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LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

WATER BALANCE REPORT

December 2011
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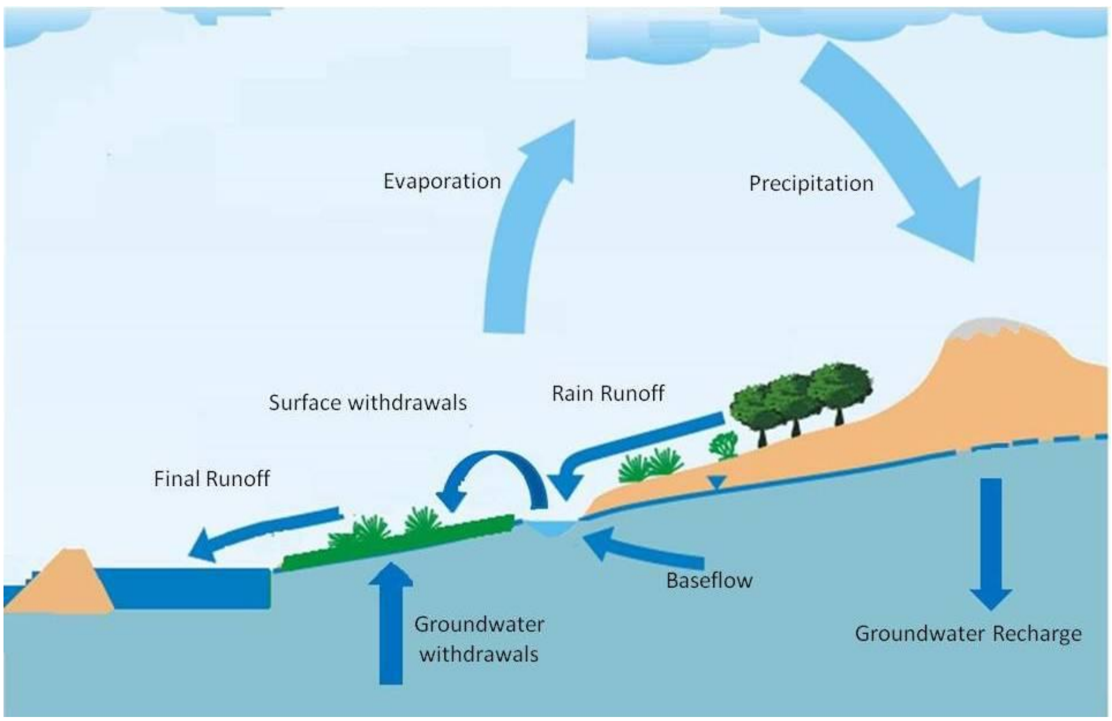
EXECUTIVE SUMMARY

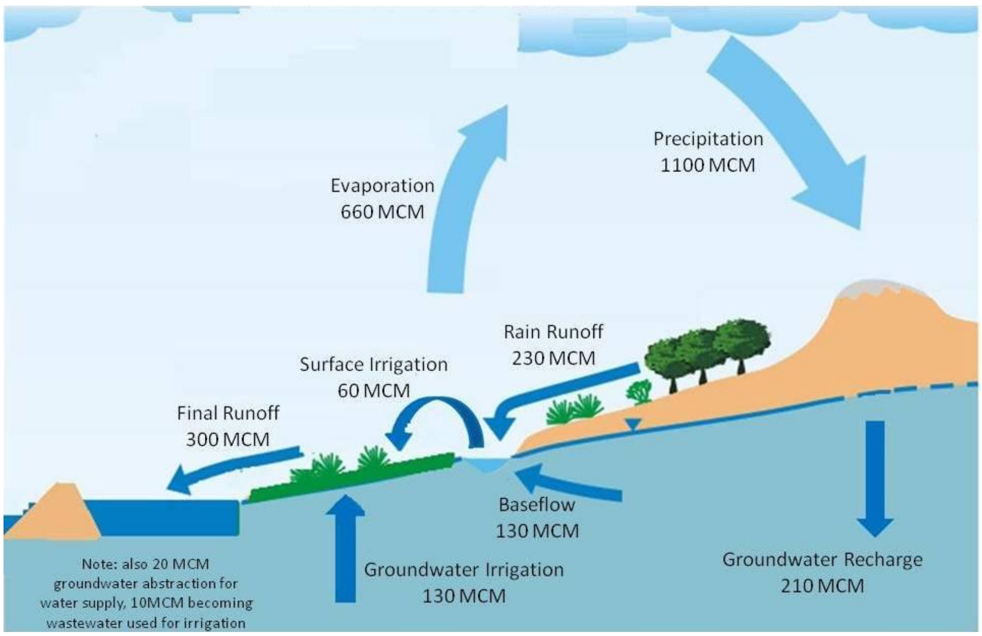
The water cycle is the never ending circulation of water evaporating from the sea to the clouds, then falling as rain and snow, flowing to rivers and lakes or recharging aquifers, being used for human activities and natural processes, and eventually going back to the sea. Even if climatic variability makes for dry and wet years, the average annual quantity of water that circulates remains somewhat constant over human scales, although longer term climate changes occurred in the past and will in the near future. Such averages can be calculated and used for water planning, management, and allocation.



A water balance (for a given area) is an evaluation of average water volumes, in terms of availability (both surface and groundwater) and uses (domestic, irrigation, industrial, etc.). It is an essential tool to compare water supply and demand, compare them, guide current allocations, and plan for the future. Such an assessment has been conducted in the upper Litani River Basin which covers about 1500 km² in the Central and South Bekaa Valley (from Ain Assaouda spring near Baalbeck down to Qaraoun reservoir). The Qaraoun reservoir constitutes a “sink” or outlet since most of the water volumes received there are currently lost to the Basin (being mostly diverted to the Bisri-Awali River to produce hydropower). Without significant inflow or outflow or diversion to other river basins, the water cycle can be translated into three main water conservation/balance equations (water is never created or destroyed, so water volumes can be traced). These are:

- Atmospheric balance: Precipitation = Evaporation + Rain Runoff + Groundwater Recharge
- Surface Water Balance: Total/final River Runoff = Rain Runoff + Baseflow – Total Surface Withdrawals (– Surface Storage Recharge if any)
- Groundwater Balance: Groundwater Storage = Groundwater Recharge – Baseflow – Total Groundwater Withdrawals

Based on available data, the current water balance of the upper Litani River Basin is the following:



The current water balance shows that:

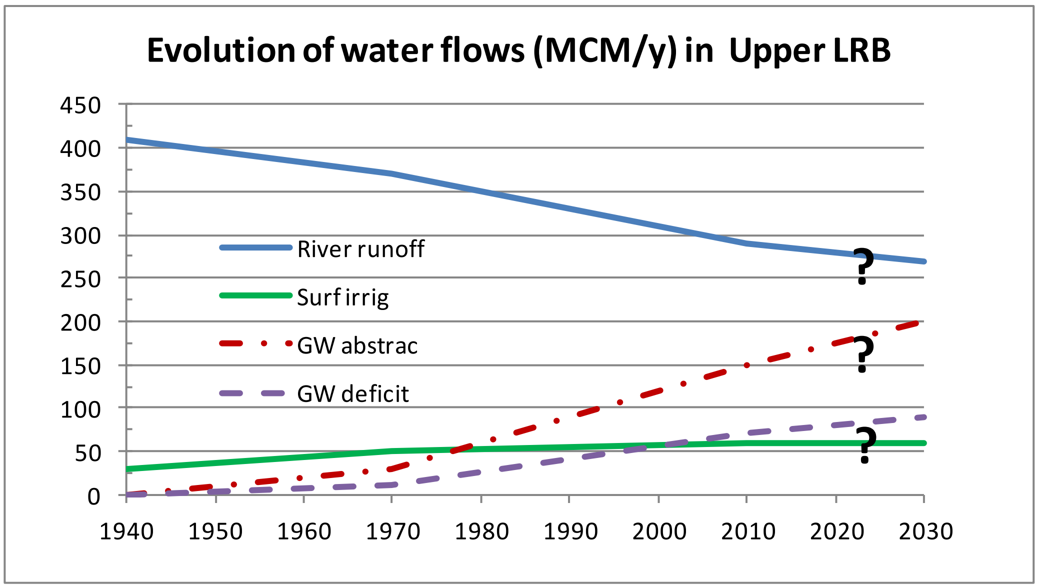
- Precipitation is around 1100 Mm3/year of which more than half evaporates directly; the remaining volumes divide somewhat equally between river runoff and groundwater recharge;
- Baseflow (annual flow from springs) and groundwater abstraction (mostly for irrigation) markedly exceed groundwater recharge, with an average annual drawdown of about 60 Mm3;
- All summer baseflow (70 Mm3) is captured by surface irrigation so summer river flows (final runoff) are low and made up of wastewater/sewage releases and agricultural return flows (almost all river runoff occurs in winter).

> **Water volumes and human needs**
> A human being needs a minimum of 1,000 m3 per year, out of which 900 is needed for food production, the rest being for domestic and industrial needs. One million m3 per year (MCM or Mm3/year) can thus provide for about 1,000 people.

Based again on available data and reasonable assumptions, historical water balance analyses have been conducted to assess the evolution of water resources availability and uses in the upper Litani River Basin. The results (millions of m^3 per year) provide interesting findings for policy and decision-making:

Component	Natural State	1940	1970	2010	2030
Precipitation	1100	1100	1100	1100	1100
Evaporation	660	660	660	660	660
Groundwater Recharge	210	210	210	210	210
Total Runoff	440	410	370	300	270
Net Surface Withdrawals	0	30	50	60	60
Net Groundwater Withdrawals	0	0	30	150	200
Groundwater Change	0	0	(-10)	(-70)	(-90)

- Human demands on water resources have drastically increased in the past half-century, chiefly for irrigation; the Litani River is now almost dry in Summer while spring flows are decreasing;
- Groundwater storage decreases annually by 70 Mm3; this drawdown will continue in the future, gradually increasing the cost of tapping of groundwater resources for irrigation and other uses.



These findings are evident indicators of unsustainable water allocation practices in the Litani River Basin. More specifically, intensive irrigation practices, uncontrolled groundwater pumping and surface water diversions are the main concerns (along with quality issues, which are not discussed here).

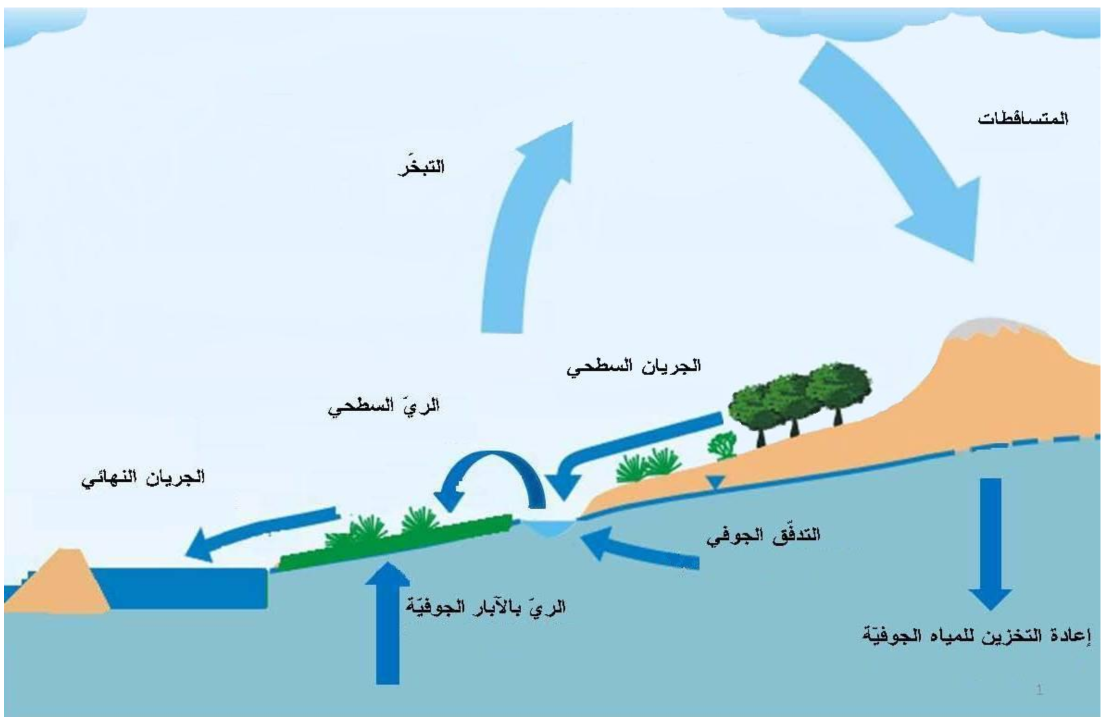
The issue of sustainable water management in the Litani River Basin clearly needs to be addressed, since:

- Current and future water balances for the river basin show that demands exceed availability; and
- Plans are being made to divert Qaraoun Lake volumes to supply Beirut with potable water (Bisri-Awali project), and to irrigate large areas in the South (Canal 800 project).

Water use practices and behaviors have to be improved in terms of water use efficiencies which can only be addressed through awareness and stewardship/empowerment of water users, and improved performance and coordination among water management agencies, while better water monitoring is also essential to confirm these water balance analyses and guide water management in the Litani River Basin.

ملخص تنفيذي

إن دورة المياه هي الدورة التي لا تنتهي ابداً فهي تبدأ بالتبخر من البحر إلى الغيوم، وبعدها تهطل بصورة شتاء او ثلوج، تتدفق بعدها إلى الانهر والبحيرات وتغذي المياه الجوفية، يجري استخدامها في الانشطة البشرية المختلفة وتمر بالمراحل الطبيعية قبل رجوعها مجدداً إلى البحر. بالرغم من ان التقلبات المناخية تجعل بعض السنوات جافة ورطبة، إلا ان متوسط كمية المتساقطات يبقى ثابتاً قياساً إلى حاجة الانسان، ومع ان التغيرات المناخية ستستمر كما كانت في الماضي وكما انها ستحصل في المستقبل القريب، الا انه سيبقى بالامكان قياس هذه التغيرات وبالتالي احتساب الكميات لاغراض التخطيط، الادارة والتخصيص.

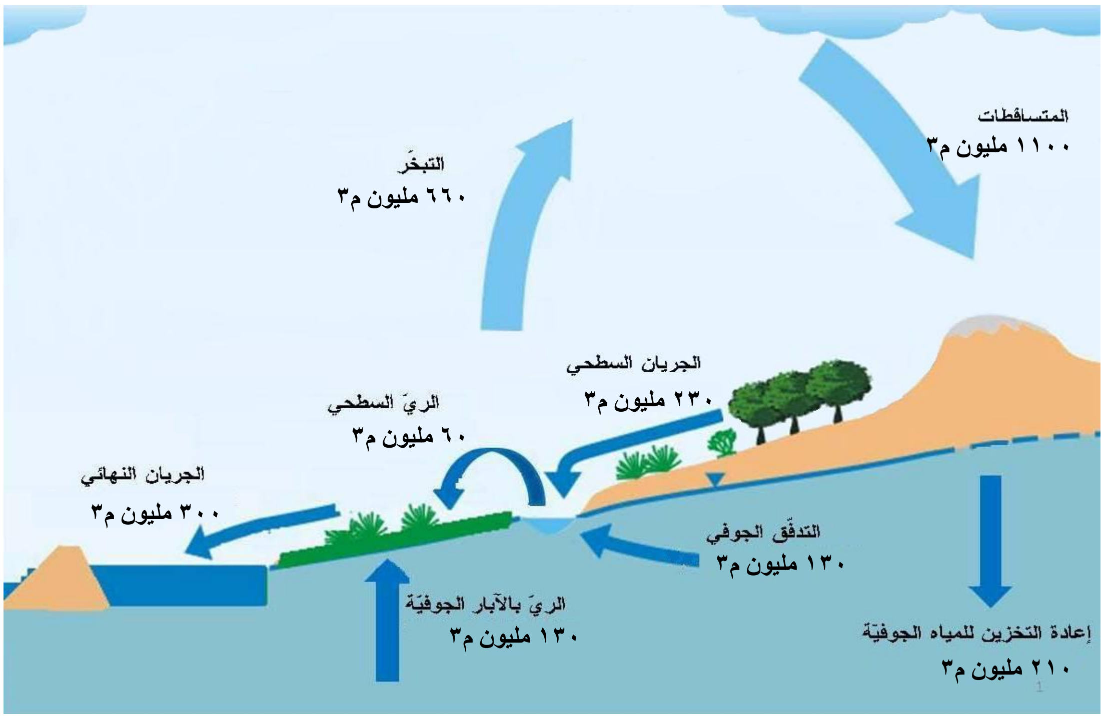


إن الميزان المائي (لمنطقة معينة) يعني تقييم لمتوسط كميات المياه المتوفرة (السطحية والجوفية) و الاستخدامات (المنزلية، الري، الصناعة، الخ.). إن مقارنة الحاجة إلى المياه والامدادات المتاحة، يعتبر اداة اساسية لاخذ قرارات التخصيص والتوزيع والتخطيط للمستقبل. تم اجراء مثل هذا التقييم في حوض نهر الليطاني العلويوالذي يغطي مساحت ١٥٠٠ كلمتر مربع، في وسط وجنوب سهل البقاع (من نبع عين السوداء حتى خزان القرعون). يعتبر خزان القرعون معبراً لمياه الحوض إلى حوض آخر هو حوض بسري-الاولي عبر نقل المياه المجمعة فيه إلى ذاك الحوض بغية انتاج الطاقة الكهرمائية). ان الاهمية القليلة للتدفق او التصريف او التحويل إلى احواض اخرى، لا يمنع من تحويل الميزانية المائية إلى ثلاث معادلات رئيسية (ان المياه لا يمكن خلقها او تدميرها او بمعنى آخر اضاعتها، لذلك يمكن تتبع كميات المياه) والمعادلات الرئيسية هي:

- توازن الاتموسفير: المتساقطات = التبخر + الجريان السطحي + تغذية المياه الجوفية

- **الميزانية المائية للمياه السطحية: جريان النهر الاجمالي/ النهائي = الجريان السطحي المطري + الجريان الجوفي – اجمالي الضخ السطحي (– اي كمية مخزنة في حال وجودها)**
- **الميزانية المائية للمياه الجوفية: تخزين المياه الجوفية = تغذية المياه الجوفية – الجريان الجوفي – اجمالي الضخ من المياه الجوفية**

بالاعتماد على المعلومات المتوفرة، فان الميزانية المائية الحالية للحوض الاعلى لنهر الليطاني هي كالاتي:



ويبين الميزان المائي الحالي على ما يلي:

- **هطول الأمطار هو حوالي ١١٠٠ متر مكعب/ في السنة منها أكثر من النصف يتبخر مباشرة؛ اما الباقي يقسيم على قدم المساواة بين جريان النهر وتغذية المياه الجوفية؛**
- **الجريان الجوفي (التدفق السنوي من الينابيع) واستخراج المياه الجوفية (في الغالب لأغراض الري) يتجاوز بشكل ملحوظ تغذية المياه الجوفية، بمتوسط تراجع سنوي يبلغ نحو ٦٠ مليون متر مكعب ؛**

كميات المياه والاحتياجات البشرية

يحتاج الانسان إلى ١٠٠٠ متر مكعب من المياه سنوياً، منها ٩٠٠ م^3 تذهب إلى انتاج المواد الغذائية، والباقي يستخدم للحاجات المنزلية والصناعية. إن ١٠٠٠ نسمة تحتاج إلى مليون م^3 سنوياً

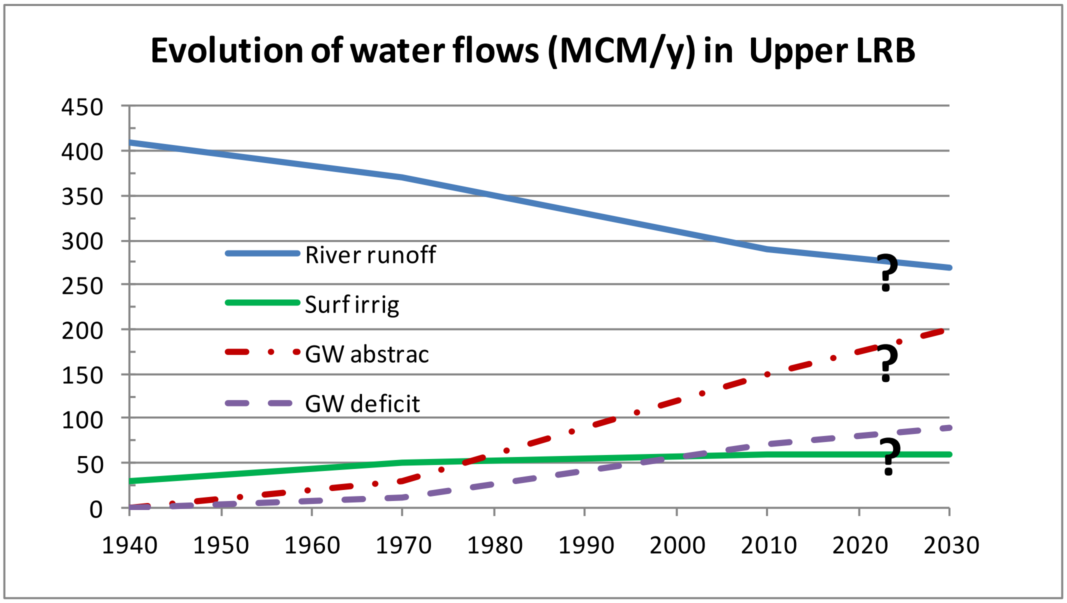
- يتم التقاط جميع الينابيع (الجريان الجوفي) في الصيف (ما معدله ٧٠ مليون مكعب) بواسطة الري السطحي بحيث يعتبر تدفق مياه النهر في الصيف (الجريان السطحي النهائي) منخفض ويتكون من مياه الصرف الصحي / الصرف الصحي بجميع مشتقاته كما ويحتوي على المياه المتبقية من النشاط الزراعي (إن الجريان السطحي للنهر يحدث بمعظمه في فصل الشتاء).

وبالاعتماد مجدداً على المعلومات المتوفرة والافتراضات المعقولة، نجد بان تحليل الميزانية المائية التاريخي يمكن اعتماده للمساعدة في تقييم تطور توافر الموارد المائية واستخداماتها في الحوض الاعلى لنهر الليطاني. النتائج (الملايين من الامتار المكعبة سنوياً) تزود باكتشافات مثيرة للاهتمام لصانعي القرار والسياسة العامة:

العنصر	الوضع الطبيعي	١٩٤٠	١٩٧٠	٢٠١٠	٢٠٣٠
المتساقطات	١١٠٠	١١٠٠	١١٠٠	١١٠٠	١١٠٠
التبخر	٦٦٠	٦٦٠	٦٦٠	٦٦٠	٦٦٠
تغذية المياه الجوفية	٢١٠	٢١٠	٢١٠	٢١٠	٢١٠
الجريان الاجمالي	٤٤٠	٤١٠	٣٧٠	٣٠٠	٢٧٠
صافي الضخ من المياه السطحية	٠	٣٠	٥٠	٦٠	٦٠
صافي الضخ من المياه الجوفية	٠	٠	٣٠	١٥٠	٢٠٠
التغير في مستويات المياه الجوفية	٠	٠	(-١٠)	(-٧٠)	(-٩٠)

- زيادة المطالب البشرية على الموارد المائية بشكل كبير في منتصف القرن الماضي، واهمها لاغراض الري، وبالتالي فنهر الليطاني يكاد يكون جافاً في ايام الصيف في حين ان تدفق اليانبيع ينخفض بشكل ملحوظ

- يتناقص مخزون المياه الجوفية بمعدل سنوي يبلغ ال٧٠ مليون متر مكعب، وسوف يستمر هذا المنسوب بالانخفاض في المستقبل، وستزداد تدريجياً كلفة الاعتماد على موارد المياه الجوفية لاغراض الري والاستخدامات الاخرى.



إن هذه الاكتشافات هي مؤشرات واضحة للممارسات الغير مناسبة لاستدامة تخصيص الموارد المائية في حوض نهر الليطاني. وبشكل ادق اي هذه المؤشرات هي: ممارسات الري المكثف، ضخ المياه الجوفية غير المراقب واستخام المياه السطحية الجائر والغير منضبط (بالتوازي مع مشاكل تدهور نوعية المياه، والذي لم نناقشه هنا).

قضية الإدارة المستدامة للمياه في حوض نهر الليطاني يحتاج بوضوح إلى العلاج، بسبب:

- التوازنات المائية الحالية والمستقبلية لحوض النهر تظهر أن الحاجات تتجاوز المتوفر; و
- قد تم انجاز خطط لتحويل مخزون بحيرة القرعون لتزويد بيروت بمياه الشرب (مشروع بسري–الاولي)، كذلك لري مناطق واسعة في الجنوب (مشروع القناة ٨٠٠).

يجب تطوير السلوك وطرق استخدام المياه، وذلك ممكن فقط عبر زيادة الوعي عند مستخدمي المياه، وتحسين الاداء عبر زيادة التنسيق بين جميع ادارات (وكالات) المياه، في حين ان المراقبة الفاعلة للمياه هي ايضاً ضرورة مطلقة للتأكد من ان تحليل الميزانية المائية سيؤدي إلى ادارة افضل للمياه في حوض نهر الليطاني.

1. INTRODUCTION

The objectives of this report are to:

1. Provide an overview of the current state of knowledge of the water balance for the upper Litani River Basin;
2. Document how this water balance has been established, what available data was used and what reasonable hypotheses were made, and also to guide future water data collection; and
3. Alert water user and decision makers as to the current and future water deficits that jeopardize sustainable water use in the Litani River Basin.

This Water Balance Report is an input to the River Basin Assessment, first step towards developing a River Basin Management Plan. This report includes five chapters:

1. An introduction;
2. Definitions of water balances, leading equations, and terms used to describe the water cycle, as well as the description of the study area;
3. A review of available data and of the evaluation methods for each component of the water balance equations;
4. Estimations for each element of the water balance equations (both past and current water balances have been investigated); and
5. Estimations for the future evolution of the water balance, due to changes in population and water use practices.

2. DEFINITIONS AND ASSUMPTIONS

2.1. THE WATER CYCLE

The water cycle is the never ending circulation of water evaporating from the sea to the clouds, then falling as rain and snow, flowing in rivers and lakes or recharging aquifers, being used for human activities and natural processes, and eventually going back to the sea. It is the same molecules of water that continuously move through that cycle, have done so for millions of years and will continue doing so in the future. Water does not appear or disappear in this cycle but can be temporarily stored in natural (aquifers, lakes) or man-made (dams) reservoirs. While climatic variability makes for dry and wet years, , the average quantity of water that circulates remains somewhat constant over human times, although longer term changes occurred in the past and will in the near future with global warming.

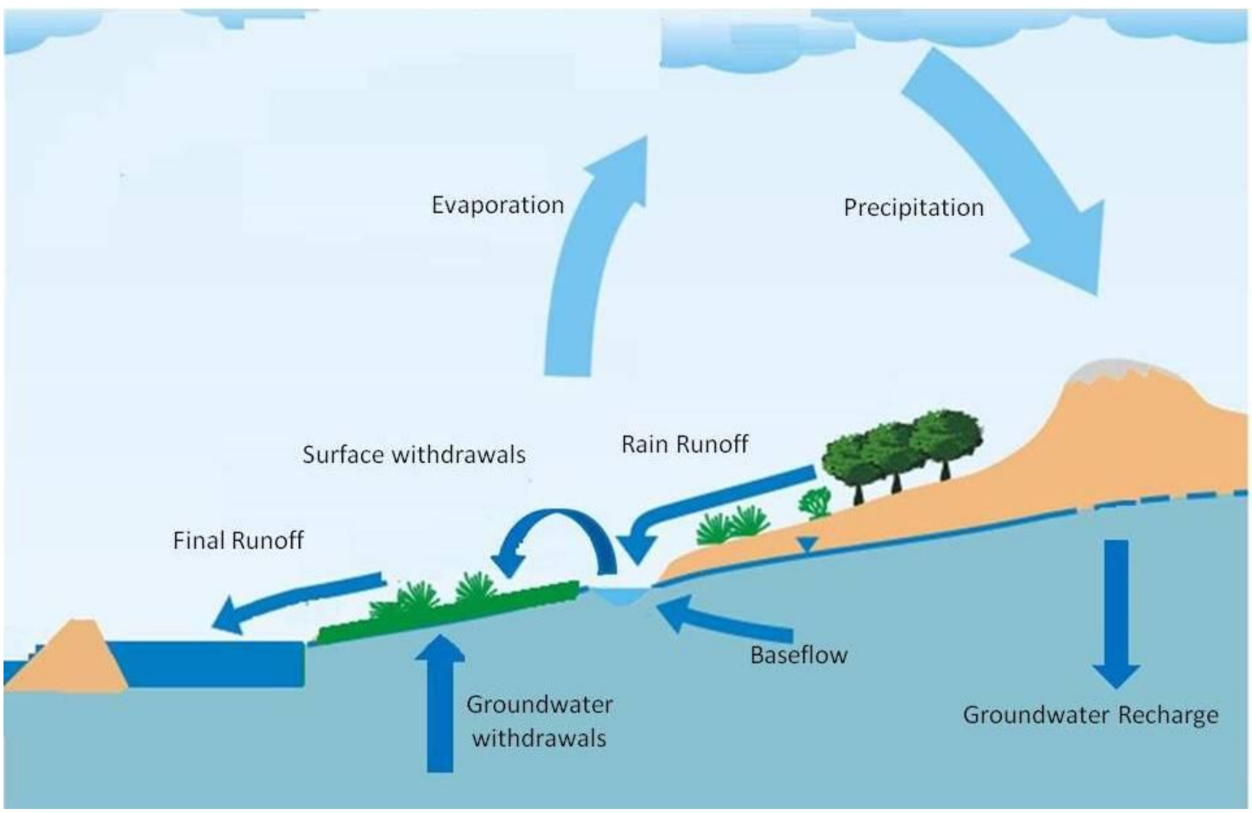
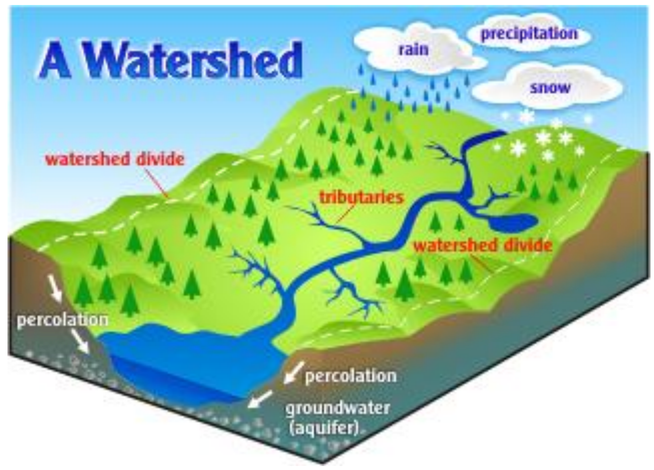


Figure 1: Water balance flows

A water balance is a summary of the current state of the knowledge of the inflows, outflows and temporary storage of water within a given area.

2.2. WATER BALANCE COMPONENTS AND EQUATIONS

A watershed or river basin is the area of land drained by a river and its tributaries. It encompasses all the land surface drained by many streams that flow downhill into one another, and eventually into one river. The final destination is an estuary or an ocean.



As a bathtub catches all the water that falls within its sides, a river basin sends all the water falling on the surrounding land into a central river and out to the sea.

There are no surface water inflows and outflows from/to other adjacent areas (except by human diversion), while groundwater inflows and outflows are usually negligible (underground transfer flows are however possible in karstic areas). It is thus simple to develop a water balance for a given river basin or watershed by considering the conservation of water volumes.

Three general conservation/balance equations translate the fact that water volumes circulate but do not appear nor disappear:

- **Atmospheric Balance**
- **Surface Balance**
- **Groundwater Balance**

2.2.1. ATMOSPHERIC BALANCE

All inflows to the river basin come as precipitations (rain or snow) which either evaporate, flow directly to rivers (rain runoff) or seep into the ground to recharge the aquifers, the equation is thus:

Total Precipitation = Evaporation + Rain Runoff + Groundwater Recharge

One should note that some of the groundwater replenished by rains naturally resurfaces through springs.

2.2.2. SURFACE BALANCE

River flows include:

- **Rain (land surface) runoff**, which basically includes the main volumes flowing down the Litani River as a direct and immediate consequence of rain events;
- **Base flow**, which is groundwater discharged from springs into rivers; these waters seeped through the ground and were temporarily stored underground as part of groundwater;
- **Surface withdrawals** which are volumes diverted from springs and waterways by human beings and consumed; and
- **Final/total runoff** which is the balance of the previous three flows, i.e. the volumes of water reaching Lake Qaraoun, the outlet of our system.

River runoff/flow usually involves both base flow and land surface runoff, but during a dry period without rain for weeks or months, a perennial river or stream has only base flow. The equation is:

Final Runoff = Rain Runoff + Baseflow (groundwater discharge through springs) – Total Surface Withdrawals (– Surface Storage Recharge if any)

Since the river basin under consideration stops at the inlet to Lake Qaraoun, no surface storage change occurs here.

2.2.3. GROUNDWATER BALANCE

Groundwater storage is replenished through groundwater recharge (precipitation seeping through the ground) and drains through resurgences such as springs, or is withdrawn for human needs through well pumping. The conservation/balance equation is thus:

Groundwater Storage = Groundwater Recharge – Baseflow (groundwater inflow through springs) – Total Groundwater Withdrawals

2.3. WATER USE AND WATER CONSUMPTION

A distinction should be made here between use and consumption: vast volumes are routinely withdrawn and supplied to domestic, industrial and agricultural users. But not all of these volumes are actually consumed in the sense of being removed from the system. Significant volumes are actually returned to waterways and aquifers (sewage discharge, industrial effluents, agricultural return flows, network and irrigation losses by infiltration, etc.). Even if the returned flows have been polluted in different ways, for **quantitative purposes** they have not been consumed.

Only evaporated or transpired volumes are considered consumed as they turn into vapor, go into the atmosphere, and are thus no longer available. Transpiration is the natural process whereby crops (and natural vegetation such as forests and pastures) consume and sweat water for their growth. Evapo-transpiration is the combined effect of evaporation and transpiration.

As a side note, most sewage/wastewater is not consumed or lost. It is often released (with or without prior treatment) into natural waterways or seeps down to groundwater (from leaking sewers or from septic tanks). Soils and rivers can assimilate small volumes of sewage by filtering, diluting and "digesting"/decontaminating it. However as seen in the Litani River, large sewage volumes cannot be assimilated and water resources (streams, rivers and groundwater) are then polluted. This does not prevent users from reusing these waters, with prior treatment, or as is by ignoring the danger and/or for lack of alternative water sources (farmers routinely irrigate with raw sewage in the Bekaa).

2.4. WEATHER VARIABILITY AND CHANGE

As a general rule, climate cannot be considered as permanent and stationary. Besides year-to-year variability, climate averages have to be handled with caution. Earth has experienced cooler/hotter and wetter/dryer periods that lasted millions, thousands or only hundreds of years throughout earth's history. These include long spells such as Ice Ages and Interglacial periods and shorter ones (Little Ice Age which was cooler period that occurred in Europe from the 16th to the 19th centuries). Global warming is also a recent and acknowledged phenomena, which remains difficult yet to measure or forecast but may already be impacting rainfall patterns in Lebanon, or will probably in the near future

This being said, it is common practice to consider that weather changes are relatively slow (as compared to the scale of human life), and thus some weather stationarity is accepted to plan water resource management, design structures and forecast future needs. Weather stationarity is defined by the fact that even if there are wet and dry years (weather variability), averages remain somewhat constant.

This is for lack of better assumptions as we do not yet have weather data series long enough and analytical tools sophisticated enough to better forecast future weather conditions. **Throughout this analysis, it has thus been considered that weather conditions have been (on average) constant in the Bekaa over the past century and will remain so in the oncoming 20 years. The only rapid and significant changes are the volumes of water consumed by human activities and their impacts on surface and groundwater flows.**

As a side note, the limited data available so far does not show any significant changes in the average rainfall volume in the Bekaa; see for example the series for annual rainfall at Zahle, which shows a non-significant decrease of 3% in the last 60 years:

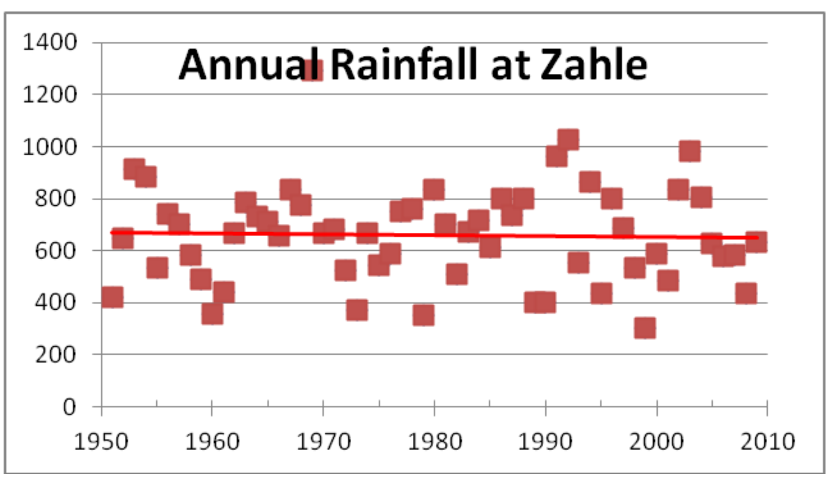


Figure 2: Annual rainfall at Zahle since 1951

Similarly it has been considered that evaporation rates have remained constant (evaporation could only have changed in a significant manner due to drastic soil covering changes such as extensive deforestation, or large changes in solar radiations, temperature, etc.).

2.5. STUDY AREA: UPPER LITANI RIVER BASIN

The water balance assessment has been conducted for the upper Litani River Basin which covers about 1500 km² in the Central and South Bekaa Valley (from Ain Assaouda spring near Baalbeck down to Qaraoun reservoir). Having a detailed water balance for this upper basin is suitable and possible because:

- The upper basin represents three quarters of the entire river basin up to its outlet in the Mediterranean Sea.
- Qaraoun reservoir constitutes a "sink" or outlet since most of the water volumes received there are currently lost to the Basin (diverted to the Bisri-Awali River to produce hydropower or supplying irrigation systems outside of the river basin); and
- Most of human activities occur in this area which hosts 400,000 people, while downstream the Litani River has a quite narrow valley with little population and water withdrawals/uses; and
- Long-term water data is available for that area.

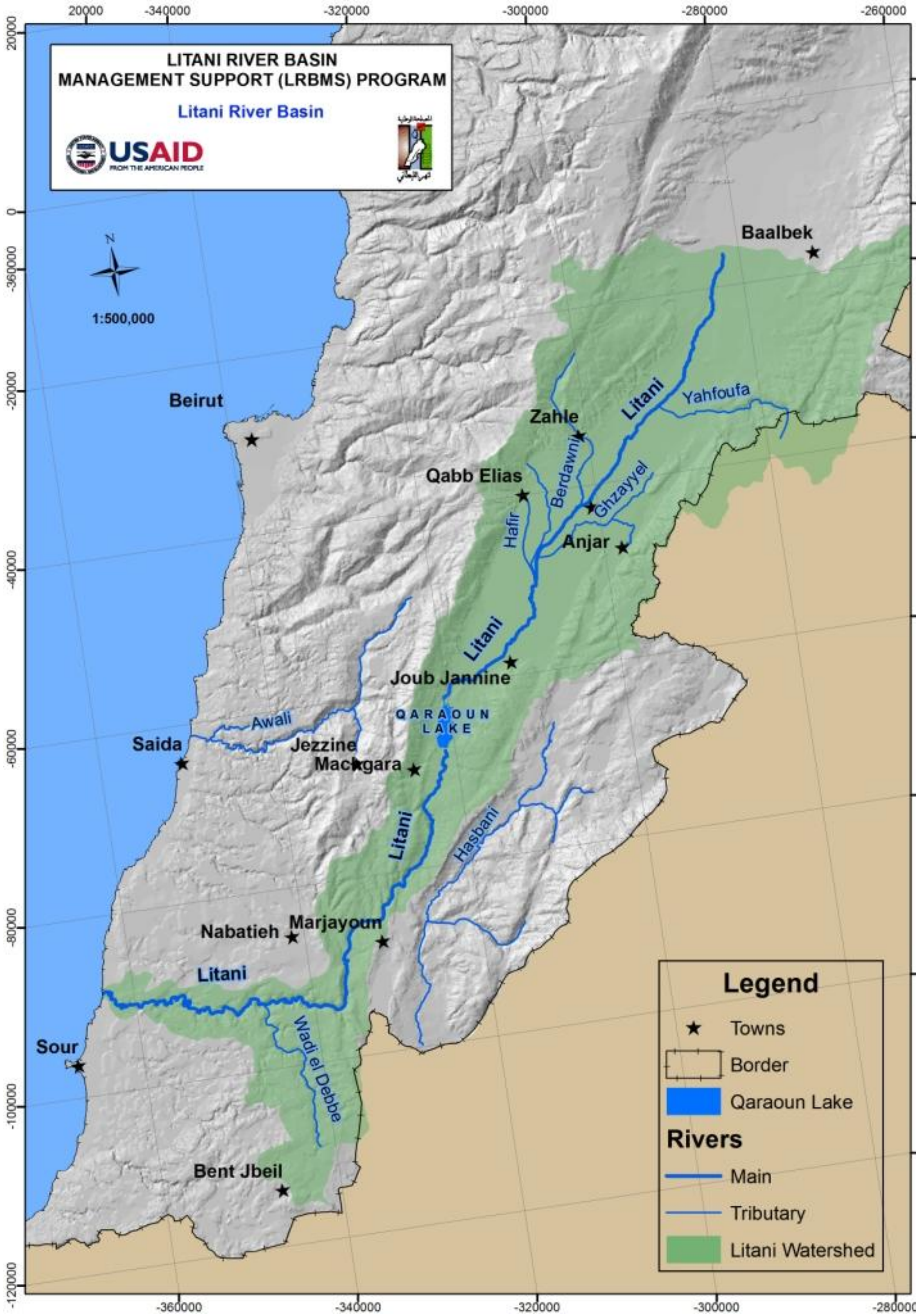


Figure 3: Hydrographic Map of the Litani River Basin

3. DATA AVAILABILITY AND COMPONENT ANALYSIS

3.1. DATA AVAILABILITY

Effective management is based on sound decision making which in turn relies on accurate information. Data collection, verification and dissemination are essential steps towards the production of such information.

Ideally, for a water balance equation, all inputs and outputs are directly measurable and sufficient amounts of data are available for the ULRB. In reality while most components of the water balance are calculated based on field data, other components are estimated, due to:

- Difficulty of measurement: for example, groundwater inflows and outflows are often difficult to measure; likewise regarding volumes used by agriculture (estimated based on standard evapo-transpiration values and estimates regarding cropped areas and cropping patterns);
- Insufficient or unreliable data: measurements exist only for the periods when a monitoring device (such as gauging station) was in place; the accuracy of the resulting data set is doubtful. Although Lebanon used to have a reasonable network of gauging stations recording river flows, the civil war starting in 1975 till the early 90s interrupted this effort. Efforts have resumed since but the lack of equipment and staff has not ensured routine collection of accurate data as it used to be; existing data series rarely shows more than 20-30 years, and the accuracy is uncertain. Focused efforts to improve both collection and quality control of hydrologic data are sorely needed.
- Issues with data access: In Lebanon, as in other developing countries, data collected by public administrations is sometimes considered:
    - Secret (for fear of mistakes, or under preposterous "national security" justifications); and
    - As a personal asset of officers collecting or accessing it, not public property.

  The sharing of public data is limited within or among administrations, and rarely if ever accessible to the public at large. As a consequence, the data produced is rarely used (even by decision makers), and of unknown reliability (without users, there is no control of quality/accuracy).

In spite of the limitations, experience has shown that water accounting, even based on estimates, can be quite useful to managers, farmers, and most importantly decision makers.

3.2. COMPONENTS, DATA SOURCES AND ESTIMATIONS

As mentioned under Chapter 2, the three balance/conservation equations are atmospheric balance, surface balance, and groundwater balance. The various components and their data sources or evaluation processes are:

- Precipitation: as known from weather stations and discussed in section 3.3.
- Evaporation: estimated as a percentage of precipitation with the usual magnitude for open and sparsely forested areas like the central and south Bekaa (see section 3.4).
- Surface flows: deducted from data at the Qaraoun and Joub Jenine gauging stations and inflows at Qaraoun reservoir, as discussed section 3.5.
- Groundwater recharge: estimated based on surface flow data, and hydrogeological assessments (see section 3.6).
- Irrigation uses: both surface and groundwater withdrawals for irrigation have been estimated from data on actual irrigated areas (see section 3.7).
- Other uses (domestic and industrial needs): these have also been considered (see section 3.8).

The remaining unknown components are thus: rain runoff, groundwater storage change, and groundwater recharge. Since we have three equations and three unknown parameters, we can deduct estimates for these from the above mentioned equations.

3.3. PRECIPITATION

3.3.1. DATA AVAILABILITY

Available data is rather limited, and involves:

- Pre-war data: annual/monthly precipitation for different villages in the Bekaa Valley (Zahle, Ksara, Rayack, Anjar, Joub Jannine, Baalbeck etc…) covering several years until the 1970s and the Plassard rainfall map of 1971 (see Figure 4) defining several rainfall areas in the river basin;
- Recent data: daily rainfall since 1998 for a few limited stations (Rayak, Zahle).

The lack of reliable long-term series is a critical issue in Lebanon.

3.3.2. ESTIMATED VOLUMES

The average annual precipitation rate ranges in the Upper Litani river basin vary between 300 mm inland and between 1300 and 1400 mm over the summit peaks. A further analysis of the different rainfall zones in the basin (based on FAO and Plassard Map, 1970-71) allows us to estimate an average of 685 mm/year of precipitation for the entire Upper basin.

The corresponding annual precipitation volume in the ULRB, whose downstream boundaries are the Qaraoun Dam, is estimated to be about 1100 Mm3/year, divided between 1,030 Mm3 in winter (December-May) and 70 Mm3 in summer (June-November).

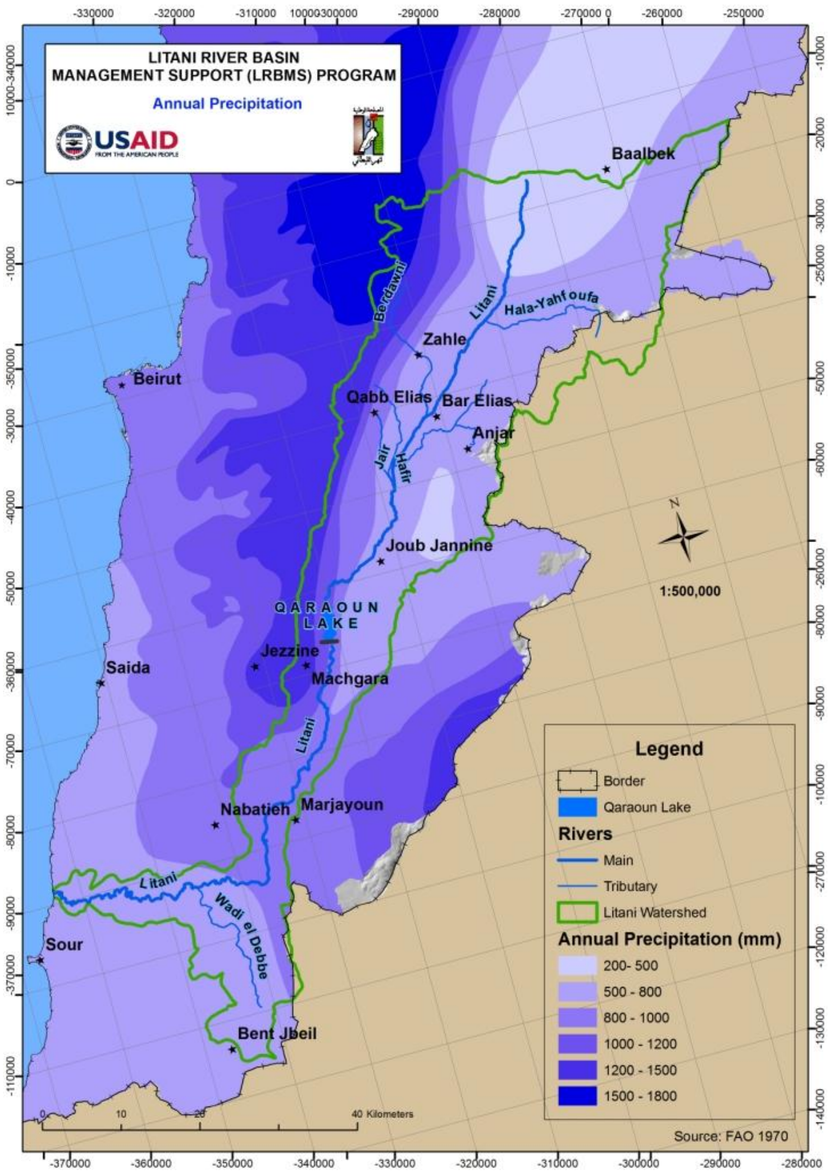


Figure 4: Annual precipitation distribution in the Litani River Basin

3.4. EVAPORATION

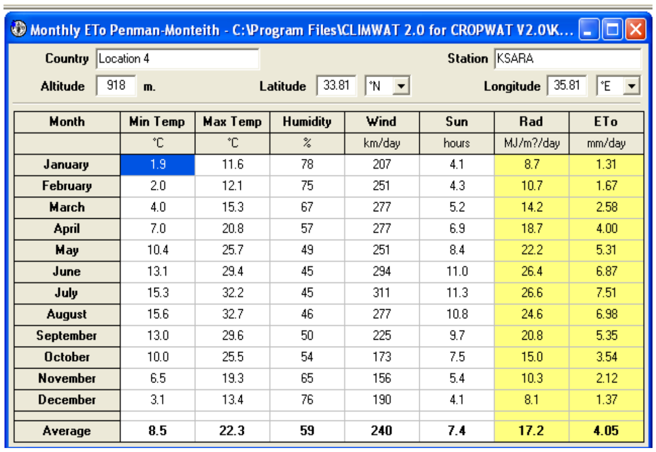
3.4.1. DATA AVAILABILITY

Evaporation here refers to water which directly evaporates without seeping into the ground or flowing to a stream and river, as well as water that is naturally consumed by vegetation and crops without any human intervention. The corresponding volumes cannot be mobilized and controlled by humans and are thus usually considered "lost". In reality those that are evapo-transpired by plants do contribute to the growth of vegetation and crops which in turn benefit human beings.

Little data is available to assess direct evaporation from precipitation in the Litani River Basin. A proxy method is to calculate evapotranspiration using the Penman-Monteith equation as advised by FAO.

3.4.2. ESTIMATED VOLUMES

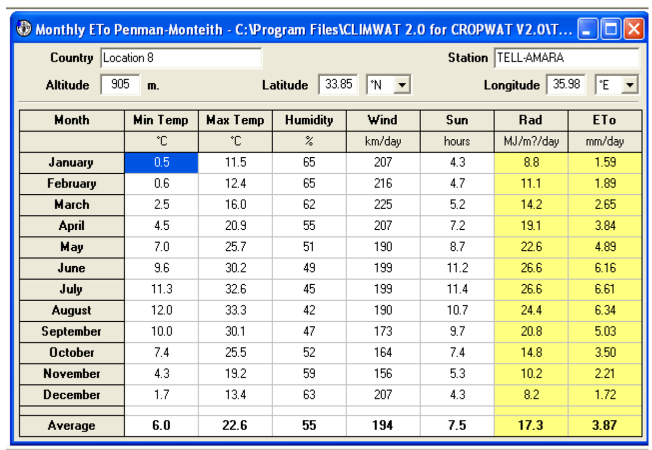
In the Bekaa, this equation provides an average evapotranspiration of about 2.5 mm/day (source FAO CROPWAT database) for the six months of the winter rainy season (December-May), which amounts to a total of about 650 Mm3 for the entire ULRB, or about 60% of precipitations.


Monthly ETo Penman-Monteith - C:\Program Files\CLIMWAT 2.0 for CROPWAT V2.0\K...

Country Location 4 — Station KSARA

Altitude 918 m. — Latitude 33.81 °N — Longitude 35.81 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	1.9	11.6	78	207	4.1	8.7	1.31
February	2.0	12.1	75	251	4.3	10.7	1.67
March	4.0	15.3	67	277	5.2	14.2	2.58
April	7.0	20.8	57	277	6.9	18.7	4.00
May	10.4	25.7	49	251	8.4	22.2	5.31
June	13.1	29.4	45	294	11.0	26.4	6.87
July	15.3	32.2	45	311	11.3	26.6	7.51
August	15.6	32.7	46	277	10.8	24.6	6.98
September	13.0	29.6	50	225	9.7	20.8	5.35
October	10.0	25.5	54	173	7.5	15.0	3.54
November	6.5	19.3	65	156	5.4	10.3	2.12
December	3.1	13.4	76	190	4.1	8.1	1.37
Average	8.5	22.3	59	240	7.4	17.2	4.05


Monthly ETo Penman-Monteith - C:\Program Files\CLIMWAT 2.0 for CROPWAT V2.0\T...

Country Location 8 — Station TELL-AMARA

Altitude 905 m. — Latitude 33.85 °N — Longitude 35.98 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	0.5	11.5	65	207	4.3	8.8	1.59
February	0.6	12.4	65	216	4.7	11.1	1.89
March	2.5	16.0	62	225	5.2	14.2	2.65
April	4.5	20.9	55	207	7.2	19.1	3.84
May	7.0	25.7	51	190	8.7	22.6	4.89
June	9.6	30.2	49	199	11.2	26.6	6.16
July	11.3	32.6	45	199	11.4	26.6	6.61
August	12.0	33.3	42	190	10.7	24.4	6.34
September	10.0	30.1	47	173	9.7	20.8	5.03
October	7.4	25.5	52	164	7.4	14.8	3.50
November	4.3	19.2	59	156	5.3	10.2	2.21
December	1.7	13.4	63	207	4.3	8.2	1.72
Average	6.0	22.6	55	194	7.5	17.3	3.87

This value of 60% for the evaporation/rainfall ratio has thus been adopted here, which is a reasonable estimate that compares favorably to other similar river basins.

3.5. SURFACE FLOWS

3.5.1. DATA AVAILABILITY

Available data includes the following:

- Period of 1921-1951: monthly inflows at Mansoura (USBR Hydrology, 1954).
- Period of 1938-1968: monthly inflows at Mansoura (UNDP 1970, Etude des Eaux Souterraines au Liban).
- Period of 1931-1973: LRA daily records at Mansoura station.

- Period of 1938-1962: LRA daily records at Qaraoun station.
- Period of 1962-2010: LRA monthly inflows at Qaraoun Dam.
- Period of 1998-2009: LRA records at Joub Jannine Gauging station.

The main issues are that:

- No data exists for the Civil War period from the mid-70s till the mid-90s; and no station exist to compare before and after;
- The Mansoura station is unreliable;
- The Qaraoun station was removed when the dam was built; and
- Other stations exist in the lower basin (Khardale, sea oulet) but are outside of our area and also do not represent natural flows since the early 1960s and the construction of Qaraoun Dam.

Unreliability of Mansoura station

Due to a lack of high flow measurements, the rating curve is most probably incorrect for high flows. When the river overflows its banks, even if the flow increases, the water level increases very slowly due to the wider area. The rating curve that converts flood levels into discharges will thus have an inflection point, where discharges increase much faster with water levels. The lack of high flow measurements makes forces to extrapolate low flow measurement and thus gives an incorrect rating curve.

3.5.2. ESTIMATED VOLUMES

The average monthly Litani River flows are summarized here:

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**	**Source**
Avg 1921-1951	Mm3	52.6	74.6	67.1	54.0	34.9	18.2	13.2	11.4	11.5	13.8	16.0	26.0	393	USBR 1954 (at Qaraoun station)
	m3/s	20.3	28.8	25.9	20.8	13.5	7.0	5.1	4.4	4.4	5.3	6.2	10.0	12.6	
Avg 1938-1968	Mm3	40	56	52	41	24	12	8	7	9	10	13	21	292	UNDP 1970 (based on Mansoura station)
	m3/s	15.3	21.5	20.0	15.8	9.3	4.7	3.2	2.8	3.4	3.7	5.1	7.9	9.4	
Avg 1938-1962	Mm3	63	79	78	55	33	17	11	9	10	13	16	28	411	Qaraoun station (LRA)
	m3/s	24.2	30.4	30.0	21.3	12.8	6.5	4.3	3.5	3.7	4.9	6.2	10.8	13.2	
Avg 1962-2010	Mm3	50.9	74.7	72.1	50.6	23.1	7.5	2.8	2.5	3.7	7.7	13.5	29.9	339	Reservoir data (LRA)
	m3/s	19.4	28.4	27.4	19.2	8.8	2.9	1.0	0.9	1.4	2.9	5.2	11.4	10.8	
Avg 1998-2009	Mm3	36.9	72.7	64.3	40.3	14.6	6.1	1.4	0.6	1.1	3.3	8.4	18.4	268	Joub Jenine station (LRA)
	m3/s	14.2	28.1	24.8	15.6	5.6	2.4	0.5	0.2	0.4	1.3	3.3	7.1	8.5	

Table 1: Litani River, Estimated Average Flows

Several comments can be made:

- Over 80% of river flows occur in winter (December-May);
- Runoff volumes in the Litani River have decreased over the past 50 years, from over 400Mm3/year in the 1940s-50s to 300 Mm3/year today; this is due to:
    - Increasing diversions from springs and river flows for irrigation (mostly in Summer); and
    - Probably also a decrease in base flows caused by the lowering of groundwater tables (due to increased groundwater pumping).

Subsequently summer flows have drastically decreased, from 4-5 m3/s in the 1970s down to 0.5-1 m3/s today; this is a direct consequence of the decrease/disappearance and/or diversion of many spring flows that used to supply the river in summer.

3.6. GROUNDWATER

3.6.1. DATA AVAILABILITY

Limited and scarce data is available regarding groundwater flows, in terms of recharge, withdrawals or existing storage and fluctuations. Groundwater recharge has been estimated based on:

- Groundwater analyses (UNDP, JICA, recent LRBMS groundwater assessment);
- Usual estimates of 10-20% of precipitation, based on averages for similar river basins; and
- Balancing of base flow (before groundwater pumping for irrigation, groundwater storage was more or less constant and it can be considered that groundwater recharge then equaled base flow, as stated in UNDP 1970).

3.6.2. ESTIMATED VOLUMES

It has been estimated that a total volume of 200-210 Mm3 annually recharge the aquifers within the Litani River Basin (UNDP Etude des Eaux Souterraines, 1970). This total estimate includes infiltration in all aquifers within the River Basin, i.e. Barouk-Niha aquifer, Jdita aquifer, part of South Bekaa aquifer (Qaraoun – Tell ed Deir), East Bekaa Aquifer (Terbol – Ras Baalbeck), West Bekaa aquifer (Zahle – Chmistar) and Quaternary alluvial aquifer in the Bekaa Valley:

	Area (km^2)	**Precip Mm3/Year**	**% Infiltration.**	**Recharge Mm3/Year**
Carbonate Aquifers	1000	800	20	160
Quaternary/Neogene (alluvial aquifers)	600	300	15	50
Totals	1600	1100		210

3.7. IRRIGATION WATER USES

3.7.1. DATA AVAILABILITY

As in many countries, no accurate data exists regarding the use of water for irrigation purposes. The usual approach in that situation is to estimate the volumes used by correlating irrigated areas (from land records or satellite pictures) with assumed rates of use (m3/ha) based on cropping patterns and climatic conditions. Limited information is available for now, sources being various general studies such as the 2005 "Atlas Agricole du Liban". These data sources are sufficient to get a first idea of current agricultural and their overall impact on water resource availability.

Since irrigation is the main water user in the Litani River Basin, it is essential in the future to develop a better knowledge of cropping patters, cropped areas, and average water needs (per type of crop).

3.7.2. ESTIMATED IRRIGATED AREAS

According to recent satellite images, total green agricultural areas in the Upper Litani River Basin amount to about 50,000 ha:

- Perennial crops (fruit and olive orchards, vineyards) occupy about 20,000 ha
- Winter crops (mostly winter wheat, also winter legumes: fava beans, chick peas, etc.) which are rainfed (little if any irrigated) and harvested in April-June, cover about 20,000 ha; and
- Irrigated crops (vegetables, potatoes, tobacco, etc.) cover about 17,000 ha and are mostly single cropping (Spring/Summer crop, but sometimes after a rainfed winter crop) or rarely double cropping (Spring then Summer/Fall).

This information relates well to recent data from the Atlas Agricole:

<table>
<tr><th>Crop type</th><th>Atlas Agricole (2005)</th><th>Recent satellite pictures (2011)</th></tr>
<tr><td>winter wheat & winter legumes</td><td>25,000</td><td>15,000</td></tr>
<tr><td>olive trees</td><td>2,000</td><td>3,000</td></tr>
<tr><td>fruit trees</td><td>8,000</td><td>7,000</td></tr>
<tr><td>vineyards/grapeyards</td><td>5,000</td><td>10,000</td></tr>
<tr><td>spring/summer first crop</td><td rowspan="2">15,000</td><td>20,000</td></tr>
<tr><td>summer/fall second crop</td><td>2,000</td></tr>
<tr><td>total</td><td>55,000 ha</td><td>50,000 ha</td></tr>
</table>

3.7.3. CROP WATER REQUIREMENTS

Using the same FAO data as provided under section 3.4, evapotranspiration in the Bekaa during the summer months (June-November) totals about 950 mm, otherwise said 9,500 m3/ha.

Now these are theoretical/optimal irrigation applications. In reality farmers irrigate based on their water availability and also based on traditional practices, which may be below requirements. Olive trees for example tend to be traditionally not irrigated (even if irrigation could increase the yields). Similarly fruit trees are often no longer irrigated after harvest at the end of summer (even if Fall irrigation would increase yields the following year). Conversely farmers with good water access tend to over-irrigate summer corps such as vegetables.

Based on these considerations, net water consumptions are estimated thus:

Crop type	ha	Net water consumption (m3/ha/yr)	Mm3/yr
Winter wheat & winter legumes	15,000	2,000	30
Fruit trees	7,000	3,000	20
Olive trees	3,000	0 to 1,000	0
Vineyards	8,000	0	0
Grapeyards	2,000	3,000	5
Single crop (potato, vegetables, tobacco, etc.)	17,000	6,000	100
Double crop	1,000	10,000	10
Totals	**50,000**		**165**

Table 2: Crop types and water uses in the Bekaa Valley

These values do not include:

- Seepage losses during conveyance and application which are not "consumed" and stay within the water system (and thus are not considered here as we deal with net withdrawals); and
- Unproductive evaporation losses, to be added and routinely estimated around 20%.

Total irrigation uses in the upper Litani River Basin can thus be estimated around 200 Mm3/year.

3.7.4. ESTIMATED VOLUMES

Even if irrigated uses have been estimated, it remains to differentiate between the volumes diverted from springs and streams and those pumped from groundwater:

According to the "Atlas Agricole du Liban" and other agricultural data:

Source of irrigation	Importance in LRB	Type of irrigation		
		Furrow	Sprinklers	Drip Irrigation
Surface	35%	45%	50%	5%
Groundwater	65%	15%	80%	5%
Total		20%	75%	5%

The total annual irrigation use is estimated around 200 Mm3 of water consumed for irrigation of which 130 Mm3 are taken from groundwater and 70 Mm3 from surface waters. This estimate is higher than the recent State of the Environment report for Lebanon which assumes a total of 115 Mm3 pumped annually from groundwater in the entire Bekaa:

- 55 Mm3 from public wells (mostly for potable needs); and
- 22+38=60 Mm3 from both licensed and illegal wells (mostly for irrigation).

The estimate for illegal wells is much lower than what can be observed in the field and thus under-estimated (probably by half). The total pumping in the Bekaa is at least 150Mm3 if not up to 200Mm3, two-thrids being in the Litani River Basin. Different aquifers are tapped:

Aquifer System	Estimated pumping (Mm3/yr)
Carbonate Aquifers	110 (20 for drinking water)
Quaternary/Neogene (alluvial aquifers)	40
Total	**150**

3.7.5. PAST IRRIGATED AREAS

Irrigated areas and corresponding water withdrawals in the upper Litani River Basin valley for the years 1940 and 1970 are estimated as follows:

- 1940: Irrigated areas are estimated at 8,500 ha in the Bekaa (Ibrahim Abd el Al studies). Assuming that half are in the upper Litani River Basin, with consumptive water use assumed to be inefficient at 8,000 m3/ha, the volumes diverted for irrigation (from sources and streams) were thus around 30 Mm3/year;
- 1970: irrigated areas with summer or perennial crops estimated at 10,000 ha in the upper Litani River Basin (UNDP, 1970), with consumptive water use estimated at 8,000 m3/ha; volumes diverted (from sources and streams) for irrigation thus being about 50 Mm3/year, groundwater pumping had started and was estimated at 35 Mm3/year (30 Mm3 for irrigation, 5 Mm3 for water supply), with groundwater depletion having started since some springs recently drying up in summer (source: GERSAR-SCP Study for South Bekaa Project).

3.8. DOMESTIC AND INDUSTRIAL WATER USES

About 375,000 people live in the Upper Litani River Basin. The Bekaa Water Establishment considers about 150 l/cap/day for domestic needs, which leads to a total needed volume of 20 Mm3/year. The Bekaa Water Establishment actually pumps larger volumes due to significant leakages (50% and more) in the networks (these leakages are not lost since they recharge the groundwater they were initially pumped from). According to BWE, the volumes annually pumped are around 50Mm3 and the volumes delivered to customers in the entire Bekaa are around 25 Mm3/year (source: BWE). Considering that the Litani River Basin covers 2/3 of the Bekaa, area- and population-wise, pumping there is around 35 Mm3.

Most losses are due to leakage and thus return to groundwater, so the net annual abstraction in the LRB (considering also some private unrecorded pumping, notably by industries) is around 20 Mm3. Most of the water used by residents, businesses, and industries is not actually consumed (that is disappearing through evaporation), but ends up as wastewater which goes either to septic tanks (where it seeps down to groundwater) or to sewers where it flows back to the river (often without treatment).

The released wastewater volumes reach waterways and are available and are usually used in summer (either raw or after dilution in the river or lake) by farmers. These return flows add up in summer to 10 Mm3 which contribute to surface irrigation.

4. PAST AND CURRENT WATER BALANCES

4.1. NATURAL WATER BALANCE

The natural water balance is a hypothetical state describing the water cycle in the Litani River Basin if no human activities were using water. It is a useful reference to compare with past, current and future water balances in order to observe, and analyze human influences on the water cycle.

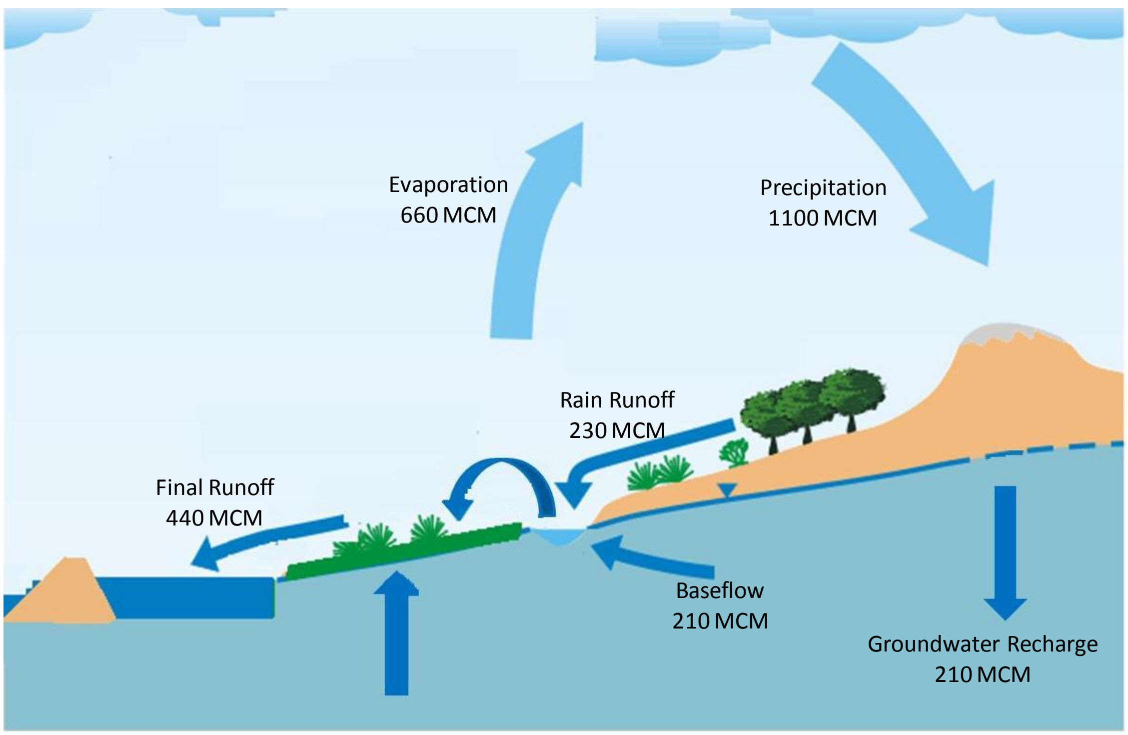


Figure 5: Litani River Basin, Natural Water Balance

In that situation, no water would be diverted and used for irrigation or other human needs, while groundwater storage would remain constant on average, with recharge balancing base flow. In such a hypothetic situation, about 440 Mm3/year would flow in the Litani River at the level of Qaraoun.

4.2. PAST WATER BALANCES

Based on available data, two past situations have been considered: 1940 and 1970. As mentioned earlier, it has been assumed that weather conditions such as rainfall and evaporation have not changed significantly in the past half century or so. Precipitation and evaporation volumes have thus been considered constant. Surface flows are provided from old data from gauging stations (see section 3.5.2). Irrigation uses have been discussed in section 3.7.5. Both water balances were still close to the natural state at this stage. The main differences between these two periods is an increase in surface diversions for irrigation purposes and the beginning of significant groundwater abstraction in the 1970s.

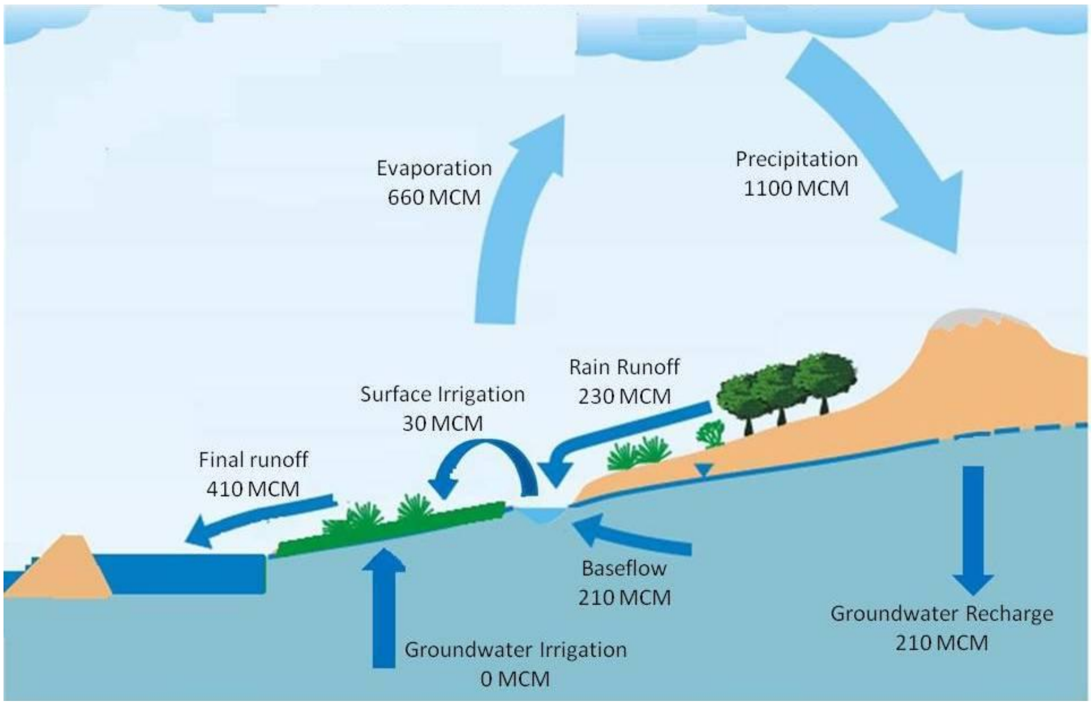


Figure 6: Litani River Basin, 1940 Water Balance

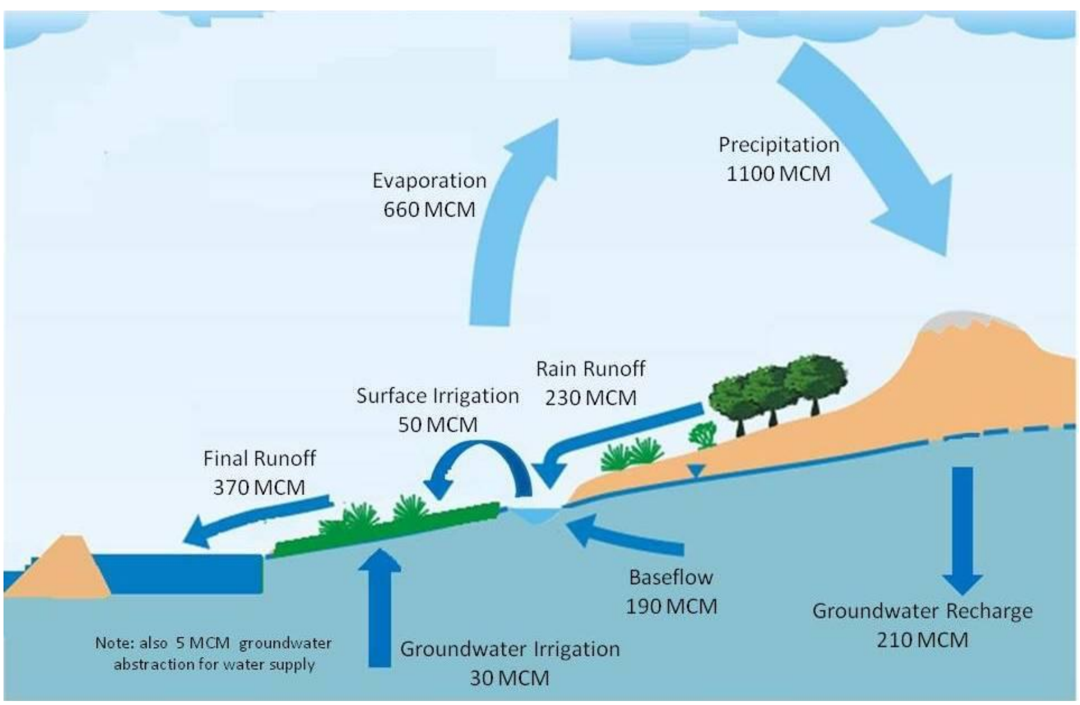


Figure 7: Litani River Basin, 1970 Water Balance

4.3. CURRENT WATER BALANCE

4.3.1. ANNUAL WATER BALANCE

The current water balance shows a marked decrease in runoff volumes associated with a deficit of groundwater recharge, both being due to increased groundwater withdrawals as well as the complete tapping of sources for irrigation. In summer, the Litani River and its tributaries no longer carry freshwater but minimal flows made of sewage and agricultural return flows.

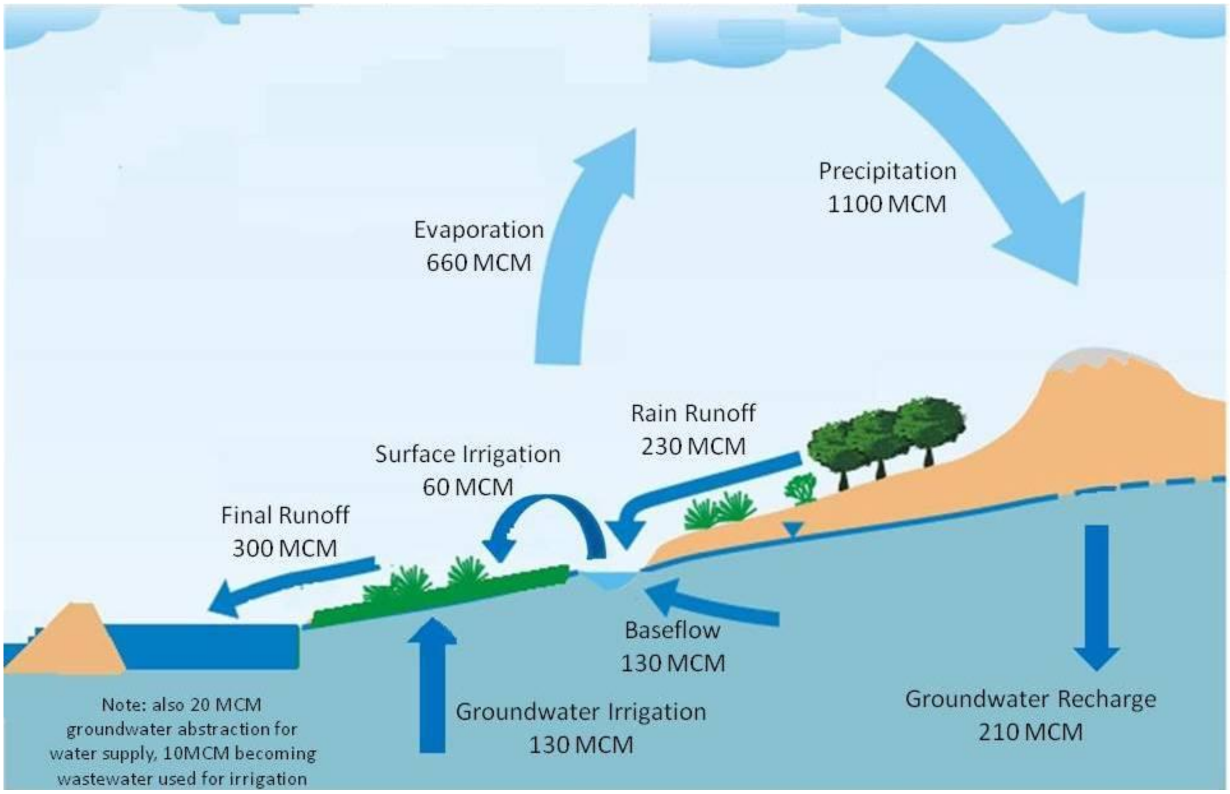


Figure 8: Litani River Basin, Current Water Balance

The main findings here are that:

- Annual runoff is around 300 Mm3/year, that is 100 Mm3/year less than what it was in the past and even in the 70s;
- Groundwater annual depletion is about 70 Mm3/year, that is equivalent to 30% of the recharge; this translates into a groundwater table decline of 0.5-2 m per year.

4.3.2. SEASONAL WATER BALANCES

In order to better understand the current water balance, two seasonal water balances have been developed: one for the dry season half-year (June-November) and one for the wet season (December to May). These two seasonal water balances further highlight the summer groundwater deficit which is only partially compensated by winter replenishments.

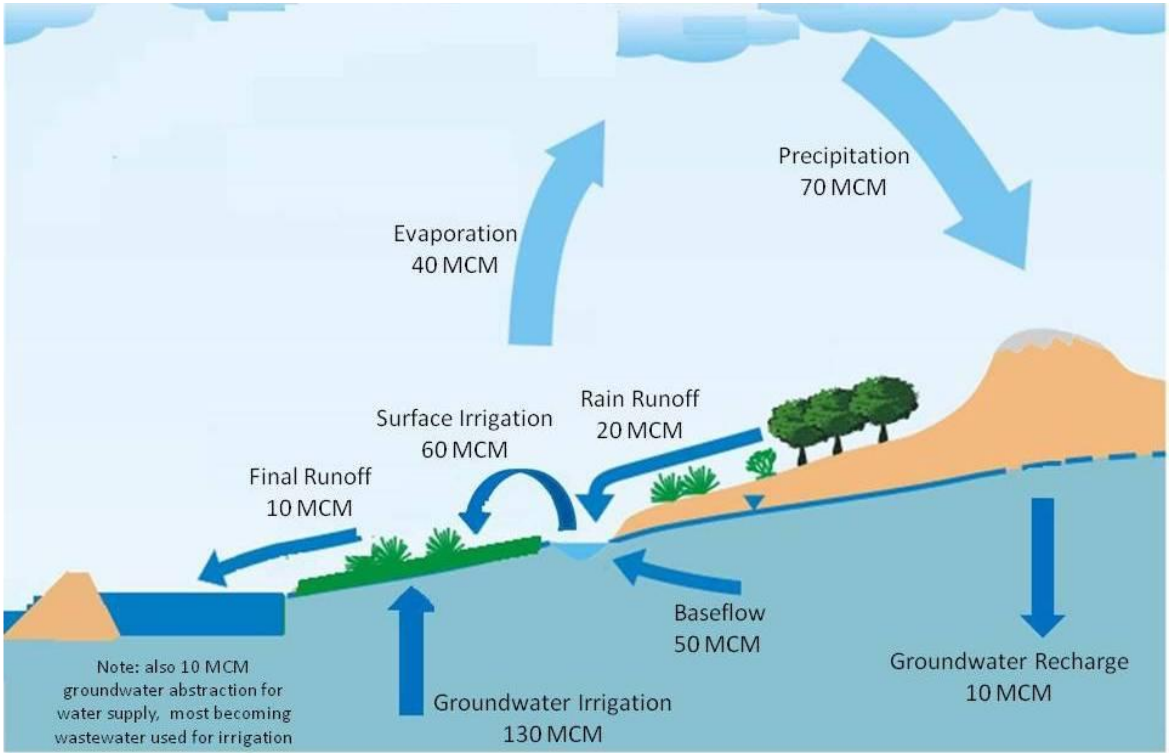


Figure 9: Litani River Basin, Dry Season Water Balance

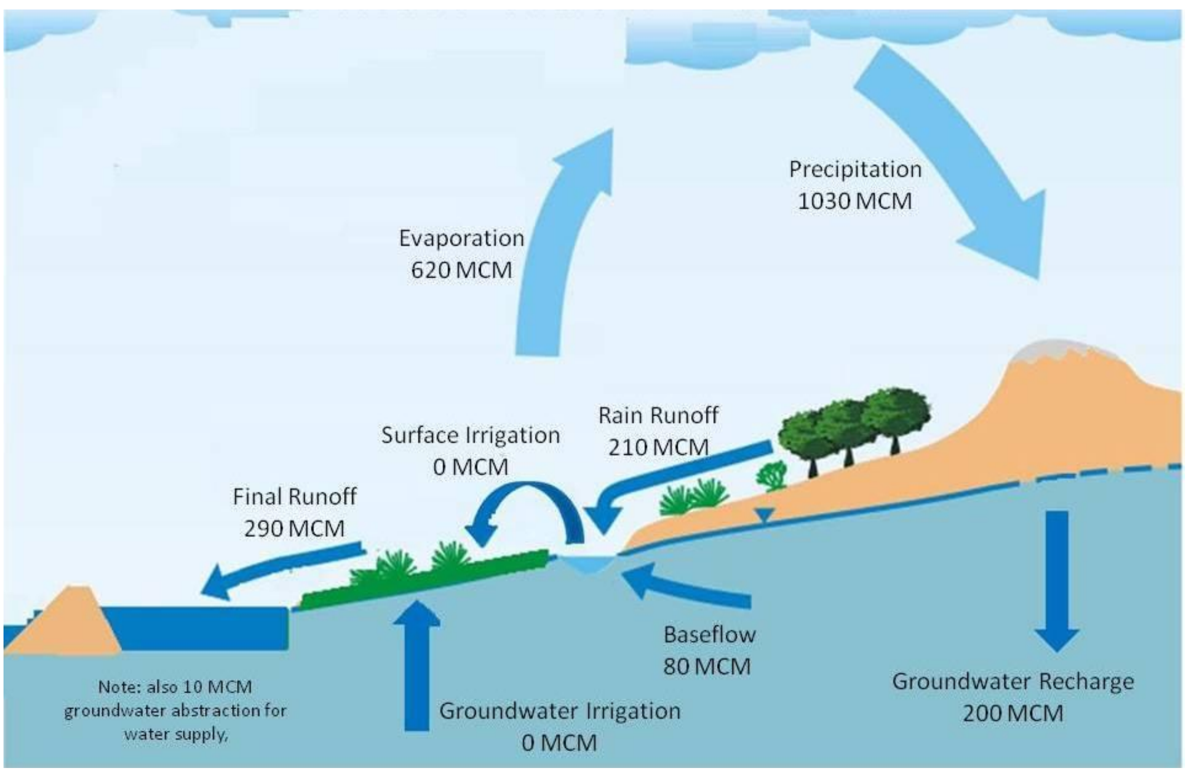


Figure 10: Litani River Basin, Wet Season Water Balance

5. TRENDS

5.1. PURPOSE

The purpose of trends and scenarios in a water balance analysis is to provide a forecast on the future situation of the Litani River Basin in terms of water availabilities and uses. Trends help decision makers and managers anticipate future issues and plan accordingly for the future well-being of water users in the river basin. A 20-year horizon is considered here (i.e. 2030).

To that end, different scenarios will specifically look into the evolution of different water uses (irrigation, drinking water and industrial water) and forecast corresponding future volumes. Inflows to the river basin (rainfall and river flows) are not concerned in this analysis, but climate change may have an impact there and reduce these along with precipitations.

5.2. DRINKING & INDUSTRIAL WATER NEEDS

Population in the Bekaa is estimated to increase by 1% a year in the near future. Population of the upper Litani River Basin will thus probably increase from 375,000 (2010 estimate) to around 450,000 inhabitants by 2030. The net groundwater withdrawals for water supply in the Litani River Basin volumes will correspondingly increase from 20 to 25 Mm3/year.

5.3. IRRIGATION WATER

Trends for irrigation water use should consider both governmental projects, as well as natural expansion of irrigated areas by local farmers.

5.3.1. PROJECTS

Regarding projects, three main projects are targeting Litani River:

- The construction of Canal 800, which demands about 110 Mm3/year, to be provided by Lake Qaraoun (works have been started);
- The extension of Canal 900, which demands about 30Mm3/year from Lake Qaraoun, as well as around 70Mm3 from groundwater (this project is currently inactive); and
- The continuing diversion of 100-200 Mm3/year from Lake Qaraoun to the Bisri-Awali River both to produce electricity and also to provide water supply to Beirut (through a new storage and diversion system whose construction is expected to start soon).

Canal 900 is the only project who would have an impact on the water balance of the upper Litani River basin (by bringing back water from Lake Qaraoun into the upper catchment and mobilizing additional groundwater resources) but it is currently dormant. The two other projects take water from Lake Qaraoun and thus do not impact the water balance.

As a side note, the combination of projects taping Lake Qaraoun, which is grounded in the allocation decided by decree 14522 promulgated in 1970, require more water than available: the development of Canal 800 and the continuing diversion towards the Bisri-Awali basin rely on more than available, especially since the continuing development of the Upper River Basin continues to decrease the inflows into the Lake.

5.3.2. GENERAL IRRIGATION DEVELOPMENT

Regarding the continuing development of irrigation in the Bekaa, this is quite difficult to predict as the capacity and willingness of farmers to increase their activities depend on:

- External factors such as crop prices, market opportunities;
- Local factors such as availability of seeds and fertilizers;
- Local constraints such as legal authorizations and enforcement of groundwater withdrawals; and
- Affordability and availability of water resources, which will respectively increase and decrease as groundwater tables decline and pumping costs rise.

What is certain is that no further surface irrigation can occur (except from tapping into Lake Qaraoun) as most of the summer flows are already tapped, so further irrigation will come from additional groundwater pumping. Actually as groundwater levels decline, the discharge of springs will probably decrease as wells, and surface irrigation will decrease as well.

5.3.3. SCENARIOS

Two scenarios are thus considered here:

- A “business as usual” steady development of groundwater pumping which brings the overall irrigation consumption to 250 Mm3/year; and
- A managed process of improved water management with a very moderate growth where additional groundwater pumping simply replaces lost surface irrigation (as groundwater tables lower, resurgences will decrease too), for a total irrigation consumption of 210 Mm3/year.

5.4. RESULTS

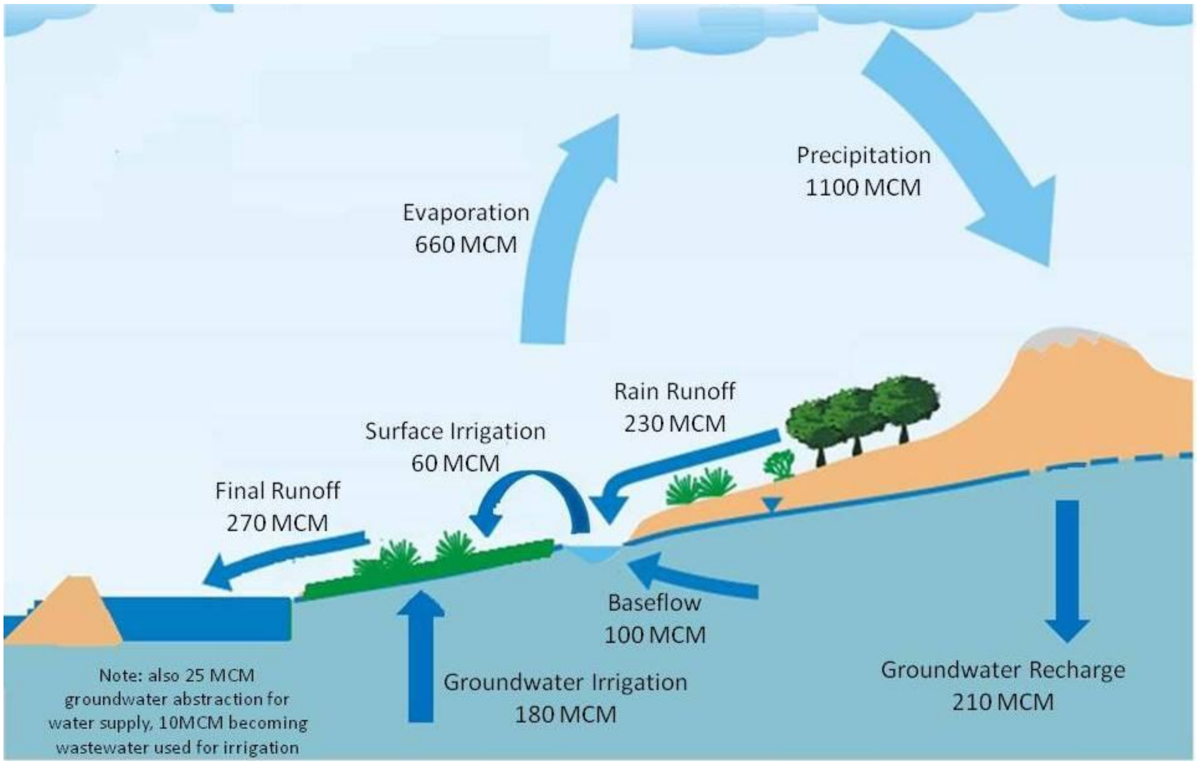


Figure 11: Litani River Basin, Future Water Balance (business as usual)

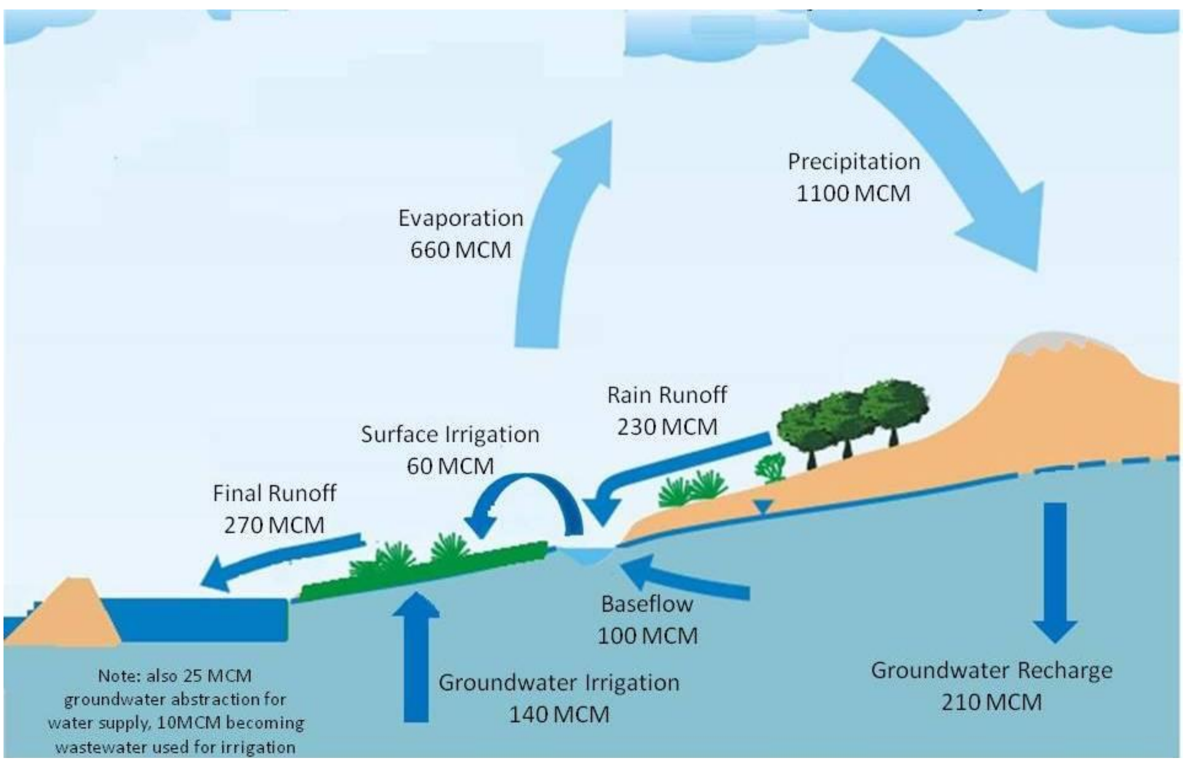


Figure 12: Litani River Basin, Future Water Balance (managed expansion of irrigation)

With business as usual, average groundwater depletion will reach 100 Mm3/year, thus accelerating the lowering of groundwater tables and decreasing well productivity. Pumping costs will increase significantly, while resurgences from springs will continue to decrease, thus providing less surface water for irrigation and pushing for more groundwater abstraction. This vicious circle has occurred in many regions of the world (North-East Pakistan and North-West India, Yemen, North-East China, south Morocco, and even the Ogallala aquifer in the US) where eventually farming becomes unprofitable due to prohibitive pumping costs and much decreased well productivities.

A managed alternative would strive to stabilize groundwater abstraction at current levels. This would require much awareness and enforcement efforts to monitor and control well digging and pumping, and still cause an annual groundwater drawdown of 50-60 Mm3.

The most promising alternative to increased groundwater pumping would be to keep more of the Qaraoun Lake volumes within the river basin (for example by extending and upgrading Canal 900), thus providing farmers with replacement water.

5.5. CLIMATE CHANGE

Beyond natural weather variability (dry or wet, and hot or cold years), there is today no doubt that human-induced global warming is happening. This will have an impact on rainfall patterns and thus on water availability. Unfortunately it is still today difficult to forecast how future rainfall patterns will change, in terms of intensity, frequency, or total volume.

Some models seem to predict a 20-30% decrease in precipitations by 2100; this would aggravate the current deficit and increase the need for better water management.

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