USAID | LEBANON
FROM THE AMERICAN PEOPLE

LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

GROUNDWATER MODELING WITHIN THE UPPER LITANI BASIN REPORT

OCTOBER 2013

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.

LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

GROUNDWATER MODELING WITHIN THE UPPER LITANI BASIN

Contract No.: EPP-I-00-04-00024-00 order no 7.

OCTOBER 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AUB	American University of Beirut
CS	Council for the South
DAI	Development Alternatives, Inc.
DEM	Digital Elevation Model
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

EXECUTIVE SUMMARY

Context and study area

The Upper Litani River Basin covers the central and south Bekaa Valley, a 60km-long by 20-km wide valley which extends from Baalbeck in the north (at altitude 1000m) to the Qaraoun Lake in the south (altitude 800m). It lies between Mount Lebanon to the west and the anti-Lebanon range to the east and is drained by the Litani River and its tributaries (**Figure 1**).

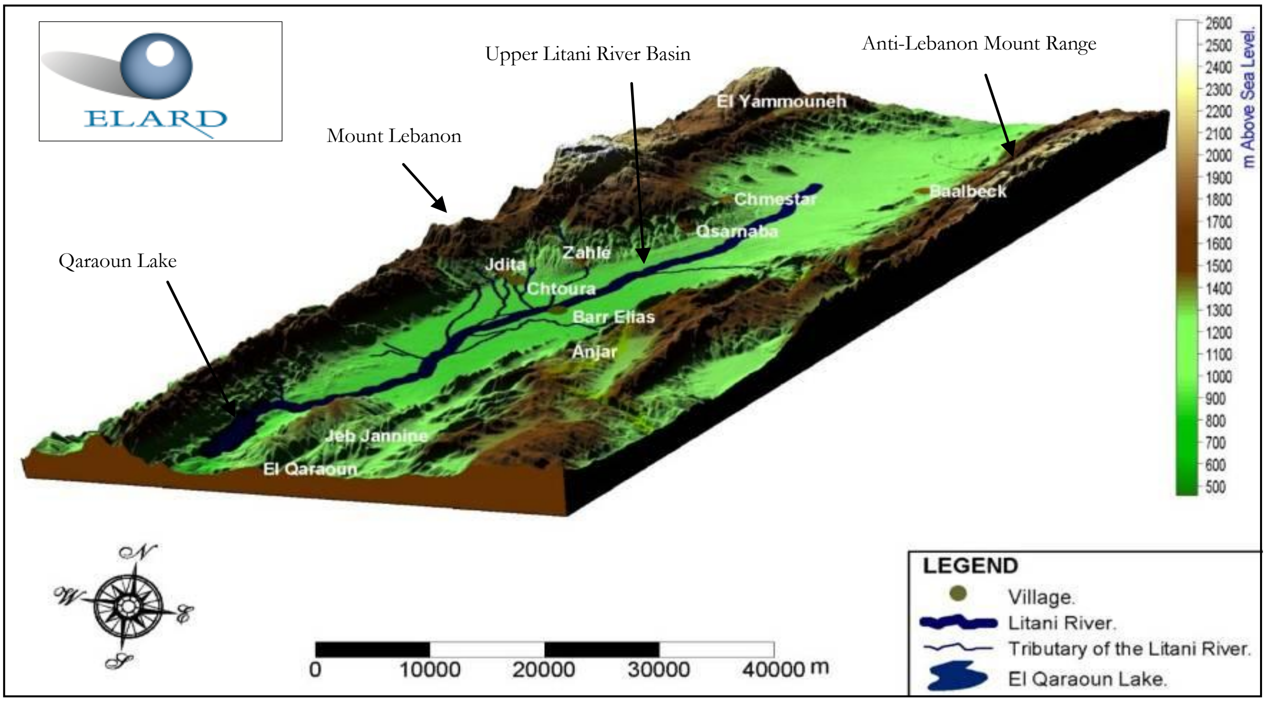


Figure 1 Study Area

It is an agricultural region with close to 400,000 inhabitants. Most surface waters have been harnessed since the 1960s for hydropower (Qaraoun Lake) or direct irrigation (from springs and rivers). Over the past 50 years, irrigation has expended significantly, from a few thousand hectares to over 40,000 ha today of partially or fully irrigated croplands. This was chiefly achieved by farmers drilling private (and often unlicensed) wells and increasingly tapping into groundwater resources. Very limited groundwater monitoring occurred during this time, but interviews and limited measurements show that groundwater tables and spring flows have significantly lowered as a consequence.

Many small and mid-size industries also use groundwater in the basin area, the majority being agro-food industries (such as dairy factories). Domestic water supply is provided by the Bekaa Water Establishment, which operates about 100 public wells.

The USAID-funded Litani River Basin Management Support (LRBMS) program recently installed fifteen observation wells for groundwater monitoring (quality and level) to be operated by the Litani River Authority (LRA). In parallel, the LRBMS program also developed a groundwater model to:

- Better understand the characteristics of the various aquifers;
- Evaluate flow interactions between these aquifers and with surface water; and
- Consider future development scenarios and assess their consequences in terms of groundwater levels and availability.

Hydrogeology (study of groundwater)

The study area contains five main geological underground layers which all contain extractable groundwater. These layers are also called aquifers. Going down from the surface these layers correspond to older time periods (**Figure 2 and 3**):

- The Quaternary aquifer is a layer of unconsolidated sediments (fine-grained silts and clays with sand and gravel), which have mainly been eroded from the mountains and deposited by the rivers in the center of the valley over the last 2.5 million years. These deposits cover the center of the Bekaa valley and constitute most of the agricultural soils.
- The Neogene (or Upper Miocene) aquifer lies below the Quaternary and consists of older alluvial deposits and conglomerates (deposited over 20 Million years). This layer also surfaces (outcrops) on both sides of the valley: at the foot of Mount Sannine up to Zahle, and from Baalbeck to Rayak.
- The Eocene aquifer is under, and separated from the Neogene and Quaternary aquifers by a low transmissivity layer, the Upper (later) Eocene Marl. The Eocene is made up of older sediments (30 to 50 million years ago) which have been compressed into karstic limestone; it surfaces mainly around Joub Jenine and in thin bands (less than 1 km in width) on the east (north of Anjar) and west (north of Zahle) sides of the valley.
- The Cretaceous aquifer is also made of karstic limestone, but even older (65 to 145 million years ago); it covers all the eastern flank of the Anti-Lebanon range, and the north-western flank of Mount Lebanon (Mount Sannine).
- The Jurassic aquifer (145 to 200 million years old) surfaces on the western flank of Mount Lebanon, from Chtaura to Lake Qaraoun.

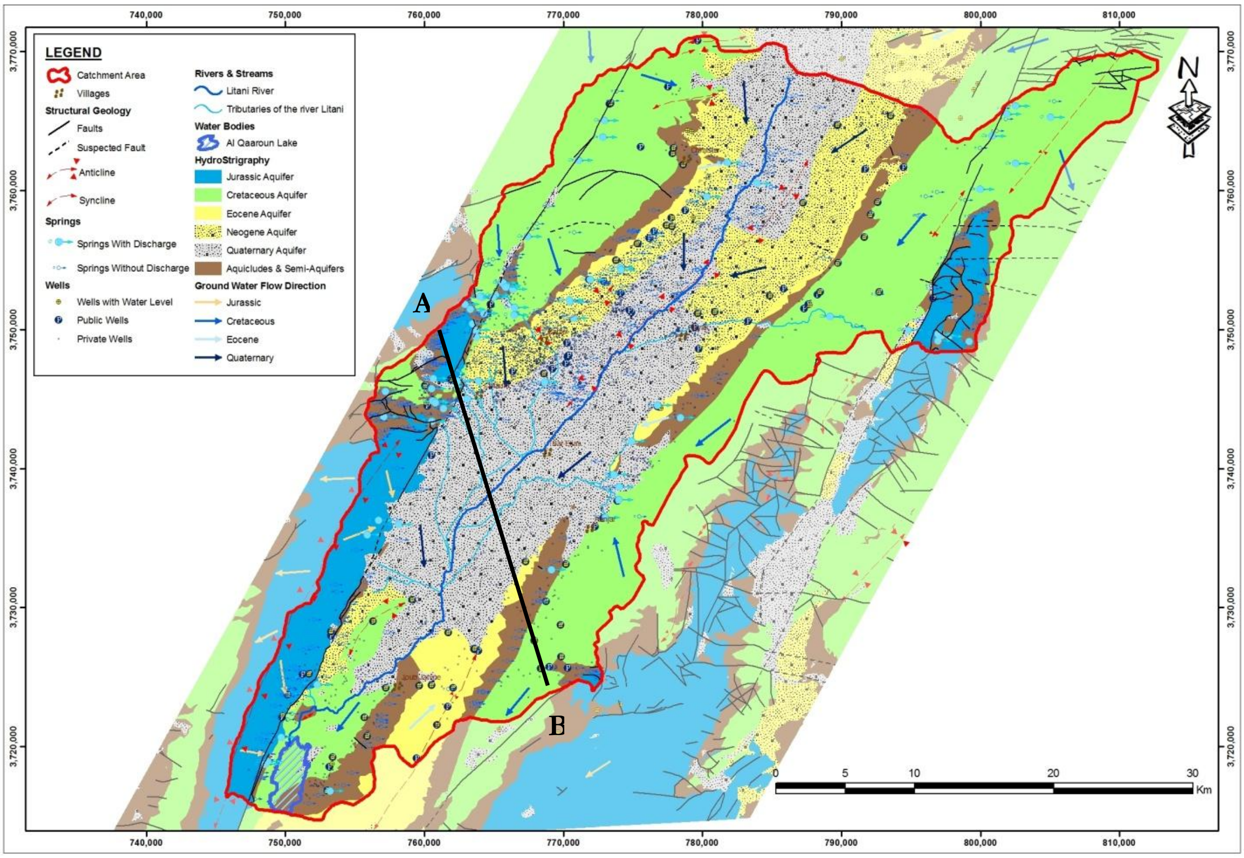


Figure 2 Hydrogeological Map of the Study Area

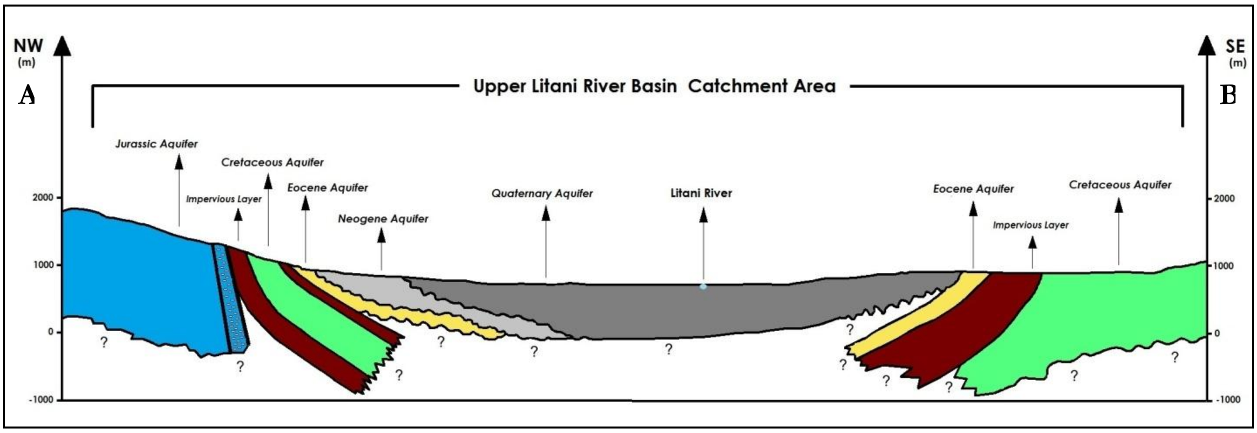


Figure 3 Hydrogeological Cross Sections of the Aquifer Units in the Study Area

Existing data and information

As mentioned earlier, limited information exists as to historical groundwater levels (before significant groundwater abstraction started in the late 1960s), except to say that water levels were at the time reasonably shallow (less than 20m) and at ground surface at places as evidenced from topographic maps that show the presence of extensive wetland areas in the valley and drainage ditches to lower the water table for agricultural use. The Litani River used to originally flow from springs next to

Haouch Barada, which have dried since. The main source of historical hydrogeologic information is the 1970 UNDP Report on Groundwater in Lebanon.

More recent groundwater level and well use information was generated through two field surveys carried out by LRBMS in November 2010 and May/June 2011. Each survey collected water level information from more than 100 wells over the Upper Litani River Basin, in order to:

- Define current water levels after more than 40 years of extraction
- Assess the seasonal fluctuation (annual variation between winter and summer)

Conceptual model

Building a groundwater computer model is a complex endeavor as it is supposed to first represent a 3D volume with different aquifers. Good geological information is needed to know where these aquifers are, how deep they are, where they meet, etc. Good groundwater information is also needed to characterize how much water they can store and the rate of groundwater movement through them.

Secondly, hydrological information is needed to assess how this volume exchanges water with the surface (inflows through seeping from precipitations and rivers, losses through springs and well abstraction).

Based on the level of accurate data for the Cretaceous and Jurassic aquifers, and also on the fact that most (80% or more) of the current groundwater abstraction occurs from the superficial aquifers, the model has been limited to the Quaternary, Neogene, and Eocene aquifers. As more information becomes available, it will be possible to extend the model to the Cretaceous and Jurassic aquifers.

The boundaries of the model are:

- To the north, matching the river basin divide (the crest/line that separates waters flowing to the Litani River to the south from those flowing to the Assi-Orontes River to the north) and considered as a no-flow boundary;
- To the east and west, the foot of the two mountains ranges (boundaries of the valley aquifers), with contributions from the mountains being from both the Jurassic and Cretaceous aquifers; and
- To the south, the northern side of Qaraoun Lake, where the Quaternary, Neogene, and Eocene Aquifers thin out and are underlain by a low permeability layer (called aquiclude) as the two mountain rages converge, thus forming a low-flow boundary.

For each aquifer the conservation equation is:

Inflows - Outflows = DS (variation of storage)

Where inflows and outflows include (**Figure 4**):

- Recharge inflows (precipitations that seep through the ground where the aquifer surfaces);
- Exchanges (inflows or outflows) with the surface streams and between aquifers;
- Springs (outflows as resurgences of groundwater in the valley after seeping through the mountains);

- Withdrawals (outflows) for irrigation, industrial and domestic purposes.

The table and graph below present the average annual outflows and inflows, as known from available data and the water balance estimated for the upper Litani river basin (LRBMS - Dec 2011), and confirmed by the model:

M m3/year	Recharge	Pumping	Springs	Transfers + to GW**	Balance
Quaternary-Eocene	80	-120	0	17 (-7 to Litani river, +24 from lateral aquifers	-21
Cretaceous-Jurassic	140	-30	-130	-24 (laterally to upper aquifers)	- 44
Total	220	-150	-130	-7	-65

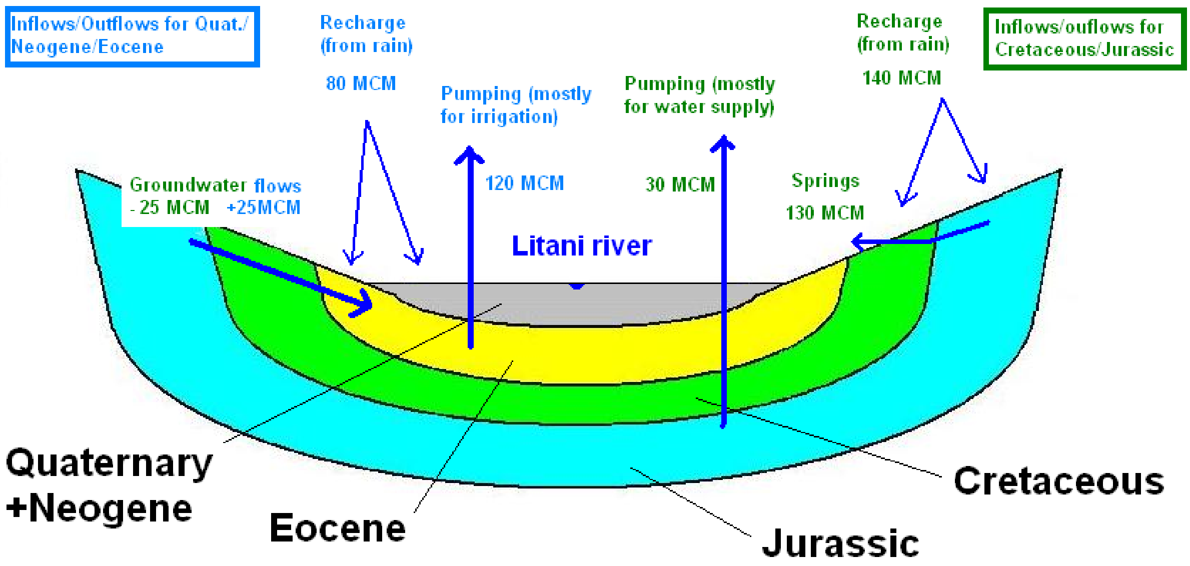


Figure 4 Schematic cross-section of the annual groundwater flows between aquifers of the Upper Litani Basin

Computer model: construction and calibration

The computer model that was used is called GMS (Groundwater Modeling System). The software operates on the MODFLOW code which was developed by the U.S. Geological Survey to simulate the flow of groundwater through aquifers. It is considered worldwide as the de facto standard code for aquifer simulation.

The model of the Upper Litani River Basin was built using geological maps (scale 1/50,000), topographical maps (scale 1/20,000), hydrogeological maps (scale 1/100,000), and cross-sections for the study area. The data were digitized using GIS (Geographic Information System) and merged to produce a scatter point distribution of aquifer thickness and top elevation. The scatter points generated by GIS were utilized to generate a 3D geological model using the GMS software for the study area. The 3D model includes the aquifer boundary and thickness, and was built with a constant grid size equal to 500 by 500 m. This was the best representation for the study area, taking into consideration the limited amount of data, computational capacity, and resolution of the model. A smaller grid would have increased the computational requirements but would have resulted in the same resolution due the lack of available data; while a larger grid size would have decreased the computational requirements to generate the model, but decreased the resolution of the model.

The representation, with limited data, of real life geological aquifers with a mathematical model requires reasonable assumptions. Here the following assumtions were adopted:

- The elevation is constant for each grid cell (500m x 500m). The following assumption does not represent localized hills or valleys;
- Bottom and south interactions are limited, and have here been neglected (these boundaries are considered no-flow);
- Interactions along the east and west boundaries represent the interchange flows between the Jurassic and Cretaceous aquifers and the Eocene, Quaternary and Neogene aquifers (this assumption puts the interchange flows between aquifers all along the sides, while these flows may be concetrated at faults/fracture areas;
- Regarding withdrawals, information is only available regarding the location of public wells and licensed private wells, without their actual withdrawal rates (which have been estimated); on the other hand, thousands of unlicensed private wells also exist, for whom no information exist; information on on irrigated areas was used to locate and estimate the abstraction rates of these.

Calibration is the next and most important step in constructing a computer model of a groundwater system. It is the process of modifying the characteristics that are unknown (such as the porosity of the aquifers) so that the model produces output data (such as water levels) that are very close to the data collected in the field. If the model, fed with input data from the field, provides output data similar to field measurements/data, the model is well calibrated, that is a faithful computer copy of reality. It can then be used to extrapolate.

Two calibrations were carried out:

- First a steady state calibration, adjusting aquifer parameters to get model results to match the data from the November 2010 field survey; and
- Second a transient calibration, where these parameters were fine-tuned using the changes in groundwater levels between the November 2010 and the April/May 2011 field survey.

The final results in both cases were considered satisfactory, with differences between observed and calculated groundwater levels being within 10 m, and often within 5 m.

A final verification was made by using the limited data available from 1970 to represent the overall evolution of groundwater levels over the past 40 years, and proved satisfactory as well (**Figure 5**).

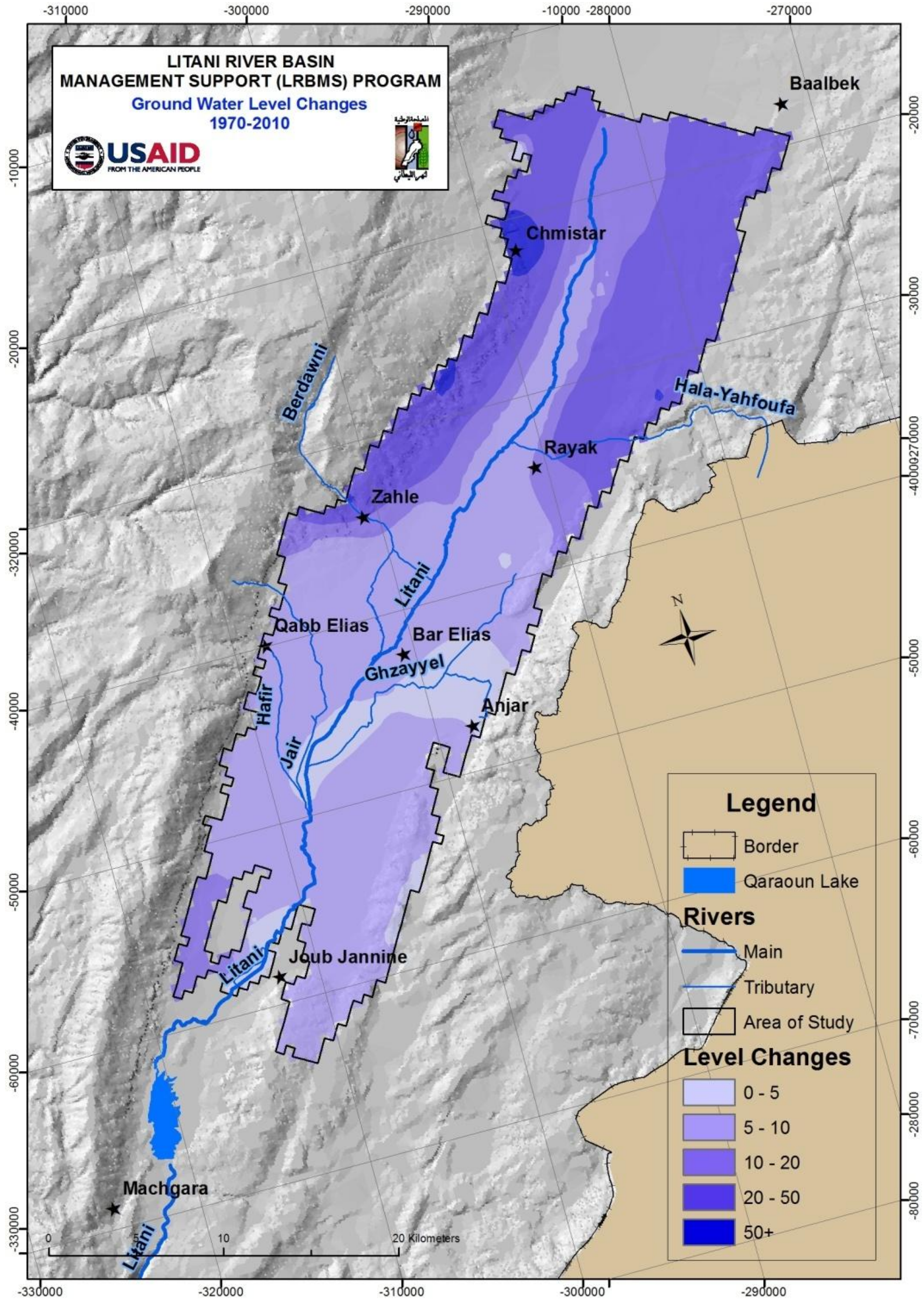


Figure 5 Changes in Water Level between 1970 and 2010

Future groundwater evolutions

The calibrated model was then used to envision future groundwater levels over a 20 year-horizon. While the overall geography and geology of the model would not change, the model parameters that were varied included:

- Groundwater abstraction, for which two scenarios were modeled (**Table 1**):
    - A "Business as usual" 30% increase (1.5% per year), which would continue the current expansion trend; and

    - A reduced 10% increase (0.5% per year), resulting from better groundwater management, increasing pumping costs, better irrigation practices, decreasing land availability, or a combination of these;
- Recharge, for which two scenarios were modeled:
    - No change with precipitation and infiltration remaining the same; and
    - A somewhat extreme 20% decrease (0.5% per year), reflecting a quite pessimistic impact of climate change.

Four scenarios (1 to 4) were thus chosen, 1 being the most optimistic, 4 being the most pessimistic, and 2 being the most probable (not much change in recharge, and significantly increased abstraction).

Table 1 Different Scenario Used

Groundwater abstraction / Recharge	**+10%**	**+30%**
0	1	2
-20%	3	4

The modeled results show that 2030 water levels will be down another 5m to 25m, with the maximum drawdown in the northeast and northwest parts of the study area (Chmistar, Ferzol and Kfar Dane in the east; Britel in the west). The minimum drawdown will be in the southern part of the study area with a minimum drawdown of 5m (**Figure 6** to **Figure 14**).

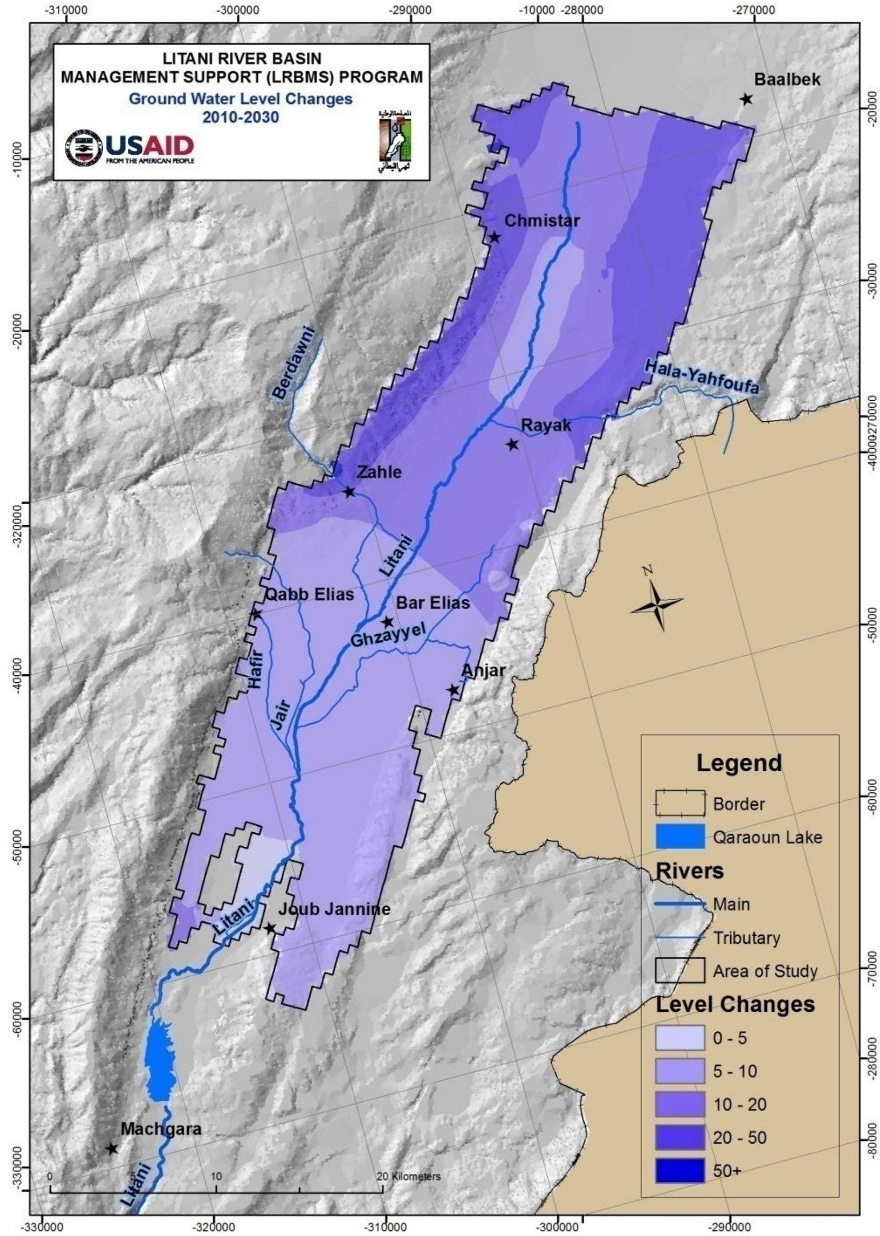


Figure 6 Change in Water Level between 2010 and 2030 for Scenario 2 (most probable)

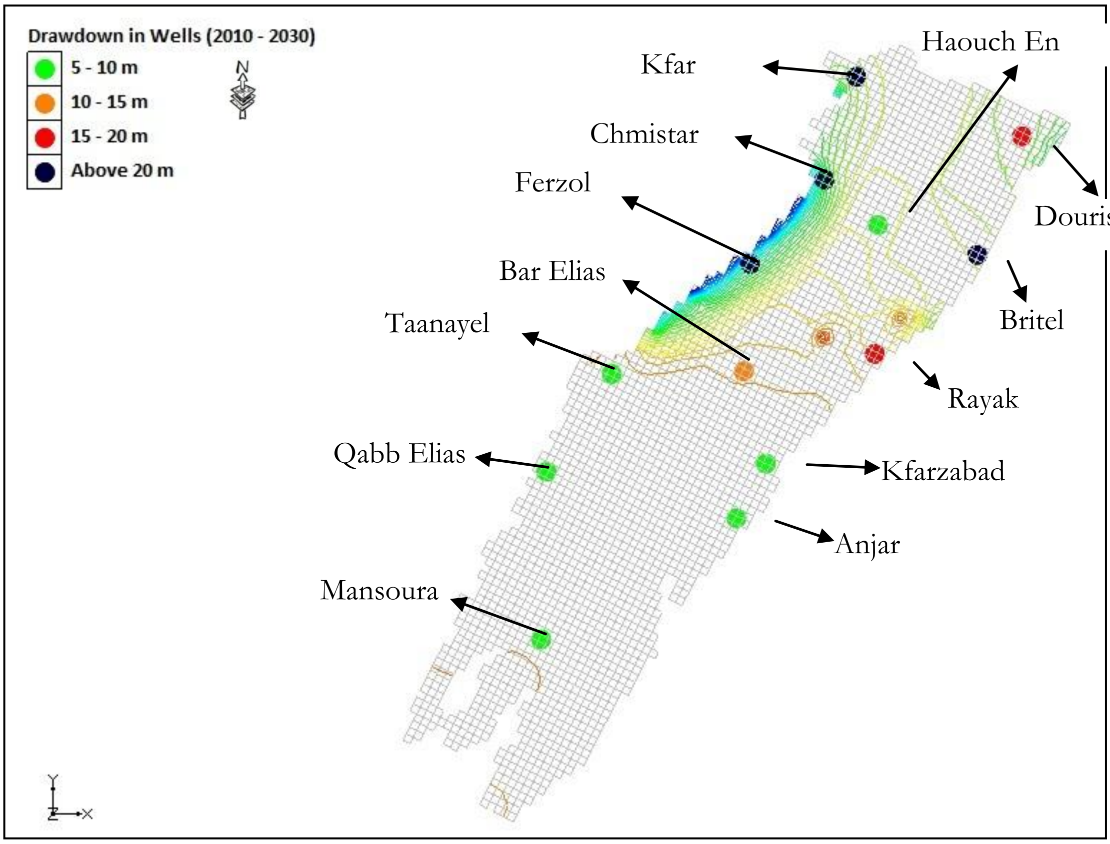


Figure 7 **Minimum Drawdown in Observation Points 2010-2030 (scenario 1)**

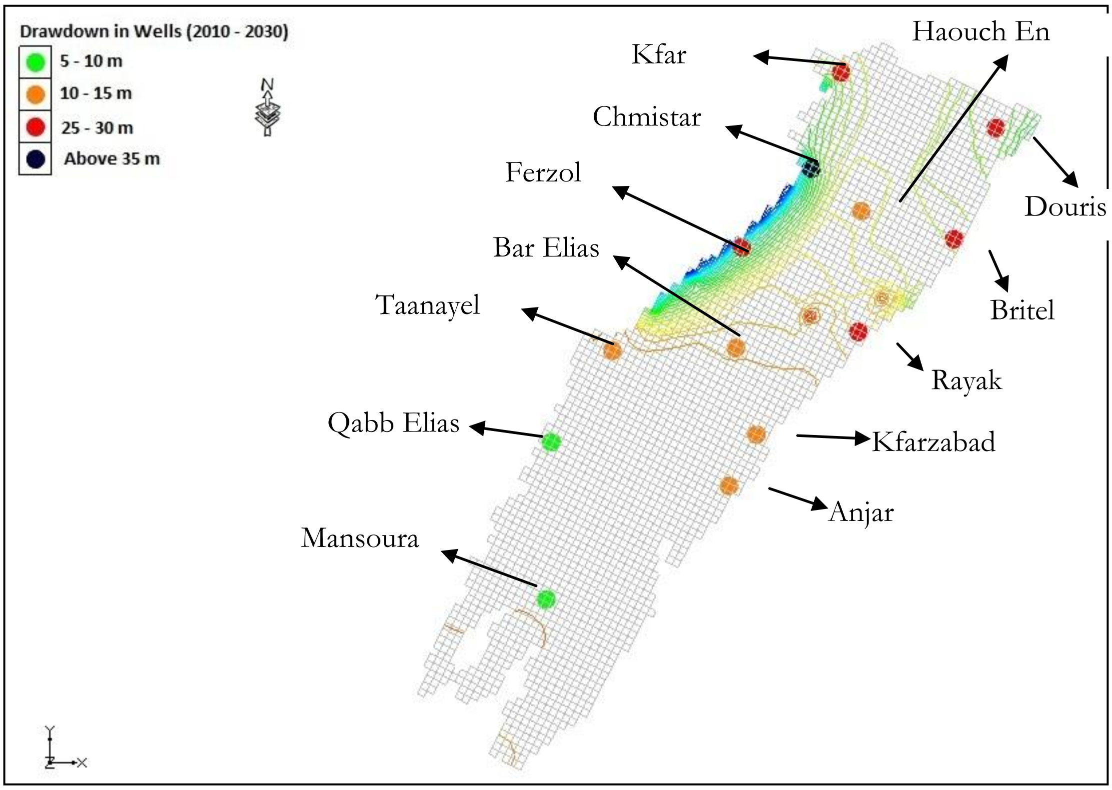


Figure 8 **Maximum Drawdown in Observation Points 2010-2030 (scenario 4)**

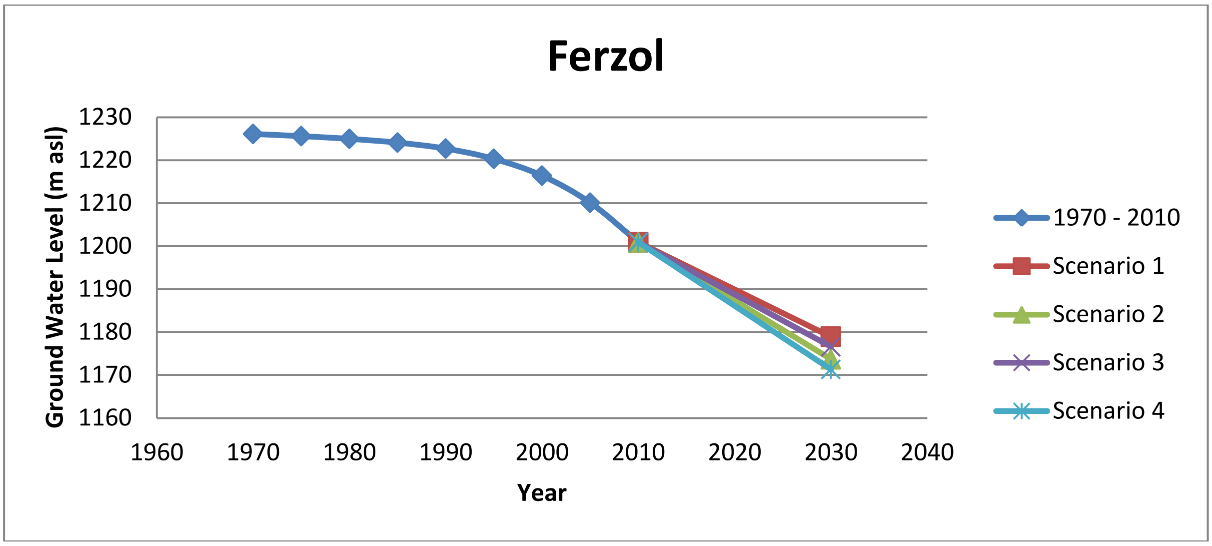


Figure 9 **Historical and Projected Drawdown for Observation Ferzol**

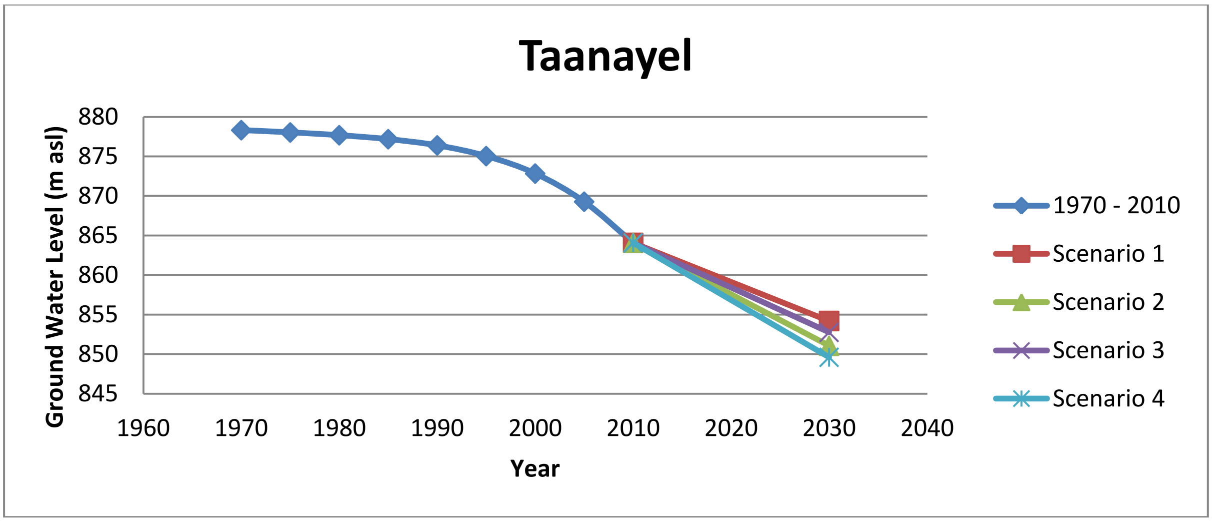


Figure 10 **Historical and Projected Drawdown for Observation Taanayel**

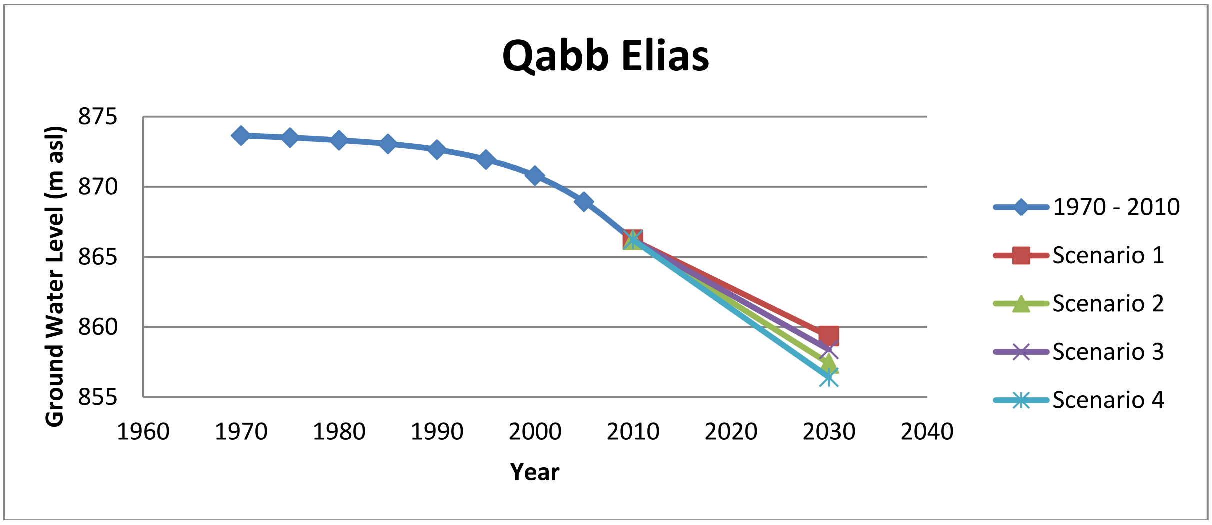


Figure 11 **Historical and Projected Drawdown for Observation Qabb Elias**

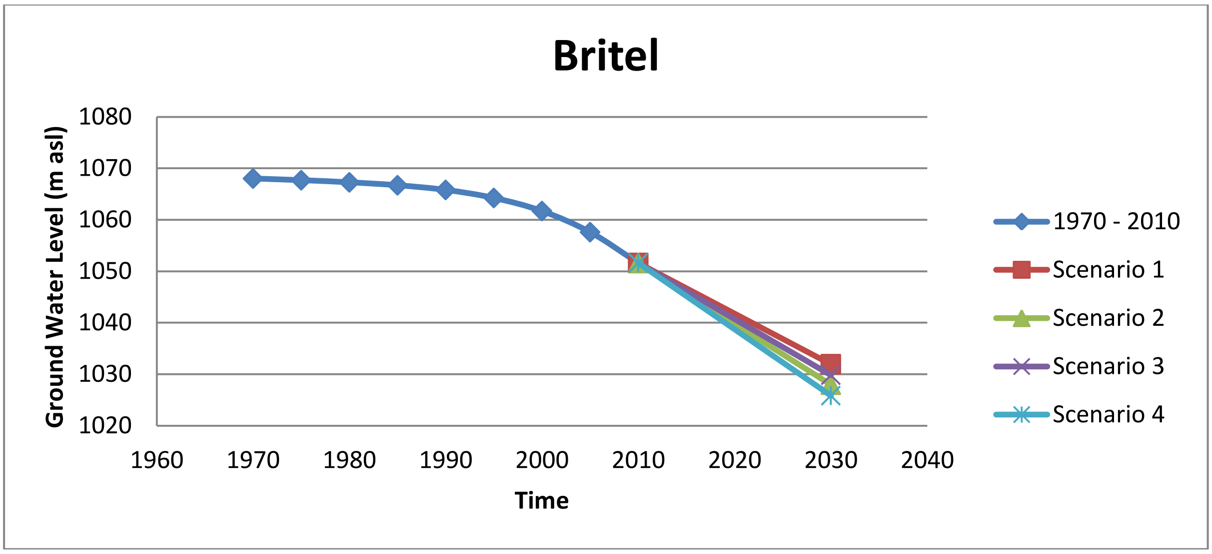


Figure 12 Historical and Projected Drawdown for Observation Baaleck

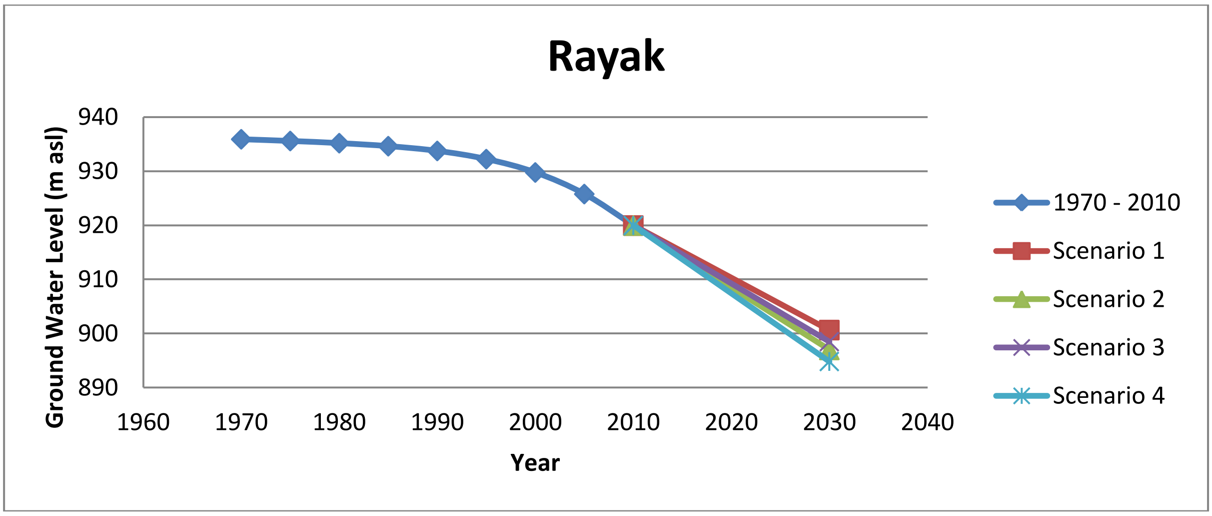


Figure 13 Historical and Projected Drawdown for Observation Rayak

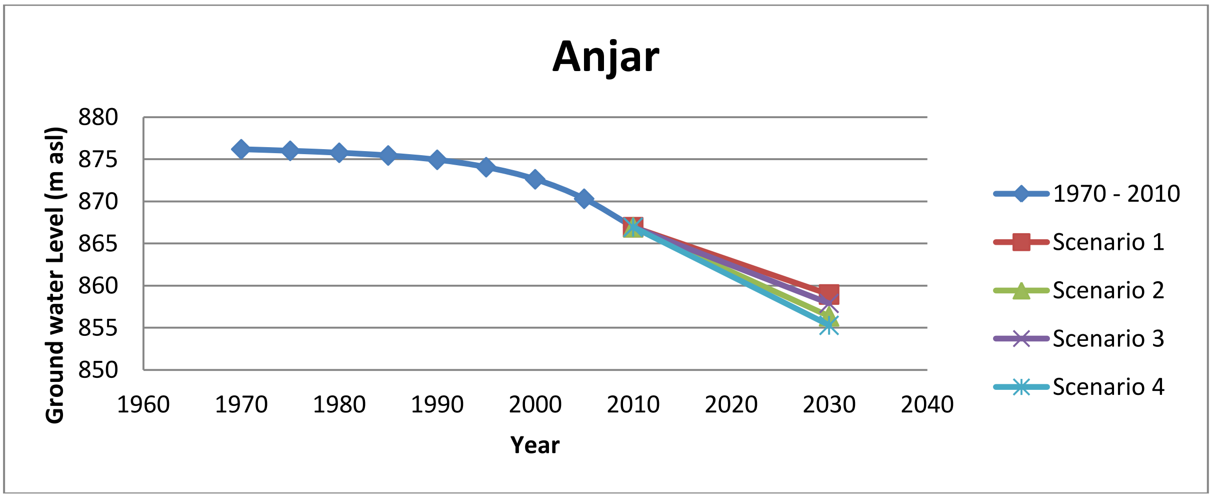


Figure 14 Historical and Projected Drawdown for Observation Anjar

Conclusion and Recommendations

The model developed here is a first attempt at modeling groundwater in the Upper Litani River Basin. Due to the limited amount of available data, some assumptions were made and the model was limited to the 3 topmost aquifers (Quaternary, Neogene and Eocene), with a resolution of 1 by 1 km grid size. The model is well suited to be used for assisting in taking major strategic decisions; however it should be revisited and refined for a better accuracy required for it to be used in detailed planning and management of the water resources of the Upper Litani River Basin. This would certainly require having a better grasp on the monitoring of its resources with respect to both recharge and discharge for the groundwater and surface water systems. This would also necessitate the improvement or establishment of a broader monitoring network that will help in better assessing its resources. This monitoring system should include but not limited to: spring discharge, groundwater level, surface water flow and quality, water extraction (or control the groundwater and surface water), and meteorological monitoring.

As part of the LRBMS program, IRG has initiated the establishment/improvement of this set of monitoring networks by installing a limited number of water-monitoring devices in several river gauging stations and groundwater monitoring wells.

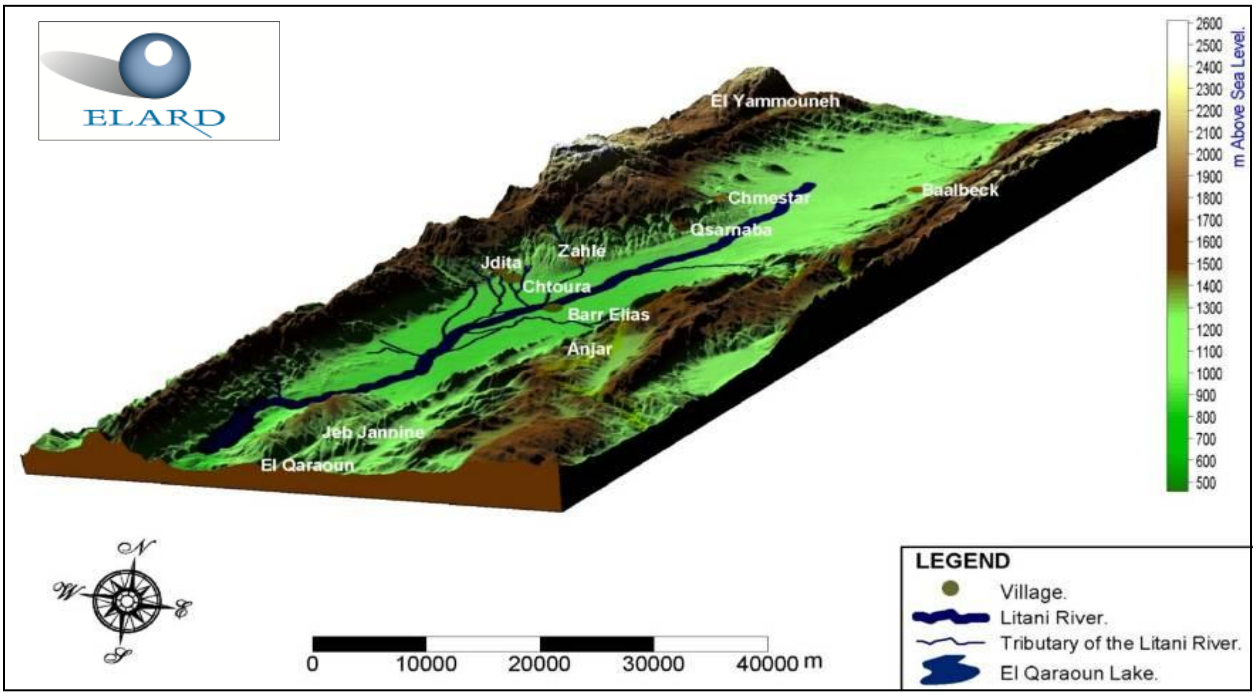
As more data become available, the following are recommendations to enhance the accuracy of the groundwater model:

- Model grid refinement to represent more detailed effects of pumping wells.
- Refine model inputs such as evapotranspiration, recharge, interaction between aquifers, discharge from springs, and river flows.
- Increase the frequency and coverage of groundwater level measurements to improve the quality and resolution of potentiometric groundwater maps.
- Assess the impact of excessive abstraction on the water quality in the basin.
- Build a 4 layer model (including Jurassic and Cretaceous aquifers) when more data becomes available.

ملخص تنفيذي

السياق ومنطقة الدراسة

يغطي الحوض الاعلى لليطاني وسط وجنوب السهل، بطول 60 كلم و20كلم عرض والذي يمتد من بعلبك في الشمال (على ارتفاع 1000 متر) إلى بحيرة القرعون في الجنوب (على ارتفاع 800 متر). وهي تقع بين سلسلة جبال لبنان الغربية والسلسلة الشرقية ويتدفق عبرها نهر الليطاني وروافده (الصورة 1).



منطقة الدراسة

هي منطقة زراعية يعيش فيها حوالي 400000 ساكن. حيث تم تسخير معظم المياه السطحية ومنذ العام 1960 لانتاج الطاقة الكهرمائية (من بحيرة القرعون) والري المباشر (من الينابيع والانهر). خلال ال50 سنة السابقة، تطورت الزراعة بشكل ملحوظ، من الاف قليلة من الهكتارات إلى 40000 هكتار في يومنا هذا من الاراضي المزروعة بشكل جزئي او كامل. وقد تحقق هذا بصورة رئيسية بمساعدة المزارعين وحفر الآبار الخاصة (وغالبا ما تكون هذه الآبار غير مرخصة) كذلك اصاء مدى الاستفادة من موارد المياه الجوفية التي هي على نحو متزايد. تم رصد المياه الجوفية بشكل محدود جدا خلال هذا الوقت، ولكن المقابلات والقياسات المحدودة بينت أن مناسيب المياه الجوفية وتدفقات الينابيع إخفضت بشكل كبير نتيجة لذلك.

إن الكثير من المصانع الكبيرة والمتوسطة تستخدم ايضاً المياه الجوفية في منطقة الحوض، ولكن الغالبية هي صناعات الاغذية الزراعية (مثل صناعات الالبان والاجبان). إن مياه الاستخدام المنزلي تزودة من قبل مؤسسة مياه البقاع، والتي تدير اكثر من 100 بئر عام.

قام مشروع ال LRBMSالممول من قبل ال USAID بحفر وتثبيت 15 بئر مراقبة للمياه الجوفية (لقياس بعض العناصر النوعية ومستوى المياه) على ان يتم تشغيلها من قبل المصلحة الوطنية لنهر الليطاني. بالتوازي، قام ال LRBMS بتطوير موديل للمياه الجوفية من اجل:

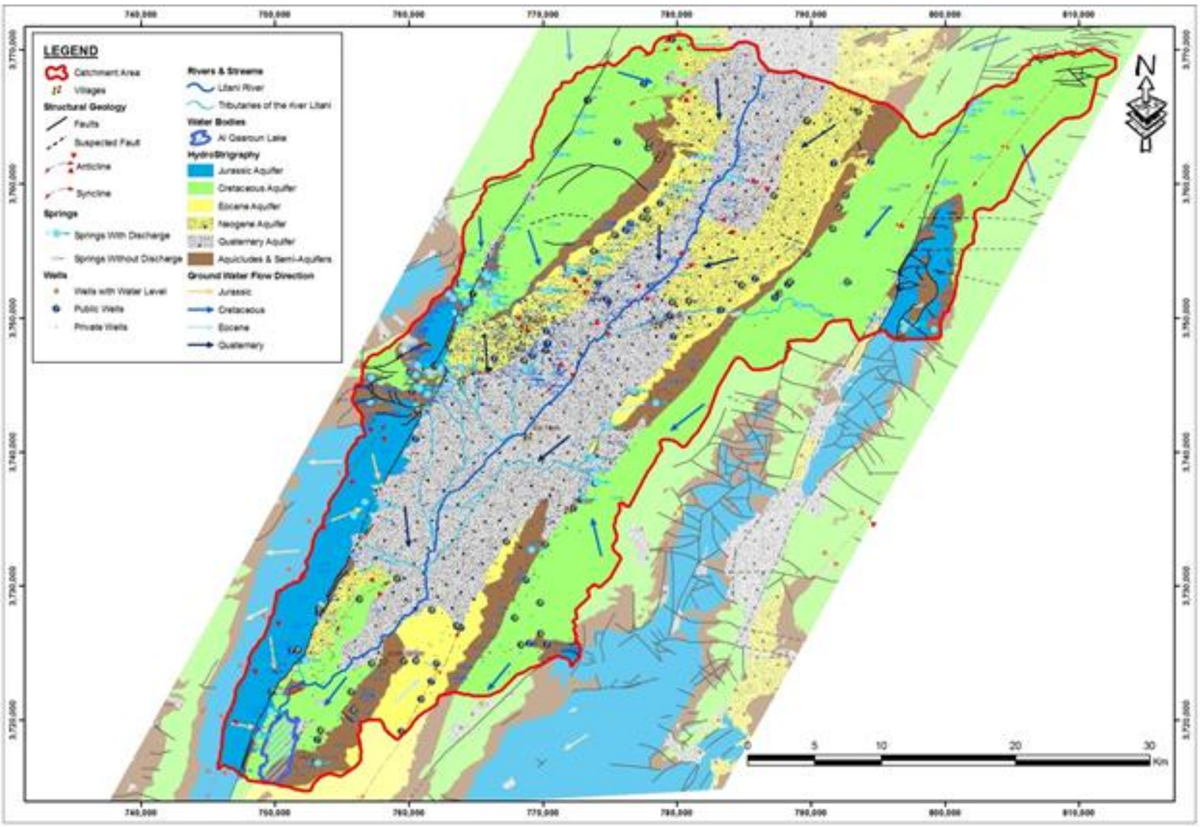
- من اجل فهم افضل لخصائص الاحواض الجوفية المختلفة؛
- تقييم التدفق المشترك بين الاحواض الجوفية والمياه السطحية؛ و
- النظر في سيناريوهات التنمية في المستقبل وتقييم نتائجها من حيث مستويات المياه الجوفية ومدى توافرها.

الهيدرولوجيا (دراسة المياه الجوفية)

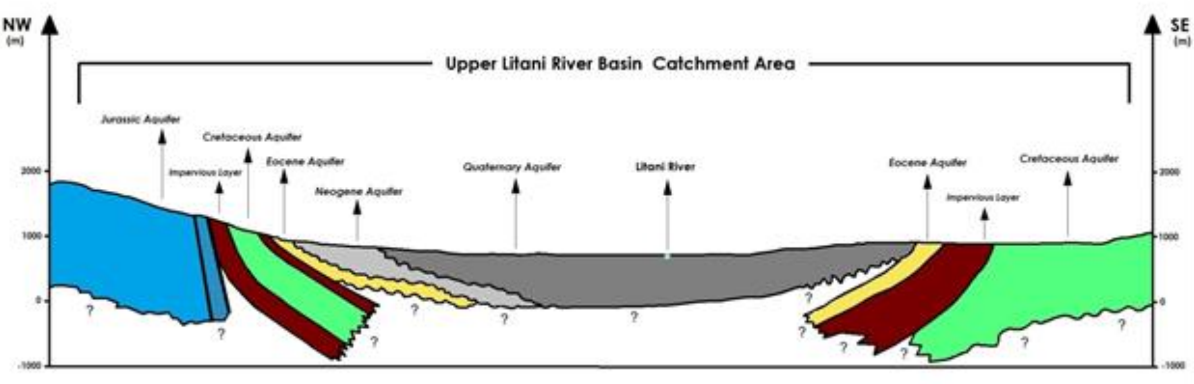
إن منطقة الدراسة تحتوي على خمسة طبقات جيولوجية تحت الارض والتي تحوي بدورها كل المياه الجوفية التي يتم استخراجها. بعيداً عن السطح فان هذه الطبقات تعود إلى فترات زمنية قديمة (الصورة 2 و3):

- إن طبقة المياه الجوفية الرباعية هي طبقة من الرواسب غير مجمعة (حبيبات الطين مع الرمل الناعم و الحصى)، والتي تآكلت أساسا من الجبال والأنهار حيث أودعتها في وسط الوادي على مدى 2.5 مليون سنة السابقة. هذه الترسبات تغطي وسط سهل البقاع وتشكل معظم التربة الزراعية فيه.
- تكمن طبقة النيوجين (أوالميوسين الاعلى) تحت الرباعية وتتكون من رواسب الطمي والتكتلات القديمة (ترسبت لأكثر من 20 مليون سنة). هذه الطبقات ايضاً سطحية (النتوءات) على جانبي السهل: من سفح جبل صنين وصولاً إلى زحلة، ومن بعلبك حتى رياق.
- تتواجد طبقة الإيوسين في الاسفل، حيث تفصل بين طبقة النيوجين والطبقة الرباعية طبقة ذات نفاذية منخفضة، ثم الإيوسين مارل إلى الاعلى. إن طبقة الإيوسين تتكون من الرواسب القديمة (منذ 30-50 مليون سنة) والتي تم ضغطها إلى الطبقة الكارستية وصخور اللايم الكلسية، ويظهر تلك الطبقة بشكل أساسي حول جب جنين في نطاقات رقيقة او ضيقة (أقل من 1 كم في العرض) في الشرق (اي شمال عنجر) وفي الغرب (شمال زحلة) من جانبي السهل.

- كذلك فان طبقة الكرتاسيوس تكونت من الكارست وصخور اللايم، ولكن (منذ 65-145مليون سنة) حيث تغطي كامل الجهة الشرقية من جبال لبنان، والجهة الشمالية الغربية من جبل لبنان (جبل صنين).
- إن الطبقة الجوراسية (145-200مليون سنة) تمتد على الجناح الغربي من جبل لبنان، من شتورة إلى بحيرة القرعون.



Hydrogeological Map of the Study Area **Figure 2**



Hydrogeological Cross Sections of the Aquifer Units in the Study Area **Figure 3**

البيانات و المعلومات الموجودة

كما قيل سابقاً، توجد معلومات محدودة عن مستويات المياه الجوفية تاريخياً (قبل بدء استخراج المياه الجوفية بشكل كبير في أواخر 1960 (قبل ذلك لم يكن استخراج المياه الجوفية ملحوظاً، ولكنه بدأ في

اواخر السيتينيات)، ومن الحق القول ان المياه الجوفية آنذاك كانت على عمق قليل نوعاً ما (اقل من 20 متراً) من سطح الأرض في الأماكن التي تتضح على الخرائط الطبوغرافية والتي تظهر وجود مناطق واسعة من الأراضي الرطبة في السهل وخنادق الصرف لخفض منسوب المياه الجوفية للاستخدام الزراعي. يتدفق نهر الليطاني الأصل من الينابيع بجوار حوش بردى، والتي جفت منذ ذلك الحين. المصدر الرئيسي للمعلومات الهيدرولوجية التاريخية هو تقرير برنامج الأمم المتحدة الإنمائي عام 1970 بشأن المياه الجوفية في لبنان.

تم إنشاء معلومات أكثر حداثة لمستوى المياه الجوفية واستخدامها بشكل جيد من خلال اثنين من المسوحات (الدراسات) الميدانية التي قام بها برنامج LRBMS في تشرين الاول 2010 وايار / حزيران 2011. جمعت كل دراسة معلومات منسوب المياه من أكثر من 100 بئر على حوض نهر الليطاني العلوي ، من أجل:

- تحديد منسوب المياه الحالي بعد أكثر من 40 عاما من الاستخراج
- تقييم التقلبات الموسمية (الاختلاف السنوي بين الشتاء والصيف)

مفهوم النموذج

بناء نموذج حاسوبي للمياه الجوفية هو مسعى معقد لانه من المفترض أن يمثل بدايةً صورة ثلاثية الابعاد D3 لطبقات المياه الجوفية المختلفة. هناك حاجة إلى معلومات جيولوجية جيدة كي نعرف أين تقع هذه الاحواض الجوفية، وما هو عمقها ، اين تلتقي، الخ. إن المعلومات عن المياه الجوفية الجيدة ضرورية ونحتاجها من اجل التحقق والتأكد من قدرة تلك الاحواض على تخزين المياه وكميتها.

ثانيا ، هناك حاجة إلى المعلومات الهيدرولوجية لتقدير مدى حجم التبادل بين هذه المياه مع التدفقات السطحية (التدفقات من خلال التسرب من الأمطار والأنهار، والخسائر من خلال الينابيع و استخراج المياه عبر ضخها من الآبار).

استنادا إلى مستوى البيانات الدقيقة من الطبقة الطباشيرية و الجوراسية، وأيضا عن حقيقة أن معظم (80 ٪ أو أكثر) استخراج المياه الجوفية حالياً يحدث من طبقات المياه الجوفية السطحية، إن النموذج يقتصر على الطبقة الرباعية،

والنيوجين، وطبقات الإيوسين. اذا ما توافرت معلومات جديدة، فإنه سيكون من الممكن توسيع نطاق النموذج ليشمل الطبقات الطباشيرية و الجوراسية.

حدود النموذج هي:

- إلى الشمال ، مطابقة فجوة حوض النهر (القمة / الخط الذي يفصل بين المياه المتدفقة الى نهر الليطاني إلى الجنوب من تلك التي تتدفق إلى نهر العاصي ، العاصي إلى الشمال) وتعتبر الحدود خالية من التدفق؛

إلى الشرق والغرب، واسفل سفوح الجهتين (حدود الاحواض الجوفية للسهل)، مع مساهمات من الجبال كونها من كل من الطبقات الجوراسية الطباشيرية ، و

- إلى الجنوب، وعلى الجانب الشمالي من بحيرة القرعون، حيث تتواجد تحتها الطبقة الرباعية ، النيوجين، والإيوسين وهي طبقة رقيقة وذات نفاذية منخفضة (تسمى aquiclude)تحيث تتقارب سلسلتي الجبال ، وبالتالي تشكيل حدود التدفق المنخفضة.

لكل حوض معادلة الحفظ هي:

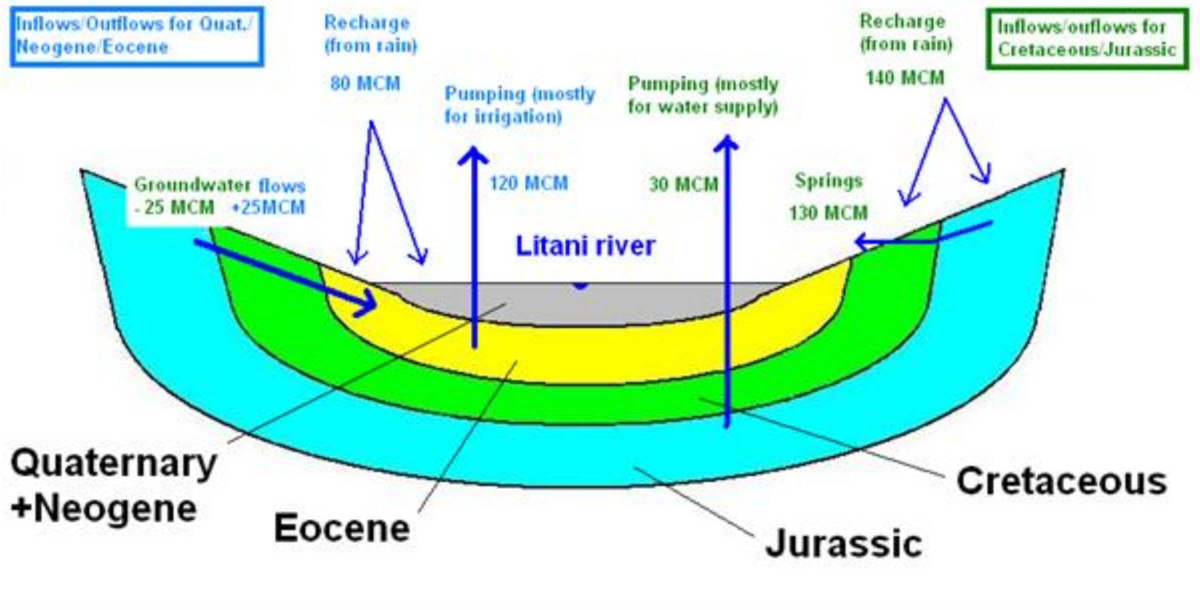
التدفق – التصريف= DS (اختلاف التخزين)

حيث تشمل التدفقات والتصريف (الشكل4)

- التدفق التغذية (الأمطار التي تتسرب من خلال الأرض حيث أسطح المياه الجوفية)؛
- التبادل (التدفقات او التصريف) مع تيارات المياه السطحية والمياه الجوفية بين ؛
- الينابيع (تدفقات المياه الجوفية من الينابيع –النوافير إلى السهل بعد ان تتسرب عبر الجبال)؛
- الضخ اوالسحب (التدفقات الخارجة) لأغراض الري والصناعة و الأغراض المنزلية.
- يمثل الجدول والرسم البياني أدناه متوسط التدفقات السنوية والتصريف، كما هو معروف من البيانات المتاحة و الميزان المائي المقدر لحوض نهر الليطاني العلوي (LRBMS – ديسمبر 2011) ، والذي أكده النموذج :

M m3/year مليون متر مكعب/سنة	Recharge التغذية	Pumping الضخ	Springs الينابيع	Transfers + to GW**	Balance الميزان
Quaternary-Eocene	80	-120	0	17 (-7 to Litani river, +24 from lateral	-21

الايوسين الرباعية–					aquifers	
Cretaceous- Jurassic الجيوراسيك – كرتاسيوس	140	-30	-130	-24 (laterally to upper aquifers)	- 44	
Total	220	-150	-130	-7	-65	



الصورة 4: مقطع تصويري لتدفقات المياه الجوفية السنوية بين الاحواض الجوفية للحوض الاعلى لليطاني.

نموذج الحاسوب: البناء والمعايرة

يسمى نموذج الحاسوب الذي تم استخدامه GMS (اي نظام نمذجة المياه الجوفية). البرنامج يعمل بحسب نظام ال MODFLOW الذي تم تطويره من قبل هيئة المسح الجيولوجي الامريكية لمحاكاة تدفق المياه الجوفية من خلال طبقات المياه الجوفية. فهو يعتبر في جميع أنحاء العالم رمز او المعيار الواقعي لمحاكاة طبقات المياه الجوفية.

تم بناء نموذج مماثل لحوض نهر الليطاني العلوي باستخدام الخرائط الجيولوجية (مقياس 50000/1) ، والخرائط الطبوغرافية (مقياس 20000/1)، والخرائط الهيدروجيولوجية (مقياس 100000/1)، و المقاطع العرضية لمنطقة الدراسة.

تم ترقيم البيانات باستخدام نظم المعلومات الجغرافية GIS (نظام المعلومات الجغرافية) ودمجها لإنتاج نقطة واحدة من النقاط المبعثرة وتحديد سماكة الحوض الجوفي وأعلى ارتفاع فيه. استخدمت النقاط المبعثرة الناتجة عن نظم المعلومات

الجغرافية لتوليد نموذج جيولوجي ثلاثي الابعاد D3 باستخدام برنامج GMS لمنطقة الدراسة. يتضمن نموذج D3 حدود الاحواض الجوفية وسماكتها، وبنيت مع حجم مقاطع ثابتة ومتساوية اي 500 ب 500 متر. كان هذا هو أفضل تمثيل لمنطقة الدراسة، مع الأخذ في الاعتبار كمية محدودة من البيانات، والقدرة الحسابية، ودقة هذا النموذج. من شأن مقاطع أصغر ان تزيد المتطلبات الحسابية ولكن قد تسفر عن نفس الدقة بسبب عدم وجود بيانات متاحة اساساً، في حين أن المقاطع الأكبر حجماً انخفضت متطلباتها الحسابية لخلق النموذج، ولكن بذلك انخفضت نظرياً دقة هذا النموذج.

إن التمثيل، ومع بيانات محدودة، عن حياة الطبقات الجوفية المائية الجيولوجية الحقيقية ومع نموذج رياضي يتطلب افتراضات معقولة. هنا تم اعتماد الافتراضات التالية:

- إن الارتفاع هو ثابت لكل خلية او مقطع (500*500 متر). لا يمثل الافتراض التالي التلال أو الوديان المحلية؛
- ان التفاعلات في الأسفل والجنوب محدودة، وهنا قد أهملت (تعتبر هذه حدود الا تدفق)؛
- التفاعلات على طول الحدود الشرقية والغربية تمثل تدفقات التبادل بين طبقات المياه الجوفية الجوراسية والطباشيرية والإيوسين، والنيوجين الرباعية لاحواض المياه الجوفية (هذا الافتراض يضع تدفقات التبادل بين طبقات المياه الجوفية على طول الجانبين، في حين يمكن تركيز هذه التدفقات في الفيالق / مناطق الطبقات المتكسرة؛
- فيما يتعلق بالاستخراج اي ضخ المياه الجوفية وتراجع مستواها، فان المعلومات متاحة فقط مواقع الآبار العامة والآبار الخاصة المرخصة، دون معدلات الضخ الفعلي (والتي قدرت)، من ناحية أخرى، آلاف الآبار غير المرخصة الخاصة موجودة أيضا، لمن ليس لديه معلومات موجودة؛ تم استخدام المعلومات على المناطق المروية لتحديد وتقدير معدلات الضخ من من خلال هذه المناطق وحسب نوعية المزروعات لتقدير حاجتها الفعلية للمياه وبالتالي تقدير الكميات التي يتم ضخها من الآبار.

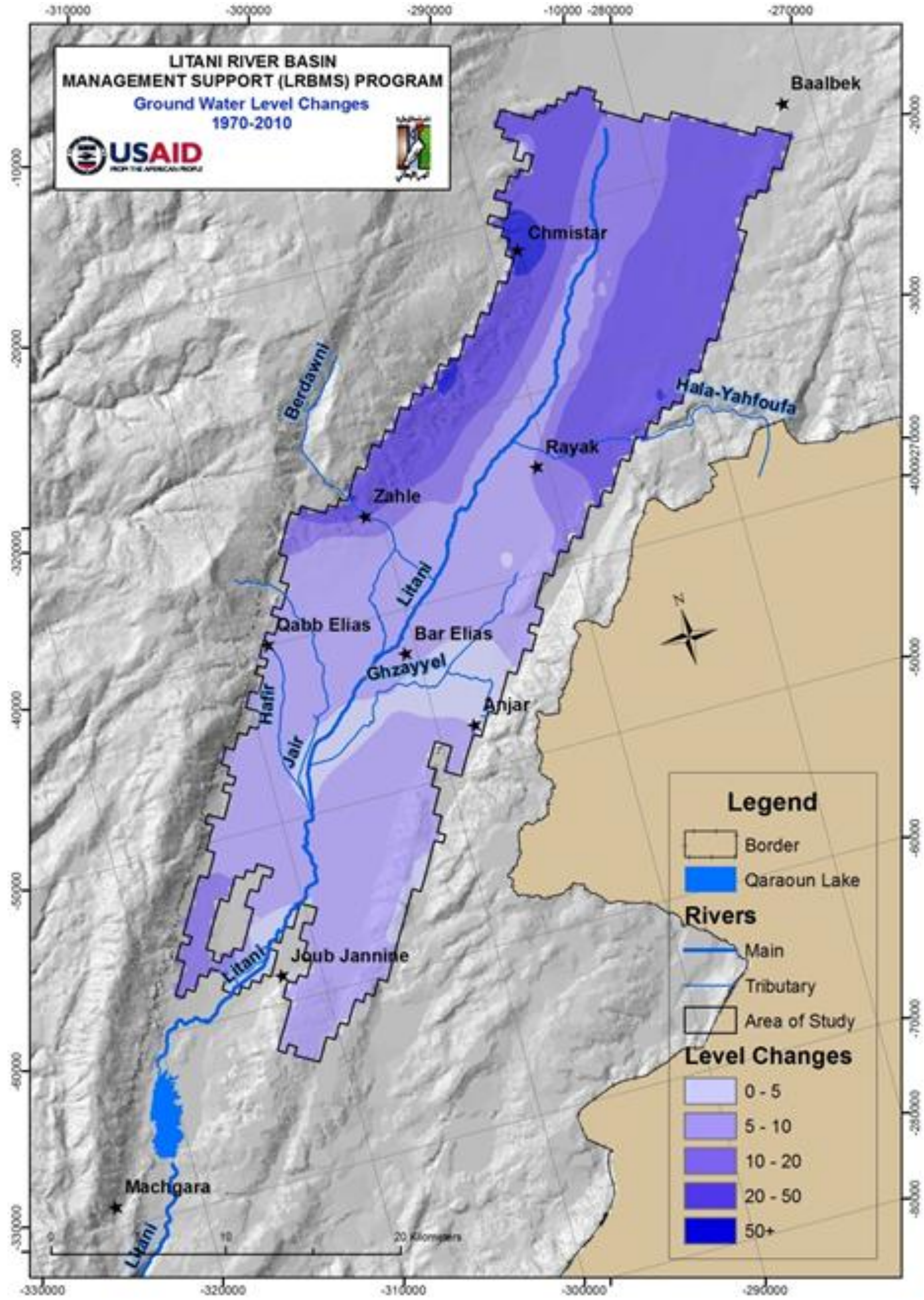
المعايرة هي الخطوة التالية والأهم في بناء نموذج حاسوبي لنظام المياه الجوفية. هو عملية تعديل الخصائص التي هي غير معروفة (مثل المسامية لطبقات المياه الجوفية) بحيث تنتج نموذج بيانات الناتج (مثل مستويات المياه) التي هي قريبة جدا من البيانات التي تم جمعها في الميدان او الحقل. اذا كان النموذج، يعتمد على إدخال البيانات من الميدان، سوف يوفربذلك بيانات للناتج مماثلة لحقل القياسات / البيانات، النموذج معاير بشكل جيد، وهذا ما سيمكن من مقاربة دقيقة للواقع. ويمكن عندئذ أن تستخدم لملىء النقص في المعلومات.

تم تنفيذ اثنين من المعايرة:

- أولا معايرة الحالة المستقرة، تعديل معطيات الاحواض الجوفية للحصول على نتائج النموذج للمطابقة بينها وبين بيانات المسح الميداني الذي تم في تشرين الاول 2010، و
- ثانيا معايرة عابرة، حيث كانت هذه المعطيات مصقولة باستخدام التغيرات في مستويات المياه الجوفية بين تشرين الاول 2010 والمسح الميداني الذي اجري في نيسان / ايار 2011.

اعتبرت النتائج النهائية في كلتا الحالتين مرضية، مع وجود اختلافات بين مستويات المياه الجوفية المرصودة والمحسوبة والفرق تراوح في حدود 10 امتار، وغالبا في 5 امتار.

تم التحقق النهائي باستخدام البيانات المحدودة المتاحة من عام 1970 لتمثيل التطور العام لمستويات المياه الجوفية على مدى السنوات ال 40 الماضية، وأثبتت انها مرضية ايضاً انظر (الشكل 5).



الشكل 5 التغيرات في مستوى المياه الجوفية بين 1970 و 2010

تقييم المياه الجوفية في المستقبل

استخدم النموذج المعاير بعد ذلك لتقدير مستوى المياه الجوفية للعشرين عام القادمة وتصور الحالة حينها. في حين أن الجغرافيا والجيولوجيا الشاملة للنموذج لا تتغيير، وشملت معطيات النموذج التالي:

- استخراج المياه الجوفية، والتي بينت سيناريوهين (الجدول 1):

- o A "العمل كالمعتاد" زيادة بنسبة 30٪ (1.5٪ سنويا)، والذي من شأنه أن يستمر هذا الاتجاه في التوسع حالياً، و
- o A انخفاض بنسبة 10٪ (0.5٪ سنويا)، الناجمة عن إدارة المياه الجوفية على نحو أفضل، وزيادة تكاليف الضخ، وممارسات الري على نحو أفضل، تناقص الأراضي المتاحة، أو مزيج من هذه؛

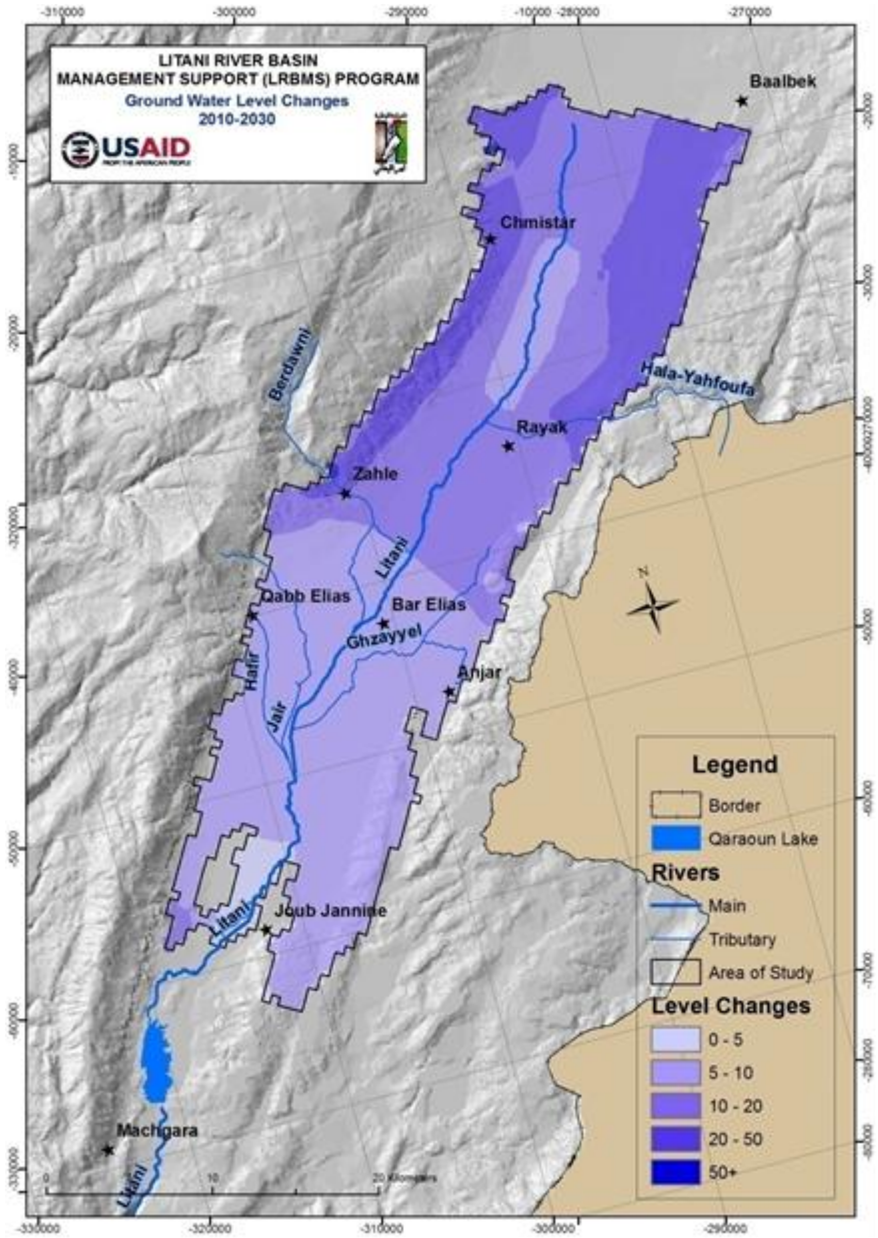
- التغذية، والتي بينت ايضاً سيناريوهين:
  - o لا تغيير مع هطول الأمطار والتسرب يبقى نفسه، و
  - o انخفاض شديد إلى حد 20٪ (0.5٪ سنويا)، مما يعكس تأثير متشائم جدا من تغير المناخ.

هكذا تم اختار أربعة سيناريوهات (1–4): (1)، هي الأكثر تفاؤلاً، 4 هي الأكثر تشاؤما، و 2 هي الأكثر احتمالاً (لم يتغير كثيرا في التغذية، وزيادة كبيرة في الاستخراج او الضخ).

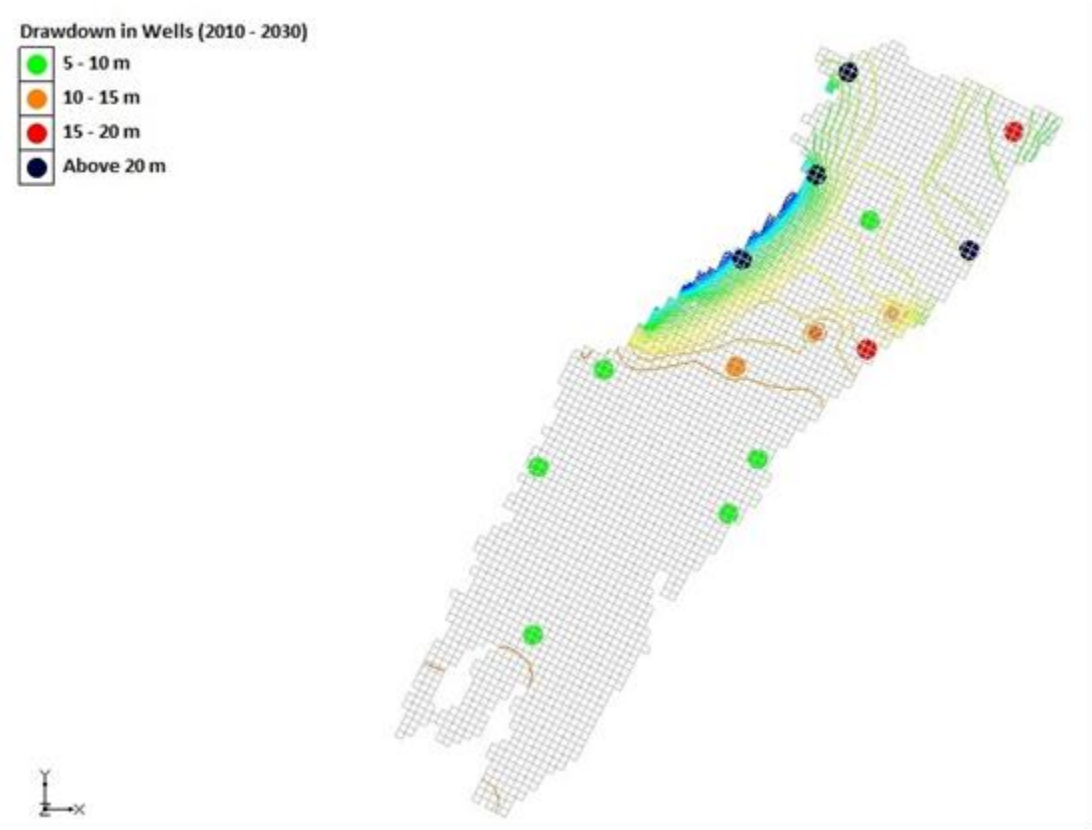
الجدول1 استخدم اكثر من سيناريو

Groundwater abstraction ضخ من المياه الجوفي / **Recharge التغذية**	+10%	+30%
0	**1**	**2**
-20%	**3**	**4**

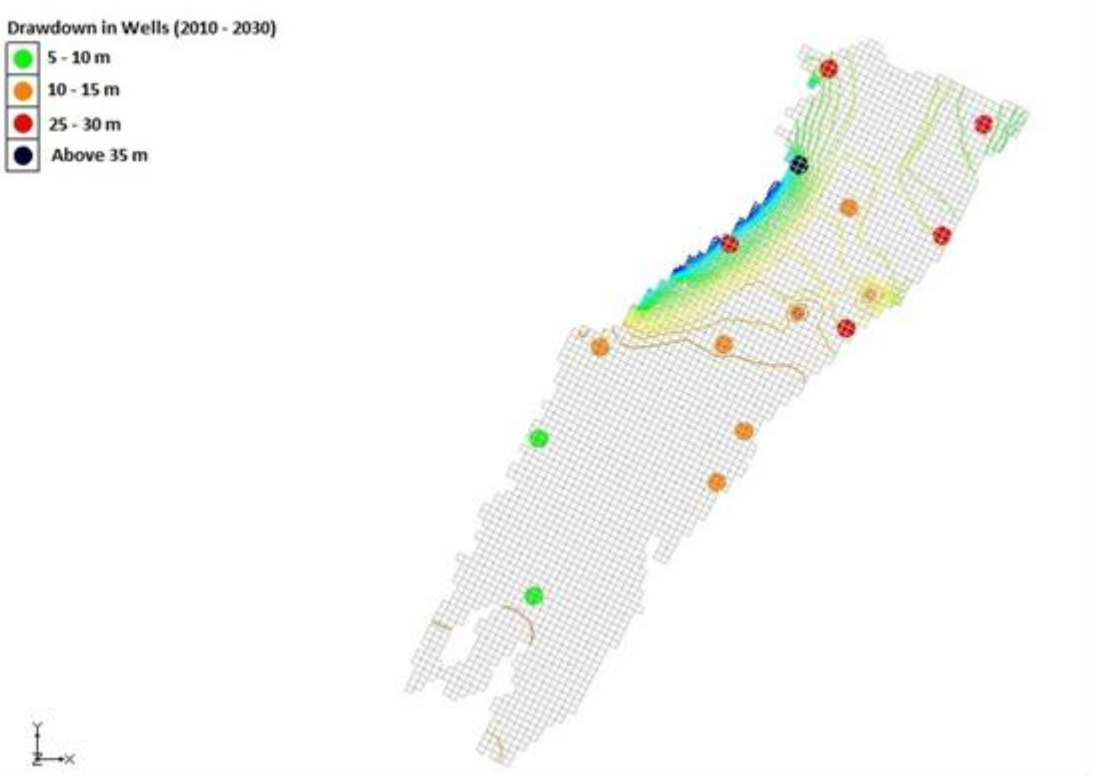
أظهرت النتائج أن سيناريو 2030 لمستويات المياه ستكون أسفل ب 5امتار وحتى 25متر، مع أقصى تراجع في الشمال الشرقي والشمال الغربي من منطقة الدراسة (شمستار، نبي شيت، الفرزل وكفاردان في الشرق؛ بريتال في الغرب). سوف يكون الحد الأدنى للتراجع في الجزء الجنوبي من منطقة الدراسة مع الحد الأدنى من التراجع 5 امتار (الشكل 6 إلى الشكل 14).



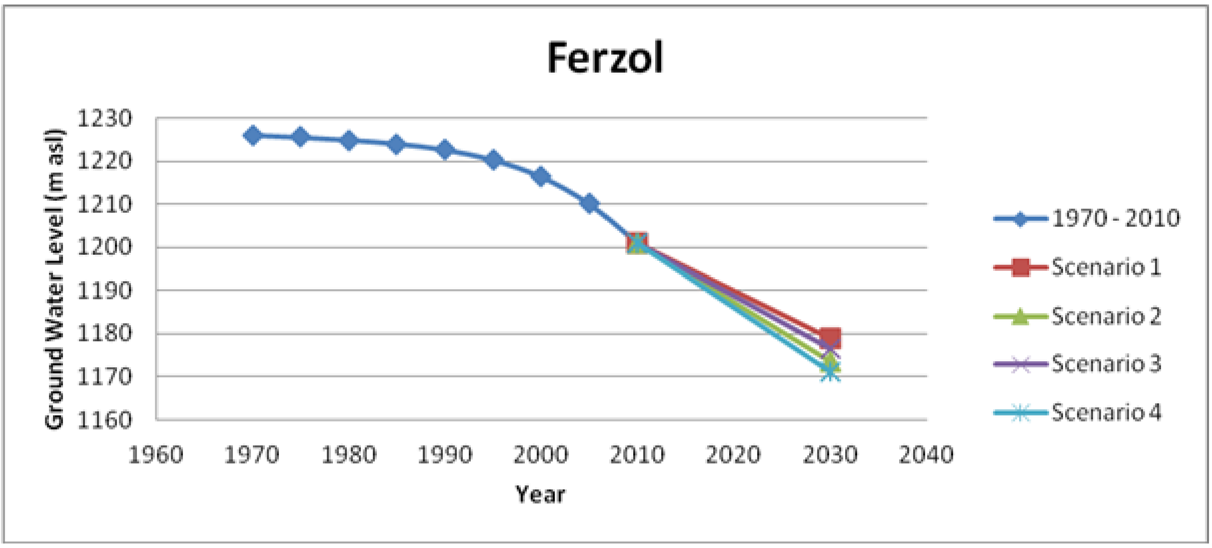
الشكل 6 التغيير في مستوى المياه بين 2010 و 2030 للسيناريو 2 **(الاكثر احتمالاً)**



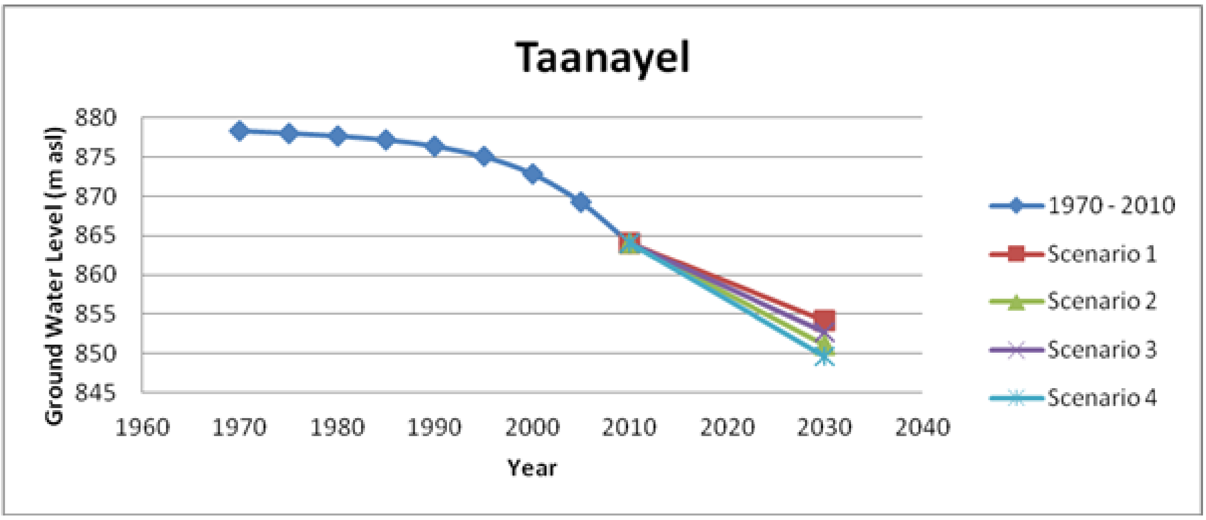
الشكل 7 الحد الادنى للتراجع في نقاط المراقبة 2010–2030 **(سيناريو1)**



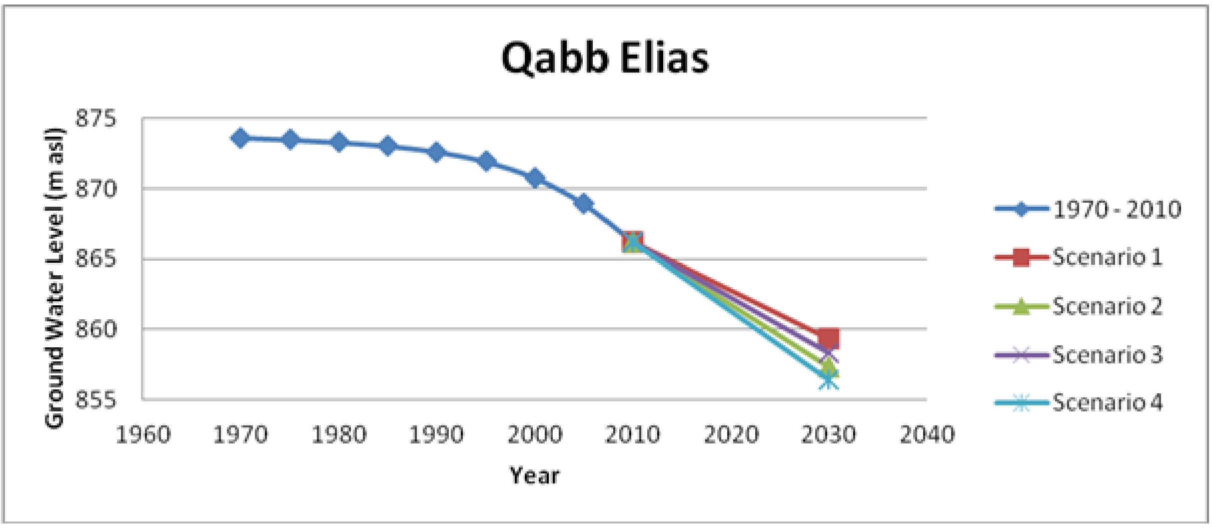
الشكل 8 الحد الاقصى للتراجع في نقاط المراقبة 2010–2030 (سيناريو 4)



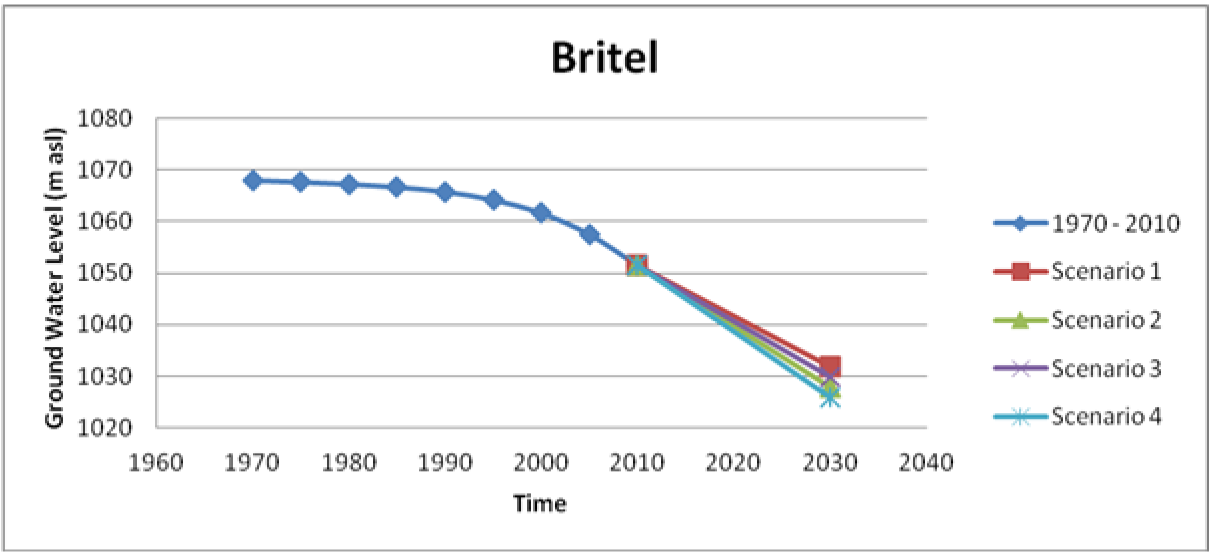
الشكل 9 التراجع التاريخي والمتوقع لنقطة مراقبة الفزل



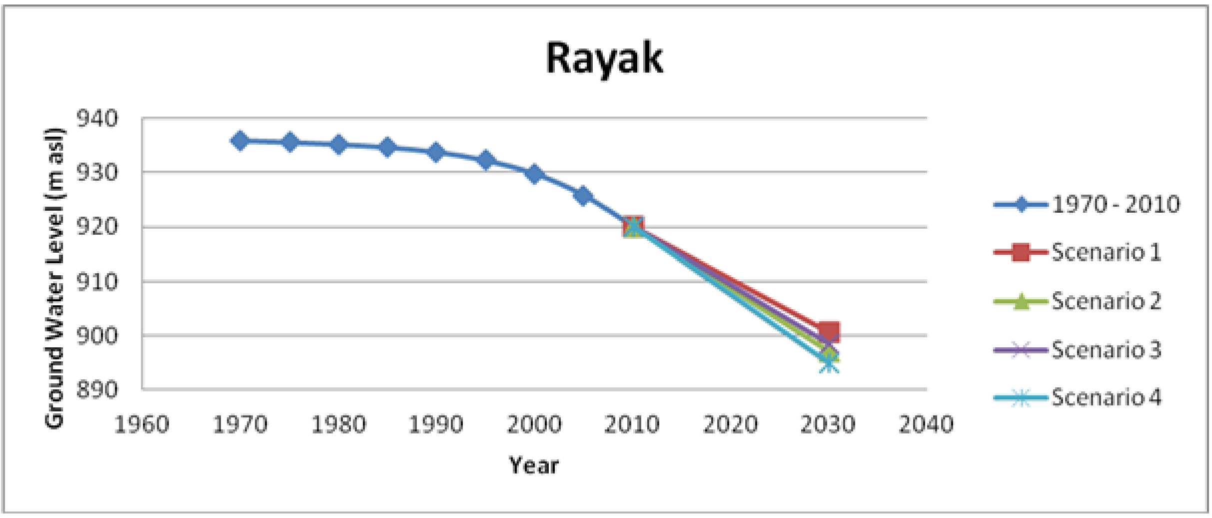
الشكل 10 التراجع التاريخي والمتوقع لنقطة مراقبة تعنايل



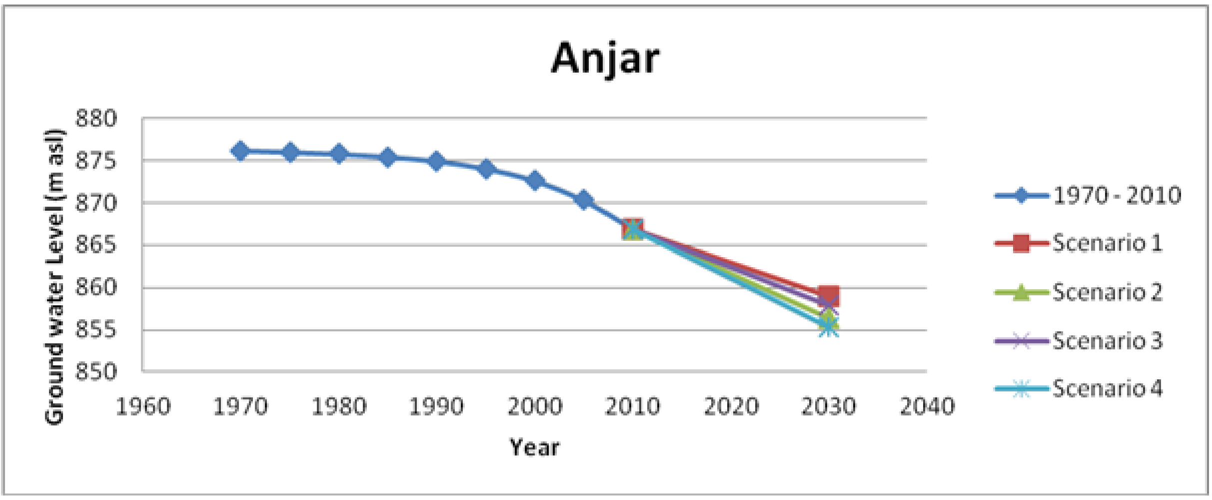
الشكل 11 التراجع التاريخي والمتوقع لنقطة مراقبة قب الياس



الشكل 12 التراجع التاريخي والمتوقع لنقطة مراقبة بريتال



الشكل 13 التراجع التاريخي والمتوقع لنقطة مراقبة رياق



الشكل 14 التراجع التاريخي والمتوقع لنقطة مراقبة عنجر

الخلاصة و التوصيات

النموذج المطور هنا هو المحاولة الأولى في نمذجة المياه الجوفية في حوض نهر الليطاني الاعلى. ويرجع ذلك إلى الكمية المحدودة من البيانات المتاحة، بالعودة لبعض الافتراضات فان النموذج يقتصر على الثلاث طبقات الأعلى (الرباعية ، و النيوجين والايوسين)، مع دقة لمقطع من 1 كم إلى 1 كم بالحجم. هذا النموذج هو مناسب تماما لاستخدامه وللمساعدة في اتخاذ القرارات الاستراتيجية الكبرى، إلا أنه ينبغي إعادة النظر فيه وصقله لتحسين الدقة المطلوبة لذلك يجب استخدامه في التخطيط التفصيلي وإدارة الموارد المائية لحوض نهر الليطاني العلوي. وهذا يتطلب بالتأكيد وجود فهم أفضل على رصد

موارده فيما يتعلق بكل من التغذية والتصريف لأنظمة المياه الجوفية والسطحية. وهذا من شأنه أيضا او يستلزم ايضاً تحسين أو إنشاء شبكة رصد أوسع من شأنها أن تساعد في تقييم أفضل للموارد المائية مع احترام وتتطوير نظم قياسات

التدفق والتصريف للمياه الجوفية والمياه السطحية. وهذا يتتطلب تأسيس نظام للمراقبة الشاملة على سبيل المثال لا الحصر : تصريف الينابيع، ومستوى المياه الجوفية، وتدفق المياه السطحية ونوعيتها، استخراج الميا (مراقبة المياه الجوفية والمياه السطحية)، ورصد الأحوال الجوية.

كجزء من برنامج LRBMS ، بدأت IRG إنشاء / تحسين هذه المجموعة من شبكات الرصد عن طريق تركيب عدد محدود من أجهزة رصد المياه في العديد من الأنهار والآبار كمحطات رصد المياه الجوفية وقياسها.

عندما تصبح البيانات متاحة اكثر، يمكن تعزيز دقة النموذج هذا لذا يوصى بالتالي:

- صقل نموذج الشبكة (المقطع) لتمثيل الآثار أكثر ولتفصيل الضخ من الآبار.
- تعزيز وادخال فب النموذج معطيات التبخر ،التغذية، والتفاعل بين طبقات المياه الجوفية ، التصريف من الينابيع ، والتدفقات النهرية
- زيادة وتيرة قياسات مستوى المياه الجوفية وتحسين نوعيتها، رسم خرائط دقيقة للمياه الجوفية.
- تحديد اثار الاستخدام الجائر للمياه الجوفية على نوعية المياه في الحوض.

بناء نموذج من 4 طبقات (يشمل طبقة الحوض الجوراسية والطباشيرية) وذلك يمكن الحصول عندما تتوفر معلومات اضافية.

التدفق والتصريف للمياه الجوفية والمياه السطحية. وهذا يتتطلب تأسيس نظام للمراقبة الشاملة على سبيل المثال لا الحصر : تصريف الينابيع، ومستوى المياه الجوفية، وتدفق المياه السطحية ونوعيتها، استخراج الميا (مراقبة المياه الجوفية والمياه السطحية)، ورصد الأحوال الجوية.

كجزء من برنامج LRBMS ، بدأت IRG إنشاء / تحسين هذه المجموعة من شبكات الرصد عن طريق تركيب عدد محدود من أجهزة رصد المياه في العديد من الأنهار والآبار كمحطات رصد المياه الجوفية وقياسها.

عندما تصبح البيانات متاحة اكثر، يمكن تعزيز دقة النموذج هذا لذا يوصى بالتالي:

- صقل نموذج الشبكة (المقطع) لتمثيل الآثار أكثر ولتفصيل الضخ من الآبار.

- تعزيز وادخال فب النموذج معطيات التبخر ،التغذية، والتفاعل بين طبقات المياه الجوفية ، التصريف من الينابيع ، والتدفقات النهرية
- زيادة وتيرة قياسات مستوى المياه الجوفية وتحسين نوعيتها، رسم خرائط دقيقة للمياه الجوفية.
- تحديد اثار الاستخدام الجائر للمياه الجوفية على نوعية المياه في الحوض.

بناء نموذج من 4 طبقات (يشمل طبقة الحوض الجوراسية والطباشيرية) وذلك يمكن الحصول عندما تتوفر معلومات اضافية.

1. INTRODUCTION

ELARD was awarded by the International Resource Group (IRG) the task of constructing a groundwater numerical flow simulation for the Upper Litani River Basin. This project is part of the various activities of the LRBMS (Litani River Basin Management System) and aims at developing a user friendly tool that can be used by the staff of the Litani River Authority (LRA) as a decision support system. The quantities of water available in the area and its dynamics can be better assessed and represented by a groundwater numerical model.

The model can/should be used as a management tool and should be updated as additional data become available for more detailed representation. Accordingly, the model should serve the following objectives:

- Evaluation of:
  - aquifer interactions;
  - the interaction between the groundwater and surface water systems;
  - the hydraulic characteristics of the aquifers;
- Evaluation and update of the water budget of the aquifers;
- An assessment tool for future policy making and abstraction regulation;
- Simulating predictions of groundwater levels based on various pumping schemes.
- The development of "Spring Protection Zones" to preserve and 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.
- Groundwater allocation planning and regulation.

This document presents the final report for the groundwater modeling of the Upper Litani Basin. It contains the data used to establish the conceptual model, the model setup, the calibrated model, and the results for the different scenarios analyzed.

In addition to this introductory section, this report presents the modeling approach, description of the study area, description of the hydrogeologic (Aquifer) units present in the study area, the conceptual model setup, the model geometry, the model parameterization, the model calibration for steady state and transient state, and the results of past and future projections of the model.

2. MODELING APPROACH

The study area is an agricultural region with close to 400,000 inhabitants. Most surface waters have been harnessed since the 1960s for hydropower (Qaraoun Lake) or direct irrigation (from springs and rivers). Over the past 50 years, irrigation has expended significantly, from a few thousand hectares to over 40,000 ha today of partially or fully irrigated croplands. This was chiefly achieved by farmers drilling private (and often unlicensed) wells and increasingly tapping into groundwater resources. Very limited groundwater monitoring occurred during this time, but interviews and limited measurements show that groundwater tables and spring flows have significantly lowered as a consequence.

The USAID-funded Litani River Basin Management Support (LRBMS) program recently installed fifteen observation wells for groundwater monitoring (quality and level) to be operated by the Litani River Authority (LRA) and provide essential groundwater information. In parallel, LRBMS also developed a groundwater model in order to:

- Better understand the characteristics of the various aquifers;
- Evaluate flow interactions between these aquifers and with surface water; and
- Consider future development scenarios and assess their consequences in terms of groundwater levels and availability.

The modeling activities were conducted using the MODFLOW 2005 Code model that was developed by the United States Geological Survey (USGS). MODFLOW is a computer code that solves the groundwater equation, to simulate flow of groundwater through aquifers. For our project, GMS software was used for the graphical interface of MODFLOW. GMS was chosen because it is a comprehensive program for groundwater modeling that is user friendly and easy to operate, with abundant support for novice users with limited hydrogeological background. A dedicated copy of GMS software package, with the developed models (steady state, transient state, and projections) will be handed over to Litani River Authority, upon completion of the work.

To ensure a good representation of the groundwater flow regime, the construction of the model was conducted in a 4- phase approach which is outlined below.

2.1 DATA GATHERING AND HYDROGEOLOGICAL MODEL CONCEPTUALIZATION

This project phase is considered to be the most critical, as it constitutes the main basis upon which the groundwater model is constructed. It involved intensive data gathering, and a comprehensive review and analysis of available pertinent information, that are required for a good understanding of the hydrogeology and the initial characterization of the groundwater flow regime.

Topological, geological and hydrogeological information are critical for defining the basin model domain (i.e., model boundaries and types), and defining the various hydrogeologic units, along with their hydraulic characteristics. The detailed geological setting of the study area is described in detail in **Appendix A**.

Potentiometric groundwater contour maps that were generated from recent data (IRG, April 2012 report) were used to assess the groundwater flow direction within the basin, and its seasonal fluctuation. The UNDP 1970 water level contour lines show major discrepancies when compared with the digital elevation model (DEM). Most of the contours indicate that the water level in the system exceeds the actual ground elevation, implying therefore that the Upper Litani Basin is flooded. Therefore, the potentiometric groundwater contour maps from the UNDP 1970 were disregarded for model calibration.

Existing information on water supply wells is critical to estimate the quantity of groundwater being extracted; this is discussed in **Appendix B**.

2.2 INITIAL MODEL SETUP

This task consists of setting up the initial MODFLOW model, using the conceptual hydrogeological model and includes:

- Setting the model boundaries and conditions;
- Defining the MODFLOW grid pattern;
- Translating the hydrogeologic units into model layers;
- Defining River Flow and Stream Flow hydraulic parameters; and
- Setting the spatial distribution of the Aquifer hydraulic parameters and the hydrologic parameters, within the Model Domain.

2.3 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

Model Calibration is performed by assigning various model parameters that affect groundwater flow to the different hydrogeologic layers. Calibration is achieved by varying spatially the different input parameters.

Sensitivity analysis of the calibrated model allows quantifying the influence of each of the model parameters on groundwater flow and on the resulting groundwater level contours. Most of the parameters used were varied within practical physical ranges.

The following parameters were considered in the calibration and sensitivity analysis: hydraulic conductivity, recharge, extraction from wells, specific yield, and storativity. Other inputs (such as River/stream flow parameters) that are likely to affect the computed head and groundwater flow rates were varied if appropriate, especially that the latter are not physically tested parameters. The sensitivity of each parameter to the model solution was evaluated by computing residual errors (between observed and simulated values).

2.4 MODEL SIMULATION AND PREDICTIONS

Upon completion of the model calibration and sensitivity analysis, a series of simulations were run to predict the groundwater level behavior in the past and into the future. Model simulations were run to simulate the groundwater levels in the 1970s, and also to simulate 20 year projections with four different scenarios. The simulations were run to predict groundwater behavior under severe drought conditions, as well as increased pumping scenarios to sensitize the LRA on the potential impacts to the groundwater system under these extreme conditions.

3. STUDY AREA

3.1 EXTENT

The Upper Litani River Basin (ULRB) as shown in **Figure 3-1** extends over a 1,389km^2 area from the eastern slopes of Mount Lebanon (Barouk–Niha range and Sannine Mountain) to the western slope of Anti Lebanon (Jabal El Cheikh and Jabal Lemnar). The ULRB is bounded on the north by the city of Baalbeck and the villages of Laat, El Saaide, Younine, Maqné and Deir El Ahmar in the central zone of the Bekaa plain and in the south by the Qaaroun Lake.

The area comprises a surface water catchment drained by the Litani River and its tributaries and the groundwater catchment area is underlying with the surface drainage system and comprised of five principal aquifer systems. The Litani River, which is the largest and the longest river in Lebanon, originates from the Olleiq springs, 10 km southwest of the city of Baalbeck, and flows 170 km in a south-western direction, passing through the Bekaa valley and Qaaroun Lake before it reaches the Mediterranean Sea. . Our study area stops at Lake Qaraoun, which represents the major part of the river basin.

3.2 TOPOLOGY

The Upper Litani Catchment area lies within an average elevation of 1569 m asl (above sea level), with a topographic high of 2620 m asl along the eastern boundary of Mount Lebanon and reaches a topographical high of 2440 m asl along the western slopes of Anti-Lebanon. The Bekaa plateau slopes towards the south, with a topographic high of 1150 m asl in the northern section and a topographic low of 830 m asl in the southern section, along Qaaroun Lake (**Figure 3-1**).

3.3 LAND USE AND VILLAGES

The basin area comprises about 99 towns of small to medium size with a population ranging from few hundred to more than 75,000 inhabitants. Domestic water is supplied mainly from the regional water establishment, which operates about 107 public water supply wells in the basin area. The basin area is characterized by intensive agricultural activities and most of the Bekaa plain is being cultivated. The agricultural lands are being irrigated using surface water (mainly from direct extraction from rivers, canals, and springs); and to a greater extent from groundwater, using irrigation wells most of which are private wells. There are many industries in the basin area; the majority of which are agro-food industries (such as Dairy), of high water consumption. Most of these industries have private water supply wells. A land use / Land cover map of the ULB is presented in **Figure 3-2**.

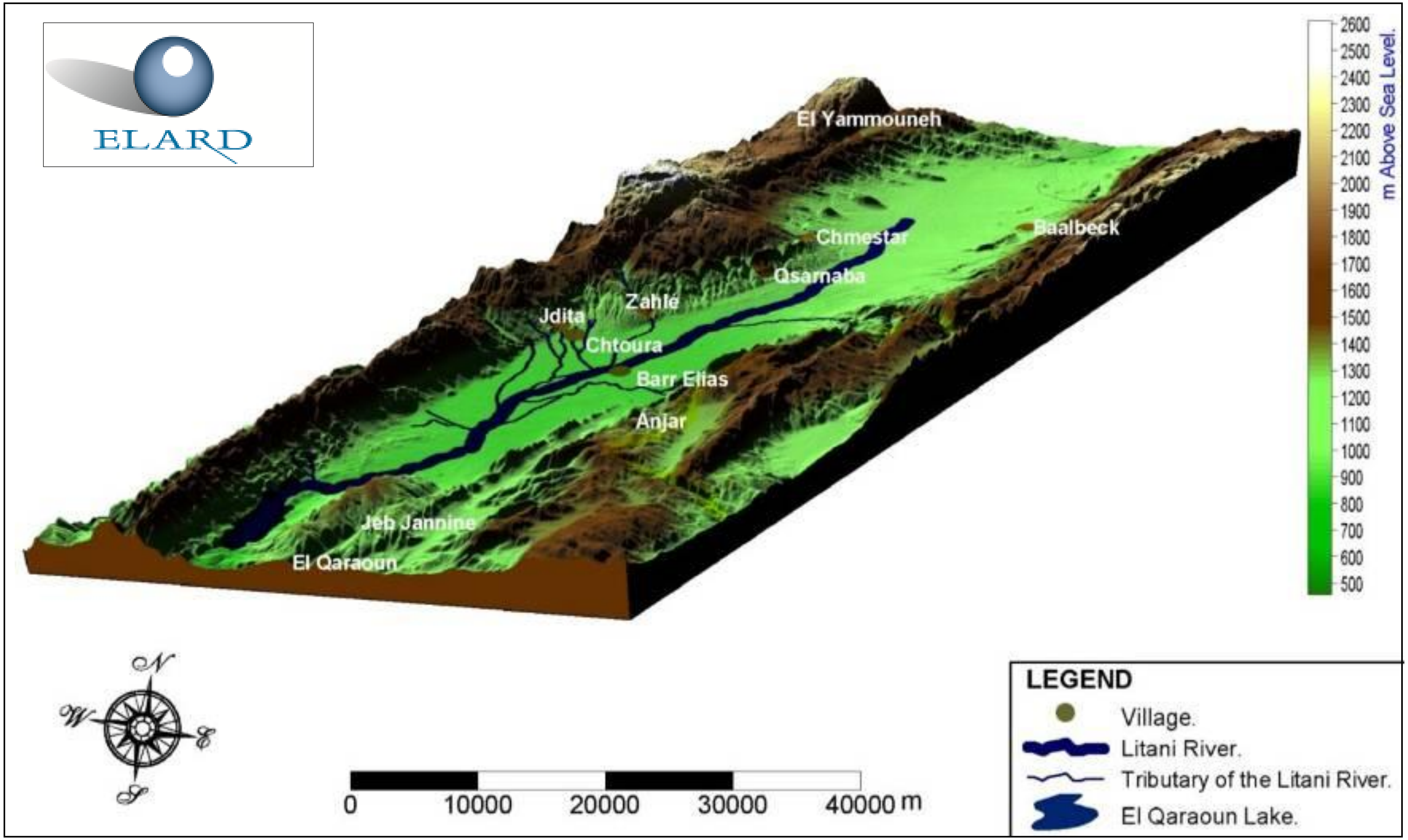


Figure 3-1 The Upper Litani Basin

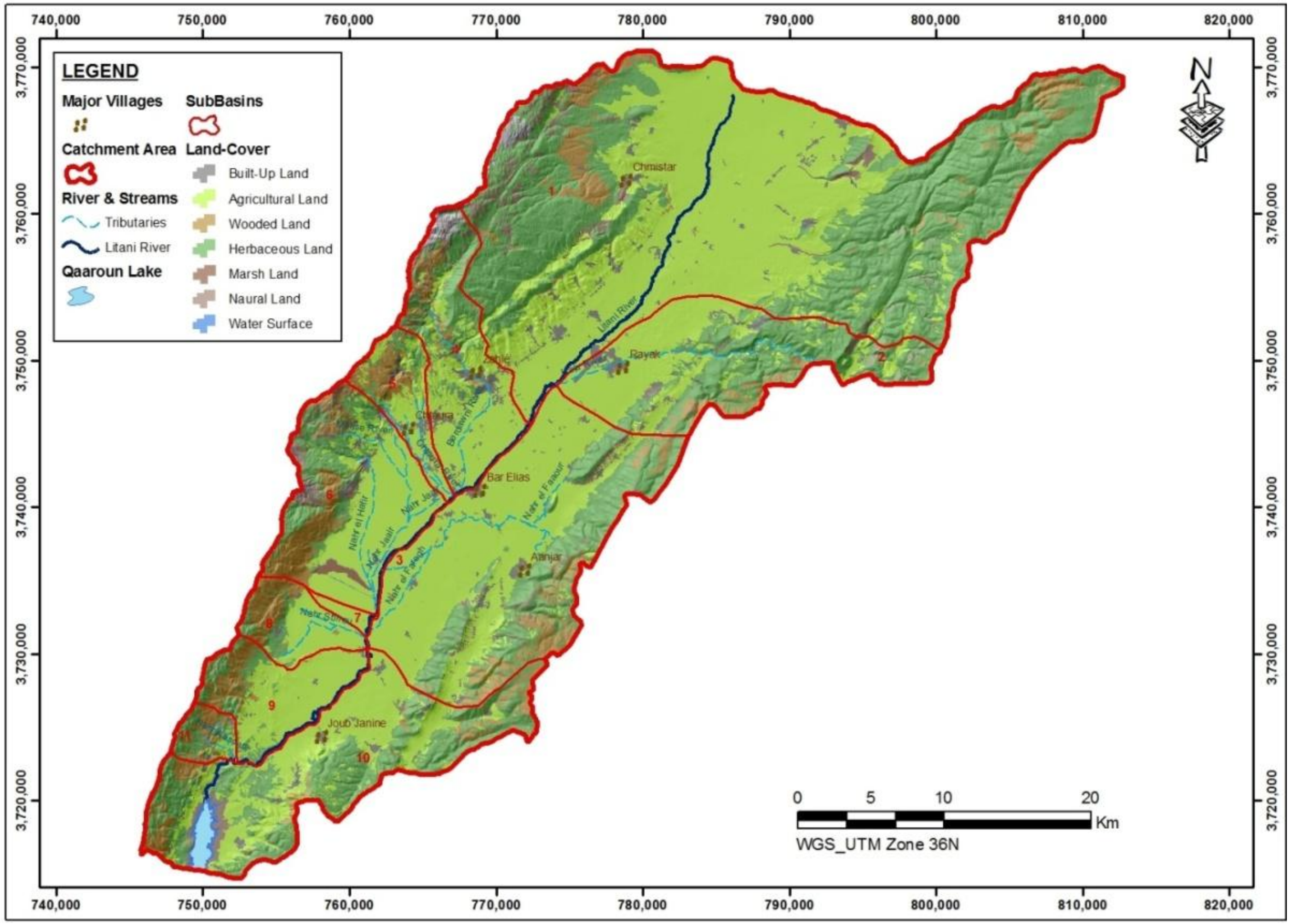


Figure 3-2 Land Use/Land Cover Map of the Upper Litani Basin

4. HYDROGEOLOGY

The geological and hydrogeological assessment of the study area was based on compiled maps by Dubertret (1955) and UNDP (1970) and digitised using GIS software.

The geological setting of the basin is discussed in this section and a more comprehensive description is provided in **Appendix A.**

The geological formations outcropping in the study area range in age from Middle Jurassic to recent Quaternary, Figure 4-1 is the hydrostratigraphical log of the geological formations available. The Jurassic formations span from Middle Jurassic to Late Jurassic and outcrop over 122 km^2 of the catchment area, out of which 3Km^2 are Basalts and volcanic tuff, while 119 km^2 are composed mainly of limestone rocks. The four (4) outcropping formations belonging to the Jurassic period are Kesrouan Formation (J4), Bhannes Formation (J5), Bikfaya Formation (J6), and Salima Formation (J7) all of which are sedimentary limestone formations except for the Bhannes formation which is formed of basalts and volcanic tuffs.

The Cretaceous formations span from Early Cretaceous to Late Cretaceous, cover an area of 633 Km^2 of the catchment area and are comprised of sandstone, limestone, and shale. The catchment area has six (6) outcropping formations of the Cretaceous period; they are the Chouf Sandstone Formation (C1), the Abieh Formation (C2a), Mdairej Formation (C2b), Hammana Formation (C3), Sannine-Maameltein Formation (C4-C5), and Chekka Formation (C6).

The Tertiary and Quaternary formations span from Eocene to Recent deposits. The Quaternary and Neogene formations cover an area of 600 Km^2 of the catchment area, while the Eocene formation composed of limestone covers an area of 111 Km^2. The catchment area has three (3) outcropping formations of the Tertiary and Quaternary period, they are the Eocene Formation (e2a-e2b), Neogene Formation (mL-mL1), and Quaternary Deposits.

Structurally the Upper Litani River catchment area is bordered in the west by the main Yammouneh Fault system and its associated highs and the Barouk-Niharange and the Sannine Mountains. The beds forming these highs dip towards the Bekaa plain. Small-scale folds such as anticlines and synclines in Hadath Baalbeck and Chlifa villages, at the foothills of those ranges, plunge into the Bekaa valley below the Quaternary deposits.

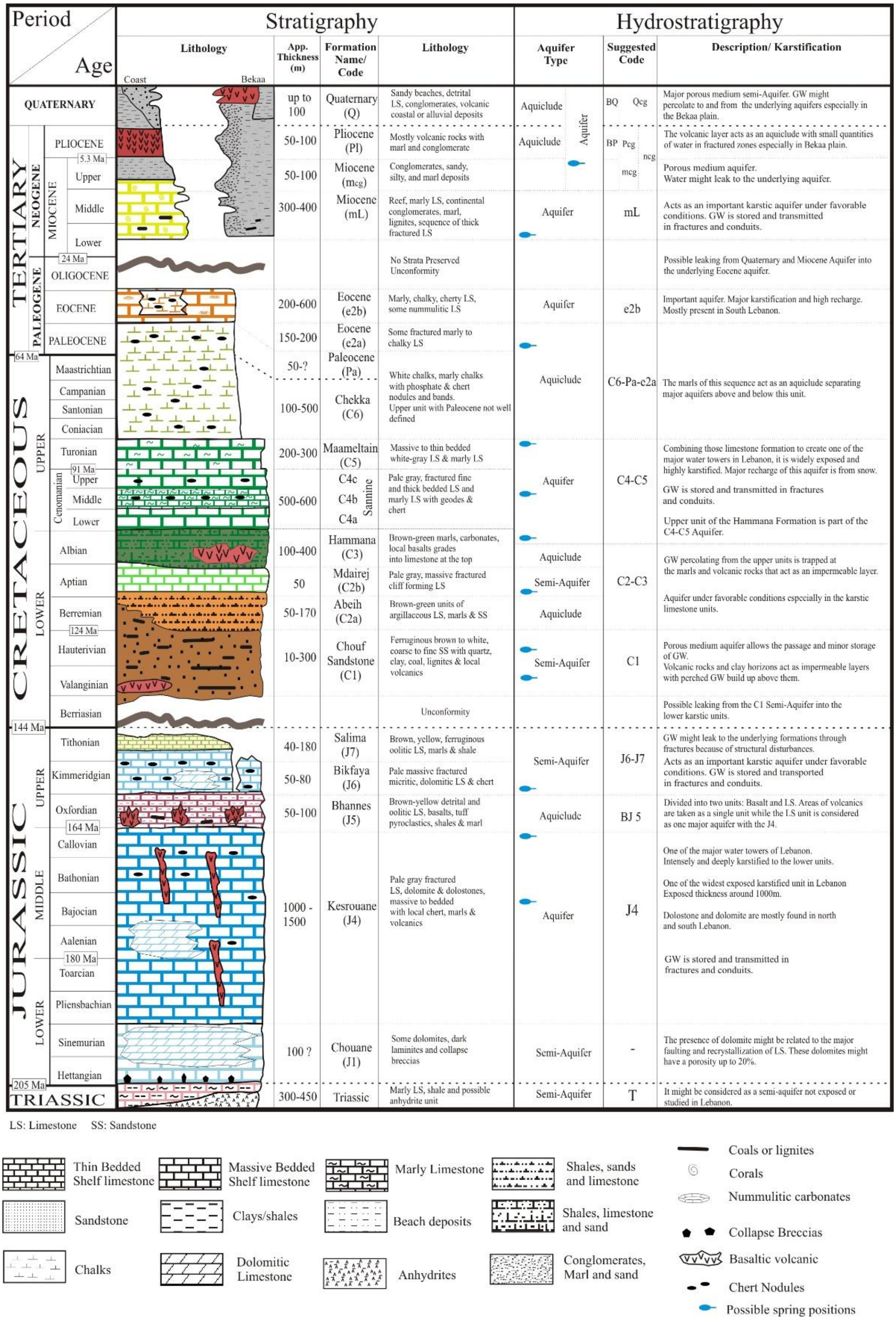


Figure 4-1 Hydrostratigraphical Log of the Geological Formations

From the east, the catchment is bordered by the main Rachayya and Hasbayya fault systems and their associated Anti-Lebanon Range (Jabal El Cheikh and Jabal Lemnar). The general inclination of beds on the western slopes of the Anti-Lebanon Mountains is towards the Bekaa valley, that is, towards the west.

Secondary faults trending in an E-W direction are also present in the study area. These faults act as passageways for groundwater from the highlands or source areas to the lowlands, which is mainly the Bekaa plain where outlets exist as springs and where the Quaternary deposits are being replenished.

4.1 HYDROSTRATIGRAPHY

The following sub-section describes the hydrogeological characteristics of the principal geological (aquifer units) formations. A simplified hydrogeological map showing the various aquifers and the tectonic structures, as well as a representative distribution of wells that were surveyed as part of the project is presented in **Figure 4-2**, and **Figure 4-3** is a hydrostratigraphical cross-section of the study area.

The Upper Litani Basin is underlain by five aquifers. A detailed 3D hydrogeological model for the basin was developed based on geological maps developed by Dubertret 1/50,000, and geological cross-sections generated across the basin. The aquifer units are:

1. Quaternary Deposits (Q) – Composed of alluvium and colluviums deposits (415 km^2 – more than 500m)
2. Neogene (mL & mL1) – Composed of conglomerate, alluvium, and colluviums deposits (186 km^2 – up to 300m)
3. Eocene (e2a & e2b) Aquifer Unit – Composed of Karstic Limestone (110 km^2 – up to 250m)
4. Cretaceous (Sannine – Maameltain) aquifer units – Composed of Karstic Limestone (564 km^2 – up to 900m)
5. Jurassic(Kesrouan) Aquifer Units– Composed of Karstic Limestone (124 km^2 – up to 1000m)

4.1.1 AQUIFERS

The main aquifer units along with their hydrogeological properties (transmissivity, hydraulic conductivity, storage coefficient) are described below from youngest to oldest, and presented in **Table 4–1**:

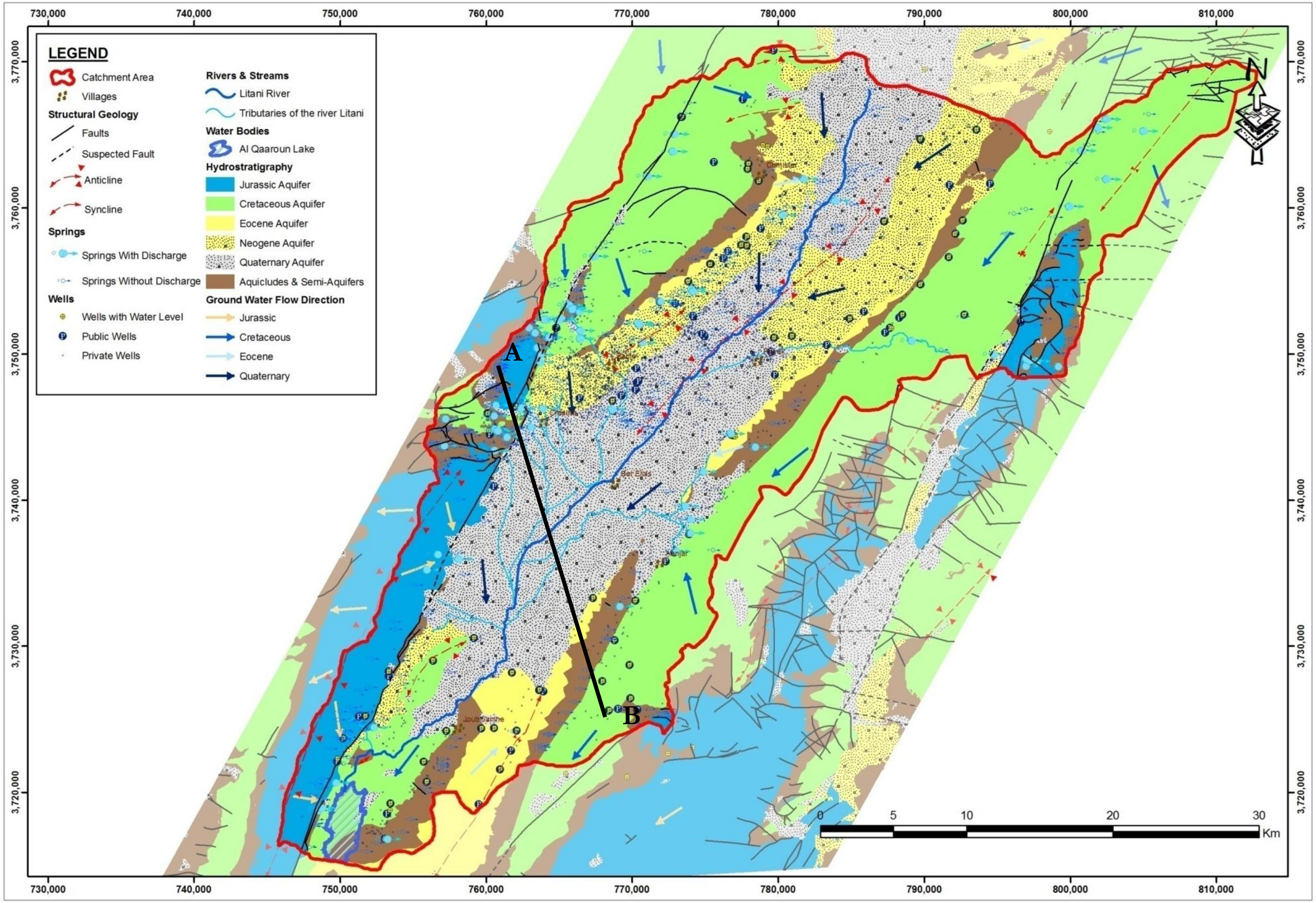


Figure 4-2 Hydrostratigraphic Units in the Study Area

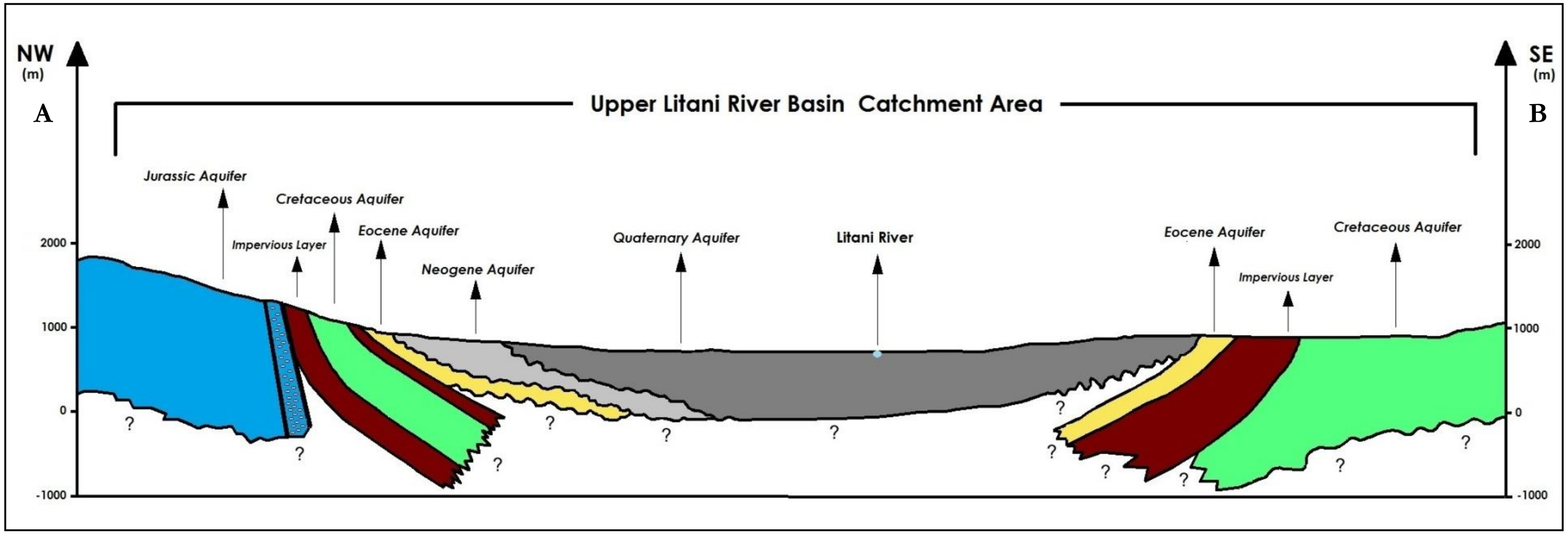


Figure 4-3 Hydrostratigraphical Cross-section of the Study Area

Table 4–1 Major Aquifers in the Upper Litani Basin Along With their Hydrogeological Characteristics

Aquifer Units	Lithology	Thickness	Transmissivity (m^2/s) – UNDP 1970	Transmissivity (m^2/s) – Pumping Tests	Surface Area (km^2)	% of Infiltration from Precipitation (UNDP, 1970
Quaternary Aquifer (Q)	Alluvial deposits (gravel, sand, silt and clay)	More than 500	10^{-4} to 10^{-3}	$3.4x10^{-4}$ to $2.0x10^{-4}$	415	~5
Neogene Aquifer (mcg/mL)	Sand, conglomerates, limestone and marls	Up to 300	Less than 10^{-3}	$1.3x10^{-6}$– $2.2x10^{-4}$	186	~5
Eocene Aquifer (e2b/e2a)	Nummulitic and cherty limestone, marly limestone and chalky marl	Up to 250	10^{-4}– 10^{-2}	$3.9x10^{-6}$– $2.9x10^{-3}$	110	38
Cretaceous Aquifer (C4-C5)	Alternating sequence of finely bedded limestone, marly limestone and dolomitic limestone	750-900	10^{-2} – 1	$3x10^{-4}$ – $9.15x10^{-3}$	564	41
Jurassic Aquifer (J4)	Limestone-Dolomitic Limestone	~1000	10^{-3} – 1	$2.35x10^{-4}$ – $1.6x10^{-1}$	124	41

4.1.1.1 QUATERNARY AQUIFER

Most of the wells completed in the Quaternary aquifer are located in the center of the Bekaa plain and have variable yields. The higher the content of fine grained materials of these deposits, the lower the well yield. Based on a field survey (IRG April 2012) the reported well yields from drillers in the area ranged from less than 5 l/sec to a maximum 15 l/sec, while the UNDP 1970 reported a maximum well yield of 10 l/sec. Three pumping tests were performed in the Quaternary deposits by ELARD in AREC, Forzoul, and El Marjin 2012. The calculated transmissivity ranged 3.4x10-4 m2/sec to 2.0x10-4 m2/sec. According to the UNDP 1970 report, the transmissivity values range between 10-4 and 10-3 m2/s. The UNDP (1970) reported a very low infiltration rate for the Quaternary Aquifer of 5%. Estimated infiltration rates of the various aquifers presented in the UNDP Study of 1970, tend to be significantly underestimated. Based on a current national study that was also launched by UNDP with a grant from the Italian Government, and executed by ELARD to update the 1970 UNDP study and re-assess the groundwater resources of the entire country, infiltration rates for the various groundwater basins were estimated to be higher than what was reported in the old study of 1970. The rate was calculated from the hydrological water balance equation:

$$\text{Precipitation} = \text{Infiltration} + \text{Evapotranspiration} + \text{Runoff}$$

The method calculated the evapotranspiration was calculated in two methods Turc and FAO Penman-Montheith methods, while the runoff was calculated based on the Curve Number and validating the results from gauging stations. The calculation was done for four consecutive years (2008 through 2012), and the infiltration rate of the Quaternary aquifer in the Bekaa was estimated at about 15%.

4.1.1.2 NEOGENE AQUIFER

The Neogene aquifer underlies the Quaternary deposits, which is also known as the Upper Miocene deposits and also outcrops in northeast; west and southwest areas of the study area. Based on a field survey (IRG April 2012) the reported well yields from drillers in the area ranged from less than 5 l/sec to as much as 30 l/sec, while the UNDP 1970 reported a yield of less than 30 l/sec. According to the UNDP 1970 report, the transmissivity values are less than 10^{-3} m^2/s. One Pumping test in the Neogene aquifer was reviewed by IRG April 2012 report (which reported a transmissivity value of 1.3×10^{-6} m^2/s. The UNDP (1970) reported infiltration rate for the Neogene Aquifer of 5%.

4.1.1.3 EOCENE AQUIFER

The Eocene aquifer 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 Louz areas down to Lake Qaaron. The Eocene underlies the Quaternary and Neogene aquifers. The reported well yields in the UNDP 1970 report reached more than 100 l/sec. According to the UNDP 1970 report, the transmissivity is relatively high, and ranges between 10^{-4} and 10^{-2} m^2/s. Eighteen pumping tests in the aquifer resulted in transmissivity values ranging between 3.9×10^{-6} m^2/s to 2.9×10^{-3} m^2/s (IRG April 2012 report). The UNDP (1970) reported infiltration rate for the Eocene Aquifer of 38%.

4.1.1.4 CRETACEOUS (SANNINE – MAAMELTEIN) AQUIFER

The Sannine – Maameltein aquifer is one of the most important aquifers in Lebanon, and is formed of developed karst with high secondary porosity. The Sannine – Maameltein aquifer is characterized by extremely high infiltration rates, whereby a great portion of the groundwater source of the basin comes from these mountains (snow melt, and high precipitation rates). The aquifer is highly karstified and is in direct contact with the Quaternary and Tertiary aquifers, at the base of the mountain flanks, acting as a source of groundwater recharge to these bounding and overlying aquifers. The well yields in the Sannine – Maameltein aquifer are reported to yield up to 150 l/sec, while the UNDP (1970) report indicated that the upper 100m which is in direct contact with the Eocene aquifer has low well yield and low transmissivity, while the lower strata has higher transmissivity and well yield values. Twenty five pumping tests were analyzed and the transmissivity values ranged between $3x10^{-4}$ to $9.15x10^{-3}$ m^2/s (IRG April 2012), while the transmissivity values indicated in the UNDP (1970) report ranged from 10^{-2} m^2/s to 1 m^2/s for the lower part of the aquifer. The UNDP (1970) reported infiltration rate for the Cretaceous Aquifer of 41%.

4.1.1.5 JURASSIC (KESROUAN) AQUIFER

The Kesrouan aquifer is one of the most important aquifers in Lebanon, and is formed of developed karst with high secondary porosity. The Kesrouan aquifer is characterized by extremely high infiltration rates, whereby a great portion of the groundwater source of the southwest part of the basin comes from these mountains (snow melt, and high precipitation rates). The aquifer is highly karstified and is in direct contact with the Quaternary and the Tertiary aquifers, at the base of the mountain flanks, acting as a source of groundwater recharge for these bounding aquifers. The well yields in the Kesrouan formation are up to 120 l/sec. The UNDP (1970) report indicated transmissivity values for the Kesrouan ranging from 10^{-3} m^2/sec to 1 m^2/sec with 5.2 x 10^{-2} m^2/sec as an average, with storage coefficients (storativity) ranging between $3.2x10^{-2}$ to $4.2x10^{-2}$. Fourteen pumping tests for the Jurassic aquifer were analyzed and the transmissivity values ranged from 2.35 x 10^{-4} to $1.6x10^{-1}$ m^2/sec (IRG April 2012). The UNDP (1970) reported infiltration rate for the Jurassic Aquifer of 41%.

4.1.2 LOW TRANSIMISSIVITY AQUIFERS AND AQUICLUDES

The catchment area has two (2) low transmissivity aquifers: the Chouf Sandstone Formation (C1) and the Mdairej Formation (C2b). The Chouf Sandstone formation contains substantial amounts of water but has a very low transmissivity estimated between 10^{-4} to 10^{-5} m^2/sec by UNDP 1970. The Mdairej formation contains high secondary porosity and developed karstic system, but due to its limited thickness, and location between two aquitards, its groundwater contribution is considered to be minimal.

The catchment area has five (5) impervious layers, the Bhannes formation (J5), the Abieh formation (C2a), the Hammana Marl (C3), the Chekka formation (C6), and the Lower Eocene (e2a). The following formations are low transmissivity and afford very low transmission of water across their boundaries.

4.2 SPRINGS

Based on the Army Topographic Maps 1/20,000, there are about 502 springs in the study area, some of which have dried up and no longer flow. **Table 4–2** summarizes the number of springs emerging from the geological formations in area; **Figure 4-4** shows the location of springs in the study area.

Table 4–2 Total Number of Springs Emerging from Different Types of Hydrostratigraphic Units

Geological Formation	Number of Springs
Kesrouan Formation (J4)	58
Chouf Sandstone (C1)	50
Abeih Formation (C2a)	26
Mdairej Formation (C2b)	42
Hammana Marl Formation (C3)	43
Sannine – Maameltein Formation (C4-C5)	40
Chekka Marl Formation (C6)	54
Lower Eocene (e2a)	5
Upper Eocene (e2b)	4
Neogene Deposits (mL & mL1)	66
Quaternary Deposits (Q)	50
Total Number	xxxxx

Most of the springs are located on the boundary between Quaternary and Jurassic formation (Amiq Spring) or Cretaceous formations (Anjar and Chamsine Springs), or along fault boundaries (Berdouni). The available discharge data for springs dates back to the UNDP (1970) report, with limited new data since that time.

On the east side of the basin, there are three major springs, Anjar Spring, Chamsine Spring, and Yahfoufa/El Gaida Spring that all emerge from the Cretaceous Aquifer. Based on the UNDP (1970) report, the Eocene Aquifer on the eastern side of the basin used to be the source for major springs, three of which (Ras El Ain (Turbol), El Faouar, and Ain El Beida) have dried up. On the western side of the basin there are five major springs, Berdaouni, Chtaura, Jdita, Ammiq, and Kab Elias. Out of the five springs, four discharge from the Jurassic aquifer and only the Berdouni Spring discharges from the Cretaceous aquifer.

There are no recent comprehensive continuous discharge measurements of springs and the available spring discharge measurements are limited to a single yearly measurement or bi-yearly measurements, and most of the measurements are performed by Litani River Authority (LRA), Figure 4-4 shows the location of the springs with discharge data. The most reliable and continuous measurements date back to the UNDP 1970 report, where continuous measurements were taken and the values. The recorded values by UNDP will be considered as an indication of the groundwater level in the 1970. **Table 4**–3 presents measured springs in the ULRB and their relative values. **Figure 4-5** shows the location of the UNDP (1970) springs. The three springs (Ras El Ain, Faouar, and Ain El Beida) that used to flow in the 1970's from the Eocene aquifer, no longer flow due to decrease in groundwater levels caused by excessive irrigation pumping from the Eocene Aquifer in the eastern side of the basin between the ICARDA Farm and Anjar.

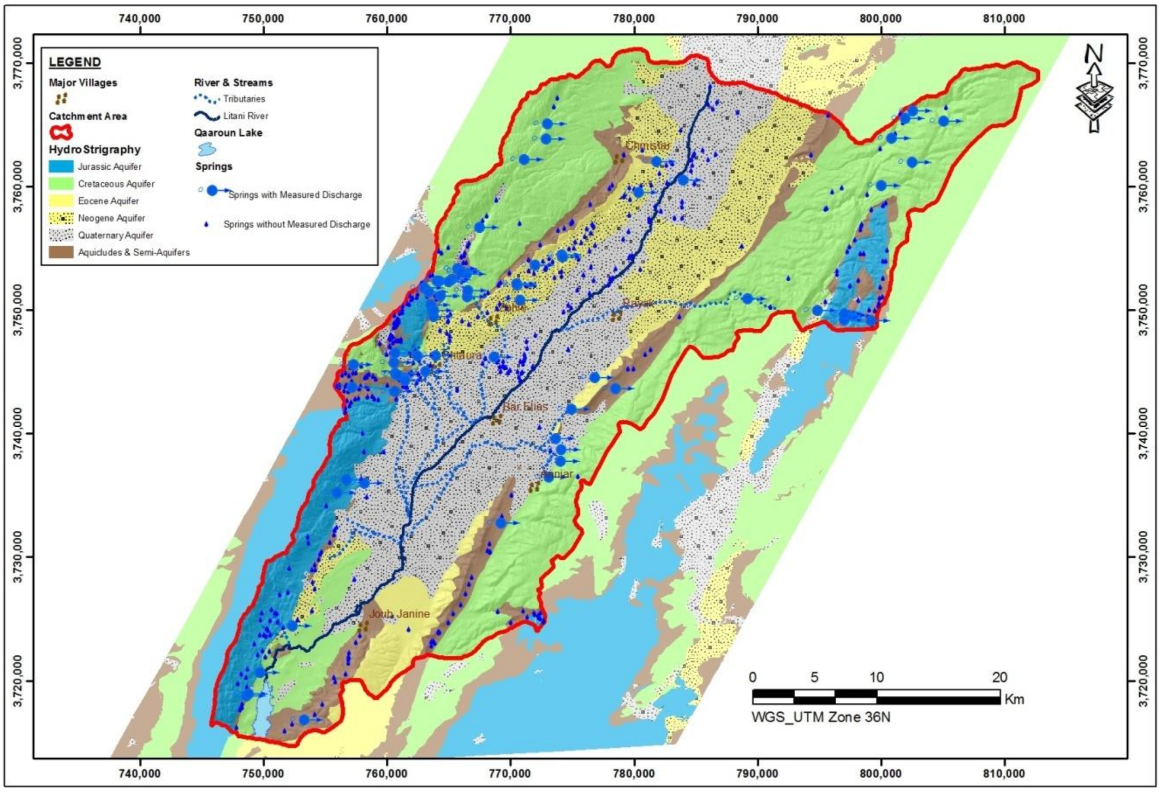


Figure 4-4 Location of Springs with Discharge Data

Table 4–3 Discharge of Springs (UNDP 1970)

West Side Springs	Aquifer	Discharge (MCM/Yr)	East Side Springs	Aquifer	Discharge (MCM/Yr)
Berdouni	Cretaceous (C4)	44.51	**Chamsine**	14.5	Cretaceous (C4)
Chtaura	Jurassic (J4)	14.5	**Anjar**	63.5	Cretaceous (C4)
Jdita	Jurassic (J4)	4.14	**Ras el Ain**	7.04 (presently dry)	Eocene
Ammiq	Jurassic (J4)	22.44	**Faouar**	3.64 (presently dry)	Eocene
Kab Elias	Jurassic (J4)	21.51	**Ain el Beida**	8.21 (presently dry)	Eocene

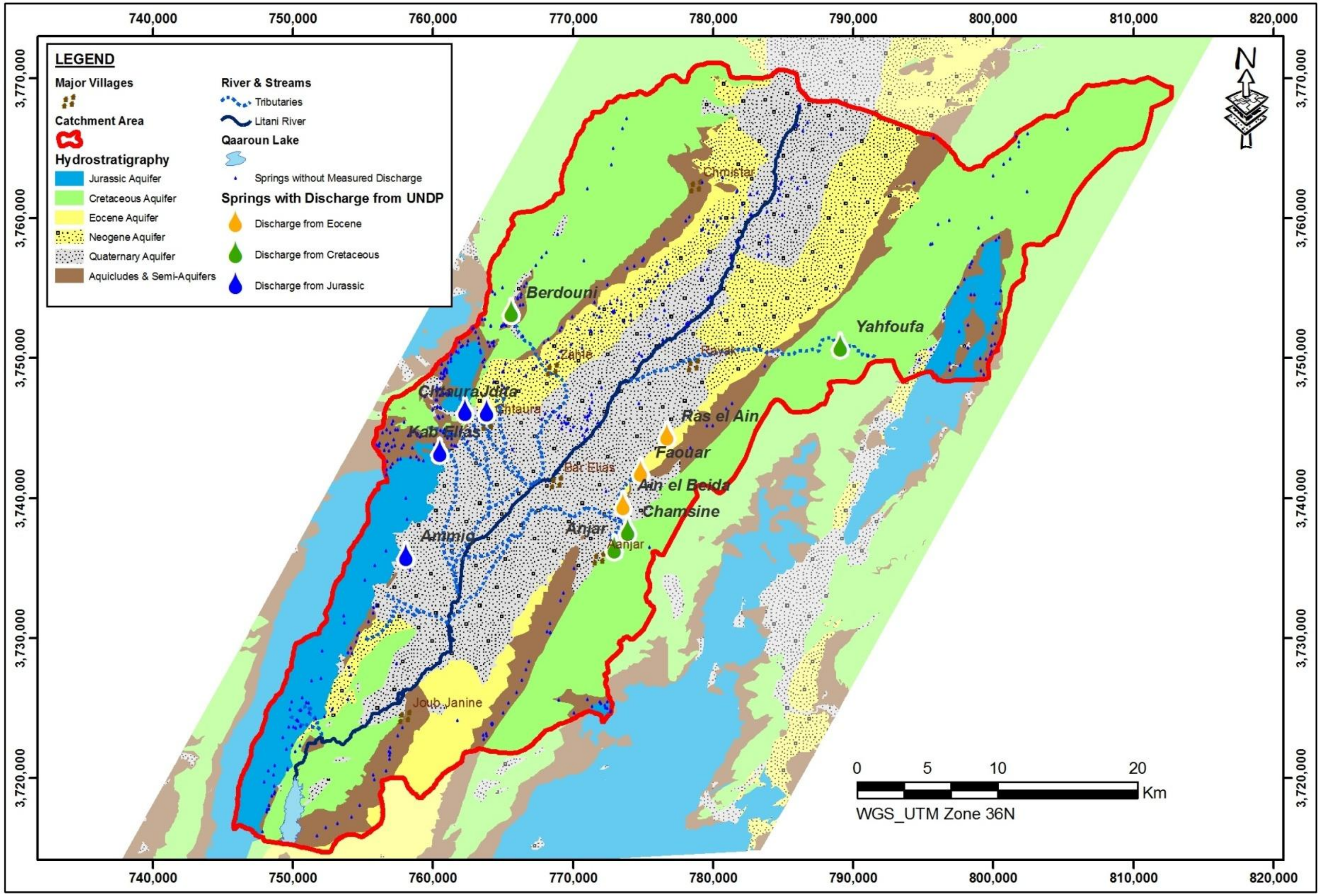


Figure 4-5 Location of Springs with Discharge (UNDP, 1970)

5. GROUNDWATER DATA

5.1 GROUNDWATER MEASURMENTS

Limited historical groundwater level data are available for the proper generation of groundwater level contour maps. Prior to 2011, there was no groundwater monitoring network in the basin. The first groundwater monitoring network was recently installed by IRG as part of the Litani River Basin Management Support Program and consists of a network of 14 wells, in which pressure transducers probes, with built in data loggers were installed for continuous groundwater level measurements in the Upper Litani Basin.

The available historical data dates back to the UNDP 1970 report, where groundwater level contour lines for the Upper Litani River were mapped with a 5m contour interval. When the contour lines drawn by the UNDP were compared to the recent topographical maps, it was found that the groundwater levels in parts of the basin are a few 10's of meters above the ground elevation, indicating flooding in the basin..

Two field surveys was conducted in November 2010 and June 2011, under the supervision of Litani River Basin Management Support Program on over 200 wells in the Quaternary, Neogene, Eocene, Cretaceous and Jurassic Aquifers in the study area. In addition, local drillers were interviewed regarding historical changes in groundwater levels in the basin. The field survey resulted in the following observations:

- In the northern part of the basin, in the Quaternary Aquifer, water levels in two wells were measured and were found at 7m and 14m below ground surface. According, to the local well owners and the drillers, the water levels have not changed significantly, since the construction of the wells.

- In the central part of the basin near Talia in the American University of Beirut (AUB) Farm, in the Neogene Aquifer, two wells were measured and the water levels were 21m and 26m below ground surface. According to the local drillers, the water level has dropped almost 20+ meters since 1970's. The local drillers also indicated that the water level in some areas in the Neogene have seen a water level drop of more than 50m since the early 1980's.

- In the central part of the basin, in the Quaternary aquifer, close to the Litani River, the drillers reported low well yields and shallow water levels.

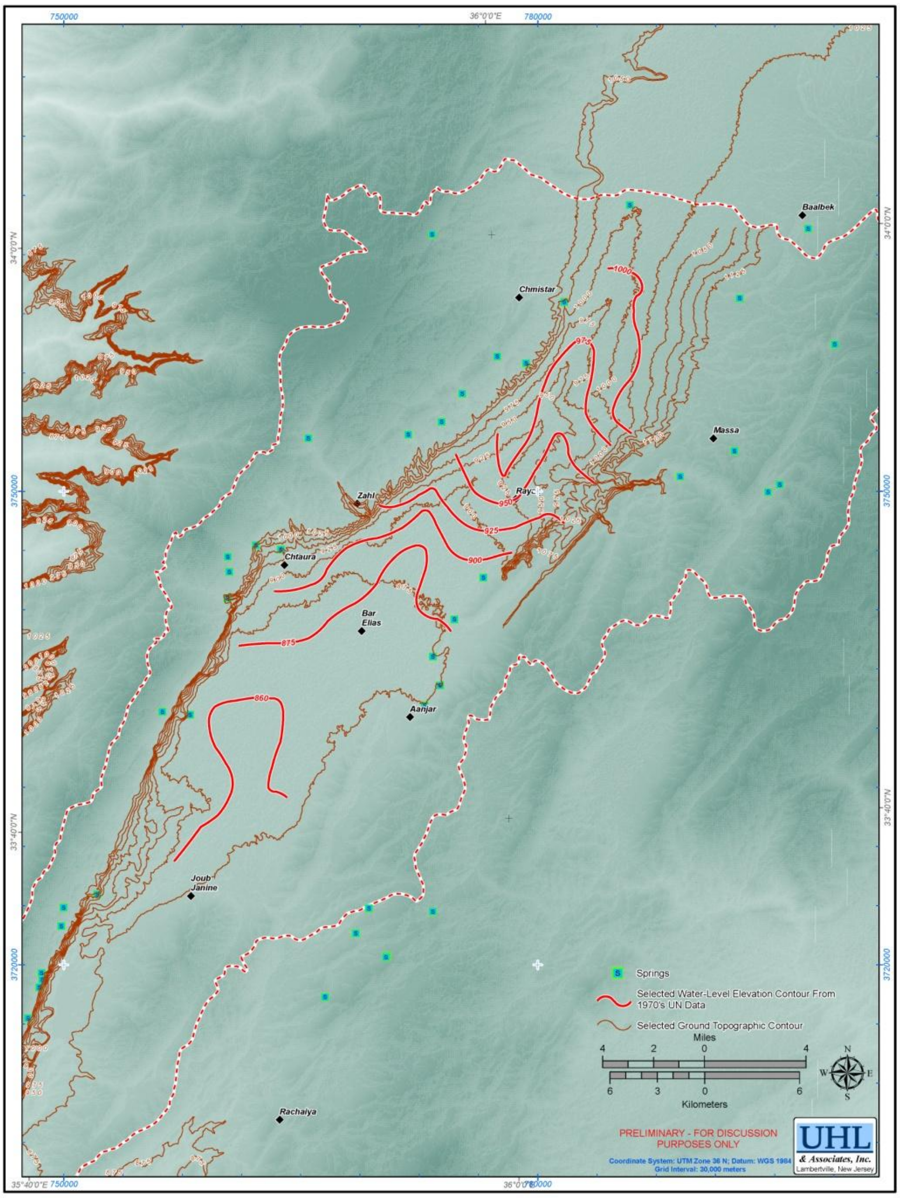


Figure 5-1 Comparison Between UNDP 1970 Ground Water Contour Lines and Ground Elevation

- In the eastern part of the basin near Terbol and South of Anjar it is reported that there has been extensive development in the Eocene and Cretaceous aquifers. The water level in an irrigation well at the International Center for Agricultural Research in the Dry Areas (ICARDA) has dropped more than 30m in the past 10 years. The drop in water level has dried up the nearby Ras el Ain Spring. Two other nearby springs (the Faouar and Ain el Baida Springs) have also dried up.
- In the southern part of the basin near Joub Jannine and Lake Qaaroun, in the Eocene and Cretaceous aquifers, the water levels have not changed significantly since the area is

being supplied by the Canal 900. The water level was measured in one well and was found to be 33m below ground surface, which is almost at the same level as the Qaaroun Lake.

- In the southwest side of the basin near Ammiq, in the Jurassic and Cretaceous aquifers, the water level was reported by drillers to be around 50m to 60m below ground surface, with limited knowledge about historical water levels.

Two field water level measurement surveys were conducted, the first in October/November 2010 at the end of the dry season, and the second in June 2011 at the end of the wet season. The water level measurements were used to:

- Map the groundwater flow direction in the aquifer systems.
- Record the change in water level between the dry and wet seasons.
- Map the cone(s) of depression that are caused from extensive pumping.
- Understand the interaction between aquifers.

Figure 5-2 and **Figure 5-3** show the interpolation of the groundwater levels measured in November 2010 and June 2011 respectively. As the maps show, groundwater in the basin is moving from the eastern and western flanks towards the center of the basin, towards the Litani River, and from north to south to reach the lowest elevation near Qaaroun Lake. The groundwater level maps were developed for the Quaternary, Neogene, and Eocene Aquifers only (there are wells completed in the Cretaceous that were measured and used in the maps). The water level in the eastern flanks of the mountain near Baalbeck reaches a high of 1100m above sea level; while on the western side of the basin the water level reaches a high of 1070m. The water level in the center of the basin decreases in the southern direction, from a high of 1025m in the northern part to reach 850m near Qaaroun Lake.

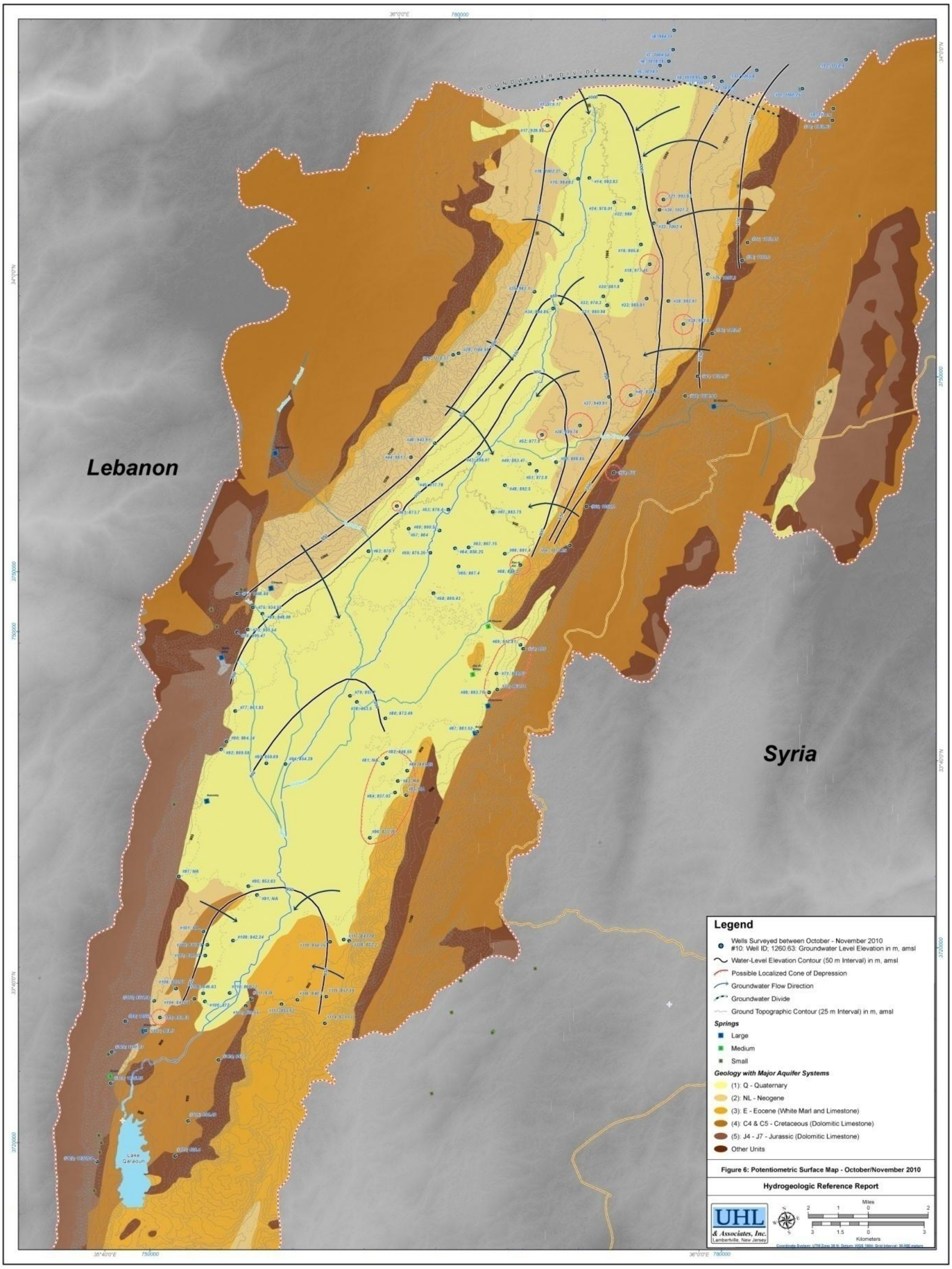


Figure 5-2 Generated Ground Water Contour Lines for November 2010

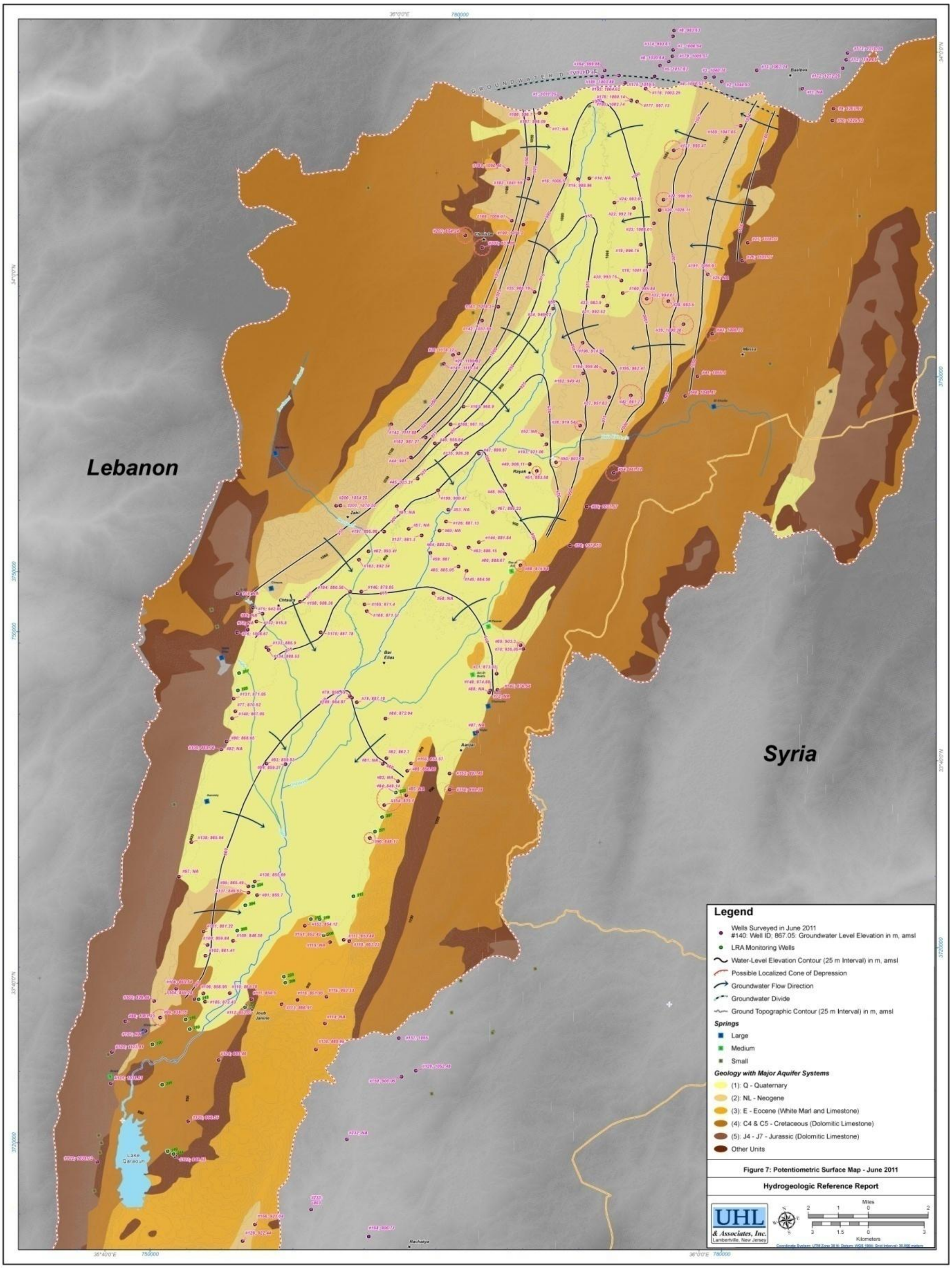


Figure 5-3 Generated Ground Water Contour Lines for May/June 2011

5.2 OVERVIEW OF PREVIOUS HYDROGEOLOGICAL INVESTIGATIONS

Apart from the current project and the supplementary reports prepared by the Litani River Basin Management Support Program, three projects focused on the hydrogeology (groundwater) of the ULRB. In chronological order, the projects are the UNDP nationwide assessment of the groundwater (1970), DAI Groundwater vulnerability Mapping (2003 & 2005), and the JICA (2003) study.

The UNDP (1970) groundwater study was the first nationwide evaluation of the groundwater resources. The study is considered the baseline for any hydrogeological study in Lebanon, with valuable data collected from 1960 until 1970. The collected data ranged from springs discharge, rivers discharge, groundwater level measurements, chemical analysis of groundwater, and groundwater basin delineation.

One of the most valuable contributions of the UNDP (1970) to our current study is the springs discharge measurements. In the UNDP (1970) report, ten major springs were identified in the ULRB and their respective discharges were measured. Out of the ten springs identified, three (3) springs do not flow anymore. The estimated discharge from the ten springs in the 1970 timeframe accounted for 205 MCM/Yr, while small springs were estimated to discharge 10 to 20MCM/year. The ten springs that were identified by the UNDP (1970) all discharge from the carbonate aquifers (Eocene, Cretaceous, and Jurassic Aquifer Units).

The DAI groundwater vulnerability mapping (2003 & 2005); also known as the BAMAS project; identified and assessed, and suggested the water quality and pollution extent for the ULRB and Lake Qaaroun, and provided different scenarios for the remediation for the ULRB. The DAI project also provided an environmental plan to solve the spread of the pollution.

The DAI/BAMAS project developed a groundwater vulnerability model to assess the effects of land use practices and contamination sources in the basin. The model did not simulate groundwater level or groundwater flow direction, but rather delineated the basin based on extent of the spread of the pollution in the basin. The study also extended the model domain beyond the physical basin boundaries of our current project in the east-south boundary, to include a part of the Hasbani Basin. The following has been proven wrong by the LRBMS work through the development of potentiometric surface maps, constructed from field derived water-level measurements.

The DAI (2003 & 2005) project estimated that groundwater recharge to the basin is in the order of 388 MCM/year.

The JICA (2003) study developed a water balance for the upper basin and estimated the groundwater recharge to be 484 MCM/yr.

Table 5–1 presents the estimated recharge calculated by the mentioned studies.

It should be noted that a national project is being implemented currently by UNDP, and executed by ELARD with a Grant from the Italian Corporation, which consisted of updating the UNDP study of 1970 and re-assessing the groundwater resources of the entire country, in light of the new data, studies, research, conducted since that time.

Table 5–1 Estimated Recharge to the Upper Litani Basin by Different Studies

Report	Estimated Groundwater Recharge (MCM)
UNDP 1970	220
DAI/BAMAS (2003 & 2005)	388
JICA (2003)	484

6. CONCEPTUAL MODEL OF THE STUDY AREA

This section presents the conceptual model of the Upper Litani Basin based on an assessment of available data and information. The conceptual model development is the exercise that precedes the numerical simulation (model run) and comprises the delineation of the model geometry (main aquifers units and boundary conditions) and the parameterization of the model (data series and initial hydraulic parameters). Due to the complexity of the hydrogeological system and limited available data for some of the aquifer units, a simplified equivalent model representing only the Quaternary, Neogene, and Eocene aquifers has been constructed for practical purposes.

Based on the adopted geometry of the aquifer and the available data, it is possible to develop estimates of the magnitude of inflow and outflow within the basin.

6.1 MODEL GEOMETRY AND PARAMETERIZATION

The Model Geometry is mostly defined by the different layers that represent the modeled system. These include the topography, the types of aquifer units (mainly the bottom to aquifers; thicknesses of units subtracted from topography) in the study area, and the delineation of boundary conditions. The main aquifer units in the Upper Litani Basin are listed in section 4, Hydrogeology. The Quaternary, Neogene, and Eocene aquifers were represented in the model. as most of the groundwater abstraction is from these three aquifers The detailed geological description of all of the layers is found in Appendix A.

6.1.1 BOUNDARY CONDITIONS

Boundary conditions were delineated based on the extent of the Quaternary, Neogene, and Eocene Aquifers. The boundary of these three aquifers is limited from the east and west to the flanks of the mountainous structures, and from the north by a no flow boundary condition - the groundwater-divide between the Litani and Orontes river basins. From the south the boundary was delineated by the thinning of the Quaternary and Eocene Aquifers, at the contact with the outcropping Cretaceous formations. The underlying boundary, Chekka Marl, does not transmit water and was considered to be a no-flow boundary

6.1.2 GRID

The modeled area was represented by a 3D grid, where the grid size is 500m by 500m cell in the horizontal direction and varies in the vertical direction based on the layer thickness. The grid was rotated 27degrees from the north in the direction of the groundwater flow. The modeled area was represented by 148 columns and 72 rows, with 2801 active cells.

6.1.3 HYDROGEOLOGICAL PARAMETERS

The main parameters that were input into the model consist of data series and fixed physical parameters as follows:

- Hydrogeological Parameters:

They consist mainly of Hydraulic Conductivities which are estimated based on the transmissivity values for each aquifer and the aquifer thickness that is to be modeled (note that hydraulic conductivity is equal to transmissivity divided by aquifer thickness). The initial values for hydraulic conductivity were adjusted during the calibration phase of the model based on the groundwater head distribution in a steady state condition. Values for Storativity and specific yield were adopted from literature values (Johnson, 1967).

- Data Time Series:

Data time series consists of time series input data, such as annual recharge to aquifer (computed based on percentage from precipitation), groundwater head distribution for calibration purposes, annual averages of abstraction from pumping wells, and annual averages of discharge from springs in spite of the scarcity of spring flow measurement data, especially for the monitored time interval. Other time series included infiltration from rivers and irrigation return flows.

6.2 PRELIMINARY WATER BALANCE

Different hydrogeloglical studies of the Upper Litani River Basin resulted in different water balance for the basin. The difference in the infiltration rate to the basin ranged from as low as 220 MCM/year in the UNDP 1970 study to 480 MCM/year based in the JICA (2003) report. The following difference is attributed to the approach adopted for calculating the infiltration rate especially due to the complexity in quantifying the recharge rate in the karstic systems.. The water balance for the following model is based on the recent study done by ELARD 2012 for the UNDP, to assess the national groundwater system. In the study the water budget calculation and infiltration rate to the aquifers is based on the conservation of mass, where Inflow to the system minus the Outflow from the system should be equal to the change in storage.

$$Inflow - Outflow = \pm \Delta S$$

6.2.1 INFLOW

Inflow to the aquifer includes infiltration from precipitation (I) and other components that are significant in the study area including irrigation return flow (RF); infiltration from the Litani River and its tributaries (RI); and input or flux from other aquifers (AI).

$$Inflow = I + RF + RI + AI$$

6.2.1.1 INFILTRATION

Based on the on-going UNDP study, conducted by ELARD (2013), to update the UNDP Study of 1970, the infiltration rate for the national groundwater basins are being updated, including the Quaternary, Neogene, and Eocene Aquifers in the Upper Litani River Basin. . The on-going study is based on a detailed investigation of the different water budget factors for the last four (4) years. Based on the new study, the average value for the infiltration rate for the Quaternary and Neogene was found to be14 to 15%, with a total estimated infiltration of about 49.4 MCM for the hydrological year 2010/2011. The infiltration rate for the Eocene aquifer in the Upper Litani Basin was divided into two (2) sections, the western section (near Zahle) and the eastern section (near Joub Janine). The infiltration rate for the western Eocene section was found to be 24%, while the infiltration rate for the eastern Eocene section was found to be 57%. The change in infiltration rate for the Eocene is attributed to the level of development of the karstic systems, slope, vegetation cover, and undeveloped area.. For the hydrological cycle 2010/2011, the total infiltration for the Eocene aquifers was estimated at about 3.6 MCM in for the western basin, and 29.7 MCM/year for the eastern section with a total infiltration of 33.3 MCM.

Table 6–1 Infiltration Rate

Aquifer	Infiltration Rate (%)	Total Infiltration (MCM)
Quaternary/Neogene Aquifer	15	49.4
Western Eocene Aquifer	24	3.6
Eastern Eocene Aquifer	57	29.7
	Total	**82.7**

6.2.1.2 RETURN FLOW (RF)

The return flow (the excess water seeping from pumping)to the system will be considered as a percentage of the water used for irrigation in the study area. Since the irrigation is usually done during summer months when evapo-transpiration is high, the return flow is estimated to be 10% of the abstraction from wells.

6.2.1.3 RIVER INFILTRATION (RI)

The Litani River acts to either recharge to the underlying aquifer system or receive discharge from the aquifer systems, depending on which section of the Litani is being studied. There are no studies that dissect the Litani River into sections where it acts as a "losing stream" (recharges the aquifer) or as a "gaining stream" (is receiving discharge from the aquifer), but with the current abstraction rates from the wells in the Upper Litani Basin and the drop in the groundwater levels, it is expected that the Litani River is generally acting as a losing stream and recharging the underlying aquifer(s). Accordingly, the Litani River and its tributaries were estimated to provide a net income to the aquifer systems of 5% of the total discharge of the river. The cumulative discharge from the Litani River is estimated to be 200 MCM/year. Therefore, the recharge from the river infiltration is estimated to be in the range of 10 MCM/Year.

6.2.1.4 AQUIFER INTERACTION (AI)

The interaction between aquifers is limited to the mountain flanks, where there is a direct contact between the Quaternary/Neogene/Eocene aquifers and the Cretaceous or Jurassic Aquifers. No detailed studies have quantified groundwater flux from the bounding carbonate rock aquifers to the Quaternary, Neogene and Eocene aquifers, and their recharge contribution to the Quaternary, Neogene and Eocene aquifers was estimated for model calibration.

6.2.2 OUTFLOW

The outflow includes abstraction from wells and spring flow as follows:

$$Outflow = Qs + Qw$$

Since the model only represents the Quaternary, Neogene, and Eocene aquifers; the outflow from springs will be minimal and was not a consideration in the modeling. The Quaternary and Neogene do not have major springs The springs emerging from the Eocene (as per the UNDP 1970 report)no longer flow due to the drop in groundwater levels in the Eocene Aquifer on the east-central side of the basin.

The only abstraction from the aquifer systems is from wells. According to a detailed survey of all public and licensed private wells in the study area, 107 public wells, and 1102 private licensed wells were surveyed in the study area. In addition to the licensed private wells, it is estimated that the unlicensed wells may be 5 times more; however, no detailed studies were done to map the unlicensed wells. The expected abstraction from wells was estimated to be in the range of 110 MCM/year which was used as a benchmark when calibrating the model.

7. MODEL CALIBRATION

7.1 STEADY STATE

The model was calibrated based on the November 2010 groundwater level measurements. The calibration was done by adjusting the hydraulic conductivity, recharge from precipitation, and river-aquifer interchange. During the calibration, an error of ±5m was considered acceptable and the calibration resulted in a root mean square error of 4.4m. **Figure 7-1** shows the locations of observation wells used in the calibrated model. The bar next to the wells indicates the error in each well, a bar that is colored green indicates an error of less than 5m, while a bar that is yellow indicates and error between 5 and 10m. The measured and computed heads for the used observation wells are found in **Appendix C**.

The hydraulic conductivity ranged from a maximum of 10 m/day to minimum of 0.002 m/day and **Figure 7-2** shows the distribution of hydraulic conductivity values in the basin used in the model. The hydraulic conductivity was highest in the southern part near Joub Jannine where the area is mainly composed of the Eocene formation, while the hydraulic conductivity is lowest in the northern section where the Neogene is present. The change in hydraulic conductivity is attributed to the difference in lithology. The Neogene contains more marl than the Quaternary, and is more compacted resulting in a lower hydraulic conductivity.

Three zones of recharge were delineated. The zones were based on the outcropping geological formation where the Eocene, Neogene, and Quaternary Aquifers had respective values 0.0006 m^3/day, 0.0004m^3/day, and 0.00025 m^3/day respectively. The recharge rate is multiplied by the area of each zone, and then multiplied by the number of days in the year to give the annual water budget of MCM/year. **Figure 7-3**shows the distribution of the recharge rates in the modeled area.

The total river – aquifer interaction is estimated to be in the range of 10 MCM/year. Accordingly, the river conductance was calibrated to reach the following value. The Litani River conductance was modeled at 0.2 m^3/day. The river recharges the groundwater in the upper section of the ULRB (at a rate of 8.3 MCM/yr.) , while in the lower section of ULRB the river is being recharged by the groundwater (at a rate of 14.5 MCM/yr.). **Figure 7-4** shows the location of the Litani River and its tributaries in the model.

The water budget for the steady state model is presented in **Table 7**–1. As per the simulated model the abstraction from wells is expected to be around 112 MCM, while the total recharge from precipitation to the system is expected to be 85 MCM. The income from other aquifers, such as Jurassic and Cretaceous, is expected to be 24 MCM.

Table 7–1 Water Balance for the Steady State Model

Source	Input (MCM)	Output (MCM)	Total (MCM)
Wells	0.0	112.3	-112.3
River	11.7	18.7	-7.0 ??
Recharge	85.4	0.0	85.4
Return Flow	10.2	0.0	10.2
Aquifer Interchange	23.7	0.0	23.7
Total	131.0	131.0	0.0

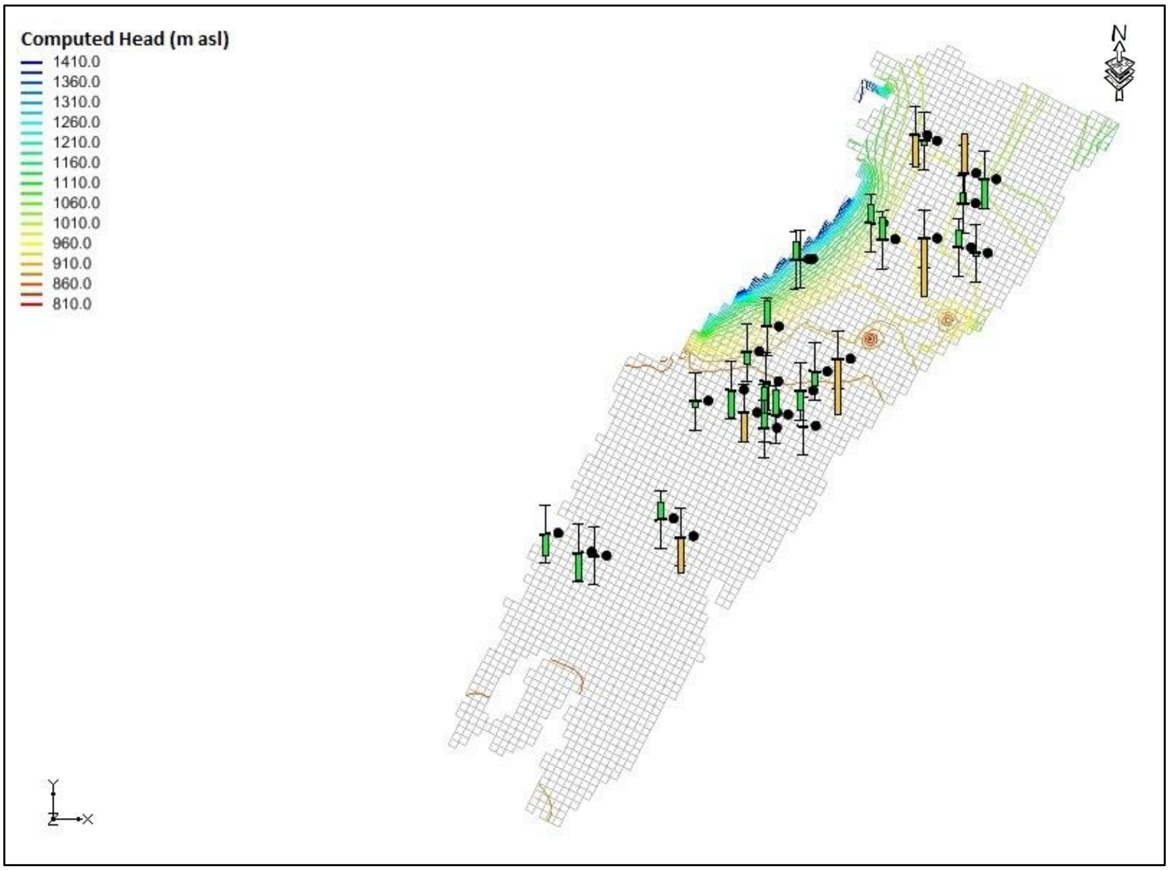


Figure 7-1 Generated Ground Water from Model and Error in Observation Wells

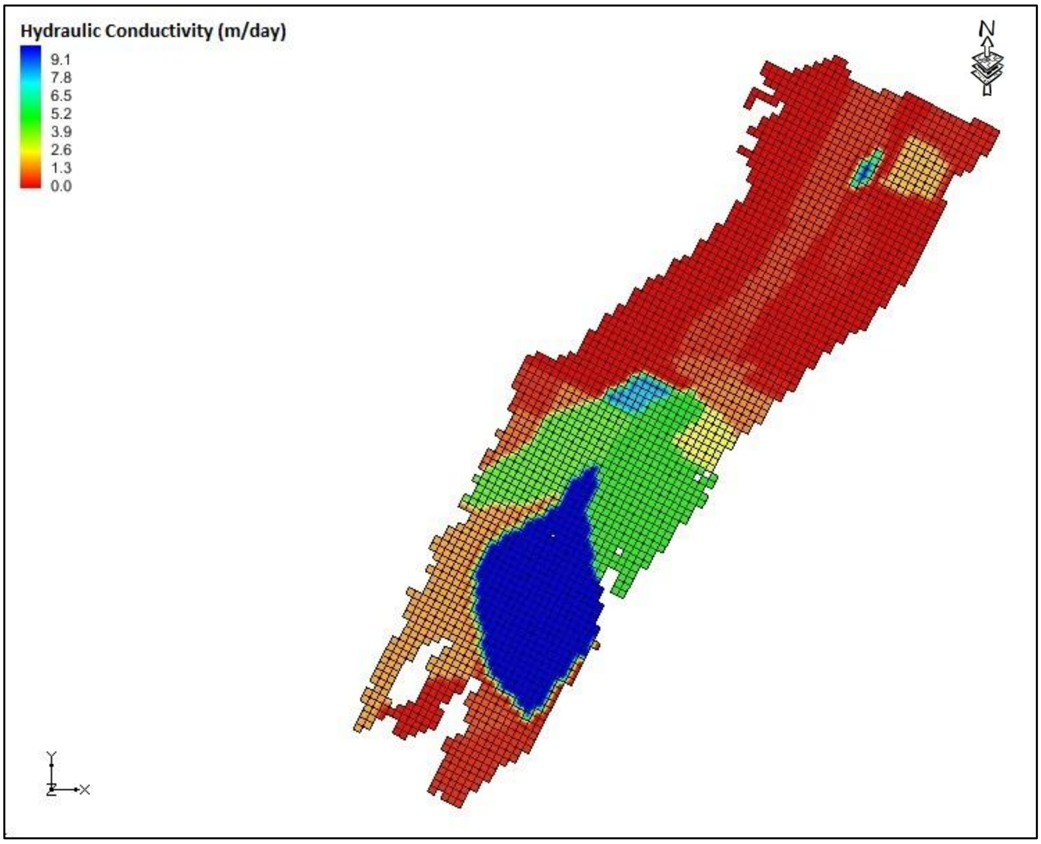


Figure 7-2 Distribution of Hydraulic Conductivity

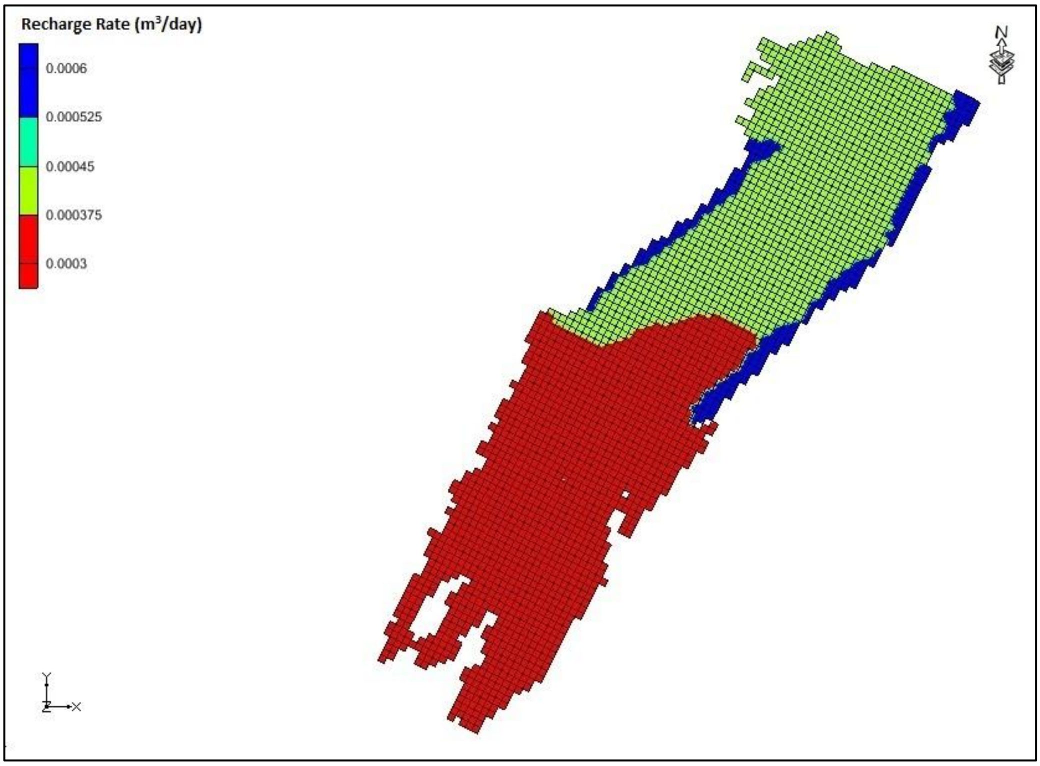


Figure 7-3 Distribution on Recharge Rate

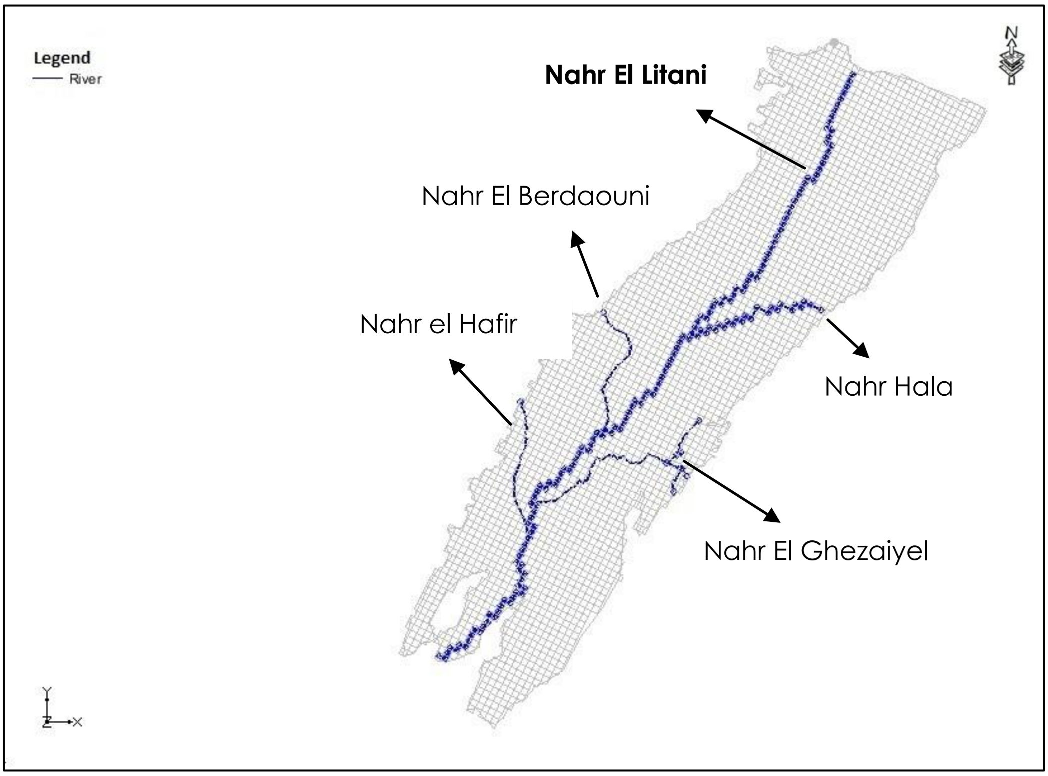


Figure 7-4 Digitization of the Litani River and its Tributaries

7.2 TRANSIENT FLOW

The model was also calibrated in transient flow to depict the response of the model under variable conditions and calibrate the values of specific storage and specific yield. The model was given the starting head calculated upon steady state for November 2010. The model was run on a monthly periods until May 2011 to simulate the effect of recharge and abstraction in different seasons. The recharge was simulated from November until the end of March. The abstraction/pumping was estimated to be 10% in the wet/winter season and 90% in the dry/summer season.

Specific storage and specific yield were varied to check the model's sensitivity to these parameters. The literature values for specific storage ranges from $10^{-3}m^{-1}$ to 10^{-7} m^{-1}. The specific storage in the model was changed to check the sensitivity of the model to this parameter. The specific storage in the model was varied from 10^{-1} m^{-1} to 10^{-9} m^{-1}, and the model had a minimal response to the change, accordingly the specific storage was considered to be 10^{-4} m^{-1}, which is an average value as reported in Batu, V. (1998).

The model's sensitivity to specific yield was also tested, where simulations with specific yield ranging from 0.3 to 0.05 were conducted. The response of the model to the specific yield was also limited, where the water level barely changed. Accordingly the specific yield was given the literature value of 0.1.

The root mean square error in calibrating the transient model using the literature values for the specific storage was achieved by dividing the abstraction between 10% in the wet/winter season, and 90% in the dry/summer season resulting in an RMS error of 7.9m. The following error is considered acceptable due to the limited information.

7.3 SENSITIVITY ANALYSIS

The aim of the sensitivity analysis of a model is to track the affect of each parameter on the model results. Each parameter was increased and decreased by 20% with respect to the values reached after calibration in the steady state run. The parameters that were varied included: hydraulic conductivity, recharge, and pumping rates. The reaction of the model was measured using the root mean square error (RMSE) - the RMSE for the calibrated steady state was 4.42m which is taken as a bench mark for comparing other values.

Table 7–2 shows the affect of each parameter on the model which was based on the RMSE. E.g., a change in a parameter resulting in an error less than 10m was considered as a low affect parameter, an RMSE error of 10 to 20 m was considered medium affect parameter, and an error above 20 m as high affect parameter. Accordingly, the hydraulic conductivity has a medium affect, and the pumping rate and recharge has a high affect.

Table 7–2 Parameters Used in the Sensitivity Analysis and the Response of the Model

Parameter	Range	RMSE (m) – Increase in 20%	RMSE (m) – Decrease in 20%	Effect of Parameter
Hydraulic Conductivity (m/day)	10 – 0.002	11.28	17.03	Medium
Recharge (m^3/day)	0.0006 – 0.00025	21.51	34.63	High
Pumping Rate (m^3/day)	110 - 250	42.41	22.6	High

8. PROJECTIONS

The model was utilized to simulate historical groundwater levels (from the 1970's) and projected groundwater levels, based on four (4) different scenarios.

8.1 HISTORICAL WATER LEVELS – 1970

The historical water level trend of 1970 was reproduced using the model to simulate the water levels in the 1970s. This simulation also aimed at assessing the water budget at that time (Table 10-1). Due to the lack of data, and the inaccuracy in the water levels generated by the UNDP 1970, two (2) types of controlling factors were used. The first was to simulate the groundwater level in the three monitoring wells measured in the 1970s that are located in the north, eastern, and middle of the model area. The second was to simulate the past measured discharge (1970) of the three springs in the Eocene that have dried up since then. This would indicate that the groundwater levels generated are close to the historical groundwater levels in the 1970's. **Figure 8-1** shows the location of the wells and springs used for the calibration of the historical water levels. The wells used for the calibration are located in the north (Quaternary Formation), the east (Eocene Formation), and the middle (Neogene Formation) of the modeled area.

The 1970 model condition was reproduced by gradually decreasing the extraction rate from private wells, while keeping the other parameters fixed (such as recharge, river/aquifer interchange, income from other aquifers, etc). The model was considered to be matching the hydrological condition of 1970 when the difference between the observed and calculated water levels in the three observation wells were less than 2 m, and the difference between the calculated discharge rates of the three Eocene springs and those measured in the UNDP study of 1970 were within 20%. The matching was achieved with a simulated total extraction rate of 36.7 MCM for 1970. In comparing the total extraction rate obtained from the model that simulated the 1970 condition, with that of 2010 (110 MCM/yr.), a total increase of about of 200% is noted, with a yearly average increase of 1.8%

The decrease in the extraction rate from wells also affected the river – aquifer interchange, due to an increase in the water levels in the aquifer systems. The increase in water levels resulted in the Litani River and its tributaries becoming a gaining river (i.e. the aquifer is recharging the river) . The following would result in a higher base flows in the Litani River.

The change in the water levels between 1970 and 2010 was monitored in 13 observation points (wells) in the model. The observation points were dispersed to be representative of the modeled area. **Figure 8-2** shows the location of the 13 points and **Table 8–**2 and **Figure 8-3** indicate the amount of drawdown in each observation point, and **Figure 8-4** is a map showing the change in water level from 1970 till 2010. As the table and figure show, the drawdown in the aquifer system reached up to 40m from 1970 till 2010 with an average drawdown in the entire basin equal to 14m.

The maximum drawdown in the basin occurred along the north western boundary near Temnine and along the north eastern boundary near Britel and Saraain. The following two areas were highly affected due to the low hydraulic conductivity. The minimum drawdown occurred in the middle of the basin, along the Litani River, and in the southern part of the modeled area. The limited drawdown in middle of the basin is attributed to the presence of the Litani River which acts as a stabilizing parameter for groundwater levels due to recharge. As for the southern section of the study area, the drawdown was minimal due to the limited groundwater abstraction as the area is supplied by the LRA through the Project Canal 900, in addition to wells supplying water from the nearby Jurassic aquifer.

It should be noted that the projected groundwater levels are a first attempt to generate previous water levels, the results are based on available data and reasonable assumptions, and additional data and a more refined model would allow more accuracy.

Table 8–1 Water Balance for the 1970 Model

Source	Input (MCM)	Output (MCM)	Total (MCM)
Wells	0	36.7	-36.7
River	7.4	43.0	-35.6
Recharge	85.2	0	85.2
Return Flow	3.3	0	3.3
Springs	0	18.7	-18.7
Aquifer Interchange	23.7	0	23.7
Storage	0	21.2	-21.2
Total	119.6	119.6	0

Table 8–2 Computed Water Level in Observation Points in the Model Between 1970 and 2010

Source	Computed WL 1970 (m)	Computed WL 2010 (m)	Drawdown in WL (1970 – 2010)
Kfar Dane	1044.5	1035.3	9.2
Douris	1068.0	1051.6	16.4
Chmistar	1185.7	1145.4	40.3
Britel	1020.5	1005.0	15.5
Ferzol	1226.1	1200.9	25.2
Rayak	935.9	920.0	15.9
Taanayel	878.3	864.1	14.3
Kfarzabda	881.1	869.0	12.0
Bar Elias	900.9	892.5	8.3
Aouch Nabi	973.4	967.9	5.5
Qabb Elias	873.6	866.2	7.4
Anjar	876.2	866.9	9.3
Mansoura	867.2	862.5	4.8

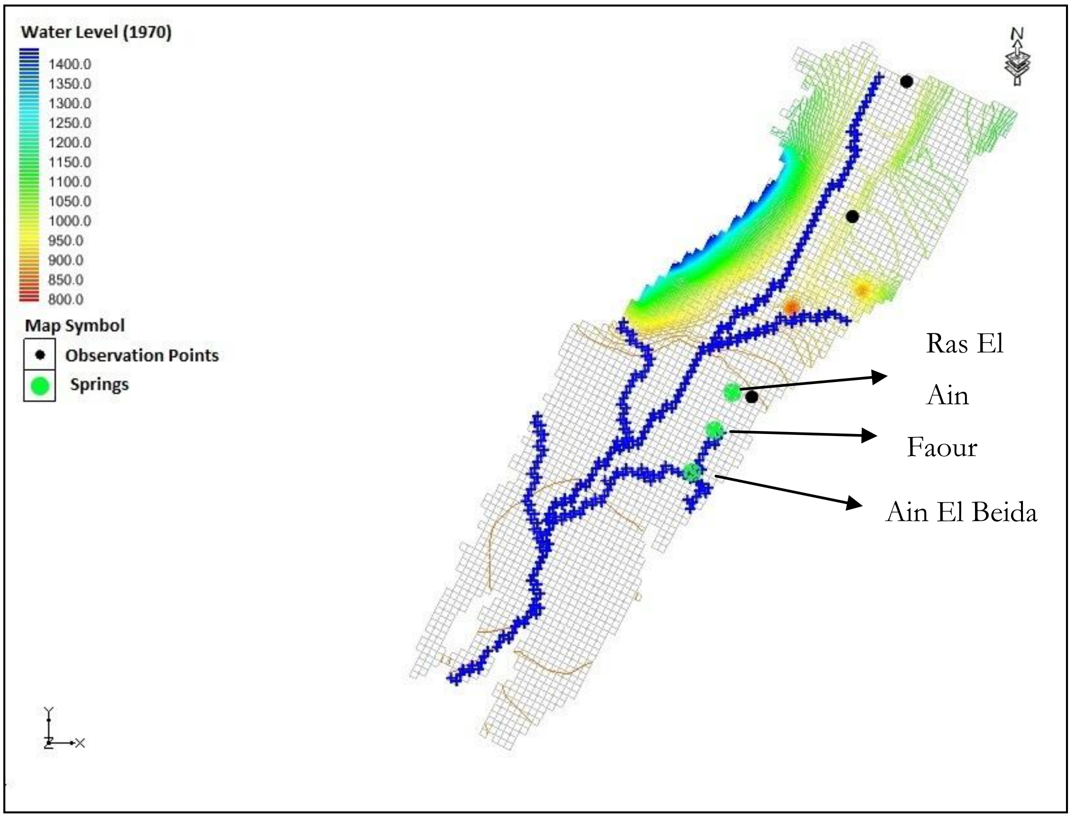


Figure 8-1 Location of Monitoring Wells and Springs for the Calibration of the 1970 Model

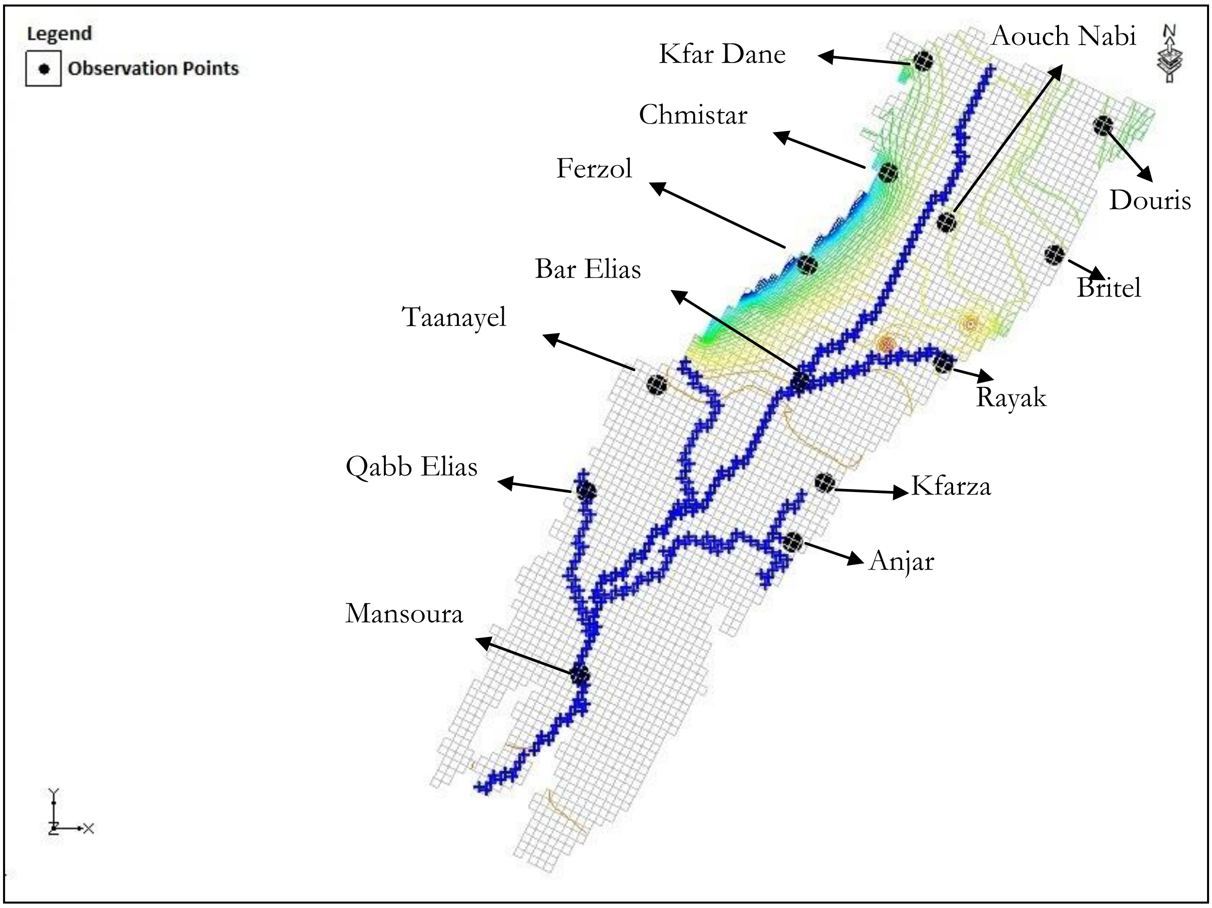


Figure 8-2 Location of Observation Points

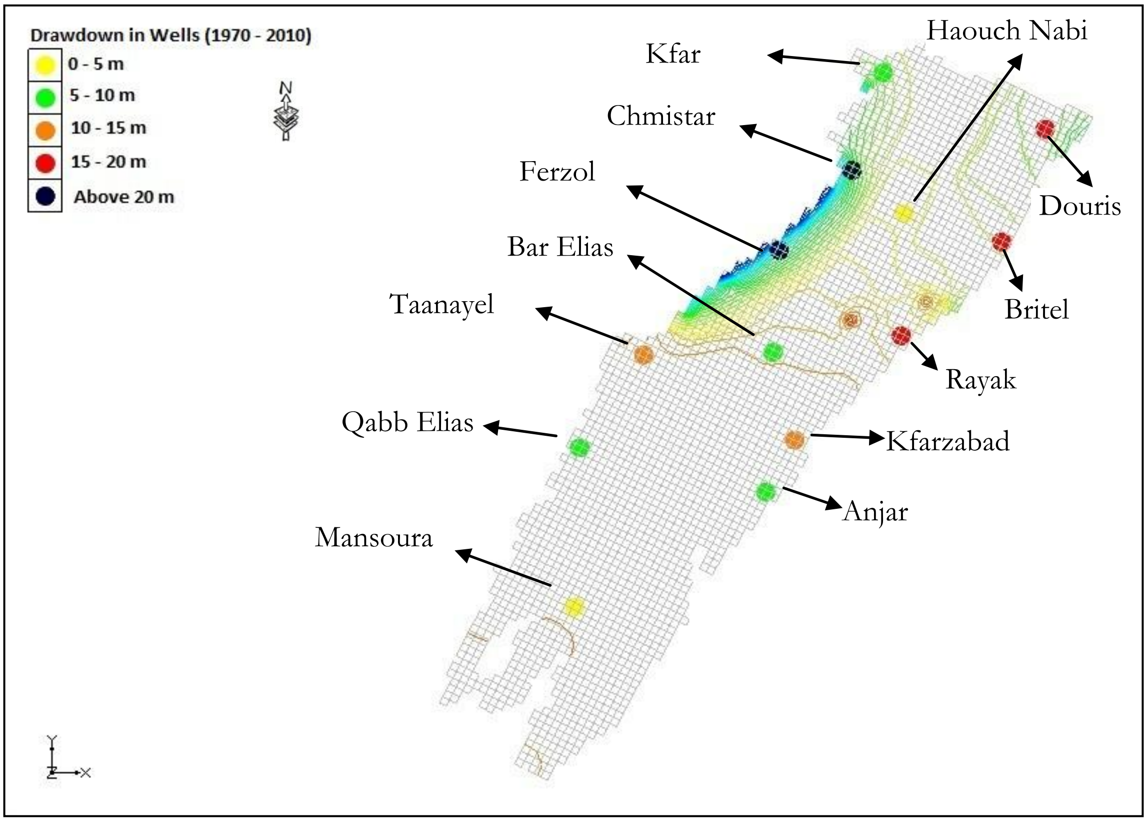


Figure 8-3 Drawdown in wells between 1970 and 2010

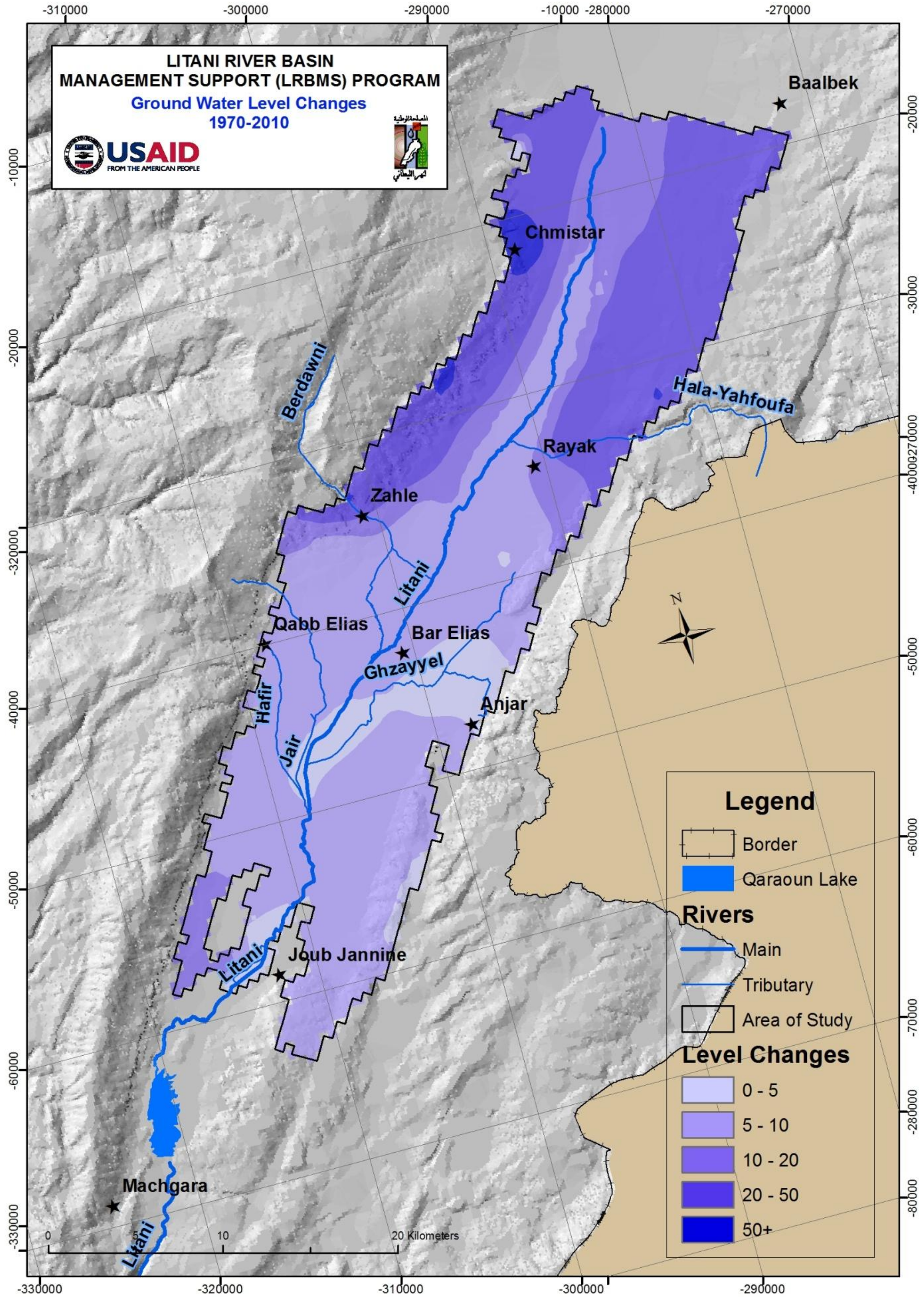


Figure 8-4 Groundwater Level Changes Between 1970 and 2010

8.2 PROJECTION OF WATER LEVELS – 2030

The model was also utilized to project groundwater levels for the coming 20 years and to study the affect of over pumping and global warming on the basin. Four scenarios were considered which studied the affect of increase in extraction from wells due to urbanization and development of agricultural land; and/or decrease in recharge due to global warming. The four (4) Scenarios are presented in **Table 8–**3.

The first scenarios considered that in the coming 20 years groundwater extraction might increase by 10% or 0.55 MCM/yr increase (i.e. 0.5%/year) as a conservative value compared to the increase of 5%/year from 1970 till 2010, while keeping the recharge at the same rate. The second scenario considered an increase of 30% (or 1.5%/year at a 1.65 MCM/yr increase) as an extreme value while keeping the recharge the same. The third and fourth scenarios used the same change in extraction as the first and second scenarios, but with a decrease in the recharge by 20% (0.85 MCM/yr) as an extreme case of adverse global warming effects.

Table 8–3 Different Scenarios Used for Projection

Name	Increase in Well extraction by 10% in 20 Years	Increase in Well extraction by 30% in 20 Years
No Change in Recharge in the coming 20 years	Scenario 1	Scenario 2
Decrease in Recharge by 20% in the coming 20 years	Scenario 3	Scenario 4

For the purpose of assessing the results of the simulations, the water level and drawdown, in the same 13 observation points were calculated.

The simulated water levels in the 13 observation points for the four (4) scenarios are presented in **Table 8–**4. The relative drawdown were calculated by subtracting the simulated water level values to the values of the steady state model simulated for the November 2010 and are presented in **Table 8–**5.

The minimum drawdown between the scenarios was in the first scenario, while the maximum drawdown was found in the fourth scenario. Nonetheless, both scenarios indicate a drastic decrease in the water level, reaching up to 37 m of drawdown in some areas in the extreme scenario (i.e., scenario 4).

The maximum drawdown in the first scenario reached up to 27m (observation Ferzol), with a minimum drawdown of 6m (observation Mansoura). The following, if incorporated with the seasonal fluctuations in the water level between dry and wet season (which ranges from 1 to 15m), might result in a drop of up to 40m in water level in some areas along the northeastern and northwestern boundaries, near highly populated areas such as Temnine and Britel.

Figure 8-3 shows the minimum drawdown (first scenario) in the 13 observation points selected. In the first scenario the maximum drawdown was along the northeastern and northwestern sections of the study area, where the drawdown ranged from 15 up to 25m, while the center of the model indicated a drawdown of 10 to 15m.

The fourth scenario simulates the extreme drawdown in the water level. **Figure 8-6** shows the drawdown in the observation points in the fourth scenario. The maximum drawdown in the observation points in the fourth scenario was in the northwestern section of the model reaching a drop of 37m, and if seasonal fluctuations in water level are accounted for, the drawdown in the dry season might reach up to 52m. The minimum drawdown was in the southern section and was equal to 7m.

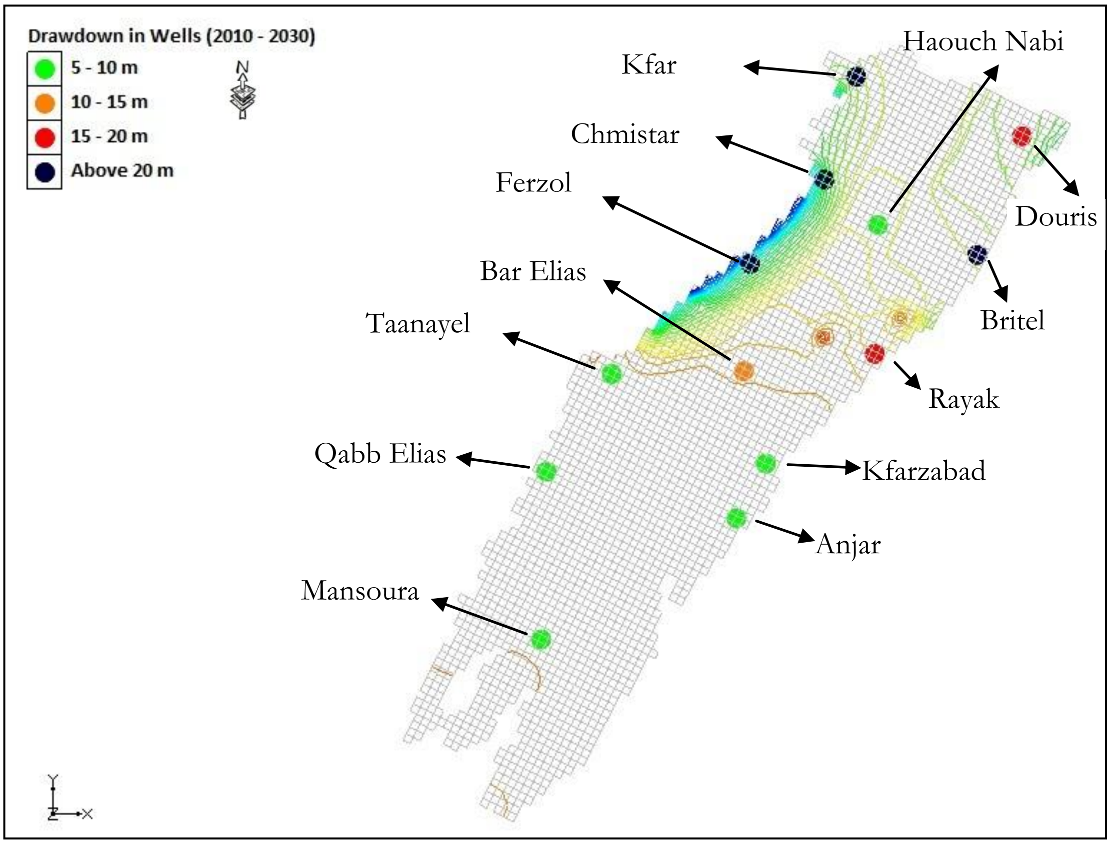


Figure 7 Minimum Drawdown in Observation Points between 2010 and 2030

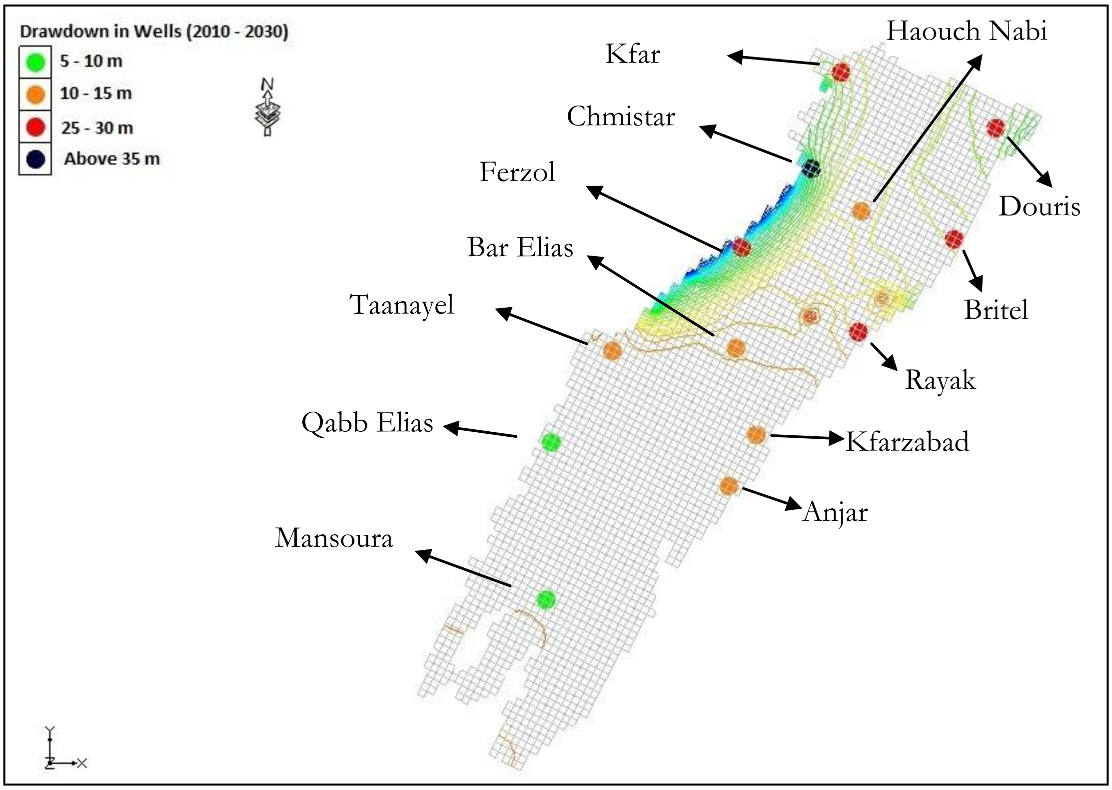


Figure 8 Maximum Drawdown in Observation Points Between 2010 and 2030

The projected drawdown, will have significant impacts on the water resources of the Upper Litani Basin. The Litani River will become an entirely losing stream, resulting in a lower flow and might cause the river to dry completely in the dry season, while currently it flows in a low discharge in the summer season. The water level in the southern section is also expected to drop, even in the most conservative scenario, by at least 5m causing the Amiq Wet Land to dry completely.

A comparison between the historical and future projections of the drawdown in the water level is plotted in **Figure 8-7** through **Figure 8-19** for the 13 observation points. The rate of increase in drawdown for the coming years (i.e., 2010-2030) will be significantly higher than the past years (i.e. 1970 to 2010), as illustrated by the steep portion of the curve after 2010. Although the percent increase in abstraction between 1970 and 2010 is higher as compared to the percent increase between 2010 and 2030, the aquifer systems post 2010 are not availing of recharge from the Litani River and tributaries and are pumping from aquifer storage.

Table 8–4 Computed Water Level in Observation Points in the Four Scenarios

Source	Computed WL 2010 (m)	WL Scenario 1 (m)	WL Scenario 2 (m)	WL Scenario 3 (m)	WL Scenario 4 (m)
Kfar Dane	1035.3	1014.8	1011.1	1012.9	1009.2
Douris	1051.6	1031.9	1028.0	1029.8	1025.8
Chmistar	1145.4	1119.6	1111.6	1116.6	1108.6
Britel	1005.0	984.4	980.7	982.0	978.3
Ferzol	1200.9	1178.9	1173.6	1176.6	1171.3
Rayak	920.0	900.6	897.0	898.5	894.8
Taanayel	864.1	854.2	851.0	852.7	849.6
Kfarzabda	869.0	860.0	856.8	858.8	855.6
Bar Elias	892.5	882.1	878.9	880.8	877.6
Aouch Nabi	967.9	960.9	958.7	959.8	957.4
Qabb Elias	866.2	859.3	857.4	858.4	856.4
Anjar	866.9	859.0	856.4	857.9	855.3
Mansoura	862.5	857.3	856.1	856.5	855.3

Table 8–5 Drawdown* in Observation Points in the Four Scenarios of 2030

Source	Drawdown in WL Scenario 1 (m)	Drawdown in WL Scenario 2 (m)	Drawdown in WL Scenario 3 (m)	Drawdown in WL Scenario 4 (m)	Difference Between Max and Min
Kfar Dane	20.5	24.2	22.4	26.1	5.6
Douris	19.7	23.6	21.8	25.8	6.1
Chmistar	25.8	33.8	28.8	36.8	11
Britel	20.6	24.3	23	26.7	6.1
Ferzol	22	27.3	24.3	29.6	7.6
Rayak	19.4	23	21.5	25.2	5.8
Taanayel	9.9	13.1	11.4	14.5	4.6
Kfarzabda	9	12.2	10.2	13.4	4.4
Bar Elias	10.4	13.6	11.7	14.9	4.5
Aouch Nabi	7	9.2	8.1	10.5	3.5
Qabb Elias	6.9	8.8	7.8	9.8	2.9
Anjar	7.9	10.5	9	11.6	3.7
Mansoura	5.2	6.4	6	7.2	2

*Drawdown calculated by subtracting the simulated water level values by the calibrated values of Nov 2010

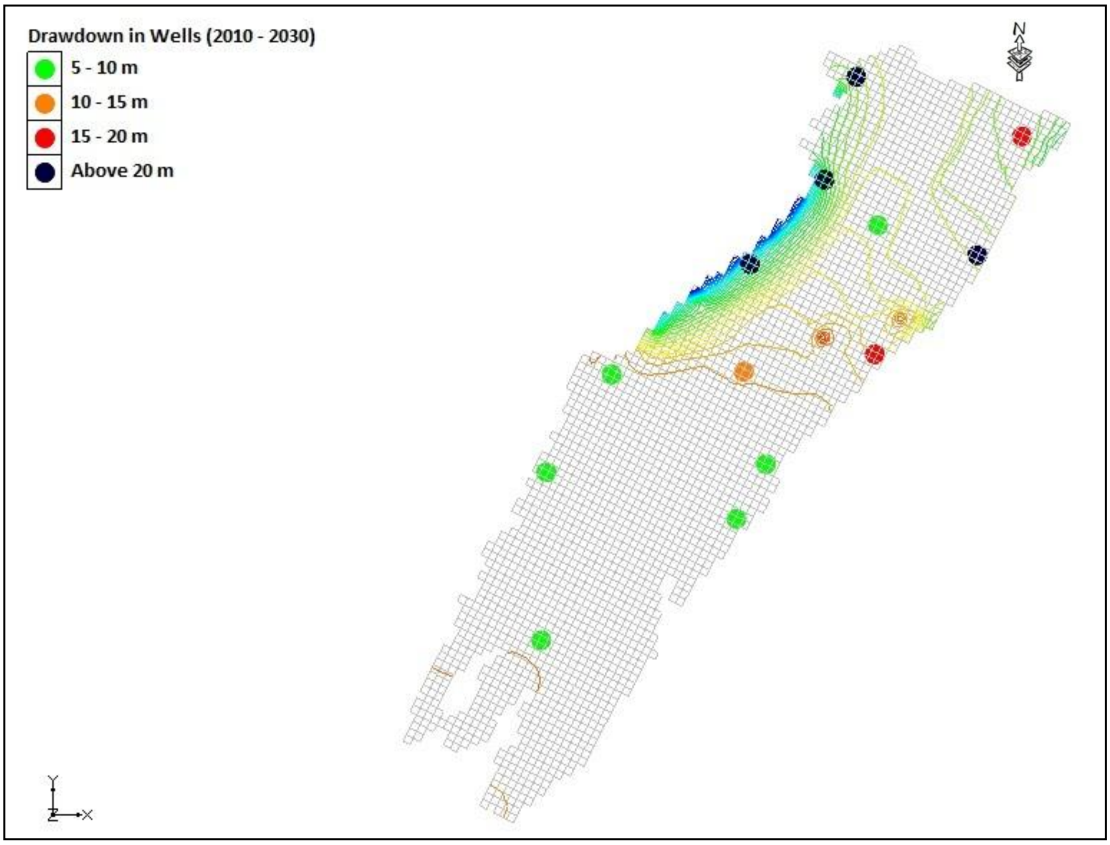


Figure 8-5 Minimum Drawdown (Scenario 1) in Observation Points between 2010 and 2030

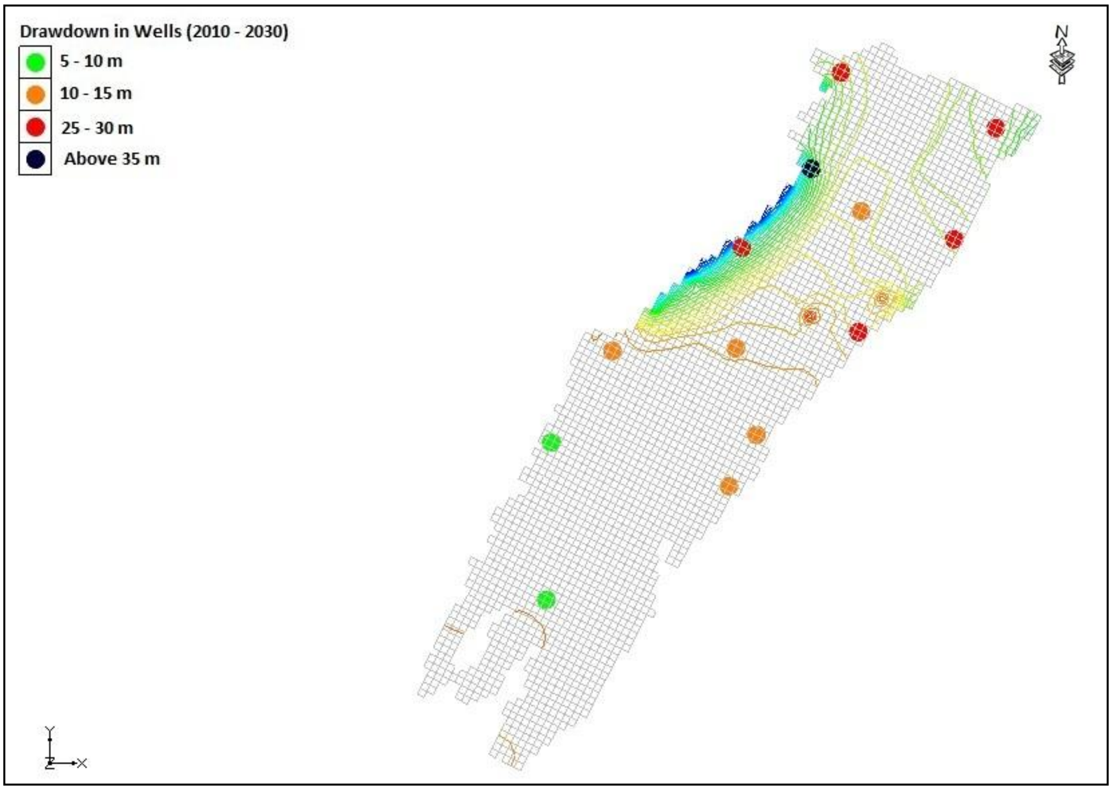


Figure 8-6 Maximum Drawdown (Scenario 4)in Observation Points Between 2010 and 2030

Figure 8-7 Historical and Projected Drawdown for Observation Kfar Dane

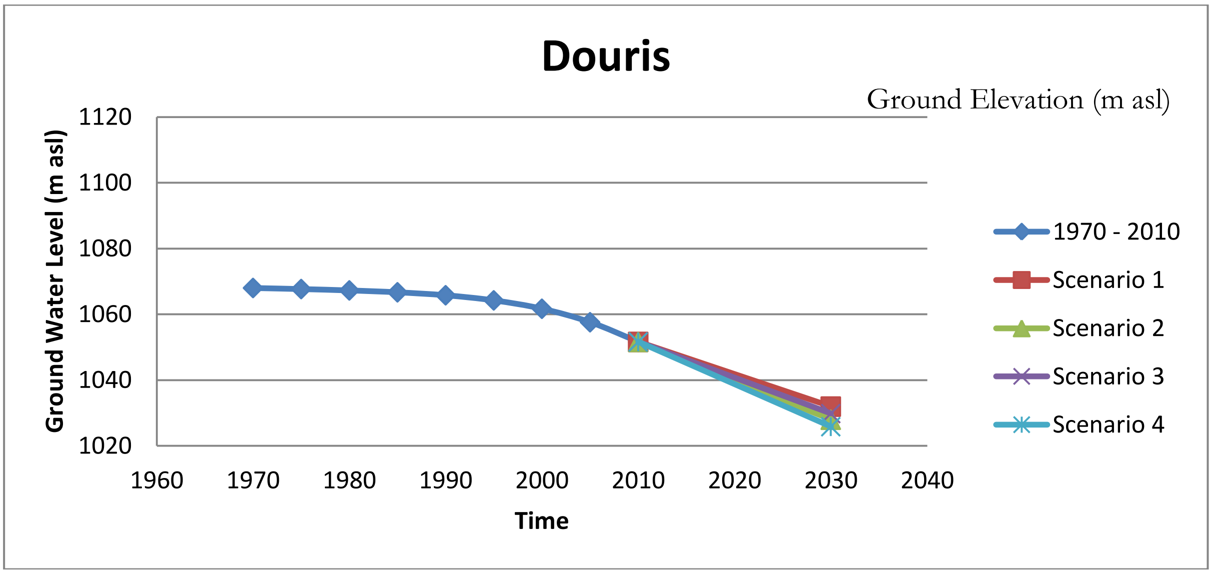


Figure 8-8 Historical and Projected Drawdown for Observation Douris

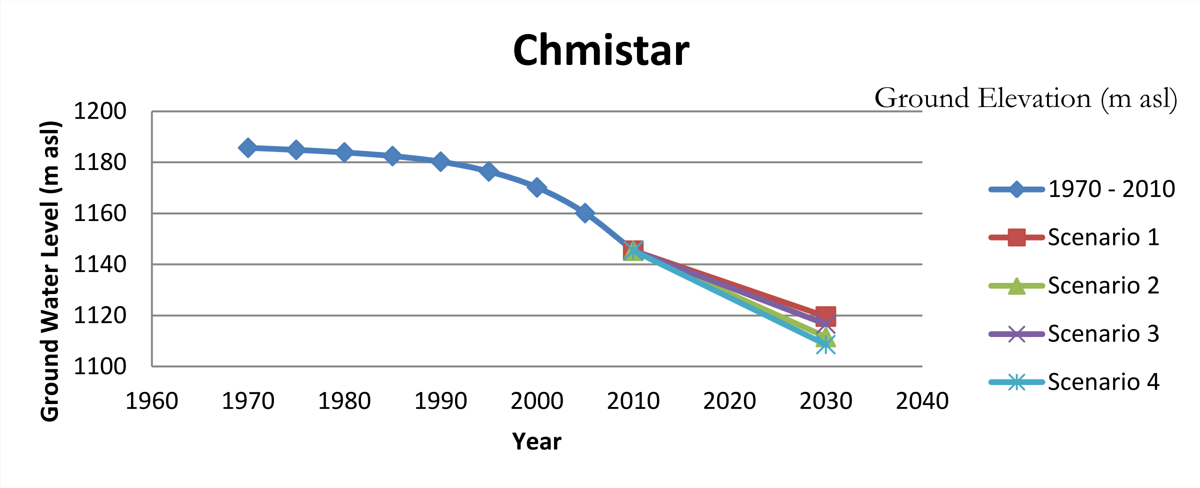


Figure 8-9 Historical and Projected Drawdown for Observation Chmistar

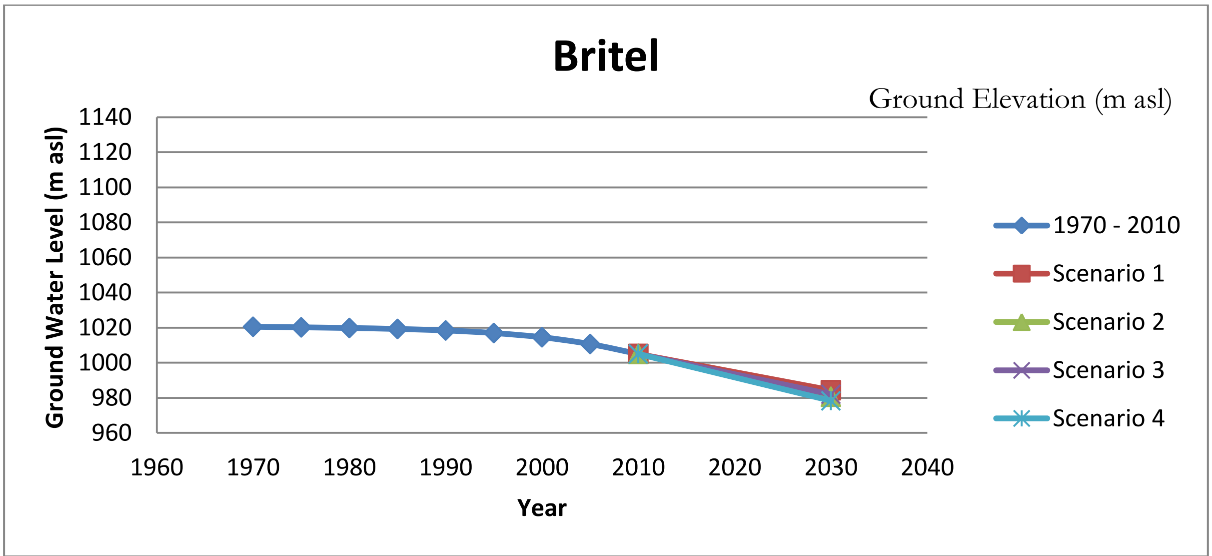


Figure 8-10 Historical and Projected Drawdown for Observation Britel

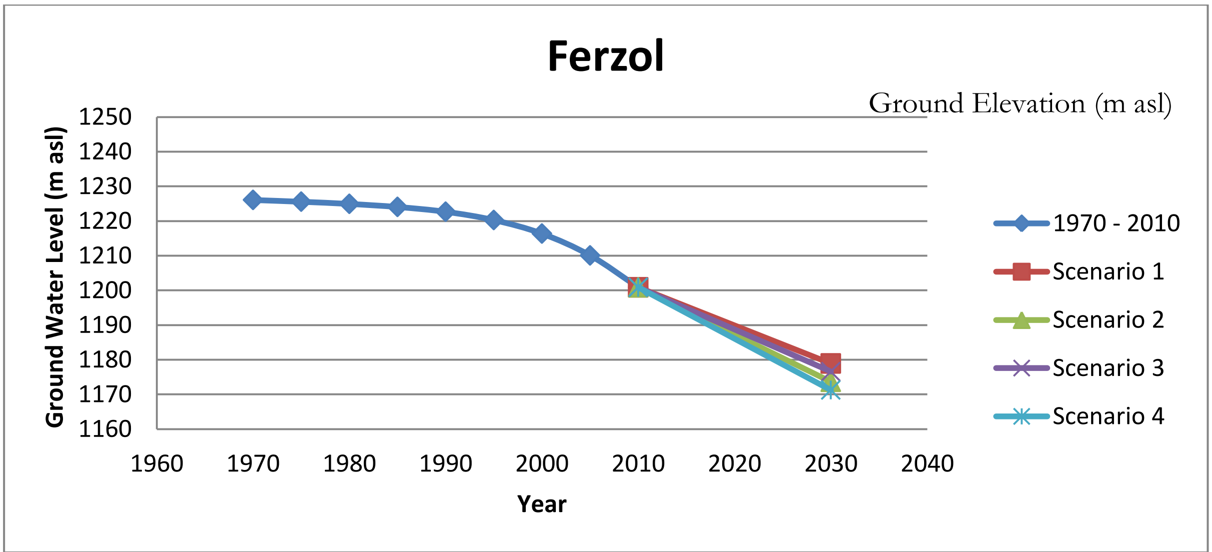


Figure 8-11 Historical and Projected Drawdown for Observation Ferzol

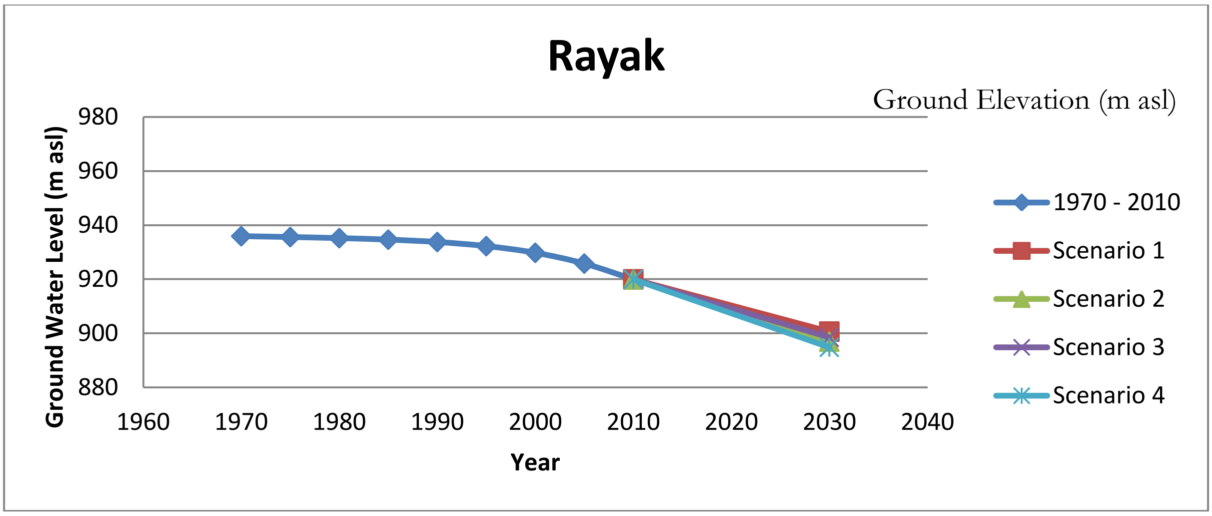


Figure 8-12 Historical and Projected Drawdown for Observation Rayak

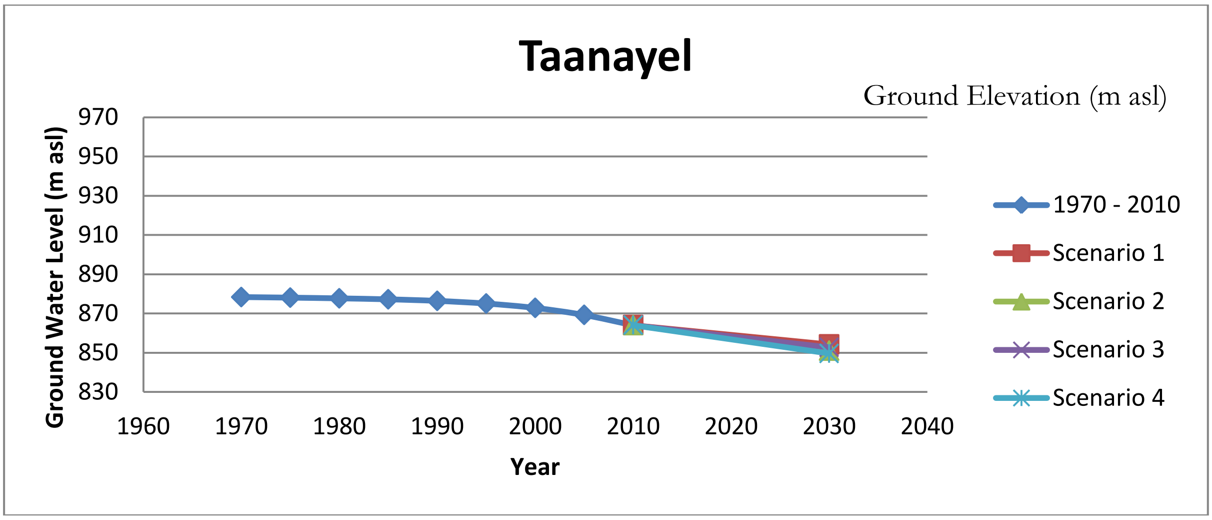


Figure 8-13 Historical and Projected Drawdown for Observation Taanayel

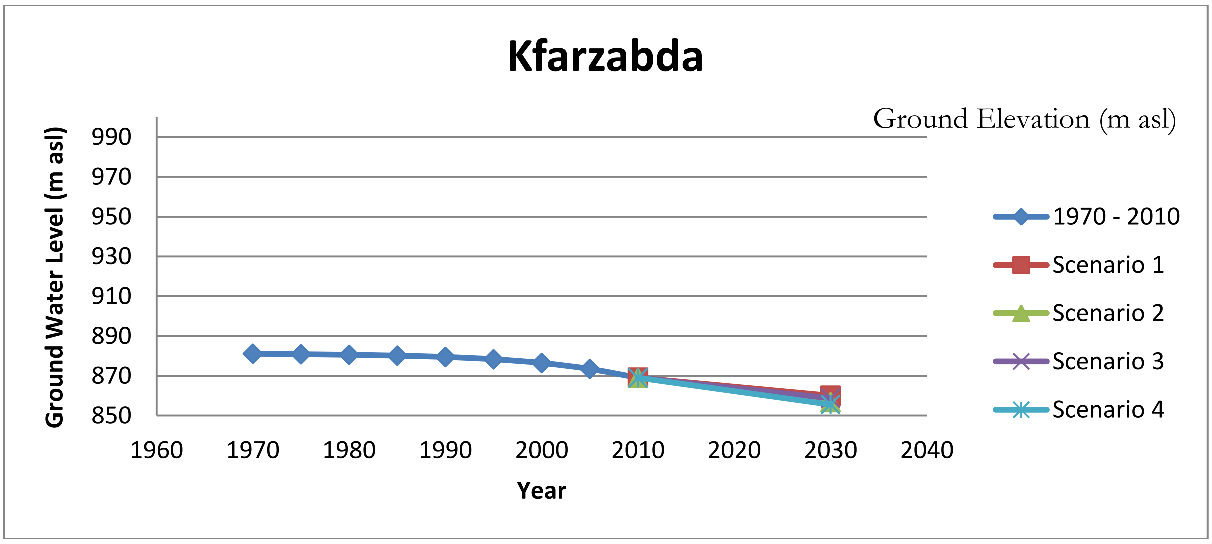


Figure 8-14 Historical and Projected Drawdown for Observation Kfarzabda

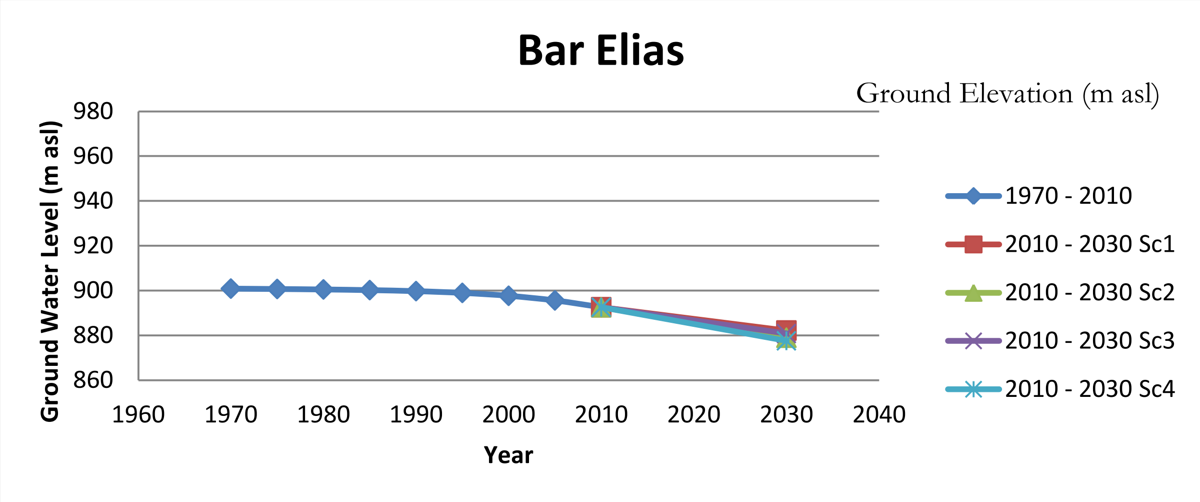


Figure 8-15 Historical and Projected Drawdown for Observation Bar Elias

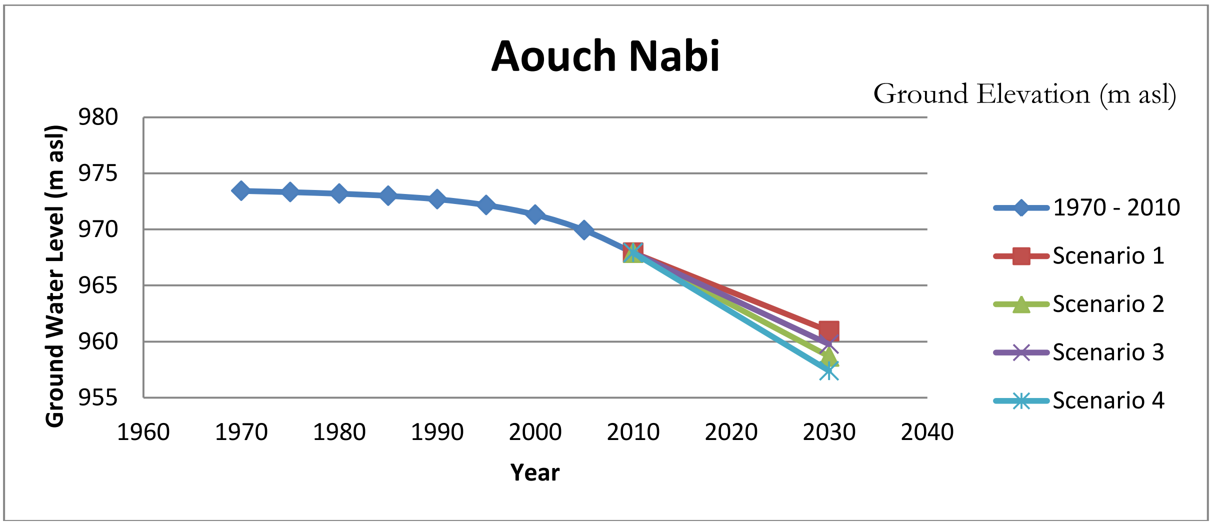


Figure 8-16 Historical and Projected Drawdown for Observation Aouch Nabi

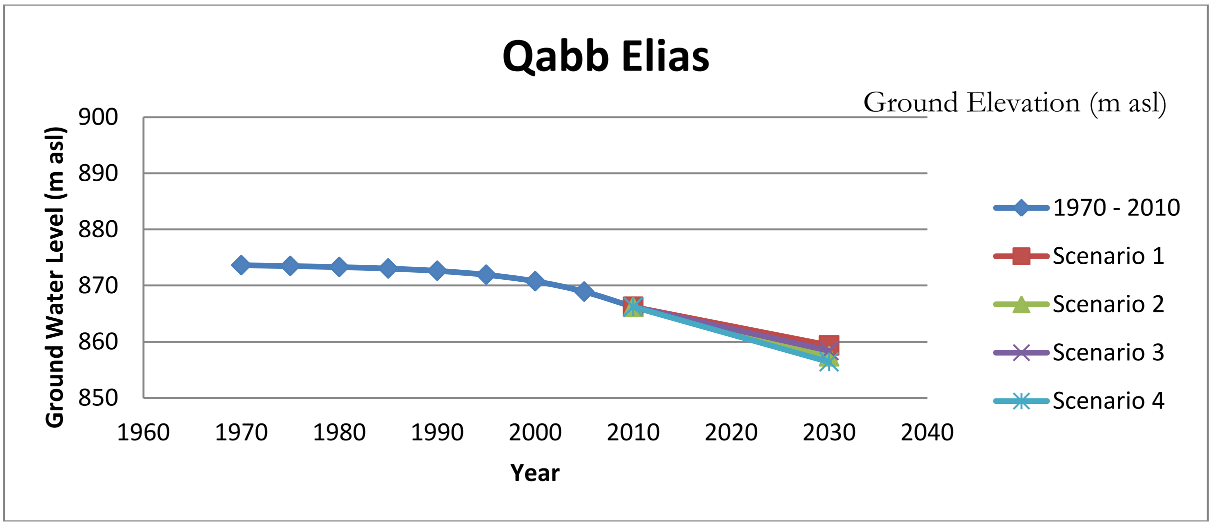


Figure 8-17 Historical and Projected Drawdown for Observation Qabb Elias

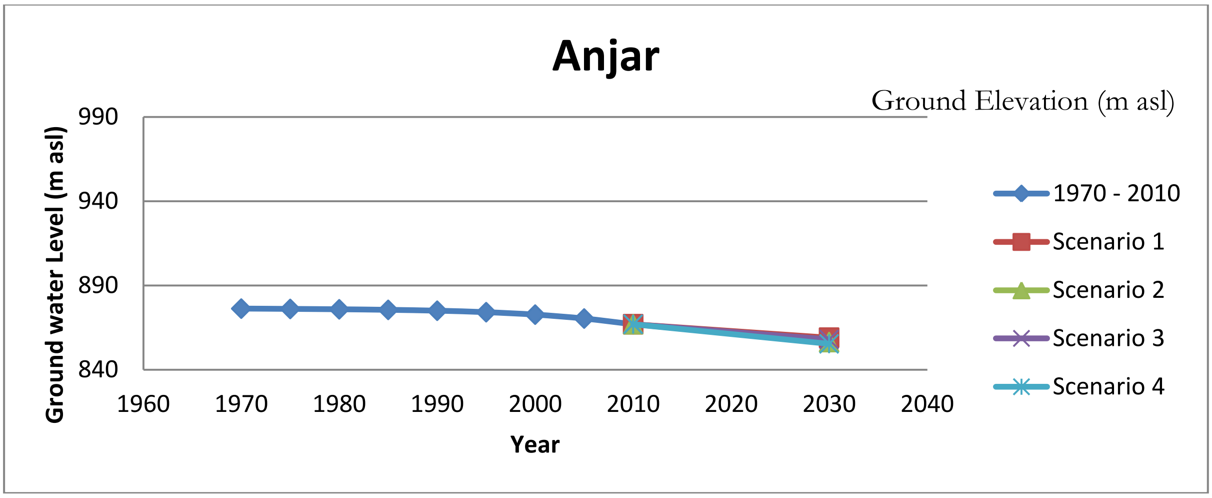


Figure 8-18 Historical and Projected Drawdown for Observation Anjar

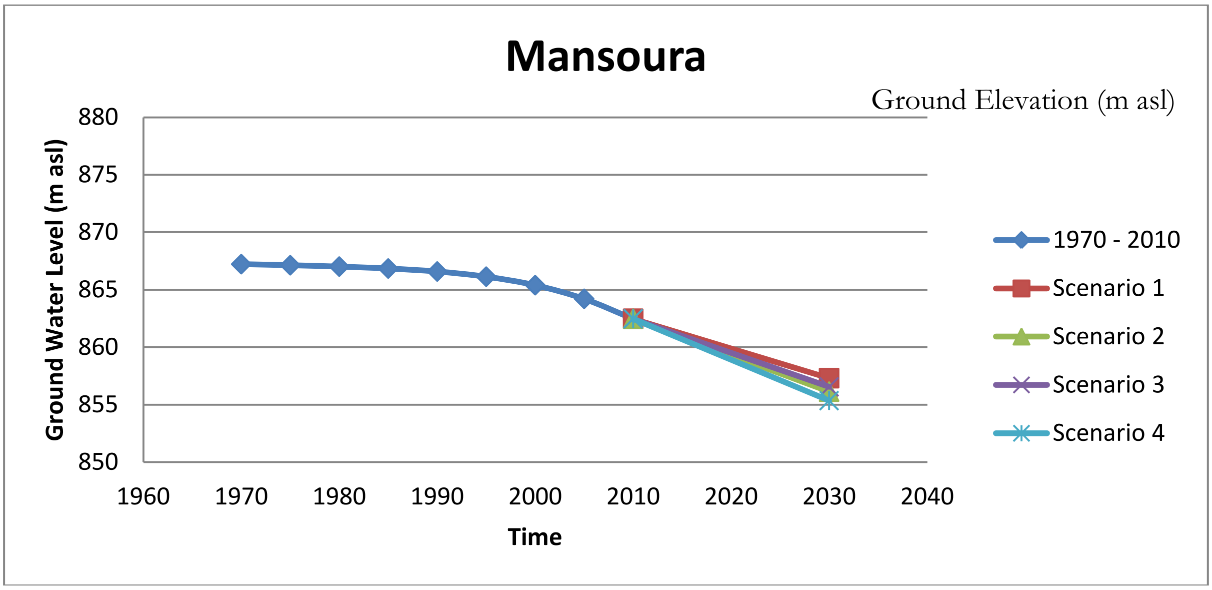


Figure 8-19 Historical and Projected Drawdown for Observation Mansoura

9. CONCLUSIONS & RECOMMENDATIONS

Based on the model's projection (past and future), the drawdown in groundwater levels from 1970 to 2010 ranged from 4.8m up to 40.3m with an average decrease of 14.2m over 40 years, at an average rate of 0.35m/year. This decline in groundwater levels is expected to increase in the coming years as more wells are being drilled and the only available water source to the area is from groundwater.

The generated model was used to predict the groundwater levels in 2030 when subject to the four different scenarios, that simulate an increase in extraction rate, and a decrease in recharge rate. Based on the results of the simulation, the groundwater resources within the upper Litani River Basin will be subject to extreme stress and are being depleted at a rate that will be increasing through time.

In the most conservative scenario (scenario 1), which simulates an overall increase in extraction of 10 %, with the same recharge rate, the average drop in the water level in the system was14m, with a maximum drawdown of 27 meters. In the most extreme scenario (scenario 4), with a decrease of 20 % in recharge and an increase of 30 % in groundwater extraction, the predicted average drop in water levels was estimated at about 19 m, with a maximum of about 37 meters

This initial model that was developed as part of the LRBMS program should be considered as a first step for the simulation of groundwater flow and an initial estimate of the water balance in the Upper Litani Basin. It demonstrates the overall continuous trend in the depletion of the groundwater resources of the upper Litani River, irrespective of any scenario adopted. The model is well suited to assist in taking major strategic decisions, however it should be revisited and refined for a better accuracy required for it to be used in detailed planning and management of the water resources of the upper Litani Basin. This would certainly require having a better grasp on the monitoring of its resources with respect to recharge and discharge of the groundwater and surface water systems.

This would necessitate the improvement or establishment of a set of monitoring network that will help in better assessing the resources. It should include but not limited to: spring discharge monitoring, groundwater level monitoring, surface water flow and quality monitoring, water extraction monitoring/or control the groundwater and surface water), and meteorological monitoring. As part of the LRBMS program, IRG has initiated the establishment/improvement of this set of monitoring networks by installing a number of water monitoring devices in several river gauging stations and groundwater monitoring wells.

As more data become available, the following are recommendations to enhance the accuracy of the groundwater model:

- Model grid refinement to represent more detailed affects of pumping wells
- Refine estimates of evapotranspiration, recharge, interaction between aquifers, discharge from springs, and river flow
- Increase of the frequency and coverage of groundwater level measurements to improve the quality and resolution of potentiometric groundwater map on an annual or seasonal basis.
- Investigation of the effect of excessive abstraction on the water quality in the basin.
- Build a 4 layer model when more data becomes available.

10. REFERENCES

Batu, V., 1998. Aquifer Hydraulics: A Comprehensive Guide to Hydrogeologic Data Analysis, John Wiley & Sons, New York, 727p

DAI, 2003.FORWARD Program. Water Quality Assessment of the Upper Litani River Basin and Lake Qaaroun, Lebanon.USAID.

DAI, 2005.BAMAS Project. Groundwater Flow Modeling and Vulnerability Mapping.Litani Water Quality Management Project. USAID

Darwish, T., M. Khawlie, I. Jomaa, M. Abou Daher, M. Awad, M. Masri, T. Shaban, G. Faour, R. Bou Kheir, C. Abdallah and T. Haddad.,2006. Digital Soil Map of Lebanon 1/50, 000.Monograph Series 4. CNRS- Lebanon.

Dubertret, L., 1955.Carte géologique de Liban. Ministère du Travaux Publics de la République Libanaise, Beyrouth, Scale 1:200,000, with explanatory notes.

FAO., 1975. Projet de Développement Hydro-Agricole de la Bekaa Central. République Libanaise, Ministère des Ressources Hydrauliques et Électriques, Beyrouth, Liban.

IRG, 2012.Hydrogeologic Reference Report.

JICA. 2003. The Study on Water Resources Management Master Plan in the Republic of Lebanon (draft). Sanyu Consultants Inc. Yachiyo Engineering Co., ltd.

Johnson, A. I. 1967. Specific yield – compilation of specific yields for various materials. U. S. Geological Survey Water Supply Paper 1662-D, 74p.

LRBMS Program, 2011, Water Balance Report, August 2011.

National Engineering Handbook, Section 4, "Hydrology" Chapter 9, August 1972

Palmer, W. C., and A. V. Havens., 1958.A graphical technique for determining evapotranspiration by the Thornthwaite method. Monthly Weather Review 86:123-128.

Thornthwaite, C. W., 1948. An approach toward a rational classification of climate. Geographic Review 38:55-94

UNDP., 1970. "Liban: Etude des eaux souterraines." New York, 186 p.

Walley, C., 1997. The Lithostratigraphy of Lebanon: A review. Lebanese Science Bulletin, 10: 81 – 108

11. APPENDICES

APPENDIX A – GEOLOGICAL SETTING

The following section describes the geological characteristics available in the basin, in terms of lithology and structural geology. The geological characteristics dictate the boundary conditions for the model.

Formations ranging from Mid-Jurassic to recent Quaternary deposits are exposed in the study area. **Figure 11-1** is a geological map (Dubertret L., 1949) showing the various geological units outcropping in the Upper Litani Basin, while **Figure 11-2**(Dubertret L., 1949)presents two cross sections along the NE-SW direction showing the extent of the geological formations below the Quaternary Litani plain in the subsurface.

JURASSIC

The Jurassic formations span from Middle Jurassic to Late Jurassic. It cover an area of 122 km^2 of the catchment area, out of which 3km^2 are Basalts and volcanic tuff, while 119 $km^2$are composed mainly of limestone rocks. The four (4) outcropping formations belonging to the Jurassic period are described below.

KESROUAN FORMATION (J4)

The Kesrouan Formation is of Batholian age, it mainly outcrops at the flanks of Mount Lebanon South West of the catchment area and in small patches North East of the study area along the flanks of Anti-Lebanon. The Kesrouan Formation is composed of massive dolomitic limestone and limestone that is highly karstified and contains some marly horizons. This formation is the oldest exposed formation in Lebanon, and until now the exact thickness is still unknown, but it is expected to be more than 1000m. The Kesrouan formation covers 116 km^2 of the catchment area.

CRETACEOUS

The Cretaceous formations span from Early Cretaceous to Late Cretaceous. The Cretaceous formations cover an area of 633 km^2in the catchment area, composed of sandstone, limestone, and shale. The catchment area has six (6) outcropping formations of the Cretaceous period, they are described below.

CHOUF SANDSTONE (C1)

The Chouf Sandstone formation is the base of the Cretaceous, and is exposed in small patches west of the catchment area on the Mont Lebanon flanks and North East of the study area on the Anti-Lebanon flanks. The Chouf sandstone is composed of cross-bedded or thin to thick bedded and massive sandstone with intercalation of siltstone, clays and shales, and is highly jointed. The ChoufSandstone reaches a maximum thickness of 75m in the study area. The Chouf Sandstone covers 12 km^2 of the study area.

ABIEH FORMATION (C2A)

The Abieh formation is of Barremian – Lower Aptian age, and is exposed in small patches west of the catchment area on the Mont Lebanon flanks and North East of the study area on the Anti-Lebanon flanks. The Abieh formation is composed of clastic limestone, thin to thick bedded jointed. The Abieh formation reaches a maximum thickness of 50m in the study area. The Abieh formation covers 6.6 km^2 of the study area.

MDAIREJ FORMATION (C2B)

The Mdairej formation is of Upper Aptian age, and is exposed in small patches west of the catchment area on the Mont Lebanon flanks and North East of the study area on the Anti-Lebanon flanks. The Mdairej formation is composed of stylolitics, partly dolomistised, medium to thick bedded and massive, partly jointed and karstified. The Mdairej formation reaches a maximum thickness of 50 m in the study area. The Mdairej formation covers 13.5 km^2 of the study area.

HAMMANA FORMATION (C3)

The Hammana formation is of Albian age, and is exposed in small patches west of the catchment area on the Mont Lebanon flanks and South East of the study area on the Anti-Lebanon flanks. The Hammana formation is composed calcareous shales interbeded with highly fossiliferous and clastic limestone, thin to medium beds and jointed. The Hammana formation reaches a maximum thickness of 50 m in the study area. The Hammana formation covers 15.2 km^2 of the study area.

SANNINE – MAAMELTEIN FORMATION (C4-C5)

The Sannine – Maameltein formation is of Cenomanian - Turonian age, and is outcrops along the bottom of the Mont Lebanon flanks and Anti-Lebanon flanks. The Sannine – Maameltein formation is composed well bedded limestone and dolomitic limestone with occasional calcareous shale intercalation, marly horizons and marly limestone, highly jointed and karstified. The Sannine – Maameltein formation reaches a maximum thickness of 700m in the study area. The Sannine – Maameltein formation covers 517.5 km^2 of the study area.

CHEKKA FORMATION (C6)

The Chekka formation is of Senonien age, and outcrops North West of the catchment area on the Mont Lebanon flanks and East of the study area on the Anti-Lebanon flanks. The Chekka formation is composed of chalky marl, chalky marly limestone, and sometimes siliceous limestone, thin to medium bedded, highly jointed. The Chekka formation reaches a maximum thickness of 50m in the study area. The Chekka formation covers 65.8 km^2 of the study area.

TERTIARY AND QUATERNARY

The Tertiary and Quaternary formations span from Eocene to Recent deposits. The Tertiary and Quaternary formations cover an area of 712 km^2in the catchment area, composed of limestone, andalluvial/fluvial deposits. The catchment area has three (3) outcropping formations of the Tertiary and Quaternary period, they are described below.

EOCENE FORMATION (E2A – E2B)

The Eocene formation is of Lutetian age, and mainly outcrops east of the catchment area on base of Anti-Lebanon flanks, and North of the catchment area along the bottom of Mont Lebanon flanks. The Eocene formation is divided into two section the Lower Eocene (e2a) and Upper Eocene (e2b). The e2a is located on top of the Chekka Formation and is composed of marly limestone. The e2b overlies the e2a and is composed of brecciated limestone. The Eocene formation reaches a maximum thickness of 250 m in the study area. The e2a formation covers 42 km^2 of the catchment area; while e2b covers 68 km^2 of the catchment area, with a total of 110 km^2.

NEOGENE FORMATION (ML – ML1)

The Neogene formation is of Miocene and Pliocene epoch. The Neogene Formation underlies the Quaternary deposits, which is also known as the Upper Miocene deposits. The Neogene Formation outcrops on the west side near Chtaura and Chmistar, and on the northeast from Rayak to Baalbek, in addition to small outcrops southwest of the basin. The Neogene Formation consists of unconsolidated deposits of mainly sands and gravels with marls and lacustrine limestone, in addition to lacustrine marls (continental succession). The Neogene formation reaches a maximum thickness of 300 m in the study area. The Neogene formation covers 186.1 km^2 of the study area.

QUATERNARY DEPOSITS (Q)

The Quaternary unconsolidated deposits cover most of the Bekaa plain within the Litani River Basin. In the center, the basin consists of a mixture gravels, sands, silts, and clay of various concentrations depending on the areas. The Quaternary deposits reach a thickness of more than 400 m in the study area. The Quaternary deposits cover 414 km^2 of the study area.

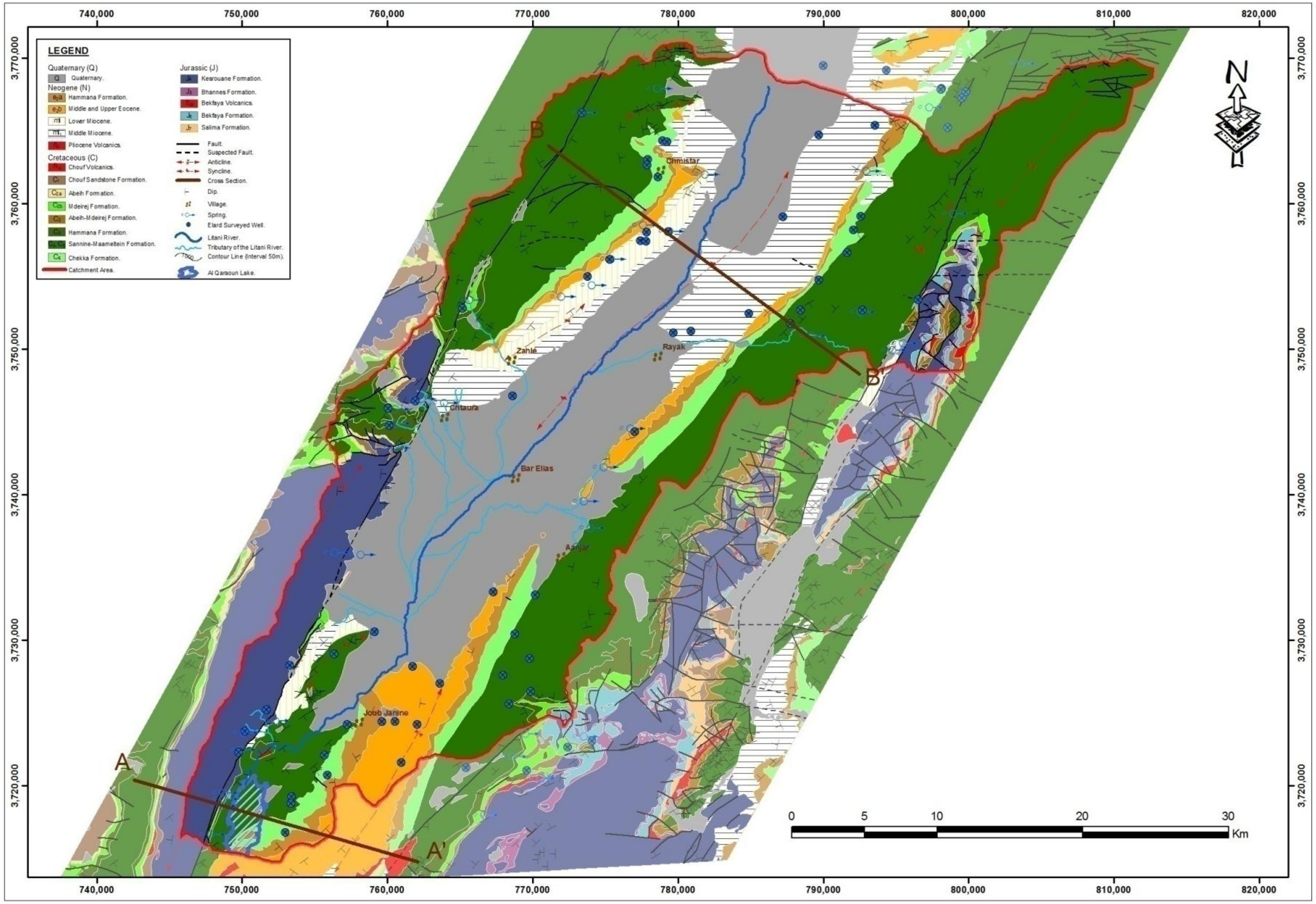
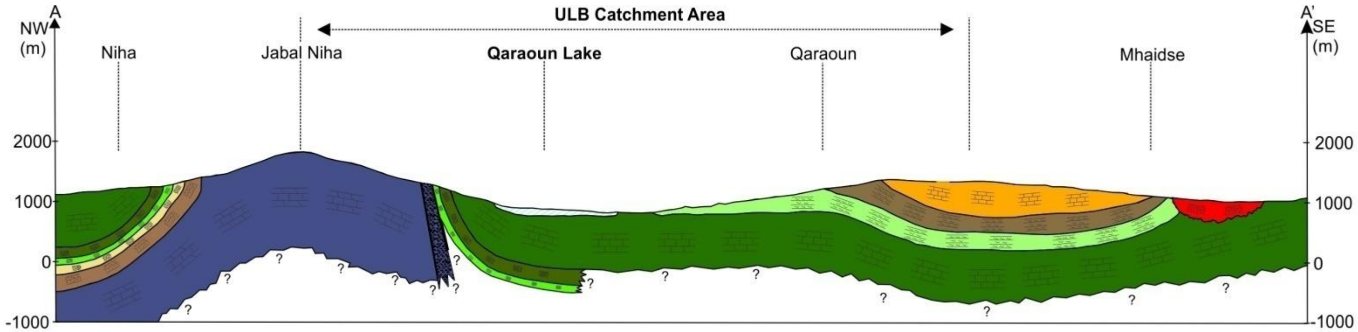


Figure 11-1 Geological Map of the Upper Litani Basin



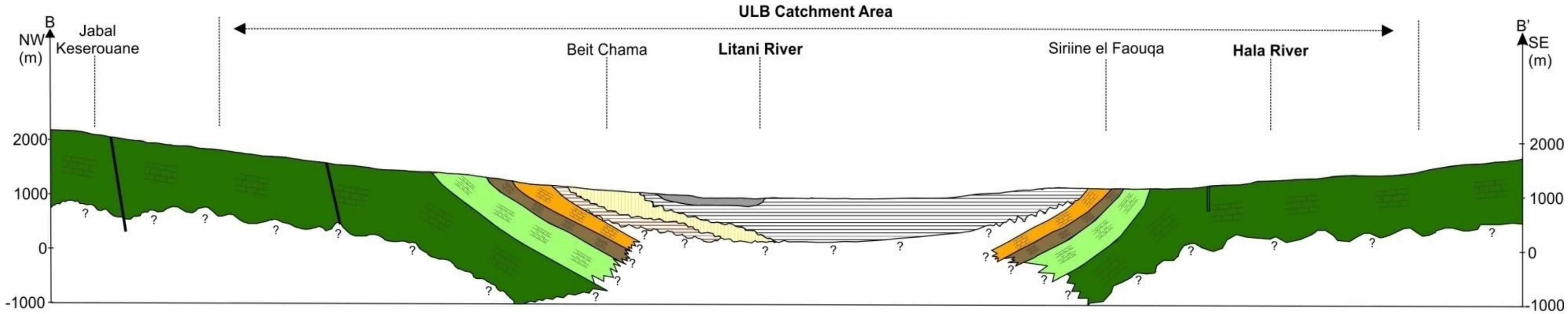


Figure 11-2 Cross sections Along A-B and B-B' in the NW-SE Direction Showing the Extent of the Formations in the Subsurface

Structurally the Upper Litani River catchment area is bordered from the west by the main Yammouneh Fault system and its associated highs: the Barouk-Niha range and the Sannine Mountain. The beds forming those highs dip towards the Bekaa plain. Small-scale folds such as anticlines and synclines in Hadath Baalbeck and Chlifa villages, at the foothills of those ranges, plunge into the Bekaa valley below Quaternary deposits. Those structural elements mainly dictate the groundwater flow direction in this aquifer, which is mainly in the direction of the general inclination of beds.

From the east, the catchment is bordered by the main Rachayya and Hasbayya fault systems and their associated Anti-Lebanon Range (Jabal El Cheikh and JabalLemnar). The general inclination of beds on the western slopes of the Anti-Lebanon Mountains is towards the Bekaa valley, that is, towards thewest. The general inclination and the structural elements in that area mainly dictate the groundwater flow direction in this aquifer.

From the north, the catchment is bordered by a minor anticline forming a hill separating the groundwater flow and surface drainage system. The anticline is trending in the east west direction.

Secondary faults trending in an E-W direction are also present in the study area. These faults act as passageways for groundwater from the highlands or source areas to the lowlands, which is mainly the Bekaa plain where outlets exist as springs and where the Quaternary deposits are being replenished.

APPENDIX B–WELLS

The wells in the catchment area are divided into three categories: public wells, licensed private wells, and unlicensed private wells. A field survey of all public wells and licensed private well was done as part of an ongoing project for the national assessment of groundwater resources in the association with the UNDP. The catchment area comprises 107 public wells and 2195 licensed private wells. The number of unlicensed wells is not known and expected to be relatively important.

PUBLIC WELLS

The public wells in the area are either operated by local municipalities or the Bekaa Water Establishment and water supply. Seven (7) wells are tapping into the Abeih Formation with a minor discharge. Eleven wells are tapping the Jurassic Formation (J4), 40 wells are tapping into the Sannine – Maameltien Formation (C4-C5), 21 wells are tapping the Upper Eocene Formation (e2b), six (6) wells are tapping the Miocene Formation (mL), and 22 wells are tapping the Quaternary deposits (Q).

Neither the municipalities nor the Bekaa Water Establishment have information about the exact extraction rate for the public wells. The extraction volume was communicated by well operators, estimated based on tank capacities, or estimated based on number of users multiplied by 180 l/day which is the water usage per capita from the last estimate by the MoEW. The number of users is calculated based on number of households connected to the water network (which was communicated by the water establishments) and multiplied by four (4; the average household is estimated to have 4 persons). **Figure 11-3** displays the location of the public wells in the study area.

Table 11–1 Total Discharge(m3/day) from Public Wells Per Well and Per Aquifer

Aquifer	Number of Wells	Average discharge (m3/day)	Total discharge (m3/day)
J4	11	930	10,230
C2b	7	97	679
C4-C5	40	572	22,880
e2b	21	916	19,236
mL	6	373	2238
Q	22	426	9,372
Total	107	3314	64,635

PRIVATE WELLS

There are about 2195 private wells, based on the database of private wells provided by the Ministry of Energy and Water (MoEW). After a field survey of all 2195 wells, 1093 wells appeared to be registered under misplaced coordinates or were not originally drilled. Accordingly, a total of 1102 operational licensed private wells exist on the study area. Those wells are tapping various aquifer units in the study area. The extraction rate for the surveyed private wells could not be calculated due to lack of information. A lump-sum value will be given to the private wells.

The unlicensed wells in the area are spread all over the basin, and are mainly concentrated in the northern part of the study area. The unlicensed wells are expected to be at least 5 times more than the licensed wells and are expected to be condensed in the central part of the modeled area, and the eastern and western flanks. Accordingly, both licensed and unlicensed private wells will be distributed evenly for the middle and upper part of the modeled area to reduce the effect of lumped wells.

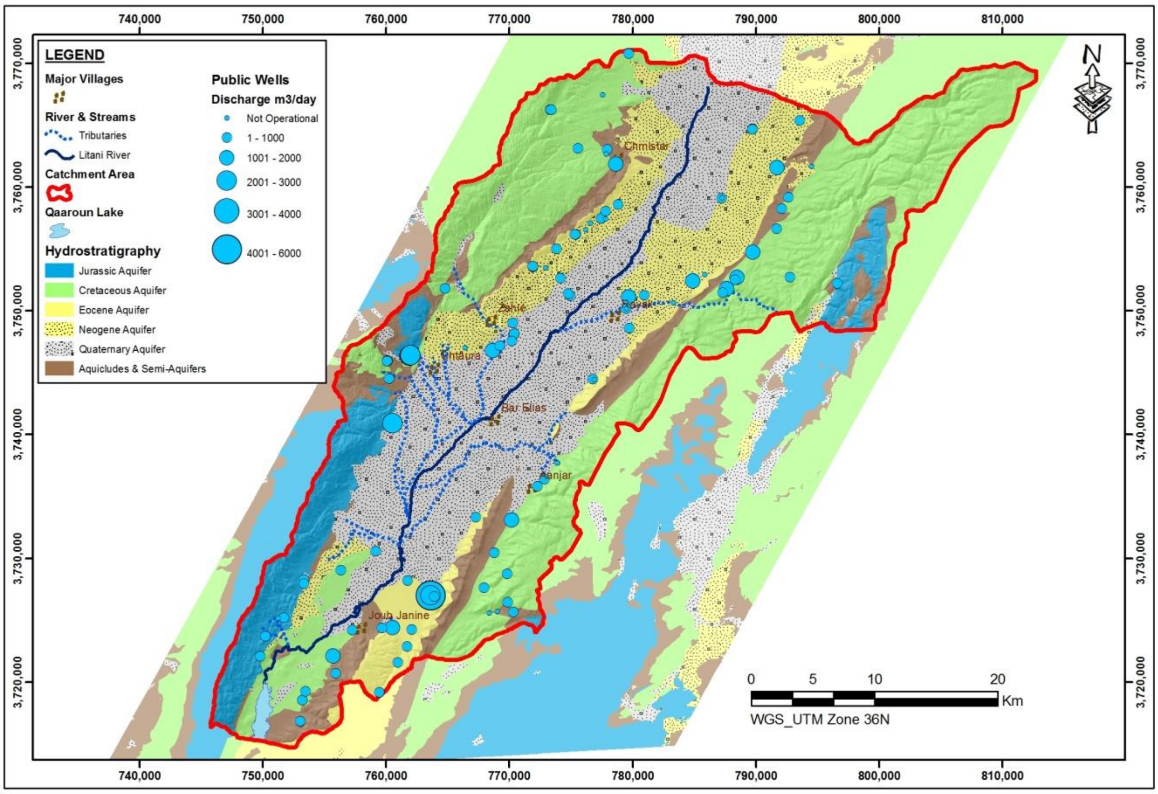


Figure 11-3 Public Wells in the Study Area Classified According to Daily Discharge Rate

APPENDIX C– MEASURED WATER LEVEL IN WELLS

Table 11–2 Coordinates of the Measured Observation Wells and Their Relative Computed and Observed Water Levels

Name	Easting	Northing	Measured Water Level (m asl)	Computed Water Level (m asl)	Difference (m)
Obs 5	784425.2	3764410	989.23	988.4178	0.8122
Obs 6	783794.5	3764776	1002.27	996.9386	5.3314
Obs 7	786990.1	3760257	995.8	997.8111	-2.0111
Obs 8	788358.7	3761862	1039.2	1034.226	4.974
Obs 9	787029.6	3762262	980	986.8691	-6.8691
Obs 11	776204.1	3756574	1166.99	1167.018	-0.028
Obs 12	775899.1	3756557	1186.17	1189.28	-3.11
Obs 14	786686.5	3757342	985.91	989.0047	-3.0947
Obs 15	784434.3	3757944	987.3	977.3552	9.9448
Obs 16	781663.9	3757883	954.85	958.7579	-3.9079
Obs 17	780876.3	3758954	993.1	996.5643	-3.4643
Obs 19	787796.1	3756976	992.97	992.4011	0.5689
Obs 20	772652.7	3750444	917.78	915.7603	2.0197
Obs 21	773960.1	3752110	944.61	949.1981	-4.5881
Obs 22	777158.8	3749126	892.5	889.9872	2.5128
Obs 23	778699.8	3749965	910.47	900.9777	9.4923
Obs 24	773921.3	3748475	889.4	884.5467	4.8533
Obs 25	771626	3747908	875	870.3217	4.6783
Obs 27	772496.9	3746399	875.25	870.1511	5.0989
Obs 29	769265.7	3747178	870.1	869.1792	0.9208
Obs 30	774565.6	3746264	867.15	871.408	-4.258
Obs 31	773838.3	3746367	866.25	870.7875	-4.5375
Obs 32	773819.2	3745369	867.4	870.2098	-2.8098
Obs 33	776392.7	3745521	872.4	872.5162	-0.1162
Obs 34	776229.2	3747853	883.75	880.4971	3.2529

Name	Easting	Northing	Measured Water Level (m asl)	Computed Water Level (m asl)	Difference (m)
Obs 35	766970.3	3739379	863.5	866.3451	-2.8451
Obs 37	768286.1	3738201	872.49	866.2449	6.2451
Obs 39	759324.1	3738408	869.58	865.6851	3.8949
Obs 40	761535.7	3737164	869.69	864.7883	4.9017
Obs 41	762528.7	3736914	864.29	864.7004	-0.4104

APPENDIX D – COMPARISON BETWEEN WELLS SURVEYED IN 2010- 2011 AND WELLS USED FOR CALIBRATION

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks
H2-6	33.61335	35.82075	1010	303	Kamed el laouz	0	0	178.87	831.13	Eocene	Eocene	Not Used
C3-7	33.874	36.07865	1035	350	Siriine el Tahta	173.23	861.77	198.57	836.43	Neogene	Eocene	Not Used
F2-7	33.71397	35.89153	877	101	Majdel Anjar	27.86	849.14	39.77	837.23	Quaternary	Eocene	Not Used
G2-1	33.69553	35.8712	870	85	El Dakwe	21.83	848.17	32.74	837.26	Quaternary	Eocene	Not Used
H2-5	33.6273	35.79897	926	150	Jibb Jinnine	59.03	866.97	70.48	839.55	Eocene	Eocene	Not Used
H2-8	33.62757	35.8085	896	200	Kamed el laouz	44.05	851.95	55.7	840.3	Eocene	Eocene	Not Used
H2-9	33.6506	35.8427	882	0	Loucy	28.12	853.88	38.82	843.18	Quaternary	Eocene	Not Used
E2-6	33.80668	35.9931	899	150	Terbol	23.36	875.64	54.8	844.2	Eocene	Eocene	Not Used
F2-9	33.72292	35.90135	879	100	Majdel Anjar	22.02	856.98	33.98	845.02	Quaternary	Eocene	Not Used
H2-11	33.6511	35.83468	893	150	Loucy	0	0	42.75	850.25	Eocene	Eocene	Not Used
H2-7	33.62572	35.82522	930	200	Kamed el laouz	66.67	863.33	78.61	851.39	Eocene	Eocene	Not Used
H2-10	33.64937	35.84558	900	150	Loucy	36.77	863.23	47.8	852.2	Eocene	Eocene	Not Used
E2-4	33.8138	35.98593	891	225	Terbol	2.33	888.67	9.6	881.4	Quaternary	Eocene	Used
C3-1	33.86552	36.04585	975	300	Ali el Nahri	55.46	919.54	75.24	899.76	Neogene	Eocene	Not Used
B2-1	33.93338	36.10732	1040	600	Talia	38.95	1001.05	62.55	977.45	Neogene	Eocene	Not Used
A3-5	34.0123	36.19445	1106	152	Baalback	38.76	1067.24	50.4	1055.6	Eocene	Eocene	Not Used
H1-7	33.64318	35.72777	954	0	Khirbit Qanafar	27.54	926.46	16.96	937.04	Miocene	Miocene	Not Used
D2-6	33.86548	36.02313	950	230	Ali el Nahri	0	0	72.1	877.9	Neogene	Neogene	Not Used

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks
C3-2	33.87563	36.06613	982	0	Siriine el Tahta	30.37	951.63	32.09	949.91	Neogene	Neogene	Used
C2-6	33.9336	36.0386	995	70	Beit Chama	8.81	986.19	13.9	981.1	Neogene	Neogene	Used
D1-1	33.8699	35.94628	990	25	Fourzol	9	981	8.3	981.7	Neogene	Neogene	Not Used
C2-3	33.91752	36.10085	1046	90	Sifri	51.93	994.07	60.09	985.91	Neogene	Neogene	Used
C3-4	33.90143	36.11808	1112	0	El Khodr	111.64	1000.46	119.97	992.03	Neogene	Neogene	Not Used
C3-3	33.91392	36.11272	1069	150	El Khodr	75.5	993.5	76.03	992.97	Neogene	Neogene	Used
B2-4	33.96223	36.12398	1054	80	El Taibe	57.05	996.95	60.38	993.62	Neogene	Neogene	Not Used
B2-6	33.9522	36.11533	1045	60	Britel	42.97	1002.03	42.6	1002.4	Neogene	Neogene	Not Used
B2-6	33.9522	36.11533	1045	60	Britel	36.99	1008.01	42.6	1002.4	Neogene	Neogene	Not Used
A2-1	34.01108	36.17317	1080	150	Baalback	35.07	1044.93	55.7	1024.3	Neogene	Neogene	Not Used
B2-3	33.95777	36.1204	1055	80	Britel	28.89	1026.11	27.8	1027.2	Neogene	Neogene	Used
A2-2	34.0141	36.16943	1066	100	Baalback	25.24	1040.76	30.28	1035.72	Neogene	Neogene	Not Used
A2-3	34.01482	36.16443	1061	80	Baalback	20.47	1040.53	41.05	1059.95	Neogene	Neogene	Not Used
B3-1	33.92202	36.13867	1137	100	Haour Taala	0	0	39.8	1097.2	Neogene	Neogene	Used
C1-1	33.9134	35.98737	1181	0	Qsarnaba	4.68	1176.32	14.01	1166.99	Neogene - Miocene	Neogene - Miocene	Used
C1-2	33.91333	35.98407	1229	0	Qsarnaba	39.18	1189.82	52.83	1176.17	Neogene - Miocene	Neogene - Miocene	Used
F2-5	33.73118	35.89138	876	0	El Rawda	13.3	862.7	27.45	848.55	Quaternary	Quaternary	Used
G1-5	33.7398	35.83377	861	9.5	Tall el akhdar	1.73	859.27	6.71	854.29	Quaternary	Quaternary	Used
F2-2	33.76457	35.87935	860	10	El Marj	1.31	858.69	2.3	857.7	Quaternary	Quaternary	Used

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks
H2-2	33.63842	35.77132	872	80	Khirbit Qanafar	10.22	861.78	9.68	862.32	Quaternary	Quaternary	Used
F2-1	33.7609	35.8824	872	8	El Marj	4.82	867.18	8.5	863.5	Quaternary	Quaternary	Used
E2-2	33.82208	35.95863	882	50	Dalhamiye	1.65	880.35	25.75	866.25	Quaternary	Quaternary	Used
E2-1	33.82097	35.96645	890	50	Dalhamiye	3.85	886.15	22.85	867.15	Quaternary	Quaternary	Used
E2-3	33.8131	35.95812	887	45	Dalhamiye	1.95	885.05	19.6	867.4	Quaternary	Quaternary	Used
H1-9	33.63718	35.75623	875	50	Khirbit Qanafar	2.57	872.43	3	872	Quaternary	Quaternary	Used
F2-3	33.74995	35.89623	875	4.5	El Rawda	2.06	872.94	2.51	872.49	Quaternary	Quaternary	Used
E1-5	33.84853	35.93165	924	180	El Karak	0	0	50.3	873.8	Quaternary	Quaternary	Not Used
D2-2	33.84607	35.99533	920	130	Haouch Hala	16	904	27.5	892.5	Quaternary	Quaternary	Used
D2-3	33.85322	36.01223	930	125	Rayyak	23.89	906.11	36.53	893.47	Quaternary	Quaternary	Used
D2-1	33.86392	35.9851	903	25	Ablah	3.13	899.87	4.93	898.07	Quaternary	Quaternary	Not Used
C2-5	33.92375	36.04677	952	10	Haouch el Rafqa	5.78	946.22	7.15	944.85	Quaternary	Quaternary	Used
C2-4	33.92355	36.07672	995	55	Sifri	11.1	983.9	24.7	970.3	Quaternary	Quaternary	Used
B2-7	33.96652	36.09592	998	95	Hizzine	5.33	992.67	19.99	978.01	Quaternary	Quaternary	Not Used
B2-5	33.96173	36.10617	1020	80	Britel	27.22	992.78	40	980	Quaternary	Quaternary	Used
B1-2	33.98178	36.07872	993	40	Tarayya	4.04	988.96	8.38	989.23	Quaternary	Quaternary	Used
B1-3	33.98525	36.07202	1008	0	Hadath	2.5	1005.5	5.73	1002.27	Quaternary	Quaternary	Used
G1-4	33.7423	35.82313	862	250	Tall el akhdar	2.07	859.93	2.31	859.69	Quaternary	Quaternary - Neogene	Used
E1-4	33.83215	35.95237	885	215	Maalaqa	0	0	24.5	860.5	Quaternary	Quaternary - Neogene	Used
E1-	33.836	35.93	89	125	Zahle	0	0	29	864	Quaternary	Quater	Used

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks
1	53	523	3								nary - Neogene	
E1-2	33.80342	35.94033	876	80	Zahle	0	0	6.57	869.43	Quaternary	Quaternary - Neogene	Used
E1-6	33.83057	35.90953	912	125	Zahle	18.59	893.41	41.9	870.1	Quaternary	Quaternary - Neogene	Used
D2-5	33.84917	36.01523	935	130	Ali el Nahri	51.42	883.58	62.2	872.8	Quaternary	Quaternary - Neogene	Not Used
E1-3	33.82272	35.94417	890	65	Zahle	3	887	14.75	875.25	Quaternary	Quaternary - Neogene	Used
D2-7	33.84105	35.96018	887	85	Fourzol	0	0	10.6	876.4	Quaternary	Quaternary - Neogene	Used
D2-4	33.85105	36.02735	952	140	Hayy el Fikani	48.61	903.39	53.15	898.85	Quaternary	Quaternary - Neogene	Not Used
D1-2	33.85912	35.9471	933	120	Fourzol	9.69	923.31	15.22	917.78	Quaternary - Neogene	Quaternary - Neogene	Used
B1-4	34.01037	36.0688	1024	0		0	0	97.05	926.95	Quaternary	Quaternary - Neogene	Not Used
D1-3	33.87378	35.96173	965	50	Ablah	9.36	955.64	21.09	943.91	Quaternary - Neogene	Quaternary - Neogene	Used
A1-1	34.02192	36.08013	1013	0	Saaide	1.75	1011.25	33.83	979.17	Quaternary - Neogene	Quaternary - Neogene	Not Used

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks
C2-1	33.92902	36.08915	1014	120	Haouch Sneid	20.25	993.75	32.2	981.8	Quaternary - Neogene	Quaternary - Neogene	Not Used
B1-1	33.98083	36.0852	990	0	Hizzine	0	0	7.17	982.83	Quaternary - Neogene	Quaternary - Neogene	Not Used
A2-7	34.04063	36.15333	1010	100	laat	26.37	983.63	25.89	984.11	Quaternary - Neogene	Quaternary - Neogene	Not Used
B2-2	33.94368	36.10508	1035	70	Talia	38.25	996.75	39.2	995.8	Quaternary	Quaternary - Neogene	Used
A2-6	34.0316	36.15015	1022	0	laat	15.06	1006.94	17.44	1004.56	Quaternary - Neogene	Quaternary - Neogene	Not Used
C2-2	33.91893	36.07768	1006	60	Sifri	13.48	992.52	25.02	1004.8	Quaternary - Neogene	Quaternary - Neogene	Used
A2-4	34.02568	36.14057	1021	130	Haouch tall safiye	3.38	1017.62	6.9	1014.1	Quaternary - Neogene	Quaternary - Neogene	Not Used
A2-5	34.02664	36.14605	1023	0	Haouch tall safiye	2.36	1020.64	4.82	1019.18	Quaternary - Neogene	Quaternary - Neogene	Not Used
H2-3	33.63302	35.78258	864	0	Jibb Jinnine	13.5	850.5	26	838	Quaternary	Quaternary/ or Cenomanian	Not Used
H1-10	33.64123	35.75643	877	0	Khirbit Qanafar	18.05	858.95	30.37	846.63	Quaternary	Quaternary/ or Cenomanian	Not Used
E2-5	33.83485	35.9849	904	140	Terbol	7.77	896.23	20.25	883.75	Quaternary	Quaternary/ or Eocene	Used

Well ID	Northing	Easting	Elev	Depth (m)	Town	Depth to Water Level in June/July 2011 Survey	Ground Water Level in June/July 2011 Survey	Depth to Water Level in June/July 2010 Survey	Ground Water Level in June/July 2010 Survey	Surface Formation	Aquifer	Remarks

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov