	35.836783	964	Borehole	1983	50	17	Yard Irrigation	Zebdol	Khalil Ibrahim el Mais		26-05-2011
76	F1-4	33.807383	35.8245	1015	Borehole	1999	150	14	Bakery needs	Makseh	Al Malaka Bakery		28-05-2011
77	F1-5	33.77045	35.81275	881	Borehole				Irrigation	Qabb Elias	Ali Hayek	In front of Azar plastic factory	29-05-2011
78	F2-1	33.7609	35.8824	872	Well	2007	8	62.2	Yard Irrigation	El Marj	El Marj Municipality	in Public Garden near municipality	06-06-2011
79	F2-2	33.764567	35.87935	860	Well	2010	10	39.37	School yard Irrigation	El Marj	Makased School		06-06-2011
80	F2-3	33.74995	35.896233	875	Well	2003	4.5	39.37		El Rawda	Al Tayeb Mohamed		09-06-2011
82	F2-5	33.731183	35.891383	876	Borehole	2010				El Rawda	Amiri Family		11-06-2011
84	F2-7	33.713967	35.891533	877	Borehole	1999	101	16		Majdel Anjar	Haytham Sabri		09-06-2011
86	F2-9	33.722917	35.90135	879	Borehole	1965	100			Majdel Anjar	Ghandur refrigerator		09-06-2011
88	F3-2	33.750367	35.958117	874	Borehole				Irrigation	Kfarzabad	Chafic Kfoury		
90	G1-1	33.757133	35.80365	891	Borehole	1960	90	18	Irrigation	Qabb Elias	Emile Kanaan		29-05-2011
91	G1-2	33.68146	35.799968	873	Borehole	2004				Mansoura	Yasine Abdel majid Fakih	Mansoura Refrigirator	30-5-2011
92	G1-3	33.75405	35.79965	890	Borehole		80			Tall el akhdar	Youssef Farran		
93	G1-4	33.7423	35.823133	862	Borehole	2009	250	14.75		Tall el akhdar	Marwan jarudi		29-05-2011
94	G1-5	33.7398	35.833767	861	Well		9.5	94.48		Tall el akhdar	Youssef Farran		29-05-2011
95	G1-6	33.686567	35.796283	883	Borehole					Mansoura	Bohsaly Farm		30-5-2011
96	G2-1	33.695533	35.8712	870	Borehole	1960	85		Irrigation	El Dakwe	Roushdi Mohamad Jaroush		07-06-2011
98	H1-2	33.636933	35.708817	1114	Borehole	1965	140	14 3/4		Khirbit Qanafar	Village		02-06-2011
99	H1-3	33.63475	35.728867	927	Borehole	2000	135		Irrigation	Khirbit Qanafar	Toni Chdid	Meds store to the east of the main road	02-06-2011
100	H1-4	33.663583	35.765317	903	Borehole	2000	175	15	Irrigation	Tell Znoub	Abdallah Mkhayel Kadery		31-5-2011
101	H1-5	33.6704	35.76495	911	Borehole				drinking & domestic	Tell Znoub	Bekaa Water Authority	Near the water tank	31-5-2011
102	H1-6	33.658783	35.762683	898	Borehole		130		Irrigation	Tell Znoub	Nasser Taha		04-06-2011
103	H1-7	33.643183	35.727767	954	Borehole				Irrigation	Khirbit Qanafar	Nadia Hallak	Restaurant	25-06-2011
104	H1-8	33.639617	35.750667	886	Borehole		150	15	Irrigation	Khirbit Qanafar	Georges Yousef karam		02-06-2011
105	H1-9	33.637183	35.756233	875	Borehole	2004	50		Farm needs	Khirbit Qanafar	Jamil Sharanek	Cow's farm	01-06-2011
106	H1-10	33.641233	35.756433	877	Borehole	1990			Irrigation	Khirbit Qanafar	Omar Zarzur		02-06-2011
108	H1-12	33.646583	35.741767	925	Borehole	1962	175		Irrigation	Kefraya	Osman Omar Osman		01-6-2011

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

50	D2-4	48.61	903.39					53.15	898.85					140		30-125	Quaternary
51	D2-5	51.42	883.58					62.2	872.8	20.7	0.27	8.73	25.1	130		60-125	Quaternary
52	D2-6							72.1	877.9	37.1	0.31	8.2	38.5	230		60-230	Neogene
53	D2-7							10.6	876.4					85		20-85	Quaternary
54	D3-1	94.78	941.22					165	876	34.1	0.27	8.4	34.9				Chekka
55	D3-2	6.43	1077.57				34	28.8	1055.2						12		Chekka
56	D3-3	14.27	1074.73					11.95	1077.05						12		Chekka
57	E1-1							29	864	19.7	0.34	8.66	22.3	125		15-125	Quaternary
58	E1-2							6.57	869.43	21.7	0.67	7.86	19	80			Quaternary
59	E1-3	3	887				34	14.75	875.25	20.9	0.63	8.02	19.9	65			Quaternary
60	E1-4							24.5	860.5					215		25-215	Quaternary
61	E1-5							50.3	873.8	21.8	0.31	8.05	20.9	180		155-180	Quaternary
62	E1-6	18.59	893.41					41.9	870.1					125			Quaternary
63	E2-1	3.85	886.15					22.85	867.15	17.1	0.59	10.85	16.9	50		20-50	Quaternary
64	E2-2	1.65	880.35				27	25.75	866.25	17.5	0.49	8.53	17.3	50			Quaternary
65	E2-3	1.95	885.05				32.5	19.6	867.4	29.9	0.59	8.22	29.6	45			Quaternary
66	E2-4	2.33	888.67					9.6	881.4	19.3	0.59	8.7	18.9	225		195-225	Quaternary
67	E2-5	7.77	896.23	20	1.21	8.26	22.4	20.25	883.75					140		60-140	Quaternary
68	E2-6	23.36	875.64					54.8	844.2								Eocene
69	E3-1	69.7	903.3					60.19	912.81								C4
70	E3-2	57.95	935.05					98	895						12		C4
71	E3-3	19.97	873.03					23.07	869.93						12		Quaternary
72	E3-4							42.66	867.34						12		Quaternary
74	F1-2			18.8	0.27	8.32	19.4	33.12	1006.88	16.8	0.17	8.74	18.9				Jurassic (J6)
75	F1-3	21.15	942.85	20.5	0.36	7.81	22.6	29.42	934.58	19.2	0.37	8.17	20.3	50	14	20-50	C3
76	F1-4	6.33	1008.67					19.53	995.47	20.7	0.28	8.16	22.2	135	12		C3
77	F1-5	10.48	870.52					19.06	861.94								Quaternary
78	F2-1	4.82	867.18					8.5	863.5	22.4	0.89	7.92	22.3				Quaternary
79	F2-2	1.31	858.69					2.3	857.7	22	3.95	7.3	23.2				Quaternary
80	F2-3	2.06	872.94	19.5	0.66	8.09		2.51	872.49	29.3	0.66	7.79	26				Quaternary
82	F2-5	13.3	862.7				26.6	27.45	848.55								Quaternary
84	F2-7	27.86	849.14					39.77	837.23					50	14		Quaternary
86	F2-9	22.02	856.98					33.98	845.02	25.5	0.37	8.18	25.4				Quaternary
88	F3-2							10.25	863.75								Quaternary
90	G1-1	22.35	868.65					26.66	864.34					90	16		Jurassic
91	G1-2	17.3	855.7							24.9	0.35	8.42	24				Quaternary
92	G1-3							20.42	869.58								Jurassic
93	G1-4	2.07	859.93					2.31	859.69					250	12		Quaternary
94	G1-5	1.73	859.27					6.71	854.29								Quaternary
95	G1-6	17.51	865.49					29.37	853.63	18.1	0.33	7.5	17.9				Quaternary
96	G2-1	21.83	848.17					32.74	837.26								Quaternary
98	H1-2	52.97	1061.03					58.5	1055.5								Jurassic
99	H1-3	70.65	856.35					83.37	843.63								Miocene
100	H1-4	43.16	859.84					55.31	847.69					175	12		C4
101	H1-5	49.78	861.22	22.1	0.28	8.4	20.8										C4
102	H1-6	36.59	861.41	19.5	0.56	7.8		48.93	849.07	17	0.27	7.68	17.9		12		C4
103	H1-7	27.54	926.46					16.96	937.04						14		Miocene
104	H1-8	30.72	855.28					43.22	842.78								C4
105	H1-9	2.57	872.43					3	872					50			Quaternary
106	H1-10	18.05	858.95					30.37	846.63	18	0.34	7.81	18.1				Quaternary
108	H1-12	59.46	865.54					78.67	846.33								Miocene/ Cenomanian

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

50	D2-4	Quaternary - Neogene	electrical submersible pump Ø 1 1/4"	0.33		5		
51	D2-5	Quaternary - Neogene	electrical submersible pump Ø 1"	0.375		5		
52	D2-6	Neogene	electrical submersible pump	0.625		6		Was not found
53	D2-7	Quaternary - Neogene		2.08		16		Was not found
54	D3-1	Cenomanian	Axial Pump	25		10		
55	D3-2	Cenomanian	electrical submersible pump Ø 3/4"			10		
56	D3-3		electrical submersible pump Ø 1"					
57	E1-1	Quaternary - Neogene	Axial Shaft pump	80		16		Could not be measured
58	E1-2	Quaternary - Neogene	Electrical submersible pump					Was not found
59	E1-3	Quaternary - Neogene	2 electrical submersible pump Ø 1" and 4"			18		
60	E1-4	Quaternary - Neogene	Axial Shaft pump			24		Could not be measured
61	E1-5	Quaternary	electrical submersible pump Ø 1 1/4"			6		The owner did not allow access to the well
62	E1-6	Quaternary - Neogene	electrical submersible pump Ø 6"			12		
63	E2-1	Quaternary	Axial pump	12		15		
64	E2-2	Quaternary	2 electrical submersible pumps Ø 2" each			22-24		
65	E2-3	Quaternary	Axial pump			8		
66	E2-4	Eocene	Axial pump	50		24		
67	E2-5	Quaternary/ or Eocene	electrical submersible pump Ø 2 1/2"			18		
68	E2-6	Eocene						Unequipped
69	E3-1	Cenomanian						Unequipped
70	E3-2	Cenomanian	3/4" pump					
71	E3-3	Cenomanian						Unequipped
72	E3-4	Cenomanian	electrical submersible pump Ø 1 1/4"					Could not access
74	F1-2	Jurassic (J6)	electrical submersible pump	313.812		14		
75	F1-3	Upper Aptian (C2b)	electrical submersible pump Ø 1 1/2"	3.6-5.4				
76	F1-4	Upper Aptian (C2b)	electrical submersible pump Ø 1 1/2"			10		
77	F1-5	Jurassic (J4)	electrical submersible pump Ø 4"					
78	F2-1	Quaternary	electrical submersible pump	3.5				Level measured 1 hour after stopping pumps
79	F2-2	Quaternary						Unequipped
80	F2-3	Quaternary						
82	F2-5	Quaternary						Unequipped
84	F2-7	Eocene	Axial Shaft pump					
86	F2-9	Eocene	electrical submersible pump Ø 4"			12		
88	F3-2	Cenomanian	electrical submersible pump Ø 4"			8		Could not be measured
90	G1-1	Jurassic	Electrical submersible pump Ø 2"			12		
91	G1-2	Cenomanian	2 electrical submersible pumps Ø 1 1/4" and 3"			3		Level during pumping 69.09 m (BG)
92	G1-3	Jurassic						well is plugged. Gas degagement was noticed during drilling
93	G1-4	Quaternary - Neogene						Unequipped - Gas smell from the well
94	G1-5	Quaternary	Electrical submersible pump					
95	G1-6	Cenomanian	Axial Shaft pump					
96	G2-1	Eocene	Electrical submersible pump Ø 10"					
98	H1-2	Jurassic						Unequipped
99	H1-3	Miocene/ or Jurassic / or Cenomanian	Electrical submersible pump Ø 4"					
100	H1-4	C4						Unequipped
101	H1-5	Cenomanian	Electrical submersible pump					
102	H1-6	Cenomanian	Axial shaft pump Ø 6"			6		
103	H1-7	Miocene	Electrical Submersible pump Ø 2"					pump at 85 m - water level measure half an hour after pumping stopped
104	H1-8	Cenomanian	Axial shaft Ø 8"			8		8h/day summer time
105	H1-9	Quaternary						unequipped
106	H1-10	Quaternary + Cenomanian	Axial shaft Ø 4"					
108	H1-12	Miocene/ Cenomanian						Unequipped

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

109	**H2-1**	33.66265	35.780267	863	Borehole	1960	90			Tell Znoub	Abdalla rizk	Horse breeding & farm	31-5-2011
110	**H2-2**	33.638417	35.771317	872	Borehole	2003	80		Domestic	Khirbit Qanafar	Litani Center		31-5-2011
111	**H2-3**	33.633017	35.782583	864	Borehole	1989			Domestic and Irrigation	Jibb Jinnine	mohamad Said Sharaneq	Near the electrical transformer station	31-5-2011
112	**H2-4**	33.630467	35.778633	869	Borehole	1992	180	17	Irrigation	Jibb Jinnine	Najib Youssef Ajram		31-05-2011
113	**H2-5**	33.6273	35.798967	926	Borehole	1988	150	14	Irrigation	Jibb Jinnine	Ibrahim Hussein El Kurdi	Near public well near secondary school	31-5-2011
114	**H2-6**	33.61335	35.82075	1010	Borehole	2010	303		domestic and drinking	Kamed el laouz	Municipality		
115	**H2-7**	33.625717	35.825217	930	Borehole	2001	200	16	domestic and drinking	Kamed el laouz	Bekaa Water Authority	Inside the secondary school	04-06-2011
116	**H2-8**	33.627567	35.8085	896	Borehole	1962	200	14	domestic and drinking	Kamed el laouz	Bekaa Water Authority	to the south of the main road	04-06-2011
117	**H2-9**	33.6506	35.8427	882	Borehole				drinking & domestic	Loucy	Bekaa Water Authority	Loucy pumping station	08-06-2011
118	**H2-10**	33.649367	35.845583	900	Borehole	1999	150		drinking & domestic	Loucy	Municipality		08-06-2011
119	**H2-11**	33.6511	35.834683	893	Borehole	1990	150		Irrigation	Loucy	Youssef el Orra	Loucy-Ghazzeh road	
120	**I1-1**	33.623917	35.69715	1179	Borehole	2000	238	12.25	drinking & domestic	Ain zebde	Bekaa Water Authority		02-06-2011
121	**I1-2**	33.609383	35.692367	1106	Borehole	1997	293	14.75	drinking & domestic	Saghbine	Bekaa Water Authority		02-06-2011
122	**I1-3**	33.5739	35.674133	1085	Borehole	1997	212	12.25	drinking & domestic	Aitanit	Bekaa Water Authority		02-06-2011
123	**I2-1**	33.567867	35.718617	896	Borehole	1988	90		Domestic & irrigation	Qaraoun	Yaacoub haymour		12-06-2011
124	**I2-2**	33.608117	35.756	976	Borehole		240		drinking & domestic	Lala	Bekaa Water Authority		11-06-2011
125	**I2-3**	33.582883	35.730633	953	Borehole				drinking & domestic	Baaloul	Bekaa Water Authority	Baaloul pumping station	12-06-2011
126	**N1**	33.83572	35.95729	890	Borehole		70		Irrigation	Fourzol	Ibrahim Al Zummar		05-06-2011
127	**N2**	33.83198	35.94164	885						Zahle			05-06-2011
128	**N3**	33.5203	35.74504	952						Kfarmechky	Public		24-05-2011
129	**N4**	33.58075	35.86538	1112	Borehole				drinking & domestic	Ain Arab	Public		24-05-2011
130	**N5**	33.60208	35.81209	1093	Borehole					El Bire	Public		24-05-2011
131	**N6**	33.77662	35.8135	885	Borehole				drinking & domestic	Qabb Elias	Bekaa Water Authority		29-05-2011
132	**N7**	33.8103	35.83682	918	Borehole		125		Irrigation	Makse	Talal El Mays		28-05-2011
133	**N8**	33.79699	35.83887	887	Hand Dug			98.42	Irrigation	Qabb Elias	Abdallah Khoury		28-05-2011
134	**N9**	33.79546	35.83982	890	Hand Dug		4.5	48.82	Domestic & Yard irrigation	Qabb Elias	Abdallah Ahmad Braidy		28-05-2011
135	**N10**	33.87068	35.9734	935	Borehole	2006	110		Irrigation	Ablah	Georges Rizk		28-05-2011
136	**N11**	33.68815	35.80057	871	Borehole		155		Irrigation	Mansoura	Fouad Bohsaly Sons		30-05-2011
137	**N12**	33.68361	35.79549	870	Borehole					Mansoura	Municipality		30-05-2011
138	**N13**	33.71384	35.77021	895	Borehole		60		Irrigation	Aammiq	Elie Skaf		01-06-2011
139	**N14**	33.75402	35.79967	887	Borehole				Irrigation	Es Safra	Wahib Gaith	Before Aammiq	01-06-2011
140	**N15**	33.76751	35.80999	887	Borehole		80		Cooling Purposes - Factory	Haouch Qeissar	Petka Co. Plastic industry		01-06-2011
141	**N16**	33.91023	35.97771	1126	Borehole				drinking & domestic	Timnine el Faouqa	Bekaa Water Authority		01-06-2011
142	**N17**	33.9262	36.00505	1109	Borehole				drinking & domestic	Bednayel	Bekaa Water Authority		04-06-2011
143	**N18**	33.88777	35.93977	1115	Borehole	1967	100		Village	Fourzol	Fourzol Committee		04-06-2011
144	**N19**	33.82229	35.97289	887	Borehole		55		Irrigation	Terbol	Moussa el Ramy		05-06-2011
145	**N20**	33.81012	35.96205	886	Borehole		90		Irrigation	Dalhamiye	Adel Abu Khalife		05-06-2011
146	**N21**	33.81239	35.9	883	Borehole				company needs	Saadnayel	Joseph Khasho		05-06-2011
147	**N22**	33.75034	35.9634	917	Borehole				Irrigation	Kfarzabad	Georges Nabahan		06-06-2011
148	**N23**	33.75127	35.95897	885	Borehole				Irrigation	Kfarzabad	Georges Assaf		06-06-2011
149	**N24**	33.76353	35.88021	867	Hand Dug		9	66.93	Irrigation	El Marj	Public Garden		06-06-2011
150	**N25**	33.70914	35.9227	971	Borehole		129		Irrigation	Majdel Anjar	Jamil Saleh		07-06-2011
151	**N26**	33.65494	35.83442	880	Borehole		100		Irrigation	Loucy	Nasib el Orra		07-06-2011
152	**N27**	33.71687	35.92489	932	Borehole				Irrigation	Majdel Anjar	Ibrahim Abd el khalek		07-06-2011
153	**N28**	33.66161	35.82265	867	Borehole				drinking & domestic	Ghazze	Bekaa Water Authority		07-06-2011
154	**N29**	33.70938	35.8838	877	Borehole		200	16		Majdel Anjar	Mohamad Yassine		08-06-2011
155	**N30**	33.7259	35.90448	876	Borehole					Majdel Anjar	Sugar Factory		09-06-2011
156	**N31**	33.52672	35.75415	978	Borehole					Majdel Balhis	Bekaa Water Authority		12-06-2011
157	**N32**	33.59803	35.86028	1067	Borehole					Mdoukha	Public		11-06-2011
158	**N33**	33.5081	35.81647	956	Borehole				drinking & domestic	Al Aqabe	Public		11-06-2011
159	**N34**	33.57956	35.85654	1075	Borehole					Kherbet Rouha	Public		12-06-2011
160	**N35**	33.92297	36.08814	1014	Borehole		125		Domestic & Yard irrigation	El Sifri	Ibrahim el Ali		13-06-2011

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

109	H2-1	14.42	848.58	26	0.28	8.34	25	20.76	842.24								Quaternary
110	H2-2	10.22	861.78					9.68	862.32	20.8	0.35	7.6	23.7		12		Quaternary
111	H2-3	13.5	850.5					26	838	19.5	0.3	7.46	21.2		12		Quaternary
112	H2-4	16.93	852.07					29.45	839.55	19.5	0.26	7.69	20.5		14		Quaternary
113	H2-5	59.03	866.97					70.48	839.55	17.8	0.26	7.77	19.2	12	12		Eocene
114	H2-6							178.87	831.13								Eocene
115	H2-7	66.67	863.33	19.9	0.03	8.64	26.7	78.61	851.39	20.1	0.18	8.15	22.8				Eocene
116	H2-8	44.05	851.95					55.7	840.3	21.1	0.17	8.03	23.4				Eocene
117	H2-9	28.12	853.88				32.2	38.82	843.18	19.7	0.29	7.96	19.6				Quaternary
118	H2-10	36.77	863.23	27.5	0.21	9.88		47.8	852.2								Eocene
119	H2-11							42.75	850.25						12		Eocene
120	I1-1	55.19	1123.81					68.97	1110.03	17.2	0.22	8.11	17.3	150	12.5	95-145	Jurassic
121	I1-2	74.49	1031.51					80.17	1025.83	16.3	0.05	8.25	17	260	12.5	135-255	Jurassic
122	I1-3	45.28	1039.72					57.96	1027.04					208	10.5		Jurassic
123	I2-1	47.47	848.53	21.9	0.31	8.82	23.6	62.6	833.4	17.9	0.29	8.13	17.1				Chekka
124	I2-2	112.54	863.82					128.8	847.2								C4
125	I2-3	96.85	856.15	18.6	0.46	9.92	18.7	112.52	840.48								C4
126	N1	2.87	887.13		1.2	8.75	27.5								10		Quaternary
127	N2	3.7	881.3														Quaternary
128	N3	29.56	922.44														Neogene
129	N4	59.52	1052.48														Cenomanian
130	N5	206.05	886.45	22	0.3	6.25											Eocene
131	N6	13.95	871.05	20.8	0.22	8.31											Quaternary
132	N7	2.2	915.8				20.2										Quaternary
133	N8	1.1	885.9				19.3										Quaternary
134	N9	1.47	88.53	16	0.31	8	16										Quaternary
135	N10	8.62	926.38	21.4	0.34	7.9	20.7								14		Quaternary
136	N11	15.31	855.69	20.3	0.5	7.88	25.4										Quaternary
137	N12	20.08	849.92														Quaternary
138	N13	29.06	865.94														Jurassic
139	N14	17.24	869.76												12		Jurassic
140	N15	19.95	867.05	21.5	0.2	8.65	22.5										Quaternary
141	N16	6.66	1119.34	13.4	0.14	8.68	20										Eocene
142	N17	71.41	1037.59												14		Eocene
143	N18	3.12	1111.88												16		Eocene
144	N19	5.16	881.84												12		Quaternary
145	N20	1.44	884.56	19.6	1.5	8.84	19.8								12		Quaternary
146	N21	3.15	879.85												12		Quaternary
147	N22	40.46	876.54	24.1	0.43	9.38	25.9								12		Quaternary
148	N23	10.12	874.88														Quaternary
149	N24	2.13	864.87														Quaternary
150	N25	71.72	899.28	19.6	0.26	9.4	20.7								12		Cenomanian
151	N26	27.57	852.43												16		Eocene
152	N27	34.55	897.45												12		Quaternary
153	N28	12.88	854.12														Eocene
154	N29	41.5	835.5												12		Quaternary
155	N30	22.43	853.57														Quaternary
156	N31	54.96	923.04	19.6	0.26	9.42	21.2										Neogene
157	N32	12	1055														Quaternary
158	N33	149.29	806.71	19.6	0.34	9.45	19.7										Lower Cretaceous
159	N34	174.94	900.06														Cenomanian
160	N35	28.16	985.84	18.4	2.1	10.6	19.2								12		Quaternary

109	H2-1	Cenomanian	Axial shaft Ø 10"			10		Water level taken 1 hour after pumping stopped
110	H2-2	Quaternary	Electrical submersible pump Ø 2"			1		Level measured 2 hours after pumping
111	H2-3	Quaternary /or Cenomanian	2 electrical submersible pumps Ø 1 1/4" each			0.5		
112	H2-4	Cenomanian	2 electrical submersible pumps Ø 4" each			4		
113	H2-5	Eocene	Electrical sumersible pump Ø 2 1/2"					
114	H2-6	Eocene	electrical submersible pump Ø 4"					Could not be measured
115	H2-7	Eocene	electrical submersible pump Ø 5"			24		
116	H2-8	Eocene	electrical submersible pump			24		
117	H2-9	Eocene	Electrical submersible pump Ø 8"	222		24		
118	H2-10	Eocene	Electrical submersible pump Ø 4"			20	4	
119	H2-11	Eocene	electrical submersible pump Ø 4"					Could not be measured
120	I1-1	Jurassic	Electrical submersible pump Ø 4"	54		8		
121	I1-2	Jurassic	Electrical submersible pump Ø 5"	54		7		
122	I1-3	Jurassic	2 Electrical submersible pump Ø 5" and 1 1/2"	32.4				
123	I2-1	Cenomanian	2 Electrical submersible pump Ø 1" and 1 1/4"					
124	I2-2	Cenomanian	Electrical submersible pump Ø 6"			8		
125	I2-3	Cenomanian	Electrical submersible pump Ø 4"					
126	N1	Quaternary - Neogene				12	2	measured to replace well 60
127	N2	Quaternary - Neogene	electrical submersible pump				2	measured to replace well 57
128	N3	Eocene					5	level measured during pumping
129	N4	Cenomanian						
130	N5	Eocene						
131	N6	Jurassic					6	
132	N7	Quaternary - Neogene					1 1/4	
133	N8	Quaternary						Unequipped
134	N9	Quaternary	Centrifugal pump		1/2 hp		1/2	
135	N10	Quaternary - Neogene			2 hp	10	1 1/2	
136	N11	Cenomanian			50 hp	8	6	
137	N12	Cenomanian		144			6	measurement was taken 1 hour after pumping
138	N13	Jurassic	Axial pump				8	
139	N14	Jurassic	Submersible pump			12	6	
140	N15	Jurassic					1 1/4	consumption of 5 m^3/day
141	N16	Eocene			100 hp		4	
142	N17	Eocene				12	4	
143	N18	Eocene					3	
144	N19	Quaternary/ or Eocene	Submersible pump				3	
145	N20	Quaternary - Neogene					2	
146	N21	Quaternary	Submersible pump 3" and 1 1/4"					
147	N22	Cenomanian					2 1/2	measured to replace E3-4
148	N23	Cenomanian	Axial pump			6	5	
149	N24	Quaternary	Centrifugal pump 1 1/4"					the well dries after 6 hours of pumping
150	N25	Cenomanian					3	
151	N26	Eocene					4	measured to replace H2-11
152	N27	Cenomanian					2	
153	N28	Eocene					6	
154	N29	Eocene						not used
155	N30	Eocene						not used
156	N31	Eocene						
157	N32	Cenomanian						
158	N33	Lower Cretaceous					2	
159	N34	Cenomanian					5	
160	N35	Quaternary - Neogene	submersible pump 1"					

Appendix B: Water Level Measurement Data Base for October – November 2010 and May-June 2011 Water Level Measurement Events

161	**N36**	33.93085	36.01609	1103	Borehole		255		drinking & domestic	Beit Chama	Public		13-06-2011
162	**N37**	33.87757	35.95732	1005	Borehole		65		Domestic & Yard irrigation	Nabi Ayla	Khalil Family		13-06-2011
163	**N38**	33.82766	35.90297	902	Borehole					Haouch el Oumara	Bekaa Water Authority		13-06-2011
164	**N39**	33.81365	35.8936	882	Hand Dug		10	58.66	Construcrion workshop	Saadnayel	Taufic el Homsi		14-06-2011
165	**N40**	33.806	35.9	873	Hand Dug		13		Domestic	Saadnayel	Ali		14-06-2011
166	**N41**	33.80257	35.9004	873	Hand Dug		6		Domestic	Saadnayel	Mohamad Al Wouss		14-06-2011
167	**N42**	33.88783	35.98287	992	Borehole					Niha	Walid Maalouf		14-06-2011
168	**N43**	33.88096	35.97318	980	Borehole				Irrigation	Niha	Youssef El Rmaily		14-06-2011
169	**N44**	33.98811	36.17771	1110	Borehole					Douris	Public		16-06-2011
170	**N45**	33.79792	35.87152	890	Hand Dug			125.98	Domestic	Taanayel	Taanayel convent		14-06-2011
171	**N46**	33.9843	36.13661	1053	Borehole				drinking & domestic	Majdaloun	Public		16-06-2011
172	**N47**	34.00343	36.24313	1352	Borehole				drinking & domestic	Baalback	Bekaa Water Authority	Aassayra 12	16-06-2011
173	**N48**	34.01	36.24805	1377	Borehole				drinking & domestic	Baalback	Bekaa Water Authority	Aassayra 10	18-06-2011
174	**N49**	34.03801	36.15191	1014	Borehole		90		Irrigation	Iaat	Ashraf El Zein		18-06-2011
175	**N50**	34.02128	36.1361	1020	Borehole					Haouch Tall Safiye	Jawhary		18-06-2011
176	**N51**	34.01646	36.1293	1017	Borehole					Haouch Tall Safiye			18-06-2011
177	**N52**	34.011382	36.12266	1012	Borehole					Haouch Barada	Sleiman Zaiter		18-06-2011
178	**N53**	34.01229	36.11951	1014	Borehole		80		Irrigation	Haouch Barada	Mohamad Tallaa		18-06-2011
179	**N54**	34.02871	36.14881	1023	Borehole					Iaat			18-06-2011
180	**N55**	34.01272	36.11949	1011	Hand Dug		12	118.11	Irrigation	Haouch Barada	Mohamad Tallaa		18-06-2011
181	**N56**	33.99402	36.04036	1111	Borehole		120		Yard irrigation	Hadath	Mohamad harfoush	Nabi Rashad	19-06-2011
182	**N57**	33.98757	36.05082	1054	Borehole				Irrigation	Hadath	Colonel Issam hamieh	Nabi Rashad	19-06-2011
183	**N58**	34.02154	36.11842	1010	Borehole					Haouch el Dahab	Shehady el radi		20-06-2011
184	**N59**	34.02971	36.10871	1002	Hand Dug		10		Domestic	AL Olleik	Mostapha Kanaan		20-06-2011
185	**N60**	34.02575	36.11603	1007	Borehole	2003	60		Domestic	Haouch el Dahab	Mohamad Abalieh		20-06-2011
186	**N61**	34.01719	36.06597	1035	Borehole	1992	150		Irrigation	kfardane	Ministry of Agriculture	Agriculture center	20-06-2011
187	**N62**	34.01639	36.06952	1028	Borehole	1965	120		Irrigation	kfardane	Ministry of Agriculture	Agriculture center	20-06-2011
188	**N63**	33.96973	36.03553	1072	Borehole		55		Irrigation	Chmistar	Hassan Zein		20-06-2011
189	**N64**	34.02709	36.10646	1012	Borehole		50		Domestic	AL Olleik	Mohamad Mahmoud Kanaan		20-06-2011
190	**N65**	33.96658	36.04152	1059	Borehole					Chmistar			20-06-2011
191	**N66**	33.92199	36.13893	1130	Borehole		137			Hortaala	Mohamad Ali El Masri (Abu Abdallah)		21-06-2011
192	**N67**	33.88982	36.05475	964	Borehole					Seriine Tahta	Ali Sobh Shuman		21-06-2011
193	**N68**	33.86069	36.02434	947	Borehole	1982	68		Domestic & Yard irrigation	Ali en Nahri	Ibrahim Moukahhal		22-06-2011
194	**N69**	33.88842	36.06739	986	Borehole		70		Irrigation	Seriine Tahta	Khoder Hazimeh		21-06-2011
195	**N70**	33.88664	36.0717	993	Borehole					Seriine Tahta			21-06-2011
196	**N71**	33.90422	36.05871	996	Borehole		130			Seriine Tahta	Ali Hellani		22-06-2011
197	**N72**	33.83806	35.92103	908	Borehole				drinking & domestic	Haouch el Oumara	Bekaa Water Authority		23-06-2011
198	**N73**	33.81464	35.86418	913	Hand Dug		12	59.05	Domestic	Taalabeya	Miriib Zaiter		23-06-2011
199	**N74**	33.85131	35.95704	914	Borehole				Irrigation	Fourzol	Abdallah Daher		23-06-2011
200	**N75**	33.85562	35.89754	1096	Borehole		200		Domestic & Yard irrigation	Zahle	Georges Jakhoury		25-06-2011
201	**N76**	33.85519	35.89996	1089	Borehole				Domestic	Zahle	Foyer Mar Youssef		25-06-2011
202	**N77**	33.96054	36.01518	1179	Borehole		480		drinking & domestic	Chmistar	Public		25-06-2011
203	**N78**	33.96813	36.00736	1186	Borehole				drinking & domestic	Chmistar	Public		25-06-2011

Wells that were not measured in this survey
Wells that were measured in this and last surveys
New wells
Wells having a Well ID that does not belong to the actual grid it is in
Values corrected from last survey

Notes: * Spring were deleted
* Wells that did not have water level in the last survey nor in this survey were deleted

161	**N36**	84.7	1018.3	19.1	0.14	10	19.5										Neogene
162	**N37**	17.73	987.27	23.6	0.03	9.17	22.7								12		Neogene
163	**N38**	9.66	892.34														Quaternary
164	**N39**	1.42	880.58	17.5	0.37	9.66	17.1										Quaternary
165	**N40**	1.6	871.4	17.3	0.6	9.2	16.8										Quaternary
166	**N41**	1.23	871.77	20.3	0.47	9.27	18.6										Quaternary
167	**N42**	23.1	968.9				20.8								12		Quaternary
168	**N43**	12.85	967.15				20.1								10		Quaternary
169	**N44**	62.35	1047.65	18.8	0.19	10	17.7								12		Neogene
170	**N45**	2.22	887.78				21.5										Quaternary
171	**N46**	57.53	995.47				28										Neogene
172	**N47**	79.71	1272.29														Cenomanian
173	**N48**	106.61	1270.39														Cenomanian
174	**N49**	20.39	993.61											90	12	20-90	Quaternary
175	**N50**	3.5	1016.5				27								10		Quaternary
176	**N51**	14.75	1002.25												12		Quaternary
177	**N52**	14.87	997.13														Quaternary
178	**N53**	13.86	1000.14												14		Quaternary
179	**N54**	13.43	1009.57				27								12		Quaternary
180	**N55**	8.26	1002.74				27										Quaternary
181	**N56**	20.54	1090.46	23.6	0.4	7.57	25								10		Neogene
182	**N57**	12.41	1041.59												12		Neogene
183	**N58**	5.38	1004.62												13		Quaternary
184	**N59**	2.12	999.88				25										Quaternary
185	**N60**	3.12	1003.88												12		Quaternary
186	**N61**	38.3	996.7														Quaternary
187	**N62**	29.91	998.09														Quaternary
188	**N63**	2.93	1069.07												12		Neogene
189	**N64**	16.52	995.48				28										Quaternary
190	**N65**	42.8	1016.2												12		Eocene
191	**N66**	74.33	1055.67				25								14		Neogene
192	**N67**	14.57	949.43														Neogene
193	**N68**	25.94	921.06												12		Neogene
194	**N69**	26.54	959.46												12		Neogene
195	**N70**	30.53	962.47				32								13		Neogene
196	**N71**	21.07	974.93				34								10		Neogene
197	**N72**	12.12	895.88				31								12		Quaternary
198	**N73**	4.64	908.36				31										Quaternary
199	**N74**	13.53	900.47												14		Quaternary
200	**N75**	61.75	1034.25				28								14		Neogene
201	**N76**	18.78	1070.22				28								12		Neogene
202	**N77**	347.95	830.9				26										Chekkka
203	**N78**	331.76	854.24				27										Cenomanian

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Notes: * Spring v
* Wells th

161	**N36**	Eocene			50 hp		4	
162	**N37**	Neogene	Submersible pumps 1" and 1/2"					
163	**N38**	Quaternary - Neogene			180 hp	12	6	
164	**N39**	Quaternary					3	
165	**N40**	Quaternary	centrifugal pump 3/4"					
166	**N41**	Quaternary	centrifugal pump 3/4"					
167	**N42**	Quaternary - Neogene					3	
168	**N43**	Quaternary - Neogene	submersible pump 1 1/2"					
169	**N44**	Eocene	submersible pump 2"					
170	**N45**	Quaternary	submersible pump 1 1/2" and centrifugical pump 2"					
171	**N46**	Neogene	submersible pump 2"					
172	**N47**	Cenomanian						
173	**N48**	Cenomanian					6	
174	**N49**	Quaternary - Neogene	submersible pump 1"			18		
175	**N50**	Quaternary						
176	**N51**	Quaternary	submersible pump 2"					
177	**N52**	Quaternary	submersible pump 2"					
178	**N53**	Quaternary	submersible pump 1 1/2"			10		
179	**N54**	Quaternary						
180	**N55**	Quaternary	submersible pump 2"					
181	**N56**	Neogene/ or Eocene	submersible pump 1 1/4"					
182	**N57**	Neogene	submersible pump 1 1/4"					
183	**N58**	Quaternary						Unequipped
184	**N59**	Quaternary						
185	**N60**	Quaternary - Neogene	submersible pump 1"			2		
186	**N61**	Quaternary - Neogene	submersible pump 2"				2	
187	**N62**	Quaternary - Neogene						Unequipped
188	**N63**	Eocene	submersible pump 1"					
189	**N64**	Quaternary - Neogene	submersible pump 3"					
190	**N65**	Eocene						Unequipped
191	**N66**	Eocene						Unequipped
192	**N67**	Neogene						Unequipped
193	**N68**	Neogene	submersible pump 1 1/4"					
194	**N69**	Neogene					3	
195	**N70**	Neogene						Unequipped
196	**N71**	Neogene						Unequipped
197	**N72**	Quaternary - Neogene	submersible pump 5"					
198	**N73**	Quaternary	submersible pump 3 3/4"					
199	**N74**	Quaternary - Neogene	submersible pump 2"					
200	**N75**	Neogene	submersible pump 1 1/4"					
201	**N76**	Neogene/ or Eocene	submersible pump 1 1/2"					
202	**N77**	Cenomanian	submersible pump 3"					
203	**N78**	Cenomanian	submersible pump 4"					

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APPENDIX C

Recharge Analysis from Precipitation

Area/Precipitation Summary Table for East

Geologic Unit	Precipitation Range	Area (KM^2)	Precipitation Input/Area (MCM/Yr.)
Carbonate Aquifer Summary			
Bc	400 to 600 mm	2.17	1.09
	600 to 800 mm	3.21	2.25
Bp	400 to 600 mm	1.22	0.61
	800 to 1000 mm	0.28	0.25
C1	400 to 600 mm	6.74	3.37
	600 to 800 mm	4.99	3.49
C2	400 to 600 mm	9.86	4.93
	600 to 800 mm	11.43	8.00
C3	600 to 800 mm	3.07	2.15
C4 & C5	400 to 600 mm	228.13	114.07
	600 to 800 mm	132.69	92.88
C6	400 to 600 mm	24.55	12.28
	600 to 800 mm	13.03	9.12
	800 to 1000 mm	0.02	0.02
	1000 to 1200 mm	0.39	0.43
E	400 to 600 mm	21.55	10.78
	600 to 800 mm	51.37	35.96
	800 to 1000 mm	27.42	24.68
	1000 to 1200 mm	16.27	17.90
G	400 to 600 mm	0.38	0.19
J4 - J7	400 to 600 mm	28.85	14.43
	600 to 800 mm	15.95	11.17
Total Precipitation for Carbonate Aquifers			**370.02**
20% Recharge (MCM/Yr.)			***74***
Quaternary and Neogene Aquifer Summary			
NCG	200 to 400 mm	1.1	0.33
	400 to 600 mm	94.26	47.13
	600 to 800 mm	2.19	1.53
	800 to 1000 mm	1.32	1.19
NL	400 to 600 mm	3.85	1.93
	800 to 1000 mm	0.02	0.02
Q	200 to 400 mm	0.13	0.04
	400 to 600 mm	138.48	69.24
	600 to 800 mm	51.09	35.76
Total Precipitation for Quaternary/Neogene Aquifers			**157.17**
10% Recharge (MCM/Yr.)			***16***
Total Area (KM^2)		***896***	
Total Recharge (MGM/Yr.)		***90***	

Area/Precipitation Summary Table for West

Geologic Unit	Precipitation Range	Area (KM^2)	Precipitation Input/Area (MCM/Yr.)
Carbonate Aquifer Summary			
C1	1000 to 1200 mm	1.07	1.18
	1200 to 1400 mm	0.96	1.25
	1400 to 1600 mm	1.9	2.85
C2	800 to 1000 mm	1.72	1.55
	1000 to 1200 mm	4.48	4.93
	1200 to 1400 mm	5.54	7.20
	1400 to 1600 mm	1.41	2.12
C3	800 to 1000 mm	2.99	2.69
	1000 to 1200 mm	6.69	7.36
	1200 to 1400 mm	4.13	5.37
	1400 to 1600 mm	3.14	4.71
	1600 to 1800 mm	0.01	0.02
C4 & C5	400 to 600 mm	0.94	0.47
	600 to 800 mm	18.19	12.73
	800 to 1000 mm	58.51	52.66
	1000 to 1200 mm	56.37	62.01
	1200 to 1400 mm	38.4	49.92
	1400 to 1600 mm	39.75	59.63
	1600 to 1800 mm	16.06	27.30
C6	400 to 600 mm	0.01	0.01
	600 to 800 mm	9.92	6.94
	800 to 1000 mm	14.17	12.75
	1000 to 1200 mm	5.68	6.25
E	400 to 600 mm	1.48	0.74
	600 to 800 mm	7.54	5.28
	800 to 1000 mm	24.3	21.87
	1000 to 1200 mm	6.08	6.69
J4 - J7	800 to 1000 mm	10.32	9.29
	1000 to 1200 mm	31.83	35.01
	1200 to 1400 mm	37.49	48.74
	1400 to 1600 mm	19.45	29.18
	1600 to 1800 mm	3.9	6.63
	Total Precipitation for Carbonate Aquifers		***495.30***
	20% Recharge (MCM/Yr.)		***99***
Quaternary and Neogene Aquifer Summary			
NCG	400 to 600 mm	15.17	7.59
	600 to 800 mm	17.87	12.51
	800 to 1000 mm	10.56	9.50
	1000 to 1200 mm	3.5	3.85
NL	400 to 600 mm	2.4	1.20
	600 to 800 mm	15.47	10.83
	800 to 1000 mm	16.14	14.53
	1000 to 1200 mm	4.6	5.06

Geologic Unit	Precipitation Range	Area (KM^2)	Precipitation Input/Area (MCM/Yr.)
Q	400 to 600 mm	60.54	30.27
	600 to 800 mm	124.6	87.22
	800 to 1000 mm	33.07	29.76
Total Precipitation for Quaternary/Neogene Aquifers			***212.32***
10% Recharge (MCM/Yr.)			***21***
Total Area (KM^2)		***738.35***	
Total Recharge (MGM/Yr.)		***120***	

APPENDIX D

GIS Layers

APPENDIX E

Technical Glossary

APPENDIX E – TECHNICAL GLOSSARY

1. *AQUIFER:* An *aquifer* is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

2. *AQUIFER TEST* is a three-part test conducted to obtain background, pumping, and recovery data from a pumping well and observation wells in order to determine aquifer characteristics and assess potential well interference.

3. *CONSTANT RATE TEST* is a pumping test conducted on a well so that discharge remains relatively constant with time.

4. *DRAWDOWN* [L] is the decline in the water level in a well measured from the static water level during pumping (it is the difference between the static water level prior to pumping and the pumping water level during pumping).

5. *HYDRAULIC GRADIENT* [dimensionless] is the change in static head per unit of distance in a given direction.

6. *INTERFERENCE* [L] is the amount of drawdown in a non-pumping or pumping well resulting from nearby well pumpage.

7. *INTERFERENCE TEST* is a pumping test conducted to determine the interference effects on one or more selected observation wells or pumping wells, resulting from pumping a subject well.

8. *OBSERVATION WELL* is any well, which is not the pumping well, utilized to obtain water level measurements during aquifer or interference testing.

9. *POTENTIOMETRIC SURFACE* is a surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells.

10. *SPECIFIC CAPACITY* [L^2T^{-1}] of a well is the discharge or pumping rate of the well divided by the drawdown of the water level in the well. Specific Capacity varies slowly with time and the time at which specific capacity is measured should be noted.

11. *STATIC WATER LEVEL* [L] is the water level in a well at rest either before or after pumping when all pumping effects on the aquifer have dissipated and the well is in equilibrium with atmospheric pressure.

12. *TRANSMISSIVITY* [L^2T^{-1}] is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

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