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LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

HYDROGEOLOGIC REFERENCE REPORT

APRIL 2012
This report was produced for review by the United States Agency for International Development (USAID). It was prepared by International Resources Group (IRG) under Contract EPP-I-00-04-00024-00 order no 7.

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ACRONYMS

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

FOREWORD

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

EXECUTIVE SUMMARY

PROGRAM BACKGROUND

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

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

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

PRINCIPAL AQUIFERS

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

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

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

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

Cretaceous C4 Aquifer: The C4 Formation outcrops extensively on both the west and east sides of the Upper Basin in relatively higher elevation areas, and in the southern part of the Upper Basin under and just north of Lake Qaraoun. This formation is up to 600 meters thick and the most extensive and prolific aquifer in the Upper Basin.

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

SPRINGS

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

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

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

GROUNDWATER SYSTEM ELEMENTS

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

Water Level Declines have been noted (measured) in several of the aquifer units and appear most marked along the edges of the valley for wells completed in the Eocene and Cretaceous Aquifers and to an extent in the Neogene Aquifer in northeast basin areas. The impacts from the lowering of water levels include: a. reduction in spring flows; b. the drying up of certain springs, and c. a reduction of well yields.

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

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

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

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

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

GROUNDWATER NUMERICAL MODELING

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

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

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

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

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

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

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

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

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

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

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

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

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

Additional Recommended Pre-Modeling Activities Include:

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

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

ملخص تنفيذي

الخلفية

يستمر برنامج دعم ادارة حوض نهر الليطاني LRBMS الممول من الوكالة الامريكية للتنمية الدولية USAID لمدة اربع سنوات بهدف تطوير ادارة المياه في الحوض الاعلى (البقاع)، والذي تنفذه مجموعة الموارد الدولية IRG بالتعاون مع المصلحة الوطنية لنهر الليطاني LRA. بدأ تنفيذ المشروع في ايلول 2009 وهو يتألّف من اربعة اقسام: بناء القدرات، مراقبة المياه (نوعاً وكماً)، دعم ادارة مشاريع الري وإدارة المخاطر.

تم تطوير التقرير المرجعي هذا للهيدروجيولوجية من اجل تقديم لمحة عامة وفهم ظروف المياه الجوفية في الحوض الأعلى لنهر الليطاني (ULRB) وذلك لطبقات المياه الجوفية الرئيسية ووضع إطار لتطبيق نموذج المياه الجوفية العددية لمحاكاة الآثار على مستوى المياه الجوفية حالياً والضخ من المياه الجوفية في المستقبل .

إن الحوض الاعلى لنهر الليطاني يتصل بالفجوة المائية السطحية بين نهري الليطاني والعاصي بالقرب من بعلبك في شمال شرق البقاع، إلى بحيرة القرعون في جنوب غرب سهل البقاع. ويتميز حوض الليطاني العلوي بسهل البقاع بعرض يقارب ال 10 كيلو مترا بالقرب من اعلى الحوضاي بالقرب من بعلبك ويخف إلى عرض بضعة كيلومترات في جنوب غرب البلاد بالقرب من بحيرة القرعون.

الطبقات الجوفية الرئيسية

إن الحوض الاعلى تمتد تحته خمسة وحدات جيولوجية وهيدرولوجية رئيسية وتعتبر كشبكات لطبقات المياه الجوفية (الشكل2) .

الطبقة الرباعية: اعماق الطبقة الرباعية غير مجتمعة (طبقات الدلغان والطين تتخللها طبقة من الرمال الرقيقة والحصى) وهي متواجدة في الجزء الأوسط من حوض الليطاني العلوي وهناك نتوء على جزء كبير من السهل شمال جب جنين. يمكن أن تكون هذه الاعماق 200 متر من السميك وأكثر.

طبقة النيوجين: تتكون من رواسب طمي النيوجين ومنطقة تواجدها أقل اتساعا من الطبقة الرباعية. وطبقة النيوجين هذه يمكن أن تصل إلى سماكة 300 متر او أكثر.

طبقة الإيوسين: تشكل نتوآت الإيوسين في نطاقات رقيقة (عموما 1 كم وأقل) على كل من الجانبين الشرقي والغربي من سهل البقاع، وفي منطقة أوسع من الجزء الجنوبي من السهل. تصل سماكة هذه الطبقة إلى 250 متر.

الطبقة الطباشيرية اوC4 : تمتد نتوءات ال C4 على نطاق واسع من الجانبين الغربي والشرقي للحوض العلوي في مناطق ارتفاع عال نسبيا، وفي الجزء الجنوبي من الحوض العلوي في الاسفل والى الشمال مباشرة من بحيرة القرعون. يصل هذا التشكيل الى سماكة 600 متر وهي طبقة المياه الجوفية الأكثر شمولا ووفرة للمياه في الحوض الاعلى .

الطبقة الجوراسية: تمتد نتوءات الطبقة الجوراسية في الجزء الغربي من الحوض الاعلى من شتورا وصولا الى بحيرة القرعون وتضم طبقة مياه جوفية وافرة.

الينابيع

إن العديد من الينابيع ذات القدرة العالية ينبع من وحدات الصخور الكربوناتية الجوفية (الايوسين ، الطباشيري و الجوراسي) التي تربط سهل البقاع من الجانبين الشرقي والغربي (الشكل 3). الينابيع الرئيسية على الجانب الشرقي من السهل (عنجر و شمسين) والمسألة هنا في الاتصال الأقل حدة بين نفاذية الطبقة الرباعية والخزان الجوفي ووحدة الطباشيرية الأكثر نفاذا .

ثلاثة ينابيع تنبع تاريخيا من طبقة الإيوسين واحتمال من الطباشيرية (رأس العين ، الفاعور ، و ينابيع عين البيضا) وتعاني حالياً من عدم التدفق بسبب الضخ الجائر للري.

يقع على الجانب الغربي من الحوض، واحد من الينابيع الرئيسية البردوني (Berdouni)تتحكم بها من منطقة فالق اليمونة.

تشمل الينابيع الهامة الأخرى على الجانب الغربي من السهل بما في ذلك شتورة، قب الياس ، وينابيع عميق. نتائج قياسات معدلات التدفق للينابيع تمت خلال دراسة برنامج الأمم المتحدة الإنمائي، نعرضه في الجدول 2. والجهود المعروضة عن قياسات التدفق للينابيع محدودة التقارير او غير مصرح عنها.

تدفق او تصريف الينابيع هو المكون الرئيسي لتصريف المياه الجوفية في حوض الليطاني العلوي حالياً وفي الماضي، تصريف الينابيع يقدر بأكثر من 90 ٪ من التصريف السطحي إلى نهر الليطاني. وذلك شكل المصدر الأساسي للري، وللاستخدامات

الصناعية والبلدية التي سببت في انخفاض التصريف السطحي و جفاف نهر الليطاني خلال الأشهر الأكثر دفئا من موسم الجفاف.

عناصر نظام المياه الجوفية

حالات المستوى التاريخي للمياه الجوفية: تتوفر لعدد من الآبار المنجزة في الطبقة الرباعية والنيوجين بيانات تاريخية من العام 1950 إلى أوائل عام 1970، وبعدها من العام 1990 إلى 2002 بعدها تم تركيب العديد من آبار المياه المعدة للشرب وذلك من قبل البلديات – بصورة رئيسية في صخور الكربونات الثلاثة.

الانخفاض في مستوى المياه (قياس) تم ملاحظة الانخفاض في العديد طبقات المياه الجوفية ويبدو ذلك أكثر وضوحا على اطراف السهل في الآبار التي أنجزت في الطبقة الطباشيرية والى حد ما في الحوض النيوجين في المناطق الواقعة إلى شمال الحوض. الآثار من خفض مستويات المياه تشمل: أ. انخفاض في تدفقات الينابيع؛ ب. جفاف بعض الينابيع، وج. انخفاض في انتاج الآبار.

حالات تدفق المياه الجوفية: إن أول جهد في تطوير فهم وقياس ظروف تدفق المياه الجوفية في الحوض الاعلى لنهر الليطاني ال ULRB، كان خلال هذا العمل في مشروع LRBMS. تم إجراء (التخطيط) لحدثين من اجل قياس منسوب المياه الاجمالي المخطط له بعناية حيث تم قياس مستويات المياه في أكثر من 120 بئرا. وبعد ذلك استخدمت البيانات التي تم جمعها عن مستوى المياه لبناء اثنين (حدود contour) من منسوب المياه السطحية في الحوض الاعلى ال ULRB – وذلك لموسم الجفاف في(2010) ولموسم الأمطار في (2011).

الخصائص الهيدروليكية للحوض الجوفي: جمعت نتائج اختبار الضخ من مصادر مختلفة وتلخيصها في الجدول 3 والشكل 8 ل 66 اختبار. هناك مجموعة كبيرة تصل إلى 3-4 للقيم المميزة الهيدروليكية (النفاذية والسعة المحددة) لوحدات معينة من طبقات المياه الجوفية. وحدات طبقة المياه الجوفية خمسة، حيث انه هناك مجموعة تصل إلى 4-5 للقيم الهيدروليكية.

تغذية طبقات المياه الجوفية: قدرت تغذية المياه الجوفية في الدراسة التي طورت على قاعدة البحث حول تدفق الينابيع الذي اجرته (UNDP 1970)، التقييم التاريخي للتدفق الرئيسي تم من خلال ال(LRBMS)؛ وكذلك تحليل المتساقطات إلى الطبقات

الجوفية الخمسة (الجدول 5). والتغذية للمياه الجوفية في ULRB تتراوح بين 200–220 مليون متر مكعب / سنة. الجزء الأكبر من التغذية اي (82٪) يغذي الطبقة الجوفية اي طبقة صخور الكربونات وعلى هذا النحو فان دراسة جادة يجب أن تعطى للتخطيط ولممارسات استخدام الأراضي في هذه المناطق الحرجة لجهة إعادة تغذية المياه الجوفية إذا انه يجب الحفاظ على تدفقات الينابيع ونوعية مياهها.

الاحتياطي الثابت للمياه الجوفية: تقديرات الاحتياطي الثابت للمياه الجوفية هي وبتحفظ في حدود ال15000 مليون متر مكعب وأكثر. لوضع حسابات الاحتياطي الثابت في منظورها الصحيح، فان تخزين المياه الجوفية او المخزون من 15000 مليون متر مكعب يعادل 90 عاما تقريباً من الضخ بمعدل 160 مليون متر مكعب / سنة. دون إعادة التغذية. في سياق التخطيط للموارد المائية، ونظم المياه الجوفية، فان هذه الطبقات الجوفية لديها احتياطي كبير للتخزين، ومع ذلك لديها قابلية كبيرة للجفاف وهذا ما يفرض مرونة في التخطيط او يجب ان يفرض مرونة أكبر لتقييم امدادات بديلة وايجاد مصادر اخرى بدلاً من نظم المياه الجوفية ولو كان ذلك مع احتياطي تخزين اصغر أو منخفض لان استخدام هذه المياه بالطريقة الحالية سوف يؤدي إلى نفاذها خلال سنوات.

استخدامات المياه الجوفية: لم يكن هناك أي احتساب لمخزون المياه الجوفية وكميات الضخ منها ومن الينابيع لصالح البلديات، القطاع الصناعي والري المستخدمة في الحوض الاعلى لليطاني ULRB. على هذا النحو، قمنا باستخدام مصادر معلومات غير مباشرة وبيانات من أجل التوصل إلى بعض التقديرات الأولية لجهة استخدام المياه الجوفية لأغراض الري، والاستخدامات البلدية والصناعية وذلك من اجل النمذجة الأولية.

النمذجة الرقمية للمياه الجوفية

إن عملية النمذجة يجب ان تكون تدريجية وذات رؤية طويلة المدى –يمكن اعتبار هذا النموذج كأداة للمساعدة في الادارة والتي يجب تطويرها من وقت لآخر ويجب ان تكون هذه المعلومات متاحة ومحللة ايضاً. انه من الواضح جدا أننا سوف ندخل مرحلة النمذجة الأولية مع بيانات واضحة وكافية في بعض المناطق وعدم كافية في مناطق أخرى. ومن اجل البدء، فإننا سوف نحتاج إلى الاعتماد على البيانات التاريخية إلى حد ما والتقديرات في مجالات ضخ المياه الجوفية من المياه الجوفية، وتدفقات الينابيع الحالية والتاريخية، الخ

اهداف النمذجة: ان اهداف النمذجة الرئيسية تحتوي على المناطق العامة التالية:

- إن تطوير نموذج للمياه الجوفية في الحوض الاعلى لنهر الليطاني يمكن ان تستخدم للاسباب التالية:

  - التوقعات المستقبلية للمياه الجوفية وتحديدها تحت سطح مجموعة من سيناريوهات التنمية.
  - تقييم المياه الجوفية – والتفاعل مع المياه السطحية.
  - استكشاف الأخطاء وإصلاحها وحل المشكلات وتحديد مناطقها.

- تطبيق نموذج للحل في بعض المجالات تمثل:

  - العمل على "حماية مناطق الينابيع" للحفاظ على تدفقها. يجب تحديد المناطق هذه تحوي على:

    - تحديد مسافة محمية لمنع حفر آبار الضخ
    - اعداد برامج لحماية الينابيع من تأثير الآبار آبار الضخ عليها

  - مناطق حماية آبار البلديات – تحديد مسافات عن آبار البلديات وحمايتها من آبار الري.
  - التوسع المستقبلي المحتمل للقناة 900 حيث جزء من مياه القناة 900 سيأتي من الآبار الجوفية الخمسة المحفورة لهذه الغاية .
  - زيادة تغذية الطبقة الجوراسية في مناطق الحوض الغربي والجنوب الغربي
  - تقييم المنطقة القريبة من حوض وحول بحيرة القرعون للتالي:

    -التغذية إلى طبقة المياه الجوفية الكامنة تحت البحيرة و

    – تحديد الجريان من الجزء الجنوبي من الحوض (منطقة النمذجة)

شروط حدود النمذجة: إن المنطقة التي ستشملها النمذجة هي نفسها منطقة الحوض السطحي لحوض في الحوض الاعلى لليطاني. وسوف لن تكون حدود الحوض في النموذج حدود التدفق باستثناء الحدود الجنوبية للحوض حيث يوجد تدفق للخارج الحوض العلوي إلى الجنوب من بحيرة القرعون.

إدارة المياه الجوفية / السياسة المائية: هناك عدد من المجالات لإدارة المياه الجوفية والسياسات التي يمكن أن تتحقق بطريقة أولية من خلال نهج النمذجة العددية. وتشمل هذه الطرق:

- تشجيع تطوير تغذية الطبقة الرباعية والنيوجين من اجل إعادة استخدامها في الري والحد من الضخ من الطبقات الجوفية اي صخور الكربونات المحيطة وعدم استخدامها في الري (الايوسين، الطباشيرية والجوراسية). وهذا النوع من الإدارة سوف يساعد في استعادة تدفقات الينابيع وبالاخص الينابيع التي جفت، حماية تدفقات الينابيع في المستقبل، والمساعدة في استعادة التدفق السطحي وذلك من اجل الليطاني وروافده.
- إدارة تخصيص التدفق من الينابيع للاستخدام في الري بهدف تخصيص نسبة من تدفق هذه الينابيع لنهر الليطاني وصيانة التدفق السطحي لاستعادة "الاحتياجات البيئية للمياه. "
- الحفاظ على طبقة الكربونات لاستخدام مياهها للشرب (وهذ بالفعل هدف الحكومة / السياسة).

التخطيط: إن تحاليل تغذية المياه الجوفية تشير بشكل واضح إلى اعتبارات استخدام الأراضي وإلى ان التخطيط هو امر حاسم وواجب في مجالات المياه الجوفية وفي طبقات الصخورالكربونية على وجه التحديد، إذا كانت كمية ونوعية المياه الجوفية (بالاضافة إلى تفريغ الينابيع) من اجل صيانتها وحمايتها. هناك العديد من الاراضي المحددة والمستخدمة في منطقة طبقة الصخور الكربونية لا يعاد تغذيتها وهذا الامر يؤثر على مخزون الينابيع من الناحية الكمية والنوعية.

قبل النمذجة يوصى ببعض الدراسات / جمع البيانات: هناك عدد من المناطق التي تم جمع البيانات فيها والعمل الميداني الإضافي عليها سوف توفر أساساً أكثر صلابة وأكثر واقعية للنمذجة و تشمل عمليات التقييم التالي:

- التقييم السريع للايوسين / المنطقة الطباشيرية في الجزء الأوسط الشرقي من الحوض (تربل إلى نبع شمسين) فيما يتعلق بالضخ لاغراض الري؛ مناسيب المياه وتحاليل التغذية المحلية / الميزان المائي.
- تقييم للمنطقة المحيطة ببحيرة القرعون والى الجنوب للمساهمة المحتملة لمياه البحيرة في تغذية الطبقات الجوفية الصخور الكربونية تحت البحيرة (الايوسين والطباشيرية) وحجم تدفق المياه الجوفية من نطاق النموذج إلى الجنوب (حالات الحدود الحرجة).
- تقييم لمنطقة نبع البردوني وهي موضوع ساخن حيال الاستخدامات المتنافسة والمختلفة؛ ندرة المياه في موسم الجفاف، الحاجة الماسة للتدفق او تدفق المياه السليمة بيئياً عبر زحلة.

- التفاعل مع برنامج الأمم المتحدة الإنمائي الذي المشترك في معظم البلادان اي نتائج فريق الدراسة الهيدروجيولوجية التي قيمت النتائج والبيانات التي من شأنها أن تساعد في أعمال النمذجة في ULRB

انشطة اضافية موصى بها قبل النمذجة تشمل:

- تنفيذ قياسات لتدفق الينابيع في موسم الجفاف والتي يمكن أن تكون ما قبل المؤشر إلى برنامج قياس التدفق للينابيع الأكثر انتظاما للمصلحة الوطنية لنهر الليطاني.
- لتشاور مع وزارة الطاقة والمياه والعاملين في حفر الآبار المحليين لاستكشاف إذا كانت بيانات اختبار الضخ الإضافية موجودة لدمجها في جهود النمذجة.
- اختبارات ضخ المياه الجوفية المراقبة: إن ندرة مراقبة اختبارات الضخ في كل من الطبقات الخمس للمياه الجوفية الرئيسية هي فجوة هامة في البيانات. نتائج الاختبارات من الطبقات المراقبة توفر الدعامة الحقيقية للنماذج الرقمية وسوف توفر قيمة حقيقية لقياسات المصلحة الوطنية لنهر الليطاني. المشارك هنا يبحث عن الفرص التي توجد فيها آبار الإنتاج القائمة والآبار القريبة التي يمكن أن تستخدم كآبارمراقبة. وهذا من شأنه توفير تكلفة الحفر ومراقبة الضخ من الآبار الجديدة. بعض الفرص توفرت لإجراء اختبارات لضخ المياه الجوفية والموضوعة في التقرير في القسم 4.3

تقييم سريع للضخ بغرض الري لمناطق مختارة مثل المنطقة الجوراسية إلى الجنوب الشرقي من قب الياس وصولا الى المنصورة .

I. INTRODUCTION

1.1. AUTHORIZATION

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

1.2. PROGRAM OBJECTIVES

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

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

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

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

1.3. PROGRAM COMPONENTS

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

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

1) Building Capacity of LRA towards Integrated River Basin Management

2) Long Term Water Monitoring of the Litani River

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

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

    b. Machghara Plain Irrigation Plan

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

    a. Qaraoun Dam Monitoring System

    b. Litani River Flood Management Model

1.4. PURPOSE OF THE HYDROGEOLOGIC REPORT

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

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

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

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

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

2. OVERVIEW OF PREVIOUS HYDROGEOLOGIC INVESTIGATIONS

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

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

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

The BAMAS project also conducted groundwater modeling to assess the vulnerability of the principal aquifer systems to land use practices and contamination sources in the basin. The modeling was conceptual in nature in that field-derived groundwater levels and aquifer hydraulic characteristics were not used to develop and calibrate the model. DAI/BAMAS extended the model domain outside or beyond the physical basin boundaries to the east-southeast where it was opined that there was an out-of-basin groundwater flow component into the Hasbani Basin. In the LRBMS work, we have shown through the development of potentiometric surface maps, constructed from field derived water-level measurements, that this is not the case and that the groundwater system boundaries in the ULRB are conterminous with the surface water system divides. This is discussed in more detail in Report Section 4.2.

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

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

3. GROUNDWATER SYSTEM FUNCTIONING/HYDROGEOLOGIC OVERVIEW

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

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

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

Table 1: Summary of Principal Aquifer Units

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

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

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

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

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

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

Present efforts at spring flow measurements are reportedly very limited.

In the past, the spring discharge provided over 90% of the baseflow to the Litani River. It has mainly been the capture of this spring discharge for irrigation, industrial and municipal uses that has caused the drying up of the Litani River during the warmer dry season months. In addition smaller springs like Ras el Ain (near the ICARDA farm in Terbol), Faonar and Ain el Bado Springs have dried up due to the lowering of water levels and the capture of spring flows from irrigation pumpage. These three springs issued from the base of the Eocene Formation on the east side of the Basin and likely had contribution from the Cretaceous Aquifer as well. The loss of baseflow, often referred to as "Ecological Flow", has impacted ecosystems such as wetlands as well as riparian vegetation and fauna.

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

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

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

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

Cretaceous C4: The C4 Formation outcrops extensively on both the west and east sides of the Upper Basin in relatively higher elevation areas, and in the southern part of the Upper Basin under and just north of Lake Qaraoun. This formation is up to 600 meters thick. It is heavily developed just north of the Aanjar area on the east side of the Upper Basin. There are also many irrigation wells in the southern part of the Upper Basin just north of Lake Qaraoun. Well yields up to 150 LPs and greater are possible. Many municipal supply wells are completed in this unit.

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

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

4. GROUNDWATER SYSTEM ELEMENTS

4.1. GROUNDWATER LEVEL CONDITIONS AND HISTORY

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

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

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

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

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

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

4.2. GROUNDWATER FLOW CONDITIONS

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

Fall 2010 Potentiometric Surface Map:

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

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

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

<u>May-June 2011 Potentiometric Surface Map:</u>

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

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

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

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

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

1970 Water Level Data

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

1990/2002 Water Level Data

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

4.3. AQUIFER HYDRAULIC CHARACTERISTICS

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

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

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

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

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

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

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

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

Table 4: Summary of Aquifer Hydraulic Characteristics

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

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

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

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

4.4. AQUIFER RECHARGE MECHANISMS AND DETERMINATIONS

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

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

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

A precipitation distribution map for the Upper Litani Basin developed by LRBMS was superimposed on the geologic map for the Upper Litani Basin and an analysis made of precipitation distribution over the principal geologic/aquifer units. The Upper Litani Basin was divided into the east and west sides for analysis purposes as outlined on **Figure 9.** The next step in the analysis was to determine the area of each geologic unit within a specific precipitation interval which is outlined on **Appendix C and Table 5** and summarized below**.**

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

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

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

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

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

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

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

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

Precipitation Recharge Summary: Groundwater recharge to the Upper Litani Basin is estimated at 210 MCM/Yr. on the basis of this precipitation-recharge analysis. 47% or almost half of the annual recharge is attributable to input from the western upland and mountainous areas that are underlain by permeable carbonate rock aquifer systems that receive the highest rates of precipitation annually. The eastern basin areas that are underlain by carbonate rock aquifer systems receive 35% of the total recharge to the basin and thus the carbonate rock aquifer units account for 82% of the total recharge of 210 MCM/Yr. to the Upper Litani Basin. A more detailed breakdown of precipitation input to the specific geologic units on the east and west sides of the Valley is provided in **Appendix C**.

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

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

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

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

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

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

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

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

4.5. ESTIMATES OF STATIC AND DYNAMIC GROUNDWATER RESERVES

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

Table 6: Estimates of Static Groundwater Reserves By Aquifer

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

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

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

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

5. GROUNDWATER USE

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

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

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

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

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

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

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

Table 7: Estimated Groundwater Withdrawals by Aquifer Unit

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

The areas of concentrated groundwater (well) pumpage include:

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

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

Southern Basin Areas:

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

Pre-Modeling Data Collection Recommendations:

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

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

6. NUMERICAL MODELING FRAMEWORK

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

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

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

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

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

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

6.1. MODELING OBJECTIVES AND APPLICATIONS

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

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

Calibration considerations include:

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

6.2. MODELING BOUNDARY CONDITIONS

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

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

6.3. MODEL INPUTS

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

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

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

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

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

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

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

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

6.4. MODELING CALIBRATION APPROACHES

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

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

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

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

6.5. POTENTIAL MODEL SIMULATIONS

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

- Municipal Use
- Industrial Use
- Irrigation Use

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

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

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

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