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Hydrological Balance of the Jeita Spring Catchment

Water & Environment Research & Study Center
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نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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عنوان الرسالة: Hydrological balance for the jeita spring catchment

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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Hydrological Balance of the Jeita Spring Catchment

By

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This Thesis was submitted in Partial Fulfillment of the Requirements for the Master's Degree in Integrated Water Resources Management (IWRM)

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COMMITTEE DECISION

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Preface

This master thesis is submitted to fulfill the requirements of the Arab-German master program Integrated Water Resources Management (IWRM), which is executed by the Institute for Technology and Resources Management in the Tropics and Subtropics, Cologne University of Applied Sciences (CUAS), and the Water and Environment, Research and Study Center (WERSC), Jordan University (JU).

This study has been conducted between from 1st of September until 24th of December 2011, in the region of Ballouneh, Lebanon, as part of the technical cooperation (TC) project 'Protection of Jeita Spring', executed by the German Federal Institute for Geosciences and Natural Resources (BGR) and supervised by Dr. Armin Margane. Establishment of a water balance is one of the objectives of the cooperation project. The water balance is modeled with the Water Evaluation And Planning software (WEAP), which has been developed by the Stockholm Environment Institute (SEI).

Since the start of the 'Protection of Jeita Spring' project in July 2010 and starting of research for this thesis, much research has been conducted by BGR. Therefore, this thesis follows up some previous work that has been elaborated before.

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I am glad having been well prepared for this practical semester, done through intensive work by the IWRM master course coordinators Marc Haering, Jörn Trappe and Elke Zimmermann from CUAS.

And finally, I would like to thank Dr. Sebastian Kracun for his remarks on my thesis.

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Abbreviations

AVSI	Associazione Volontari per il Servizio Internazionale
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMZ	Bundes Ministerium für wirtschaftliche Zusammenarbeit und Entwicklung (*Federal Ministry for Economic Cooperation and Development*)
BOD	Biochemical oxygen demand
C	Cretaceous
CDR	Council for Development and Reconstruction
CUAS	Cologne University of Applied Sciences
DAG	Directorate of Geographic Affairs
DEM	Digital Elevation Model
DSS	Decision Support System
E	Evaporation
EP	Effective precipitation
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FC	Financial Cooperation
FRA	Forest Resources Assessment
IWRM	Integrated Water Resources Management
J	Jurassic
JSC	Jeita Spring sub-surface catchment
JU	Jordan University
KfW	Kreditanstalt für Wiederaufbau (*German development bank*)
LAI	Leaf Area Index
LRA	Litani River Authority
m.s.l.	Meter above sea level
MCM	Million cubic meter
MENA	Middle East and North Africa

MoEW	Ministry of Energy and Water
MoPW	Ministry of Public Works
mm	Millimeter
m/h	Meter per hour
ONL	Office National de Litani
P	Precipitation
PEST	Parameter Estimation Tool
PET	Potential Evapotranspiration
PPMCC	Pearson product-moment correlation coefficient
R	runoff
SC	Sub-catchment
sec	second
SEI	Stockholm Environment Institute
TC	Technical Cooperation
TCM	Thousand cubic meter
UNDP	United Nations Development Programme
WEAP	Water Evaluation And Planning
WEBML	Water Establishment Beirut Mount Lebanon
WWTP	Wastewater treatment plant

HYDROLOGICAL BALANCE OF THE JEITA SPRING CATCHMENT

BY PHILIP DORIAN SCHULER

SUPERVISOR: DR. JACKSON ROEHRIG, PROF.

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Abstract

Approximately 63% of Beirut's fresh water demand is supplied by Jeita Spring, which makes this spring of major importance to 1.9 million of Lebanon's total of 4.1 million inhabitants (CIA FACTBOOK 2011). The quantity of fresh water deliveries to Beirut is highly dependent on the karst spring Jeita and its varying seasonal discharge, which ranges between an average monthly minimum of 1.55 m^3/sec. during August and November and a maximum of 8.65 m^3/sec in March, between 1966 and 1972, according to measurements by Litani River Authority (LRA). This study was conducted within the technical cooperation project 'Protection of Jeita Spring' under supervision of the Federal Institute for Geosciences and Natural Resources (BGR); it is a practical attempt to set up a Water Evaluation and Planning (WEAP) environment for the JSC in order to model hydrological components of the catchment's water budget for one year, taking into account land-use (i.e. agriculture and housing) and land-cover (i.e. vegetation, soil and rocks), within the catchment. For a precise representation of JSC's spatial diversity, the catchment is sub-divided into 9 sub-catchments (SC), allowing attribution of more accurate mean monthly average rates of precipitation and reference evapotranspiration (ET_0) to the single SC's catchment nodes and also consideration of different geologic units that show differences in hydraulic conductivities, rates of recharge and specific runoff concentration. Results of the WEAP model show

that, based on a total annual precipitation of 462.5 MCM, approximately 53% of rainfall contributes to groundwater recharge, 20% evapotranspirate and 27% concentrate as surface-runoff; 27% of the model's input is 'lost'. Based on this finding, the study promotes an incentive on supply management by making use of the surface runoff. Namely, the proposal to construct dams on top of low-permeable geological units within unsettled areas, in order to capture and store surface-runoff during the rainy season. Stored water shall be conveyed to Beirut, especially between August and November, when supply to the capital is limited by the low discharge of Jeita Spring.

Keywords: BGR, technical cooperation, Jeita, karst spring, WEAP, supply- and demand management, seasonal water shortage, hydrological budget

1. Introduction

1.1. Background

On a global scale, less than 1% of all fresh water resources are available for use by humans and ecosystems (UN WATER 2011). This share is kept in different interconnected storage systems, like lakes, rivers, reservoirs or aquifers, whose dimensions vary in space and time. According to Koeppen's climate classification (FAO AND SDRN 1999), western and central Europe is categorized as 'temperate' while almost all regions of the Middle East and North Africa (MENA) countries are categorized as 'dry'. In dry regions, total annual potential evapotranspiration exceeds annual mean precipitation. Dry seasons lead to a general unsuitability for growing crops that need continuous moisture. Temporal shortages of water resources are often associated with physical water scarcity; however, in many cases it is human activities that are the driving forces, which accelerate physical water scarcity. It is both, unsustainable water abstraction rates above the safe-yield and unsustainable socio-economic activities that decrease availability of fresh water resources, either by over-pumping or by deterioration of water quality. Concrete problems include the absence of wastewater treatment plants, leaking cesspits and waste disposals, drilling of unlicensed wells, unregistered and unaccounted water abstraction and over-use of resources. Within a framework of unclear laws, missing regulations almost non-existent water monitoring, the process of deterioration of water quality and quantity is often a neglected one. In fact, in general it is less the result of neglected water management but the complete absence of water management that fails to prevent these problems.

Within the MENA region, high population growth, inefficient high agricultural water consumption rates, arid or semi-arid climate conditions, difficulties in data availability, centralized governmental structures and weak economics are issues related to water management. With respect to these problems, Integrated Water Resources Management (IWRM) becomes a key approach to tackle these challenges. At the same time as water use efficiency has to be highlighted and water quality must be maintained so that water resources can serve the specific sectors' demands.

In order to sustain a satisfying water quality, the German Federal Institute for Geoscience and Natural Resources (BGR) works in a scientific way to aid the prevention of groundwater pollution mainly caused by domestic and agricultural activities. Its approach of technical cooperation with national counterparts implies detailed hydrogeological studies of the local or regional setting in order to support a comprehensive protection of aquifers. For this approach, understanding of water supplies and demands within a catchment is a prerequisite in order to assess their specific impact on water quality, as well as on the whole hydrological budget.

However, this comprehensive approach faces various challenges. Unclear governance systems lead to opaque responsibilities of ministries, governmental institutions and agencies. Responsibilities might overlap, or, worse still, issued to single actors that are not accountable. Opacity leads to problems affecting technical cooperation; consequences include inefficiency in project conduction due to difficulties in data collection – if data are present. Data availability is certainly the most serious challenge for the conduction of this study. Regarding population records, climate, hydrology, geology, water consumption and water-use, almost no comprehensive and updated data is available. Therefore, the output of this study should be regarded as a road map for the elaboration of a WEAP model within an uncertain environment; the conceptual structure and the built model shall serve as the basis for data that will be recorded in the future. However, besides weak data availability, it is the extent of the study area, the Jeita Spring sub-surface catchment (JSC), which adds uncertainty to the model; at the time of writing, delineation of its hydrogeological boundaries is still in progress because sub-surface boundaries are not equal to its surface boundaries. With respect to the complexity of the regional hydrogeological catchment borders, they will certainly change in the future, and therefore, they will have to be adjusted in the model.

Nevertheless, this research is a practical attempt to set up a WEAP model under uncertain conditions, which might exist in a similar way in other MENA or emerging countries in the world. Research has been conducted within the technical cooperation project 'Protection of Jeita Spring' that is supervised by BGR.

1.2. BGR: Protection of Jeita Spring

The technical cooperation (TC) project 'Protection of Jeita Spring' was launched in July 2010; its first phase will last until June 2012, the second phase is predicted to last from June 2012 to December 2013. The project is funded by a grant from the German government through the Ministry for Economic Cooperation and Development (BMZ). It is carried out by BGR, under supervision of the project leader Dr. Armin Margane. In cooperation with the Lebanese project partners, the Council for Development and Reconstruction (CDR), the Ministry of Energy and Water (MoEW) and the Water Establishment Beirut Mount Lebanon (WEBML), the project aims to provide hydrogeological studies of Jeita

Spring's sub-surface catchment in order to allow implementation of protection activities, based on these studies. For this approach, three main objectives are integrated, including (MARGANE 2011, [a]):

I. *Integration of water resources protection aspects into the investment planning and implementation process in the wastewater sector*

II. *Integration of water resources protection aspects into land-use planning and improved spring capture and water conveyance*, [and]

III. *Establishment of a monitoring system.*

These three objectives imply the need for boundary definition of Jeita's sub-surface catchment. Therefore, within the TC, several tracer tests and hydrogeological assessments are carried out in order to comprehend groundwater flow and to further delineate the sub-surface catchment of Jeita Spring's aquifers. Based on these tests and the geological setting, vulnerability of groundwater, i.e. high contamination risk zones, are identified. Assessment of this is the basis for a land-use management master plan and for recommendations regarding suitability of selected locations for the construction of a wastewater treatment plant (WWTP); this treatment plant will be designed and constructed as it is part of the scope of the financial cooperation (FC) project 'Protection of Jeita Spring'. As with the TC project, the FC project is funded by BMZ; it is implemented by the Kreditanstalt für Wiederaufbau (KfW) and by CDR. Both of the projects, the TC and the FC, are necessary to avoid bacteriological contamination of groundwater. According to MARGANE (2011, [b]), *the combination of financial cooperation projects, which establish wastewater and geotechnical facili-*

ties, and technical cooperation projects, which provide advice to the former in all geoscientific aspects, is a new approach that aims to reach a better protection of water resources.

1.3. Problem Statement

Among the other MENA countries, Lebanon faces intra-annual water shortages that occur mainly during dry summer periods between July and November. During this time, there are not enough natural resources available to cover disproportional water demand, i.e. mainly irrigation for agriculture and the daily domestic per capita consumption of 200-250 liters (FAO AQUASTAT). In July and August (1955 to 1975), regional average monthly rainfall is 0.5 mm (ATLAS CLIMATIQUE DU LIBAN 1988. In: THE STUDY OF NAHR EL KALB WATERSHED 2009).

To compare the water budget between nations, LAWRENCE, ET AL. (2002) established an interdisciplinary water poverty index that takes into consideration national resources, access to them, their capacity and different users, including the environment. According to their results, Lebanon has an index of 55.8 (Yemen: 43.8; Jordan: 46.3; Syria: 55.2; Egypt: 58.0; Germany: 64.5). This indicates that Lebanon has a relatively high water budget, which however differs notably in space and time. On the top of the Lebanon Mountains, total annual precipitation can reach up to 2 000 mm, whereas on the eastern side of the Anti-Lebanon Mountains, precipitation declines up to 200 mm (MOE/LEDO 2002).

However, sophisticated scientific statistics about Lebanon's present water budget do basically not exist: […] *there is an urgent need to fully update the hydrological data in terms of quantity of precipitation, river flows and groundwater characteristics. A centralized water-*

data management system for information dissemination is essential for water resource assessment. (EL-FADEL, ET AL. 2000) Besides the supply side, it is also the demand side that is difficult to quantify. Regarding abstraction rates of groundwater, which is the major water source of water in Lebanon, there is a huge uncertainty about absolute figures. According to the MINISTRY OF ENERGY AND WATER (2010), a total of 650 governmental wells supply annual 270 MCM. In addition to this, there is an estimated number of approximately 43 000 unlicensed private wells that are mainly run by the agricultural sector. It is estimated that total annual abstraction of these wells is approximately 440 MCM; in reality, however, groundwater abstraction from private wells may be much higher. The sum of both abstraction figures is higher than Lebanon's annual safe yield of groundwater that is estimated at 500 MCM (MINISTRY OF ENERGY AND WATER 2010). It is the recent 30 years in which development has mostly contributed to this: *It is not an exaggeration that the number of wells drilled since 1980 is more than the number of wells drilled in Lebanon since its existence* (KHAIR, ET AL. 1994).

For an analysis of a water budget, it is crucial to study the corresponding hydrogeological setting because this influences the amount and also the rate of groundwater recharge. With respect to the amount of recharge, in case of Jeita Spring, it is the sub-surface catchment that matters, rather than only the surface catchment. Total annual discharge of Jeita Spring (144.59 MCM) cannot be explained only by the size of the surface catchment because discharge is too high; therefore, the spring's sub-surface catchment, which exceeds the surface catchment, is the reference space for this study. However, with respect to groundwater recharge, rates are generally high because of the high share of karstified limestone geology in the region. Within the Jeita Spring catchment, there are several different geological units, being part of the Jurassic (J) or Cretaceous (C), with specific compositions, degrees of karstification and hydraulic conductivities. Within these geological units, it is the J4, J6 and C4, which have the highest degree of cracks and fissures; intense karstification allows not only high groundwater recharge rates but also high flow velocities. Velocities within the saturated zone can reach up to 2 000 m/h (MARGANE AND MAKKI 2011). This, in turn, causes relatively short residence times of groundwater within the aquifers. Due to this, spring discharge varies throughout the season, with quick responses to rainfall events; spring discharges decrease significantly between July and November and many small springs dry out in the summer. Since all regional streams are fed by springs, all of them are periodic; even the Kalb River may dry out at the end of summer. It is this period, between July and November, in which springs offer only very limited amount of water resources and in which groundwater abstraction can be considered as being unsustainable, if only focused on this summer period. Thus, water supply from Jeita to Beirut is limited and distribution of available resources between different demand sites must be considered carefully.

Various factors intensify the discrepancy between available resources and demands. Population growth leads to an increasing absolute demand for water. Table 1 shows domestic water demand projections for Lebanon between 2000 and 2030 (EL-FADEL, ET AL. 2000). According to these figures, between 2010 and 2020, the population is predicted to grow by 21.8%, while total domestic water demand is predicted to increase by 41.8%. Based on this, it can be concluded that increase in total water demand is not only caused by absolute population growth but also by a relative surge, i.e. an increasing per capita consumption.

Table 1: Domestic water demand projections and population of Lebanon between 2000 and 2030.

Year	Population [in million]	Consumption rate [l/capita/day]	Total domestic demand [MCM/year]
2000	4.5	190	312
2010	5.5	225	452
2015	6.0	243	532
2020	6.7	262	641
2025	7.6	281	780
2030	8.0	300	876

Source of data: EL-FADEL, ET AL. (2000).

Absolute and relative increase in water demand is accompanied by a physical surge of urban space, which develops horizontally rather than vertically. In the recent past, within the JSC, sealed surfaces have significantly increased in absolute terms: *Urban growth and unplanned strip development has a considerable impact on the environment and constitutes a real pressure on the natural resources* [...i.e.] *water cycle disturbance* (THE STUDY OF NAHR EL KALB WATERSHED 2009). Replacement of open soils, bare rocks or vegetation by impervious concrete prevents infiltration of rainfall and increases absorption of solar radiation. This replacement leads to changes in the micro and meso-climate, i.e. increase temperatures, which results in an increase in evapotranspiration and a decrease in infiltration. Decreasing infiltration of consistent effective precipitation causes an increase in surface runoff and faster concentration of this towards open water bodies. This development has a crucial impact on the hydrological balance because it decreases total groundwater recharge and therefore total groundwater availability and in turn increases water loss via evaporation.

Besides natural population growth, it is migration towards the catchment that increases regional demand for water. Due to its close distance to the Lebanese capital of Beirut, the catchment attracts people to move permanent or temporary in to it; generally steep topography and accelerating altitude, which ranges from 60 m.s.l. to 2 626 m.s.l., implies moderate temperatures during summer and therefore favorable living conditions. In fact, 'summer residents', who only live during this period within the catchment, increase pressure on the hydrological system. Within the main area of JSC, which expands within the administrative unit, 'Qaza', of Keserwan (Figure 2 & 3), approximately 68% of all existing housing units are occupied only during winter (THE STUDY OF NAHR EL KALB 2009); domestic water demand varies according to the seasons, and, based on this, there is seasonal variation of water consumption, water use and wastewater return-flow. This variation of water demand corresponds to both, the time of year and to the geography because the spatial distribution of seasonal housing depends on the lands' site characteristics.

Spatial urban development demands physical infrastructure, i.e. paved roads, power lines and a water supply system. If wastewater is not treated at the household level, homes should be connected to a centralized wastewater collection system. In Lebanon, 60% of houses are connected to a wastewater collection line. However, only 4% of total discharged wastewater is actually treated, compared to a MENA average of 32% (MINISTRY OF ENERGY AND WATER 2010). According to unpublished data, within the catchment of Jeita Spring, only a negligible share of households empties their cesspits; due to the high potential of leakage, emptying is not necessary. Therefore, wastewater, no matter if previously collected through a central network or not, may concentrate towards streams, infiltrate into the unsaturated zone and/or percolate into the saturated zone. The consequence of this is partially groundwater recharge by untreated wastewater. Return-flow from households towards aquifers is one component of the regional water balance.

Besides households, it is also the agricultural sector that is an important demand site within the JSC. At the time of sowing, almost 100% of the crop’s water consumption is related to evaporation. When the crop reaches its full extent, still, more than 90% of the crop’s water demand is related to transpiration (FAO 1998). Both growing development periods show the consumptive characteristic of crops, as well as for other vegetation; and of course temporal variation of this consumption, with respect to the crop’s or plants’ specific physiologic development. Because of the dry summer period (chapter 4.2), farmers within the study area have to apply irrigation. In Kfar Debianne (Figure 3), for example, between May and the end of September, 86% to 96% of the total agricultural land is irrigated (CDR 2002). An irrigation efficiency of approximately 60% leads to both, water loss through evaporation and return-flow towards the unsaturated- and possibly saturated zone. Water for irrigation comes exclusively from sources within the catchment; water might be stored in ponds and open reservoirs in order to use it for the dry period.

The Importance of the direct- and indirect impacts of supply- and demand sites on the hydrological balance of the Jeita Spring sub-surface catchment has to be evaluated within the context of the importance of the spring itself. Jeita is the major source of drinking water, i.e. water that is safe for drinking (WHO 2011), for the Lebanese capital. According to BROOKS AND MEHMET (2000), Beirut’s annual domestic water demand is approximately 80 MCM. Approximately 62.5% of this share, which corresponds to 50 MCM, is provided by Jeita Spring.

1.4. Justification

Problems and issues, affecting the hydrology within the JSC are diverse, yet, in principle related to each other. Already today, there are water shortages for several months in the year, typically between August and November. In order to manage these shortages as sustainable as possible, it is essential to understand the interaction between supply- and demand sites. This leads to the need for a spatially explicit assessment on the scale of a catchment (within this study, the 'catchment of Jeita Spring' corresponds to its sub-surface catchment), which is the basis for land-, water-, supply- and demand management alternatives (HOFF, ET AL. 2011). Such an assessment, based on Water Evaluation And Planning supports decision makers in (re-) distributing available resources efficiently inside the system, i.e. the catchment of Jeita. With respect to the demand side, water conservation is important. Conservation implies strategies related to the agricultural sector, e.g. irrigation schemes or crop-based policies, as well as to the domestic sector, e.g. improving water use efficiencies or promoting water re-use. With respect to the supply side, water allocation is important. As part of the actual 10 year water plan, there are currently 38 proposed dams and lakes, most of them for the purpose of irrigation and potable water. Altogether, the proposed reservoirs are predicted to increase storage capacity to 800 MCM (MoE/UNDP 2010). A WEAP model offers the possibility to interconnect the domestic and agricultural sector, to evaluate the present water allocation and distribution scheme and to plan for the future. This is done by developing demand- and supply management scenarios, whose results shall contribute to elaboration of further strategies. With reference to the current water plan, integration of existing and future reservoirs into the balance of catchments is important in WEAP; and so, it is also the case for the Jeita Spring catchment since there is already one existing reservoir, the Chabrough dam.

The WEAP model includes assessment of the impact of housing on groundwater recharge. On the one hand, sealing of surfaces limits infiltration of precipitation; on the other hand, discharged wastewater contributes to groundwater recharge. In terms of quantities, a WEAP model shall make both processes comprehensible. Based on this, simulations of future housing surges will be performed, resulting in predicted reduction in infiltration and increased volume of discharged wastewater. Results will be addressed to the Department of Land-use Planning, which is under supervision of the Ministry of Public Works (MoPW). In doing so, hydrogeological facts can be incorporated into future urban and spatial development plans; and, not least, promote increased cooperation between responsible ministries and institutions, i.e. MoPW, MoEW and Water Establishments.

WEAP offers the possibility to assess total water consumption of certain crops with respect to their irrigation system, and therefore their impact on the total modeled water budget. Analysis of seasonal evapotranspiration will be a strategic tool for advanced water strategies in the future: e.g. introduction of more water efficient crops might be a strategy to reduce water loss through evapotranspiration within the JSC. Another issue is a cost/benefit calculation that may reveal present profitability of agricultural practices in comparison to supposed future ones (see: ASSAF AND SAADEH 2008; FORNI 2010). Another strategy could deal with the use of non-conventional water resources, e.g. wastewater re-use. After construction of the wastewater treatment plant, as part of the FC project, scenarios can thus be used to calculate total wastewater re-use by the agricultural sector and evaluate its impact on the whole water budget of the JSC.

WEAP offers the needed connectivity to assess human actions with respect to the physical environment. If a model is set up and calibrated once, decision makers, planners and researches can use this model in order to develop specific scenarios. Population growth (demand side) and changing climate (supply side) are urgent and performable contents for future scenarios. Modeling of such scenarios is crucial in a country like Lebanon, where population growth contributed to an increase in total water demand by almost 45% between 2000 and 2010 (FADEL, ET AL. 2000). As part of *a centralized water data management system for information dissemination* […] *for enhanced water resource assessment* (FADEL, ET AL. 2001), WEAP offers the right features to use this data effectively.

However, elaboration of a WEAP model is a sophisticated task, especially under the conditions of current data unavailability. Thus, objectives are to be regarded within this framework.

1.5. Objectives

The overall objective of this study is to create a conceptual WEAP environment within the present delineated borders of the sub-surface catchment of Jeita Spring; this WEAP environment shall serve as the basis for the calculation of the monthly hydrological balance for one water year, based on data from 1967 to 2010. This hydrological balance includes all relevant supply- and demand sites, and the reservoirs and rivers that need to be identified and quantified, with respect to their specific water in- and outputs. Based on empirical research, relevance of the supply- and demand sites needs to be evaluated and represented by specific demand- and supply priorities. The established hierarchical network, as it becomes the model, shall be finalized so that hydrological data can be entered in order to qualify and quantify the variation of water distribution. The calibrated model shall represent an assumed correlation between precipitation, infiltration, percolation, and discharge of Jeita Spring, with respect to current (year 2011) setting of land-use and land-cover within the catchment. 'Current accounts' is the year 2011 that starts in September 2010 and lasts until August 2011. For this one-year period, the following assessments will be able to be conducted:

- Assessment of the relationship between water input (precipitation) and output (runoff and discharge of Jeita Spring)
- Assessment of the share of total monthly water demand within the JSC by agriculture
- Assessment of the share of total monthly evapotranspiration within the JSC by agriculture
- Monthly evaporation from sealed surfaces within the JSC
- Monthly water demand by the domestic sector (water use and water consumption)
- Identification of 'water shortage months' with respect to agriculture and domestic supply

Within an environment of data shortage, establishment of a hydrological model is a challenge because data from different years are used to represent one water year. The methodology of this study shall contribute to answer questions regarding this situation, and what the implications might be when setting up such a model within a technical cooperation project.

1.6. Literature Review

Selected literature of this review can be categorized as being related to ‘modeling and WEAP’ and to ‘regional studies’, which deal with characteristics of the JSC and the closer surroundings. Literature shall serve as a source of data, source for understanding of the hydrogeological and anthropogenic system, ‘Jeita Spring catchment’ and as source for methodologies. There are many publications about WEAP, available from SEI (2011), whereas the number of publications about the region is rather limited.

Some studies, related to the region are published and openly accessible; however, most of the studies, which are used in this thesis, are project-internal reports by consultants or institutions that are not accessible to the general public. Within a TC project, conducted by BGR, project leaders frequently have to give accounts of the progress of a project, which is done through Technical Reports. The Technical Report No.2, MARGANE (2011, [a]) assesses the hydrogeological setting of JSC in terms of suitability for a wastewater treatment plant (WWTP); suitability is visualized through groundwater vulnerability maps. Hydrogeological flow paths and their dimension are followed and verified through tracer tests. According to the results, there is a direct hydrological connection between the proposed location at Nahr (نهر = river) es Salib and Jeita Spring, making this location unsuitable for the operation of a WWTP because of potential contamination of the spring due to overflow of the WWTP. Overflowing wastewater could reach Jeita Spring very rapid; within the unsaturated zone, flow velocities reach up to 45 m/h. Within the report, the theory is expressed that Jeita is also indirectly fed through infiltration of effective precipitation from an area between Ballouneh, Aajaltoun, Raifoun and Qleyyat (see Figure 3). Regarding the eastern part of the catchment, a hydrogeological connection is supposed between the sub-surface catchment of Assal Spring (1 540 m.s.l.) and Labbane Spring (1 644 m.s.l.) and the Jurassic aquifer (J4) (see Figure 13 & 14). This surmise is based on the fact that discharge of Assal and Labbane Spring is relatively low throughout the year; Labbane does even almost dry up during at the end of summer. Therefore, loss from these sub-surface catchments is caused by groundwater leakage through the lower Cretaceous aquifer, which is between Assal- and Labbane Spring and the J4 unit. The southern border of JSC does partially overlap with the flow path of Nahr el Kalb (see Figure 14); there is no hydrogeological connection between the sub-surface catchment of Jeita Spring and the sub-surface catchment of Kashkoush Spring, which is located further south of the Kalb River.

Another hydrogeological study is the UNDP report 'Jeita - the Famous Karst Spring of Lebanon' (BAKIC 1972). It contains secondary data from ONL (Office National de Litani) to which further studies often refer to due to the data's exclusiveness. Figure 1 visualizes monthly discharge records of Jeita Spring and Nahr el Kalb, for the period 1966 to 1971, as measured by ONL. On average, total annual discharge is 144.59 MCM, ranging between a minimum in October and a maximum in March. As can be seen, discharge of Jeita Spring correlates with discharge of Nahr el Kalb, as measured at 'Mokhada station' below Jeita Spring. Calculation proves that both discharge records correlate highly with each other (*referring to Pearson Chi-Square 0.933 (-1 to +1) and r2=0.872 - high positive significant*).

Data that is used within this study comprises of 210 samples recorded between 1966 and the end of 1971.

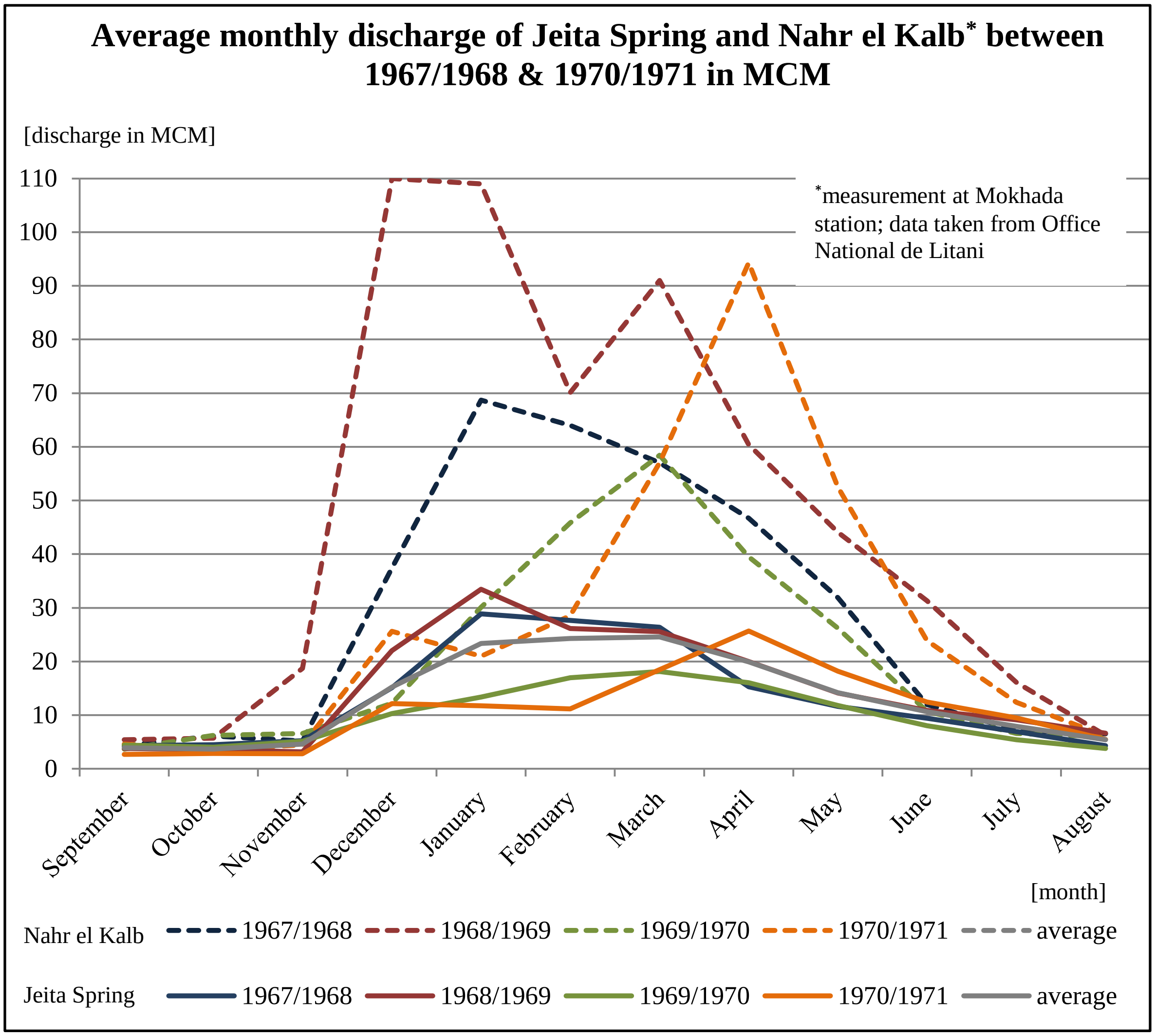


Figure 1: Average monthly discharge of Jeita Spring (measured upstream from Hrache) and Nahr el Kalb (measured at Mokhada station) for the period 1967/1968 to 1970/1971 in MCM; source of data: ONL. In: BAKIC (1972).

FADEL, ET AL. (2000) gives an overview of the water balance of Lebanon, as well as hydrogeological and socio-economic characteristics of the country. Major groundwater recharge occurs during a period of 80 days in winter. The domestic, agricultural and industrial sectors demand water throughout the year, thus, the demand sites contribute to non-sustainable water consumption and/or water-use, which will lead to a water deficit in the future. Estimations about the population's average water consumption rates range between 150 liters/capita/day and 300 liters/capita/day. Based on these listed estimations, for the year 2000, average domestic water demand was estimated to be 190 liter/capita/day, whereas this figure is predicted to grow by 1.75% per year. Besides a surge of per capita demand, it is the population growth of between 2.0% and 2.2% that increased total domestic demand.

Another socio-economic study about the region is THE STUDY ON THE NAHR EL KALB WATERSHED (2009). It is sub-divided into three books: 1. 'Integrated river basin management monitoring and data management of groundwater aquifer', 2. 'The watershed of Nahr el Kalb: Urban development & environmental impact' and 3. 'Impact of agriculture on the watershed area of Nahr el Kalb'.

The first book stresses the issue of urban growth within the surface catchment of Nahr el Kalb. During the civil war (1975 to 1990), the area was a destination for many refugees, leading to a surge of total population during this period. Today, staying population varies in time and space. For the district of Keserwan, the study estimated a total population of 191 600. This number is broken down into 'summer-' and 'winter population'. During summer, approximately 152 500 inhabitants (80%) stay in Keserwan; during winter, this figure decreases almost by half to 86 950 (45%).

The second book, published by YAZIGI AND FADEL, analyzes and relates the impact of poor water- and land management on urban sprawl, land degradation and overexploitation of water resources within the surface catchment of Nahr el Kalb. For the analysis of land-use and land-cover, the authors sub-divide the catchment into 5 zones; however, coastal zone 1 is not relevant for this study and is therefore excluded here:

Zone 2, up to 660 m.s.l.: The rear country, occupied in summer and winter. Land-use and -cover: 51.2% forest, 3.4% agriculture, 45.4% urban.

Zone 3, from 660 to 1 200 m.s.l.: The low villages, summer villages with medium dense urban fabric, including Aajaltoun, Bikfaya and Broumana. Land-use and -cover: 58.4% forest, 4.1% agriculture, 37.5% urban.

Zone 4, from 1 200 to 1 400 m.s.l.: The rural area, summer villages with low dense urban fabric. Land-use and -cover: 74.9% forest, 9.5% agriculture, 15.6% urban.

Zone 5, from 1 400 to 2 000 m.s.l.: The high mountains, very low population density, tourism and ski resorts. Land-use and -cover: 83.7%, 10.6% agriculture, 6.7% urban.

The authors highlight the inter-related processes of urban growth, disturbance of stream geomorphology and forest fragmentation. Altogether they contribute to disturbance of the regional hydrological cycle.

Within the third book 3, ZIND, points out the role of agriculture and its changing locations within the surface catchment of Nahr el Kalb. In lower altitudes, agricultural land is replaced by housing, whereas in higher mountainous regions, agricultural land is expanding; crops are mainly fruit trees, i.e. apples and peaches. Farmers use either drip- or surface irrigation, but they have little technical knowledge regarding the required quantities of irrigation water. Sources of irrigation water are wells, smaller local springs, and Labbane- and Assal Spring. On all 24 investigated farms, soil texture can be described as coarse-grained, without any silt or clay, rather with coarse gravel or sand.

Studies about modeling approaches and applications of WEAP are included in the following section.

HÖLTING AND COLDEWEY (2005) includes a recommendation/guideline for the establishment of a numerical groundwater model whose approach can be assigned to a conceptual/numerical WEAP model. The methodology contains following steps: I. Precise problem statement, II. Collection and analysis of present data, III. Conduction of a problem oriented program for completion of data, IV. Setting up the model and calibration (building-up, calibration and simulation) and V. Interpretation of the results with respect to the quality of data. For a three dimensional groundwater model, several kind of data must be considered, which does not apply to a catchment- and surface-based WEAP model. For the present model, following aspects shall be sufficient: geology and its permeability, potential (quantities) of surface waters, storage coefficient and leakage coefficient of specific surfaces (land-use and land-cover), flow between groundwater and surface waters, abstraction rates, groundwater recharge, evaporation, precipitation and infiltration.

LÉVITE, ET AL. (2003) applies WEAP on a water-stressed basin in South Africa. Farmers and citizens depend on precipitation that is subject to large seasonal variations. According to the authors' findings, WEAP indicates that additional resources can be allocated by increasing water efficiency and total storage capacities. Construction of reservoirs is one solution to increase storage capacity, as well as to reduce fluctuation of stream flow. However, lacking data is one critical aspect that constrains the study's results. Due to missing data, groundwater flows have to be declared not to play a major role within the balance. In spite of lacking data, WEAP is acknowledged as an important research tool that shall be a helpful tool to promote water management in the public.

ASSAF AND SAADEH (2008) use WEAP as an integrated decision support system (DSS) for the assessment of water quality management strategies for the upper Litani River catchment in Lebanon. The authors analyze two existing and proposed management plans for the construction of WWTPs. The analysis is run for a period of 25 years; during this period, seasonal variability of expected biochemical oxygen demand (BOD) levels are simulated, based on hydrological and spatial parameters. As part of this approach, the authors conduct an economic analysis, using the 'cost-calculation tool' that is embedded in WEAP. Assessment of the present situation indicates significant water pollution, especially during dry periods. For an improvement of water quality, the authors present advantages and disadvantages of the two proposed plans. Recommendation for the location of 'Zahle' is based on a 'best buy plan', the cheapest removal of a unit BOD.

Another practice-oriented application of WEAP is conducted by SALEM, ET AL. (2010). The authors explicitly addressed their integrated, catchment-based WEAP model for the 'Ziz' catchment, Morocco, to spatial planners and land-use regulators; administrative separation of the research area increases difficulties for the management of the catchment. In using the 'rainfall runoff method' of the Food and Agriculture Organization (FAO), which is embedded in WEAP, the authors model input of the supply sites. Modeling implies the rate of effective precipitation, surface runoff towards water bodies and aquifer recharge. On the demand side, agricultural activity and population growth are the main driving forces. Within their two users' scenarios, the authors simulate population growth (domestic sector) and water need for livestock and irrigation requirements (agricultural sector). Results show a concentration of higher water demand during summer months. As a strategy against this seasonal water deficit, the authors suggest to increase soil's share of organic matter. This would improve and stabilize the soil's structure and would reduce surface runoff.

MOUNIR, ET AL. (2011) applies WEAP on the catchment of the River Niger in western Africa. The study region is characterized by high population growth and high demand by the agricultural sector; local food production and -supply has high priority. The authors use WEAP's integrated 'water year method', which allows modeling of hydrological variations (very dry, dry, normal, wet, very wet) and connect it to population growth scenarios. According to their results, there demand will be unmet in the future. Towns, farms and industry will demand more supply in the future. In order to bridge the gap between supply and demand, the authors propose the construction of a dam. This would contribute to a better allocation of the resource river. A dam would also control the flow of the river and thus, limit large seasonal fluctuations in flow.

The study on 'Groundwater Availability on the Central Valley Aquifer, California (FAUNT 2009) analyses the relationship between population growth and intensive agricultural activity. Both sectors, domestic and agricultural, are subject to an inter-sector competition for water because both of them depend on the same groundwater resources. Groundwater pumping has heavily stressed thy hydrological cycle in the past. A numerical, three-dimensional finite-difference groundwater MODFLOW-model is set up in order to assess the disturbance of the hydrological balance. Elements of this balance are precipitation, excess irrigation, artificial recharge and pumping. Natural evaporation (E) is basically replaced by groundwater pumping and crops' evapotranspiration (ET). Groundwater abstraction is wide spread throughout the region, thus, it is a crucial component of the water balance, hence, also the most uncertain one. Uncertainty is caused by the fact that pumping is not centrally registered, and so, there is no reliable data about pumping records available. For calculation of total groundwater abstraction by the agricultural sector, the authors estimate crop requirements of each crop. Calculation of requirement consists mainly of crop's consumption, i.e. its (evapo-) transpiration. In addition to crop requirement, data about surface-water supply, effective precipitation and irrigation efficiency contribute to the calculation of groundwater pumping. The authors conclude that the regional hydrological system is mainly driven by surface water deliveries and groundwater pumping. Surface water deliveries towards groundwater include precipitation, stream loss and excess applied irrigation water, whereas irrigation water is the main input of the mentioned; between 1962 and 2003, 79% of groundwater recharge is attributed to landscape processes, including excess applied irrigation. Groundwater pumping is the dominating cause for loss within the groundwater system.

2. Location of the study area

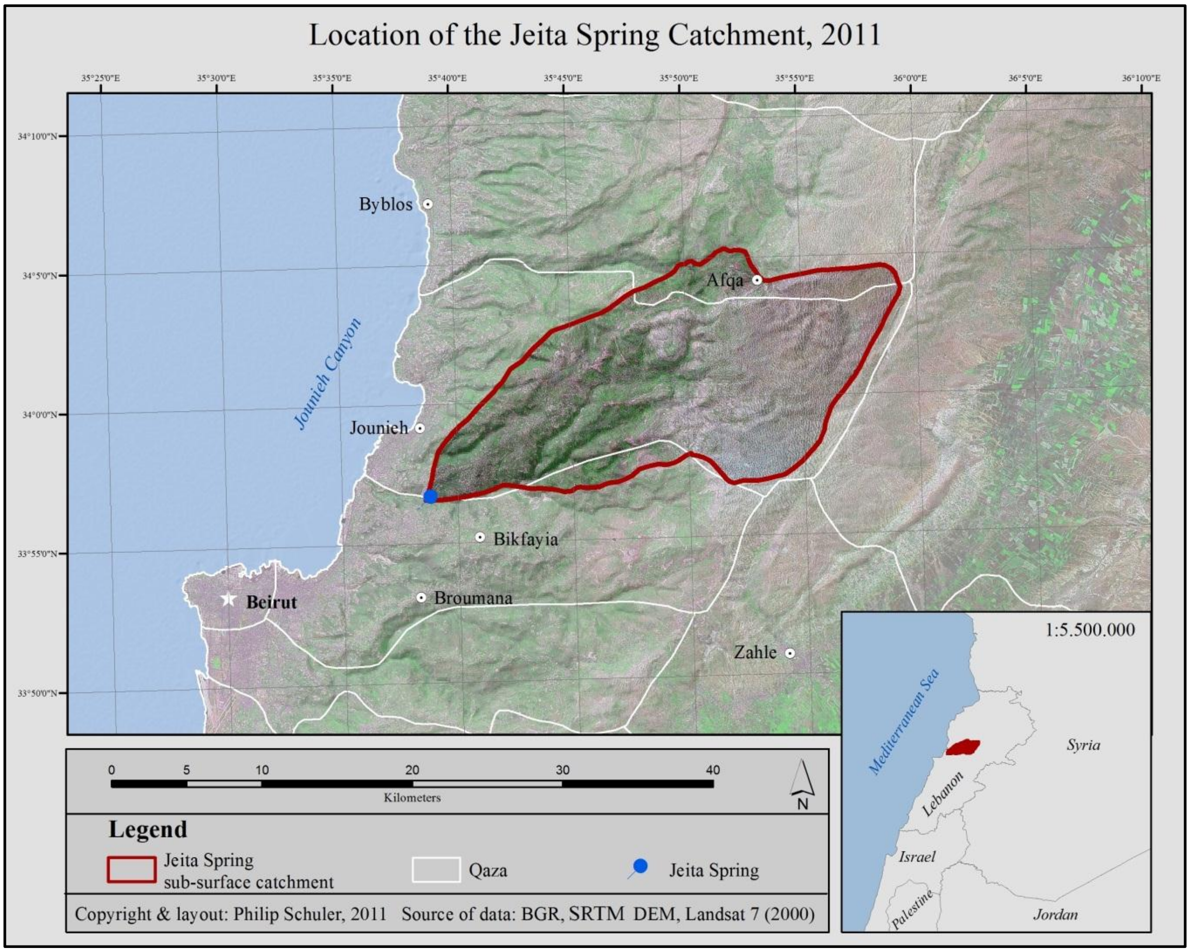


Figure 2: Location of the sub-surface catchment of Jeita Spring (study area) in Lebanon.

The study area, as presented in Figure 2 and 3, is located in the center of Lebanon, 15 km north-east of Beirut, on the western exposed side of the Lebanon Mountains. It ranges north-south between the geographic coordinates 34°5’10’’ and 33°56’30’’ and east-west between 35°59’10’’ and 35°38’30’’. These coordinates are located on UTM sheet 36, northern hemisphere.

The study area has a total size of 310.7 km² and is located within three administrative districts [Arabic ‘Qaza’ = قضاء]. 14.9 km², 4.8% of the whole area, lies within the southern Qaza of Metn [قضاء المتن]; 33.0 km², 10.6%, lies within the northern Qaza of Jbayl

[ق ضاء جـ بـ يل] and 263.1 km², 84.6% of the JSC is located within the central district of Keserwan [اءة ض ک سروان]. Jeita Spring is located just south of the border between Keserwan and Metn, within the Metn district.

The catchment is connected to Beirut via the Sea Side Road and the Keserwan main road; Jeita Spring is in 21 km (45 minutes) distance to Beirut (parliament), making both of them easily accessible.

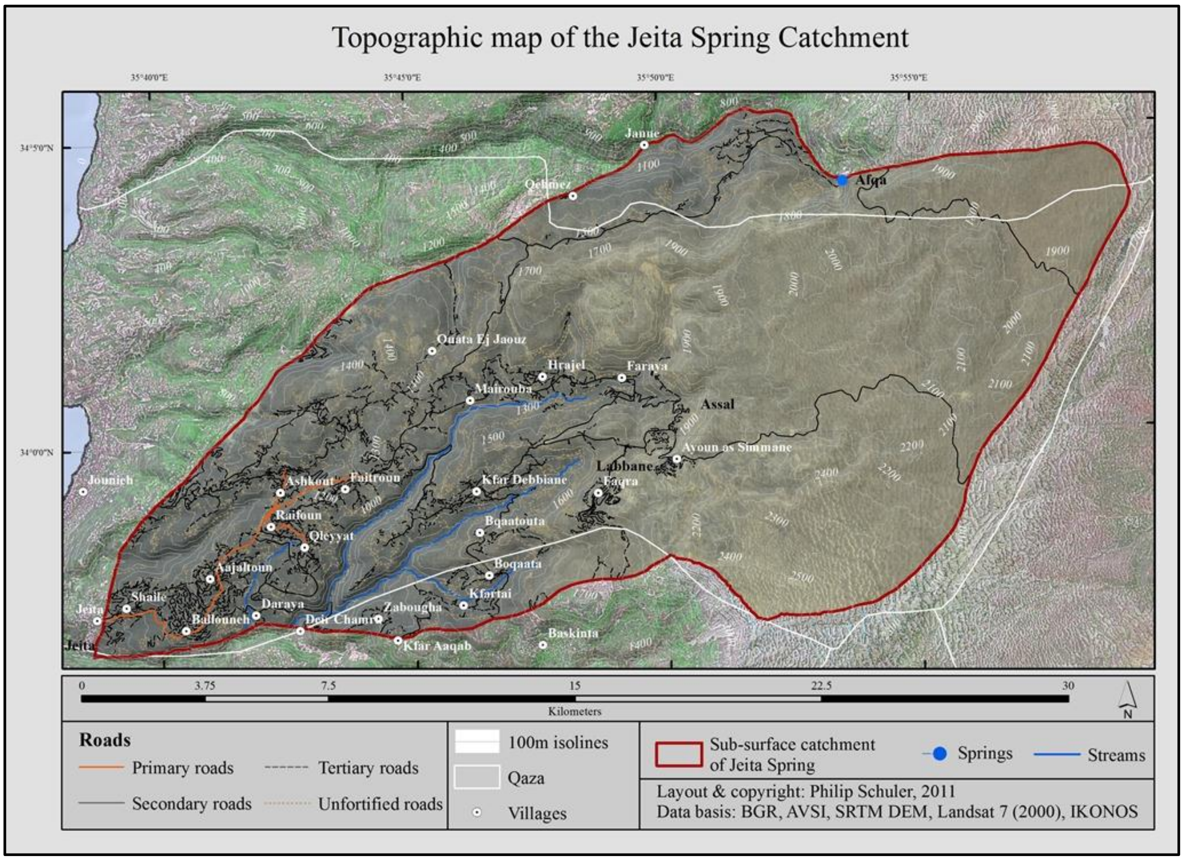


Figure 3: Topographic map of the Jeita Spring Catchment.

3. Methodology

This section deals with the process of elaboration of the WEAP model. It includes the basic equation of the hydrological budget, which is the mathematical basis for the conceptual model. Further on in this chapter, procurement and processing of data is presented.

3.1. Hydrological balance

For the assessment of the hydrological budget of the catchment, it is referred to the basic equation of hydrology. Its components are precipitation (P), runoff (R), evapotranspiration (ET) and storage in the system over time ($\triangle S$); it is valid for a certain period of time at a certain location on land:

$$P = R + ET + \triangle S \qquad \text{(Equation 1)}$$

P is derived from three meteorological stations in the region. ET is based on FAO's CLIMWAT data base, calculated by the Penman-Monteith equation, as recommended by ALLEN, ET AL. (1998). For calculation of the reference evapotranspiration (ET_o), which corresponds to the potential ET, by the Penman-Monteith equation, records on solar radiation, wind-speed, humidity and temperature is needed. This implies difficulties because in many cases, not all of this data is available. And despite the already challenging data input for this formula, […] *estimates of Ep* [potential ET] *show* […] *systematic overestimations in winter months.* (MILLS 2000) For a certain type of land-use, evapotranspiration is calculated based on the crop coefficient (K_c) and the respective ET_o (ALLEN, ET AL. 1998; FAUNT 2009). Within the JSC, ET_o varies according to topography. Therefore, different ET_o values are used with respect to the mean altitude of the representing reference space; in turn to this, K_c-values can be generalized for changing spatial conditions, as similar K_c-values are used in many different studies (FAUNT 2009) and are proposed by FAO (ALLEN, ET AL. 1998).

It is important to stress that ET includes canopy interception. This is an important factor since […] *interception loss from forests is usually a significant component (25 to 75%) of overall evapotranspiration*. (DAVID, ET AL. 2006) The difference between total precipitation and interception loss is effective precipitation (EP). Within the present WEAP model, interception loss is regarded as a share of evapotranspiration loss.

If EP exceeds ET, $\triangle S$ becomes positive, i.e. water that reaches at least the unsaturated zone or the soil layer. If EP reaches saturated soil, infiltration decreases and generation of runoff increases. For this study, runoff data from the gauging station at Daraya (Figure 14) is used. Daraya station registers surface runoff that has previously concentrated in Nahr es Salib and Nah res Zirghaya. Quantities of remaining runoff, leaving JSC westwards, northwards and via Nahr el Kalb below Daraya, must be derived from existing runoff data and its premises. Within this study, calculated runoff from the sub-catchments of Nah res Salib and Nahr es Zirghaya (Figure 14), measured at Daraya, is the basis for calculations of runoff of sub-catchment 4 and 5 (Figure 27).

Runoff is split into surface runoff (creeks, streams) as well as interflow and groundwater flow. Groundwater flow, i.e. flow within the saturated zone, is one of the most uncertain hydrological components of this model. There is basically no data about groundwater levels of aquifers available and thus, also no data about change in groundwater storage over time.

Parameters of the water budget equation are calculated with reference to the specific spatial extent of their hydrological response units. The basis for this calculation is land-cover and land-use that are digitalized in ArcGIS (Figure 4 and Table 2).

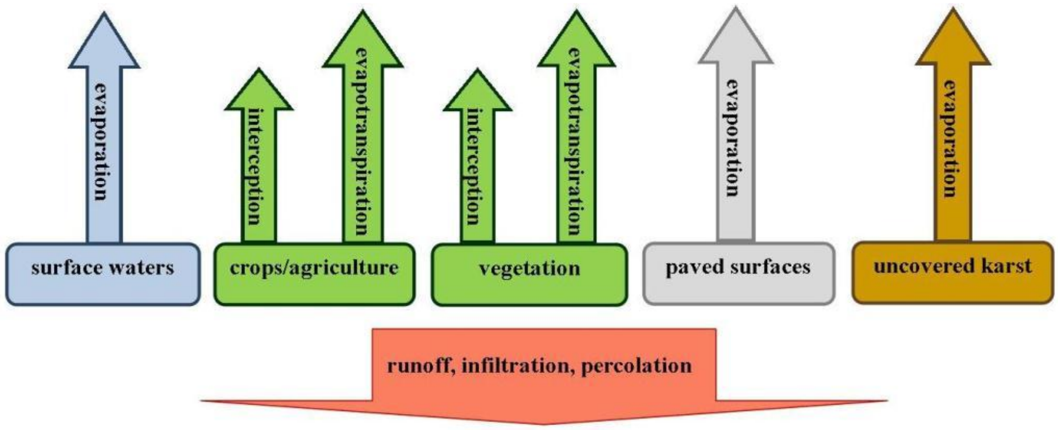


Figure 4: Hydrological response units with specific evaporation, transpiration and interception for the hydrologcial budget of the Jeita Spring catchment.

Table 2: Specific hydrological response units and their classification into land-use and land-cover.

	Hydrological response units			
land-use	housing	roads	agriculture	ponds/reservoir
land-cover	vegetation	open soils	bare rocks	

Land-use (Figure 20) consists of roads, housing, agricultural classes and ponds/reservoir; land-cover (Figure 23) consists of 10 classes, including vegetation classes, open soils and bare rocks.

3.1.1. WEAP

Water Evaluation and Planning (WEAP) is a cutting point between the physical-hydrological and the anthropogenic sphere. It is an integration of both of these spheres, making it to a valuable tool for assessing and modeling available water resources (MOUNIR, ET AL. 2011). Within these two spheres, demand sites, which consist of agricultural, domestic, commercial, industrial and ecological users, compete with each other for water resources.

The software has been developed by the non-profit organization Stockholm Environment Institute (SEI) and is free of charge for non-profit users in developing countries. Users in industrialized countries have to pay for use; thereby they support research in developing countries (SEI 2011).

The general approach of developing a WEAP model includes several steps. First, boundaries of the area and the temporal scale of the system's modeling process need to be defined. Boundaries are usually represented by river- or spring catchments. Based on this definition, elements (demand and supply sites, reservoirs, etc.) of the system are identified and connected to each other via transmission links or diversions. Data may be attributed to flow paths, transmission links, supply- and demand sites. After data input, quantification of flows and calibration of the model can be conducted. In this stadium, the model represents a basic definition of the 'real hydrological system' that is called 'Current Accounts'. It is the […] *best available estimate of the current system in the present*. (SEI 2005) Based on this, a 'reference' or 'business-as-usual' scenario is established that may include a variety of additional economic, demographic, hydrological and technological trends. After definition of this, simulation of the model leads to assessment and interpretations about water distribution. Output is visualized either through diagrams or tables.

For the working process, WEAP contains five different views (SEI 2005):

I. Schematic View. This graphical window represents the physical structure of the supply- and demand system that can be easily modified through ‘drag and drop’.

II. Data View. This shows a hierarchical tree in which relationships between the system’s elements are represented. Hierarchy can be modified and element’s data can be accessed.

III. Results View. It displays charts and tables referring to supply- and demand sites.

IV. Overview View. This can show a group of charts simultaneously.

V. Notes View. This is a simple word processing tool for documentation and references for each branch of the hierarchical tree (Data View).

WEAP includes some additional features, as the ‘water year method’, a tool that takes into consideration the temporal variability of the hydrological system. This is done through scenario analysis. Seasonal variation of stream flows, precipitation or groundwater recharge can be established and defined as different climate regimes (dry-wet, hot-cold); these regimes are relative to the ‘Current Accounts’ (MOUNIR, ET AL. 2011).

Another important tool is the ‘rainfall runoff method’ that is based on the methodology of FAO. Also this tool takes into account the variability of rainfall, which is more distinctive in arid and semi-arid regions, rather than in temperate ones (CRITCHLEY AND SIEGERT 1991). The rainfall-runoff method calculates the ratio between demand of the crop and the runoff. It […] *uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet*. (SALEM, ET AL. 2010) Within this study, this method is used to calculate crop water requirements and irrigation demand, considering irrigation efficiency. Besides this, surface runoff is modeled based on the FAO rainfall-runoff method.

3.1.2. Boundaries of the JSC

Within this study, the sub-surface catchment of Jeita Spring (JSC) is defined as an own hydrogeological system that loses water via surface runoff, (evapo-) transpiration and via discharge of Jeita Spring; JSC receives water only through precipitation within the boundaries of the delineated area of JSC. All precipitation that reaches the relief of the delineated surface of JSC enters the catchment. It is only a share of this precipitation, which might concentrate via inter-flow and groundwater flow towards Jeita Spring. Thus, it is only precipitation with the spatial reference of the JSC that must be accounted for the hydrological balance of Jeita Spring. It is neither presumed that additional groundwater, recharged from precipitation outside the JSC, enters JSC nor that any groundwater, which has accumulated within the boundaries of the JSC, crosses the catchment's boundaries.

Delineation of the hydrogeological boundaries of the JSC has been done by MARGANE ([a] 2011) and DOUMMAR, ET AL. ([a] 2011; [b] 2011). The eastern border is defined by the subsurface catchment of Afqa- Assal and Labbane Spring (see chapter 4.4.1. - 4.4.3.). The southern border of JSC, between Labbane Spring and Deir Chamra (Figure 3), follows the surface catchment of Nahr es Zirghaya (Figure 14). Between Deir Chamra and Jeita Spring, the southern border is defined by Nahr el Kalb, which follows the extent of a fault (Figure 13). The north-western border follows for approximately 15 km the extent of the flexure (see chapter 4.3.); from the end of the flexure until Afqa Spring, the border is defined by Amezh fault and Tannourine fault (MARGANE [c] 2011).

3.1.3. Conceptual basis for WEAP

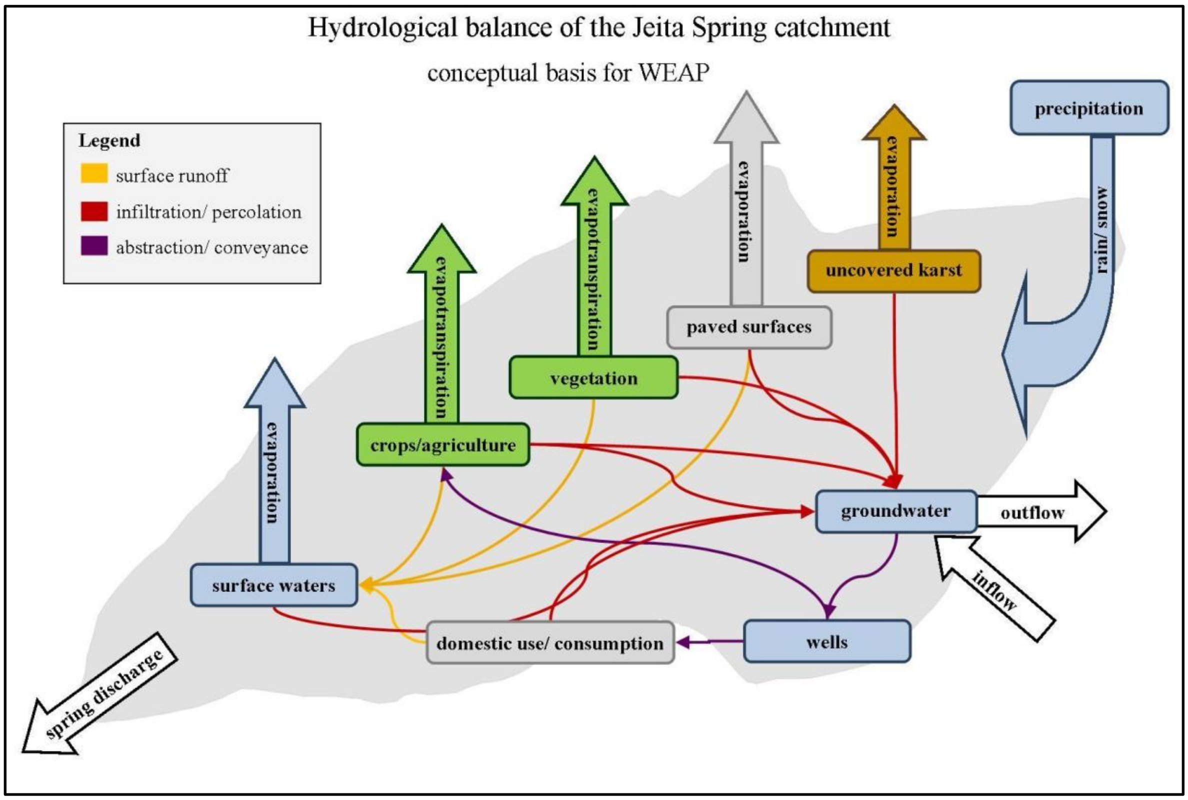


Figure 5: Hydrological response units within the conceptual input/output schema as used for the WEAP model.

The conceptual basis for the model is framed by the outline of the Jeita Spring catchment, as pointed out within the previous chapter. Hydrological input consists of (effective) precipitation only; as mentioned before, no groundwater in- or out flow is predicted to exist. Besides this hydrological input, solar radiation is the second input variable. Solar radiation constitutes temperature, and both of them contribute to determination of ET_o.

Surface runoff, sub-surface runoff, evapotranspiration and discharge of Jeita Spring are the output variables. For this model, it is runoff at Daraya gauging station and total infiltration that is used for calibration of the model.

As outlined before, each of the specific surfaces has a specific rate of evaporation/transpiration, depending on the type of cover and its density; besides this, each of the surfaces does also imply a specific rate of infiltration/percolation, which depends upon effective precipitation, soil characteristics (effective field capacity, texture, thickness) and the geology below the surface. Thus, groundwater recharge rates are subject to the specificity of surface cover of certain areas, which are generalized for the WEAP model (see Figure 27).

'Natural' groundwater recharge is caused by effective precipitation; besides this, 'anthropogenic' groundwater recharge originates from wastewater discharge (return flow) and excess irrigation. Within this current WEAP model, it is only wastewater that is considered in the calculation of return flow. As part of the regional hydrological circle, 'natural-' and 'anthropogenic-' recharged groundwater is again abstracted via wells or captured via tapped springs. Allocated resources are then conveyed to the various users within the JSC; from there some share returns again towards the unsaturated- and saturated zones.

This general concept of the model will be picked up again in chapter 5, in which JSC is further sub-divided into nine sub-catchments (SC).

3.1.4. Model calibration and validation

Calibration of conceptual rainfall-runoff models is a major challenge within the elaboration process of such models. The reason for this is the complexity of a hydrological system, including the large amount of input variables, their distribution in space and the variables' parameters. This complexity impedes adjustment of observed and estimated flow hydrographs. According to COOPER, ET AL. (2006), calibration procedure for rainfall-runoff models is comparable to a 'black-box approach'; input parameters are modified within a certain 'search space' in order to fit better to measured output parameters. This, however, is often done neglecting physical characteristics of the whole system. Besides the challenge of calibration, which is related to the complexity of the system, shortage in data series and uncertainty about data reliability causes further difficulties for calibration. If there is no certainty about the quality of data, it is very difficult to limit the 'search space' in which parameters are modified. With reference to these challenges, HOFF, ET AL. (2011) disclaims any calibration or validation process for their WEAP model.

Due to lack of data, within this study the hydrological balance is modeled for one year only, which imposes one more problem on the calibration procedure because calibration is usually done based on a longer period of time in order to consider inter-annual changes. Modeling period for calibrated models ranges between 8 and 16 years (INGOL-BLANCO AND MCKINNEY 2009; BLANCO-GUTIÉRREZ, ET AL. 2011; YILMAZ AND HARMANCIOGLU 2010).

For calibration of the present WEAP model, subjective criteria are used to adjust estimated parameters to observed ones. Modeled runoff from sub-catchment (SC) 1 and 3 is adjusted to observed records at Daraya gauging station. In addition to observed runoff, it is also the rate of total infiltrating rainfall that is used to adjust modeled runoff and crop coefficients. This 'trial and error' method is based on visual comparisons (ARRANZ AND MCCARTNEY 2007). The method implies frequent repetitions of simulation in order to approach estimated parameters to observed parameters. Modification of demand priorities is one way to adjust estimated to observed values (ARRANZ AND MCCARTNEY 2007) because flow quantities might change, and thus, supplied water at a specific demand site.

In spite of the fact that WEAP contains the Parameter Estimation Tool (PEST), an in-built calibration tool, this feature has not been used for calibration because after tests, results have not proven to be more satisfying than subjective calibration.

Calculation of the model's accuracy, by using the Nash–Sutcliffe model efficiency coefficient (BLANCO-GUTIÉRREZ, ET AL. 2011; YILMAZ AND HARMANCIOGLU 2010), for example, is not done within this study.

3.2. Sources of data

According to the UN, Lebanon is part of the 'developing region of Asia', even though there is not a general definition of a 'developing country' (UN STATS). Characteristics, related to this appreciation, include presence of corruption, a weak economy, political instability, overlapping and/or unclear responsibilities of ministries, etc. These issues are driving forces for incoherence and opacity in data availability and distribution. In 'developing countries' or rather 'countries of transition' poor and non-existing records are a major obstacle for a proper water management (FADEL, ET AL. 2000; CHEN AND ZHAO 2009). For Lebanon, […] *there is an urgent need to fully update the hydrological data in terms of quantity of* *precipitation, river flows and groundwater characteristics. A centralized water-data management system for information dissemination is essential for water resource assessment.* (EL-FADEL, ET AL. 2000) During 1975-1990, the period of civil unrest, hydrological measurements have not been continued and climate stations were destroyed or have deteriorated. For this period, there is almost no hydrological data available; recording has started very slowly afterwards.

Therefore, the situation of this study is comparable to KHAIR (1994): […] *with such a lack of data, it would not be possible to estimate accurately the water budget and to assess the environmental impacts of human on the quality and quantity of groundwater. This study, however, is somehow synoptic. It is a trial to give an idea about these impacts with some empirical values* […]. This is why collected data that are used in this study, are heterogeneous, i.e. they stem from various sources and different decades.

Secondary climate data, used in this study, consists of precipitation (P) and reference evapotranspiration (ET_o). ET_o is extracted from FAO's climate database CLIMWAT; within this data base, monthly long-term average (period not known) ET_o records for three suitable stations, as they are considered as being representative for this region, are available: Al-Arz (1 916 m.s.l.), Beirut, American University (35 m.s.l.) and Beirut, Airport (19 m.s.l.). For Beirut, average value from the station at American University and the airport is calculated in order to use an average record, Beirut, Mean (27 m.s.l.) for further calculations.

P is taken from ATLAS CLIMATIQUE DU LIBAN (1977) that contains monthly average records for the period between 1931 and 1960 for the following three climate stations: Qartaba (1 140 m.s.l.), Faraya (1 325 m.s.l.) and Raifoun (1 050 m.s.l.).

Primary hydrological data is obtained from Litani River Authority (LRA), Water Establishment Beirut and Mount Lebanon (WEBML) and BGR.

- Average monthly discharge of Jeita Spring (1966/1967-1970/1972): LRA
- Average monthly discharge of Afqa Spring (2000/2001-2009/2010): LRA
- Average monthly discharge of Assal Spring (1968/1969-1972/1973): LRA
- Average monthly discharge of Labbane Spring (1971/1972-1972/1973): LRA
- Average monthly flow of Nahr el Kalb at Daraya gauging station (1967/1968-1973/1974): LRA
- Average monthly discharge and storage volume of Chabrough dam (September 2010/ August 2011): WEBML
- Maximum possible well abstraction rates of public run wells: WEBML
- Average monthly precipitation (1931/1960): ATLAS CLIMATIQUE DU LIBAN (1977)
- Average monthly reference evapotranspiration (period not specified): FAO, CLIMWAT

GIS data are obtained from:

- IKONOS satellite image (2005): DAG. Cell size 0.8 m. Coverage: JSC

- Landsat 7 satellite image (2000): NASA. Cell size 14.25 m. Coverage: Lebanon
- SRTM DEM (2000): BGR. Corrected cell size 110 m. Coverage: Lebanon
- Boundaries of Afqa-, Assal-, Labbane- and Jeita Spring's sub-surface catchment (shapefile): BGR (2011). Coverage: JSC
- Administrative boundaries (shapefile): DAG. Coverage: JSC
- Land-use and land-cover (shapefile): AVSI (2005). Coverage: Nahr el Kalb surface catchment
- Water supply network (reservoirs, wells, pipes) (shapefile): WEBML. Coverage: JSC
- Geology (shapefile): BGR (2011). Coverage: JSC
- Streams (shapefile): Schuler (2011). Coverage: JSC
- Roads (shapefile): Schuler (2011). Coverage: JSC
- Housing (shapefile): Schuler (2011). Coverage: JSC

Other data:

- Population records: INCEPTION REPORT (2011), municipalities within Jeita Spring Catchment

3.3. Data processing

3.3.1. Quantification of land-use and land-cover

Roads (line features) and housing (polygons) are digitalized in ArcMap 10 by referring to IKONOS satellite image. Both of them, housing and roads, compose for the total spatial extent of sealed surfaces. In order to derive a spatial extent from digitalized roads, different buffer around line features are used (Appendix A 1). Width of primary roads is defined as 14 meters, of secondary roads 9 meters and of tertiary roads 7 meters. Therefore, respective buffer around roads is 7, 4.5 and 3.5 meters. To prevent possible overlapping of housing features and buffered road features, which would imply double-counting of surface areas, both layers are merged to one shape file (Appendix A2). Spatial extent of polygons is derived from the 'calculate geometry' option within the attribute table, while running the editor modus (Appendix A3).

Present land-use and land-cover is based on AVSI (2005); it covers the extent of the surface catchment of Nahr el Kalb. This data is empirical assessed, modified and extended to the coverage of JSC, based on the IKONOS satellite image and on the geology layer. Furthermore, land-use and -cover classes of AVSI (2005) are generalized and aggregated to the present land-use and land-cover classes.

All boundaries of surface catchments within the JSC are delineated through the 'Spatial Analyst - Hydrology – Tool' in ArcMap 10, based on the SRTM DEM with a corrected cell size of 110m. Progress of delineation includes following steps: First, gaps of the DEM are filled in order to have a raster layer without any depressions (Appendix B1). Afterwards, this raster with filled gaps is used to calculate the flow direction (Appendix B2). This flow direction raster is input for calculation of surface catchments for any desired location. This desired location represents the drainage location of the delineated surface catchment. This specific location is then added to the flow direction raster (Appendix B3); it can be existent either as raster- or as vector file.

3.3.2. Climate data

For each of the nine sub-catchments (Figure 27), which are represented as an own catchment node within the WEAP model (Figure 28) monthly average P and ET_o are used; in order to assign representative climate data to each sub-catchment (SC), average altitude of each SC is calculated by using the DEM. Based on calculated mean records, respective ET_o and P are calculated. This is done by interpolating monthly climate records between the vertical heights of the stations. The result is a monthly parameter, which is further used for calculation of each monthly average record for each single catchment; depending on the SC's mean altitude, and the difference between this mean altitude and the difference to the referring altitude of the interpolated stations, each SC will have specific ET_o and P values, as presented in (Figure 12).

In order to express reliability of interpolation of precipitation records, correlation between altitude and precipitation is conducted. Therefore, total annual precipitation between 1930 and 1961 of 15 regional climate stations (ATLAS CLIMATIQUE DU LIBAN 1977) (distributed on the western side of the Lebanon Mountains) are correlated with their respective elevation. Both variables (elevation and rainfall) show a positive correlation of 0.726 (*Referring to Pearson Chi-Square 0.726 (-1 to +1) and r2=0.53*). Based on this, linear regression between these two variables is conducted (Figure 6).

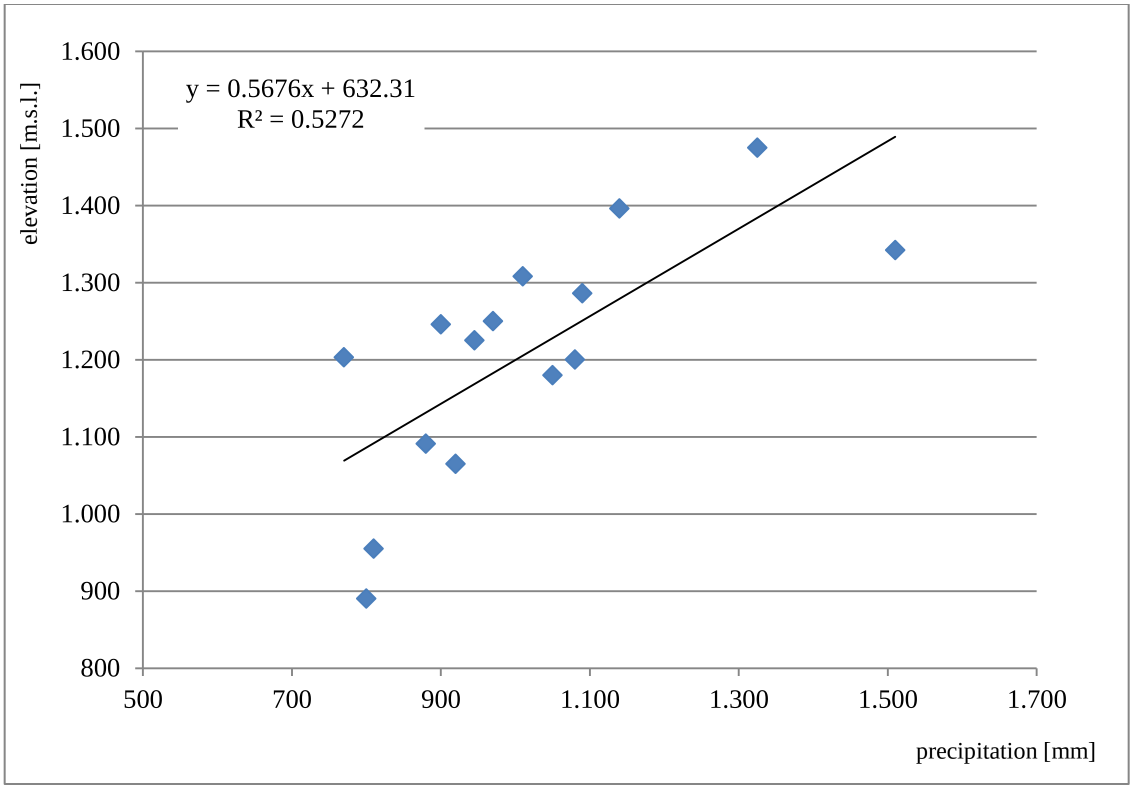


Figure 6: Linear regression between average annual precipitation between 1931 & 1960 from 15 selected regional climate stations and the stations' elevation; source of data: ATLAS CLIMATIQUE DU LIBAN (1977).

3.3.3. Other data

Secondary population data was obtained from INCEPTION REPORT (2011) while primary records have been obtained from municipalities through face-to-face questionnaires and via telephone interrogations with municipality representatives. Total population records are either based on estimations of questioned representatives, or derived from figures about registered apartment-units per municipality. In the latter case, total numbers of apartment units are multiplied with an average number of 4 persons per unit (INCEPTION REPORT 2011).

4. Study Area

This chapter gives a detailed overview on the JSC in order understand the conditions for modeling of the hydrological balance within WEAP. Thus, following sections can be clustered according to hydrological supply or demand (Table 3):

Table 3: WEAP elements, attributed to supply- and demand site.

Demand	vegetation	Urban land-use [domestic]	Agricultural land-use [agriculture]
Supply	Climate [effective precipitation]	Hydrology [groundwater flow, surface runoff]	Fresh water supply [wells, reservoirs]

4.1. Topography

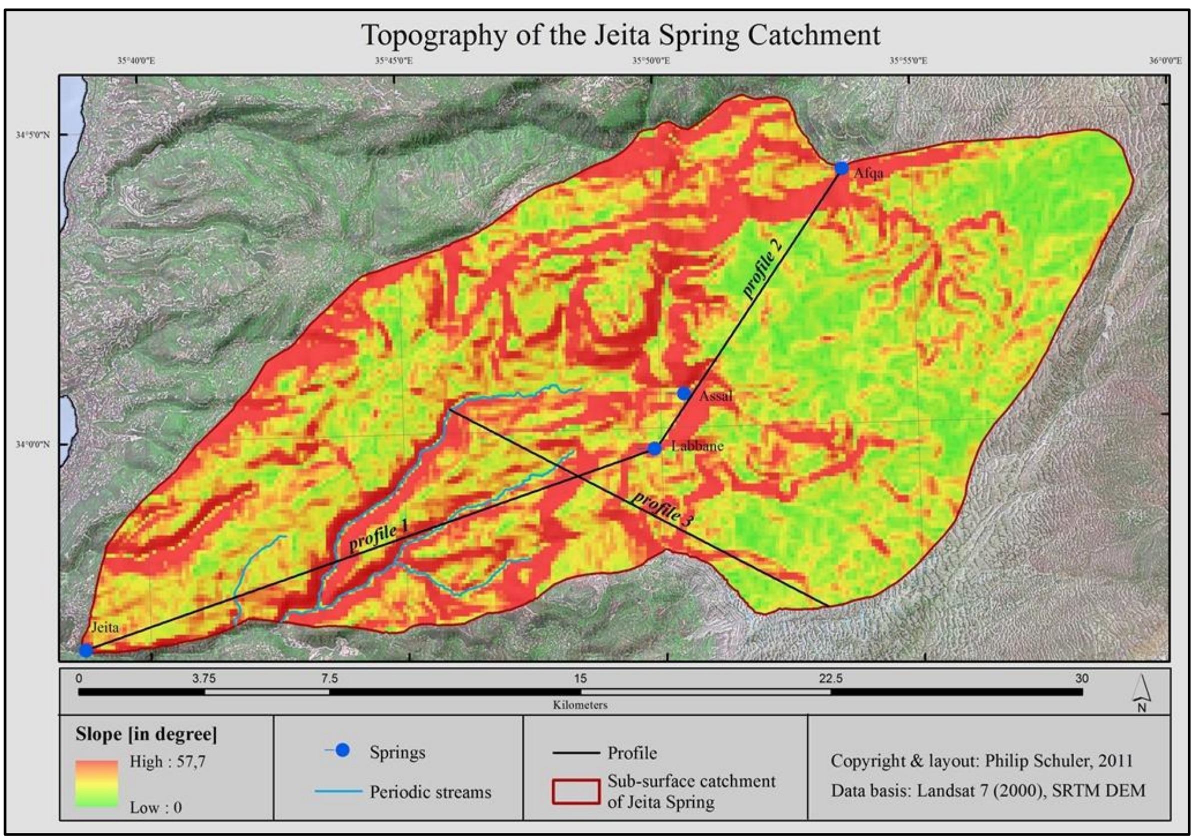


Figure 7: Topography of the Jeita Spring catchment, including slopes in degree and the course of three profiles.

The catchment of Jeita Spring has a total area of 310.7 km²; it ranges between 60 m.s.l. at Jeita Spring, and the catchment's highest location on 2 626 m.s.l. at Mt Sannine. The study area, located on the west-exposed side of the Lebanon Mountains, is dominated by a change between very high and very low slopes. Mean records of the slope raster in Figure 7 (cell size 110m x 110m) is 14.3°, maximum values reach 57.7°. Steepest reliefs occur along the hillside of fluvial shaped valleys in the southern center of the catchment (Figure 8: between distance 7 000 & 9 000 from Jeita; Figure 10: in distance 12 000 meters from the highest location) and along the catchment's northern border, above the J4 unit (Figure 13). Besides fluvial shaped valleys, it is the geological C2a unit that crops out as a north-south stretching bank, leading to very high slopes (Figure 8: in distance between 15 650 and

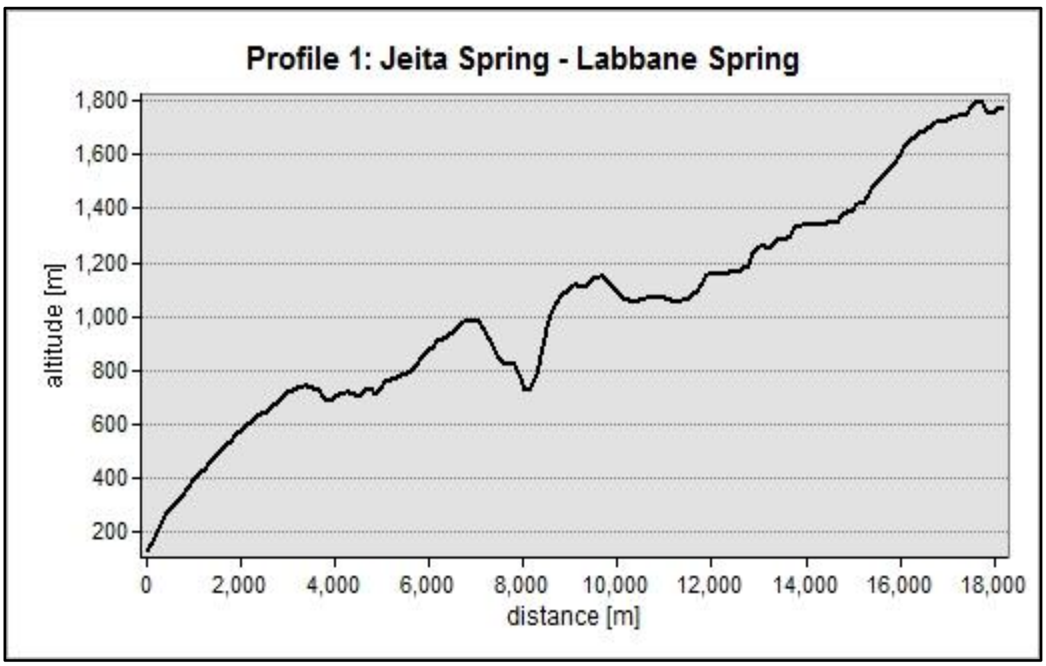


Figure 8: Profile between above Jeita Spring and Labbane Spring, ranging between 130 and 1 785 m.s.l.

16.120 meters from Jeita Spring; Figure 10: in distance between 8 240 and 8 500 meters from the highest location); parallel to this bank, it is the lowest part of the C4 unit that has a very steep relief (Figure 10: in distance between 8 570 and 10 130 meters from the highest location). High slopes lead to high velocities of surface runoff, especially when vegetation cover is missing. In this case, high velocities increase the potential of erosion, denudation and concentration time of runoff in streams.

High rates of groundwater recharge occur in the east of the catchment, above the steep bottom of the C4 unit; starting on approximately 1 850 m.s.l., the relief becomes flat towards the east, forming a plateau that covers the whole eastern part of the catchment (Figure 9: in distance between 3 330 and 8 570 meters from Labbane Spring). It is this high-plateau, on which snow accumulates during winter. Through melting of this solid snow layer in spring, water can infiltrate into the high permeable Cretaceous unit.

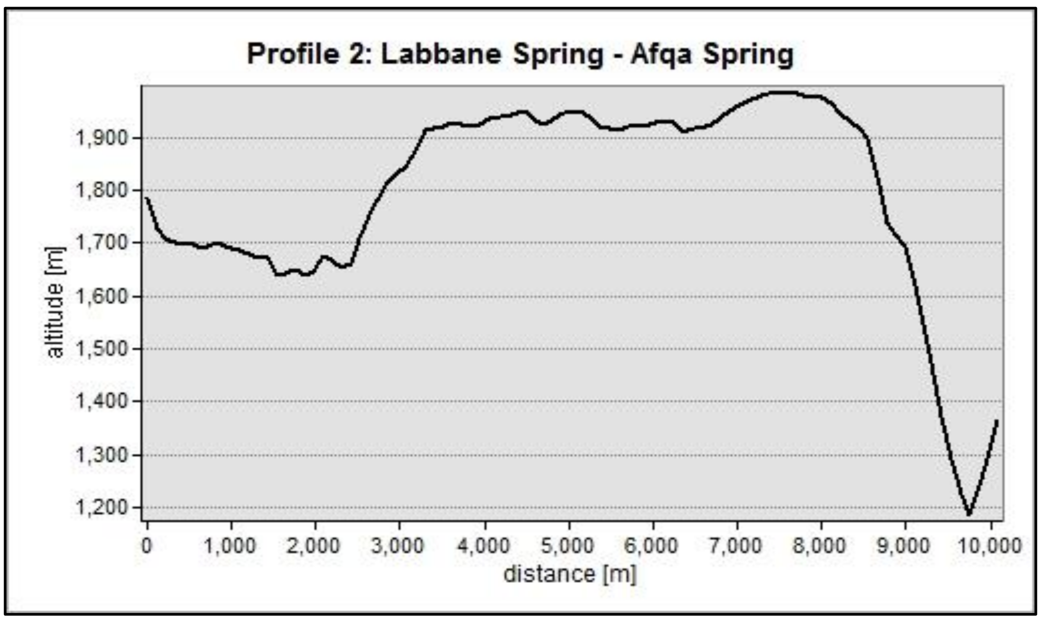


Figure 9: Profile between Labbane Spring and Afqa Spring, ranging between 1 785 and 1 365 m.s.l.

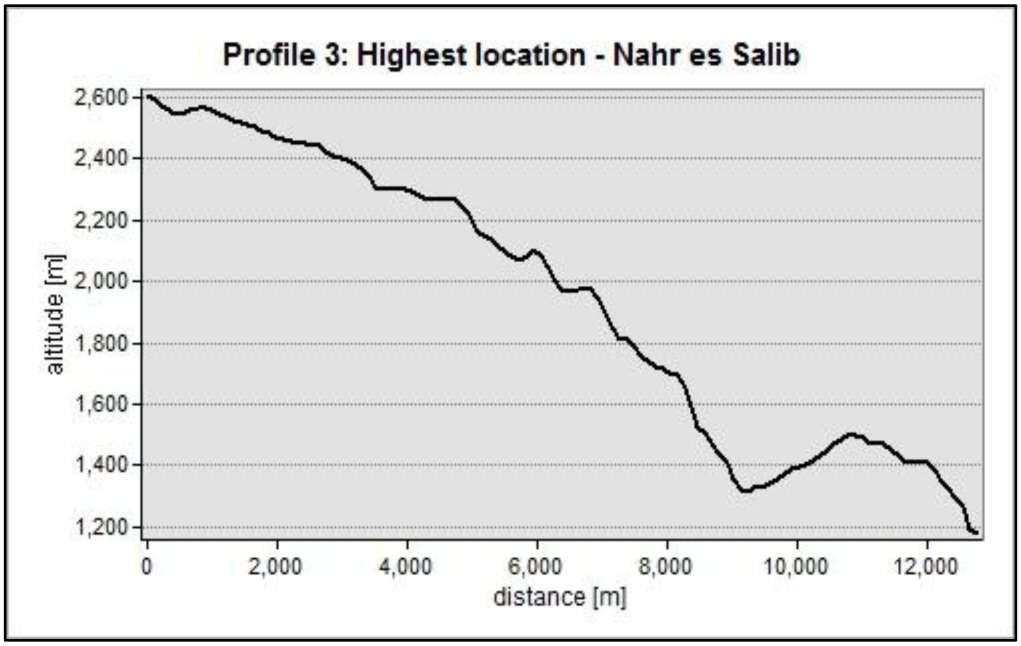


Figure 10: Profile between the catchment's highest location and Nahr es Salib, ranging between 2 626 and 1 190 m.s.l.

4.2. Climate

The regional climate is described as 'Mediterranean', with oceanic, i.e. wet, conditions during winter and sub-tropical, i.e. dry, climatic conditions during summer. Summer is referred to as being the period between 1st of June and 15th of September, whereas winter is referred to as the period between mid of November and mid of April; periods of transitions of climatic regimes occur from mid of April to the 1st of June and from 15th of September to mid of November (ATLAS CLIMATIQUE DU LIBAN 1977).

The narrow and flat coastal strip, extending north-south, is openly exposed to the Mediterranean Sea, which leads to maritime, semi-tropical conditions; on the other side, due to the ascending altitude, conditions in the Lebanon Mountains are generally cooler and more humid. In April conditions are classified as 'semi-humid', 'arid' from May to the end of October, 'humid' in March and November and 'wet' from December until end of February

(BAKIC 1972). At Laqlouq (1 700 m.s.l.), which is 8 km north of Afqa Spring, total annual precipitation can reach up to 3 047 mm (ATLAS CLIMATIQUE DU LIBAN 1977).

Due to regional topography, precipitation varies heavily in space: for the period between 1931 and 1960, average annual rainfall ranges between 1 200 mm for Raifoun (1 050 m.s.l.), 1 435 mm at Qartaba (1 140 m.s.l.) and 1 500 mm at Faraya (1 325 m.s.l.). Minimum monthly average precipitation for the three stations occurs in July and August (1 mm), the maximum in January (275 mm, 313 mm, 328 mm) (ATLAS CLIMATIQUE DU LIBAN 1977). Figure 11 shows the spatial distribution of average annual precipitation for the peri-

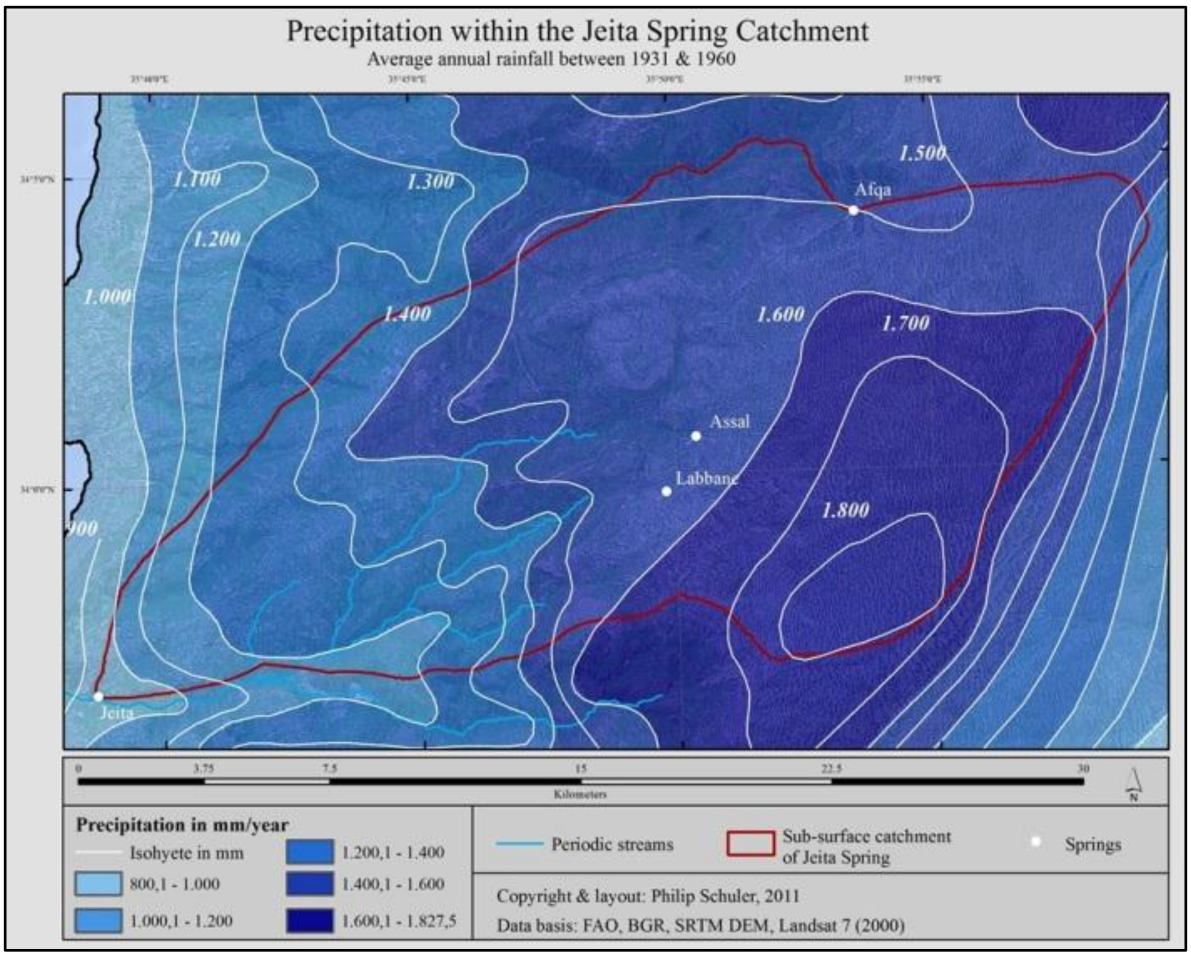


Figure 11: Spatial distribution of annual average precipitation for the Jeita Spring catchment between 1931 and 1960, ranging between 930 mm and 1.827,5 mm; source of data: FAO (1973).

od 1931-1960. Correlation between accelerating altitude towards the east and increasing rainfall can be derived when comparing Figure 7 and 14 with Figure 11. For an estimated size of Jeita Spring's catchment of 288 km², BAKIC (1972) calculates 1 415mm of total average annual rainfall. This amount seems to be consistent with an average annual rainfall of 1 450 mm, as calculated for a catchment size of 310.7 km² within this study, according to the present rainfall data. Spatial variation of precipitation reflects the effect of orographic lifting along the relief of the Lebanon Mountains; lifted air that is moist in winter, moves from western direction towards the east. In general, wind direction ranges between WWS to NNE.

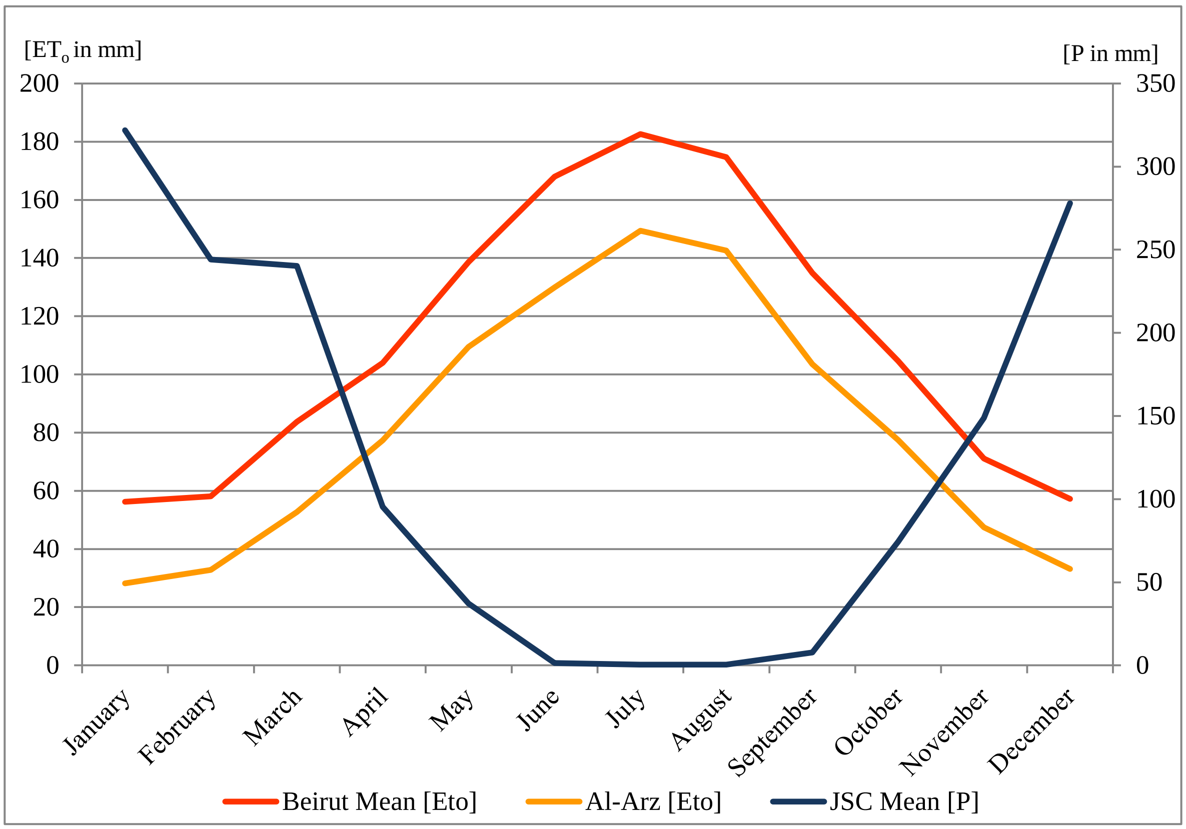


Figure 12: Average monthly precipitation for Qartaba, Raifoun and Faraya for the period 1931-1960 and average monthly reference evapotranspiration for Al-Arz and Beirut in mm; source of data: ATLAS CLIMATIQUE DU LIBAN 1977, FAO CLIMWAT Database.

Ascending air loses temperature and becomes less dense and has therefore less capacity to transport moisture. The consequence is formation of clouds, fog, or the start of rainfall; intensity of rainfall events in higher altitudes depends on the seasonal wind regime and seasonal rate of air's humidity. Besides precipitation, reference evapotranspiration ET_0 is the other climate variable that matters for WEAP. Figure 12 shows the contrarian seasonal peaks of ET_0 and P. ET_0 ranges between a minimum of 28.21 mm in January in Al-Arz and a maximum 182.59 mm in Beirut in July.

4.3. Geology

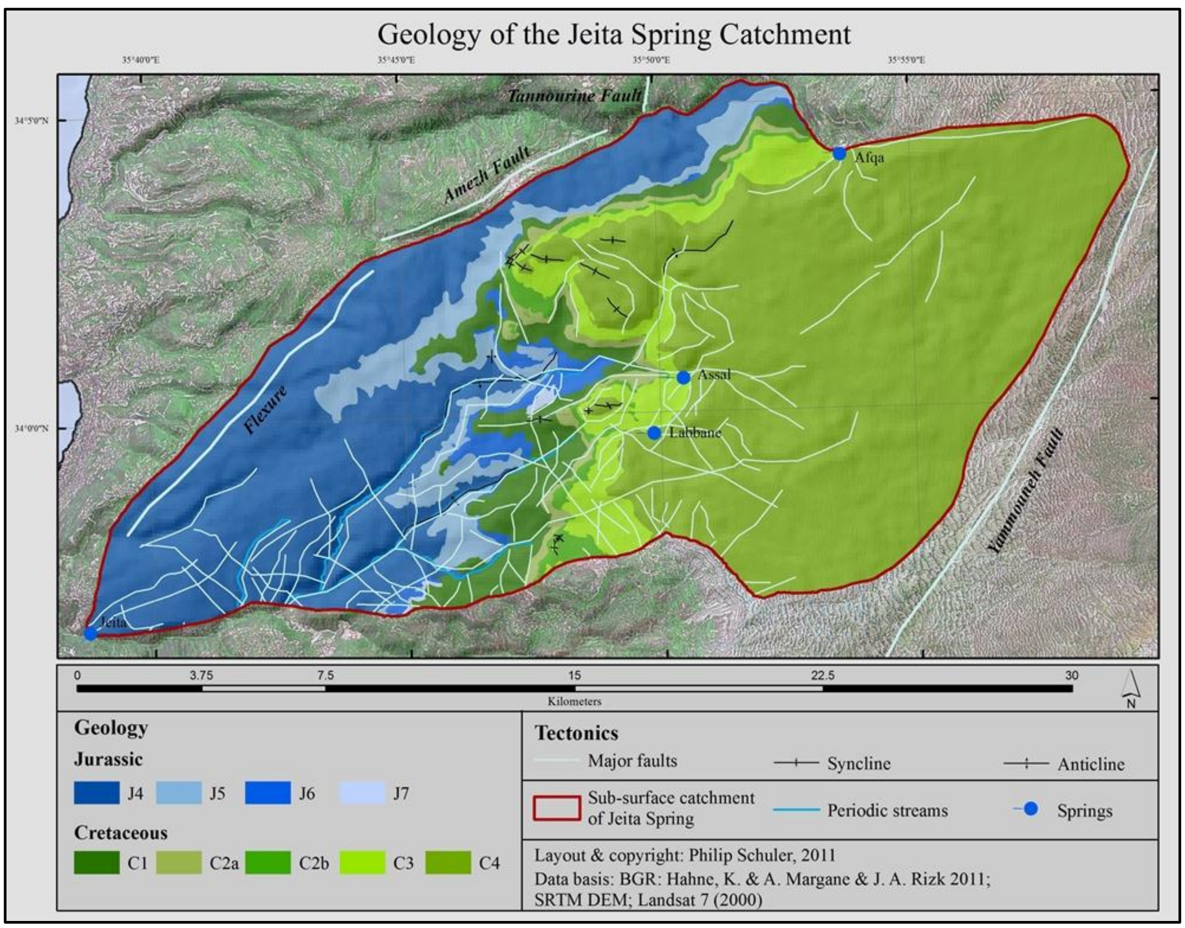


Figure 13: Geological setting of the Jeita Spring Catchment, including units of C1, C2a, C2b, C3, C4, J4, J5, J6 and J7.

In Lebanon, there is no national geological survey that is responsible for geological research. Since 2011 there is updated geological data, mapped in 1:10 000, established by A. MARGANE and K. HAHNE from BGR (Figure 13), which is not published at time of writing. As previously outlined in chapter 4.1, the catchment is located on the east side of the Lebanon Mountains. Between south of Beirut and Tripoli, along the very western strip of the Lebanon Mountains, a flexure expands for 100 km in NNE-SSW direction (WALLEY 1997). This tectonic feature implies steep to vertical dipping of geological layers towards the Mediterranean Sea. Extent of the flexure overlaps with the western part of the JSC.

Faults are other features, related to tectonic activities; they are widespread within the JSC. Lebanon's major fault, the left lateral NNE-SSW 'Yammouneh Fault', expands outside of JSC; however, still it is important to mention it because from this fault, there […] *are a number of subparallel and divergent fault splays which divide up much of the country*. (WALLEY 1997) This is also true for the study area. Faults arise through tectonic pressure along 'geologic weak' lines. Breaking of geological structures allows later on fine particles to accumulate within these cracks, or faults; therefore, these cracks become consolidated, acting as 'hidden barriers' for groundwater flow. One result is disturbance of regional subsurface hydrology because flow paths change, according to these faults extent. Groundwater flow becomes more difficult to comprehend, and so, also the process of defining boundaries of a sub-surface catchment. Above surface, faults may be identified through outcropping of geological layers or through flow paths of streams. Since formation of streams develops along lines of little resistance, shape and extent of stream-flows correlates with shape and extent of faults (Figure 13).

Geological units within the JSC mainly consist of lime stones, dolomites and clastic sediments. Lime stone layers are highly karstified, leading to high flow velocities in the saturated zone. The age of the oldest outcropping geological layer is less than 200 million years, starting with the Jurassic. The oldest Jurassic formation is the J4 unit (Keserwan Formation), on which Jeita Spring is located. Within the study area, this formation is up to 1 070 m thick and highly karstified (HAHNE 2011). Above J4, extent of the J5 unit starts (Bhannes Formation). Thickness varies between 50 and 150 m (WALLEY 1997), whereas locally it can reach 340 m, which is fault-related (HAHNE 2011). J5 has a high content of basalt, little share of marl, siltstone, claystone and limestone that is thin bedded. Karstification of J5 is low, and therefore also its permeability. Above J5, the unit of J6 (Bikfaya Formation) follows. Thickness ranges between 60 m and 80 m (WALLEY 1997); however, it has a fault-related local maximum of 160 m (HAHNE 2011). J6 forms a cliff-formation of massive micritic limestone. Above J6, there are two mapped areas of outcropping J7 (Salima Formation). Maximum thickness is 180 m, which is related to faulting (HAHNE 2011). J7's lithology contains clay- and silt stone, marls, fine ferruginous sandstone and limestone. Limestone banks are up to 4 m thick. Due to these fine components, J7's permeability is lower than J4's but rather similar to J5's.

On top of previously described Jurassic formations, Cretaceous units are located. So, genesis of the Cretaceous follows genesis of the Jurassic. The oldest Cretaceous unit, the C1 (Chouf Sandstone Formation), is up to 144 million years old. C1's thickness ranges between 10 m and 300 m (WALLEY 1997), whereas there is a local maximum of 380 m where two faults cross each other (HAHNE 2011). C1's basis is partly intruded by brownish to black colored basalt. However, C1's lower layer contains dolomite, followed by yellow limestone, grey marl and fine sandstone (HAHNE 2011). Massive sandstone banks may contain some clay- and siltstone layers, locally also lignite. This composition makes C1 being a very low permeable unit, considerable as aquitard. Therefore, C1 contributes only marginal to groundwater recharge of the JSC.

Besides the here described extent of C1, located above the J4, some C1 expands below the J4, outside the south-western border of the JSC. This spatial setting leads to banking up of the J4 aquifer's groundwater. The result is discharge of the J4 aquifer at the location of Jeita Spring.

Within the JSC, above C1, the C2a unit follows (Abieh Formation); C2a is the basis for the C2b unit (Mdairej Formation). Thickness of C2a ranges between 80 m and 170 m (WALLEY 1997). It contains sand- and claystones, marls and grey fossilferous limestone that may be sandy at few locations. On top of C2a, on the bottom of C2b respectively, basaltic intrusions may occur. C2b has a thickness of approximately 50 m (WALLEY 1997), whereas locally it can reach a fault-related thickness of approximately 80 m (HAHNE 2011). This unit consists of massive micritic and highly karstified limestone. Above C2b, formation of C3 (Hammana Formation) follows. Thickness ranges between 100 m and 400 m (WALLEY 1997). This layer contains various claystones, marls and limestone, which are thin-bedded. On top of these layers, dolomites, limestone and soft marls may occur (HAHNE 2011). The very top of the catchment (Mount Sannine) is covered exclusively by C4 (Sannine Formation), which is the 'coastal type' (vs. 'inland type'). C4 forms an east-dipping high plateau of the Lebanon Mountains. Thickness is approximately 1 050 m (HAHNE 2011). It consists of micritic light limestone that is generally karstified. As a proof for karstification and as a result of seasonal snow cover with following melting processes, dolinas are ubiquitous on top of the C4.

The intensity of karstification of a geological unit leads to the unit's specific rates of vertical permeability for infiltrating water towards the saturated zone. Each geological unit has a specific conduit, i.e. matrix characteristics of the bedrock. Based on the methodology for the creation of a numerical expression (*k*-value) for karst networks (MARGANE 2003), geological units of the Jeita Spring catchment can be attributed with *k*-values, as listed in Table 4. It is important to stress that appreciation of values is based on an empirical approach. According to this classification, J4, J6, C2b and C4 show the highest degree of developed fractures and networks – and therefore the highest degree of karstification. A value of 0.25 expresses the characteristic 'developed karst with the absence of surface layers'. C3 shows less developed fractures. Even though C3 is not a karst unit, it shows the characteristic of 'scarcely developed or dissolution features with the absence of surface layers'. J5, J7, C1 and C2a have lowest vertical permeability. They are attributed with a value of 0.75.

Table 4: *k*-values and extent of the geological units within the JSC.

unit	J4	J5	J6	J7	C1	C2a	C2b	C3	C4
area [km²]	87.1	19.7	6.4	0.6	20.5	5.9	4.8	17.9	148.5
share of total catchment [%]	28.0	6.3	2.0	0.2	6.6	1.9	1.5	5.8	47.7
k-values	0.25	0.75	0.25	0.75	0.75	0.75	0.25	0.5	0.25

4.4. Hydrology

Figure 14 shows the sub-surface catchment of Jeita Spring. Partly overlapping with Jeita's sub-surface catchment, there are four delineated surface catchments that drain into Nahr el Kalb at a location below Jeita Spring. Surface runoff of two of these sub-catchments, i.e.

Nahr es Salib and Nahr es Zirghaya, is measured at Daraya gauging station (Figure 14) by

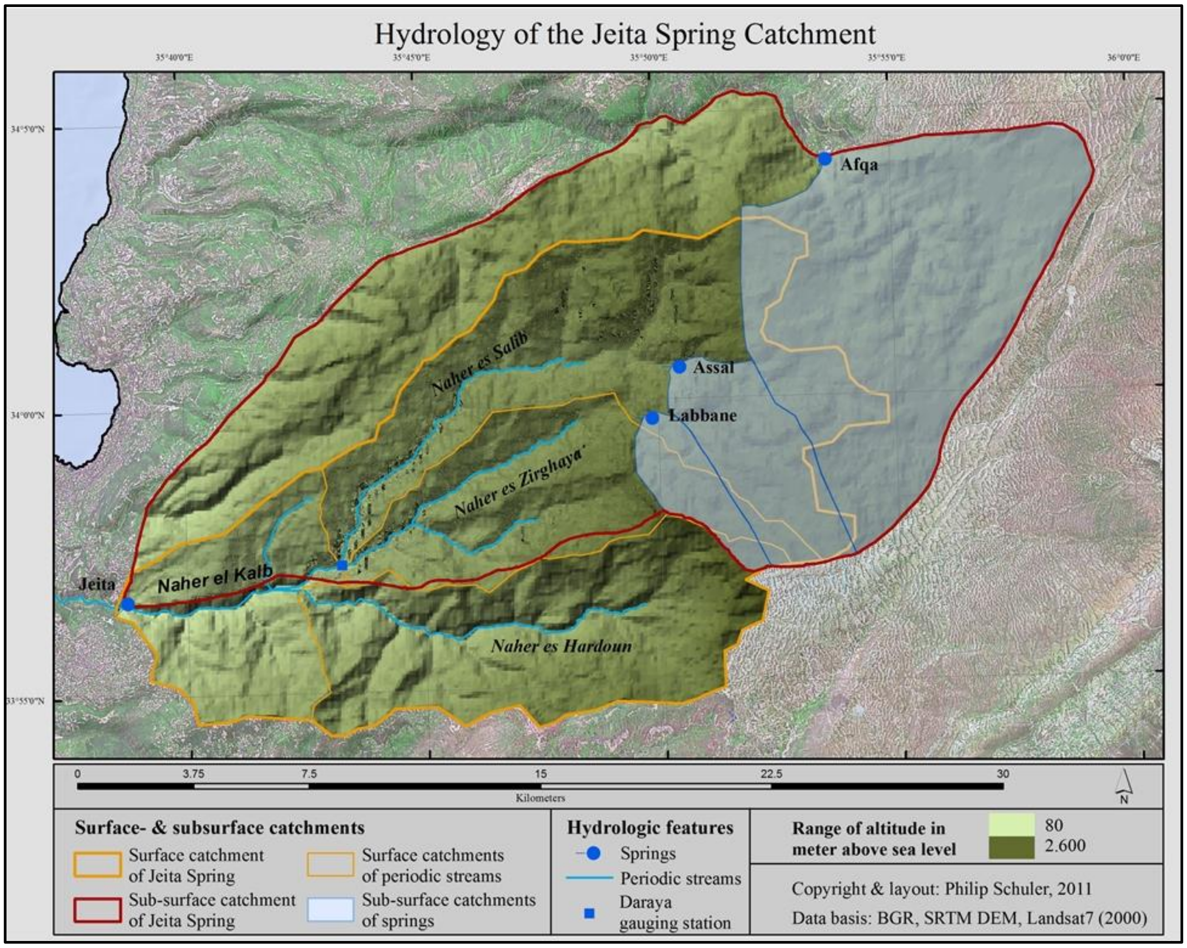


Figure 14: Hydrology of the Jeita Spring catchment: surface catchments of Nahr es Hardoun, -es Zirghaya, -es Salib and -el Kalb. Sub-surface catchments of Afqa-, Assal- and Labbane Spring.

Litani River Authority (LRA). Further south, outside of the sub-surface catchment of Jeita Spring, the surface catchment of Nahr es Hardoun expands.

All runoff of these three surface catchments is drained together to Nahr el Kalb, approximately 11 km before its drainage to the Mediterranean Sea.

Besides the mentioned surface-runoff catchments, from which Nahr es Salib and Nahr es Zirghaya are of major importance for the WEAP model, three sub- surface catchments are delineated as they define discharge of Nabeh [نبع = spring] al Afqa, Nabeh al Assal and

Nabeh al Labbane. However, the catchments of these three springs cover not all of the extent of the C4 unit; above the C4 unit, there is some feeding space (SC 2) that feeds local springs (Figure 27).

4.4.1. Afqa Spring

Afqa Spring is located on 1 300 m.s.l. Its sub-surface catchment has a total size of approx-

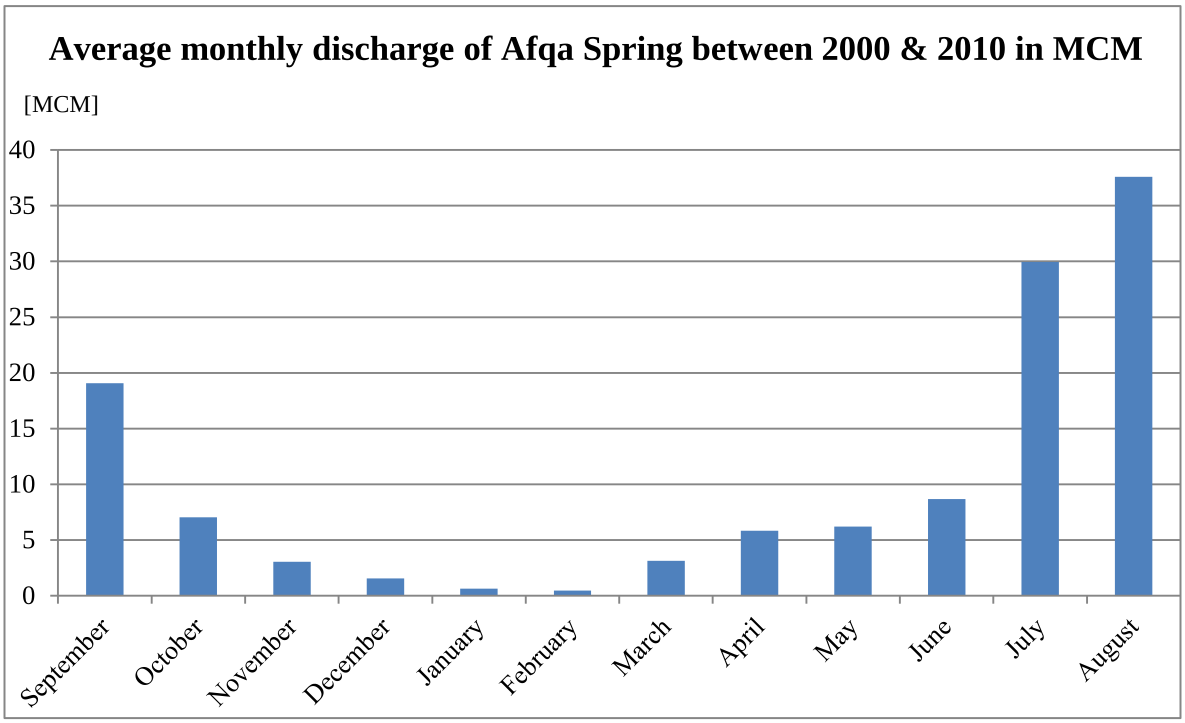


Figure 15: Average monthly discharge of Afqa Spring between September 2000 and August 2010 in MCM; source of data: LRA 2011.

imately 93.0 km² and reaches up to 2 500 m.s.l. Delineation of the south-western border of the catchment of Assal Spring is based on a successful tracer injection in May 2011 (DOUMMAR, ET AL. [a] 2011). Furthermore, extent is defined based on topography and geological assessments that take into consideration the slope of dipping geological units. Afqa is completely fed through the C4 unit; discharge varies throughout the year. Figure 15 shows average monthly discharge of Afqa between 2000 and 2010; there are no historic discharge records available, which would make discharge of Afqa Spring more comparable to the other springs. Average annual discharge is 123.22 MCM, with a monthly minimum in February with 0.48 MCM (0.20 m^3/sec.) and a monthly maximum in August with 37.59 MCM (14.04 m^3/sec.). There is a high seasonal variation of discharge, as it is common in karst-geology; however, in comparison to Assal's and Labbane's seasonal discharge development (Figure 16 and 17), Afqa Spring's discharge curve is 3-4 months delayed.

All of Afqa's discharge leaves the JSC via Nahr Ibrahim, which flows westwards, along the northern border of JSC towards the Mediterranean Sea. From Nahr Ibrahim, an estimated 30% of the previously discharged spring water of Afqa Spring re-enters JSC through river bank infiltration into the J4 unit. It is mainly the period between July and August, in which groundwater of the J4 unit receives important recharge by Afqa Spring.

Water from Afqa Spring is used for domestic purpose in the north-east of JSC, as well as for agricultural activity. For both purposes, an unknown figure of discharge is conveyed outside the catchment.

4.4.2. Assal

Assal Spring is located on 1 570 m.s.l. Its sub-surface catchment has a total size of approximately 21.5 km^2 and reaches up to 2 626 m.s.l. Definition of the catchment's north-eastern and southern border is based on a successful tracer injection in May 2011 (DOUMMAR, ET AL. [a] 2011). Furthermore, extent is defined based on topography and geological assessments that take into consideration the slope of dipping geological units. Next to this, discharge records of the spring are used to conclude the necessary extent of the feeding sub-surface catchment. Assal is completely fed through the C4 unit; for the average water year

1968/1969-1972/1973, average monthly discharge is 2.02 MCM (0.77 m^3/sec.) (Figure 16), which is summed up to a total annual discharge of approximately 24.19 MCM. Highest discharge occurs in May, with an average discharge of 4.87 MCM (1.82 m^3/sec.), as response to snow melting on top of Mt. Sannine. Lowest average monthly discharge is measured for November, with 0.73 MCM (0.28 m^3/sec.).

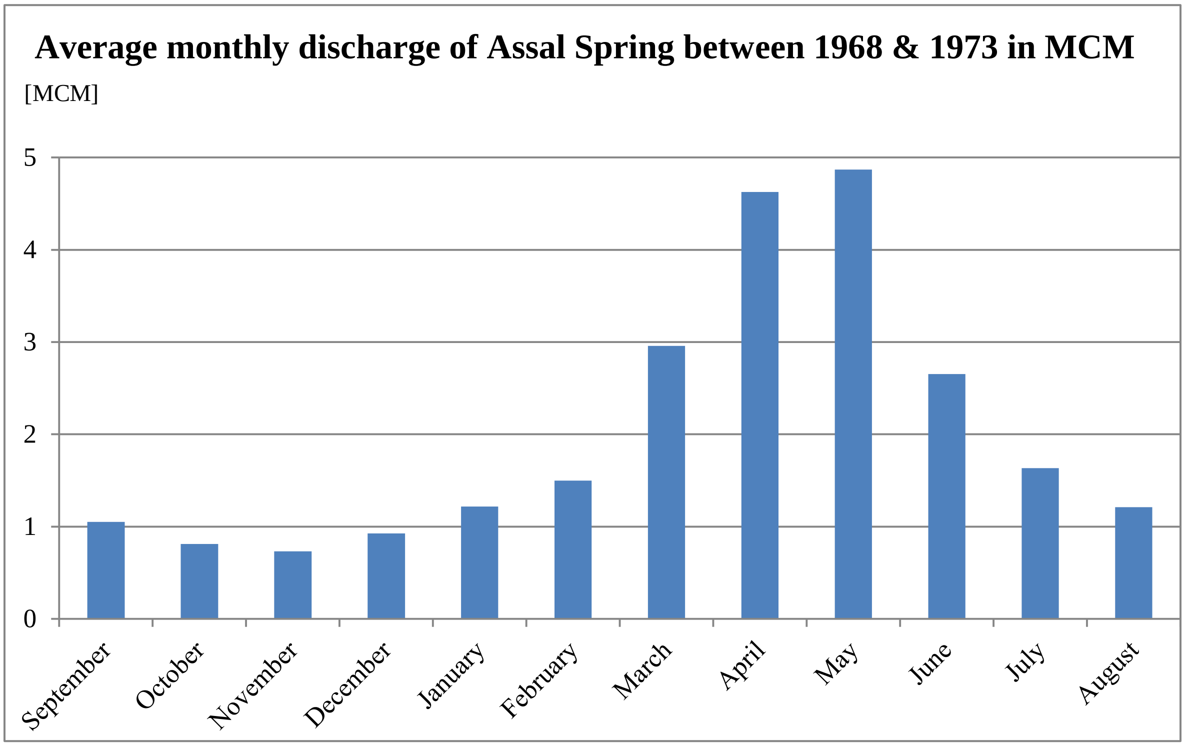


Figure 16: Average monthly discharge of Assal Spring between September 1968 and August 1973 in MCM; source of data: LRA 2011.

4.4.3. Labbane Spring

Labbane Spring is located on 1 785 m.s.l. Its sub-surface catchment has a total size of approximately 9.5 km^2 and reaches up to 2 500 m.s.l. Definition of the catchment's extent is inferred from topography and spring discharge; quantity of discharge is used to conclude the necessary extent of the feeding sub-surface catchment. Labbane Spring is completely fed through the C4 unit; for the average water year 1971/1972-1972/1973, average monthly discharge is 1.27 MCM (0.48 m³/sec.) (Figure 17), which is summed up to a total annual discharge of approximately 15.27 MCM. Highest discharge occurs in May, with an average discharge of 5.96 MCM (2.23 m³/sec.), as response to snow melting on top of Mt. Sannine. Lowest average monthly discharge is measured for October and December, with 0.03 MCM (0.01 m³/sec).

Labbane Spring indicates a high variability in seasonal discharge; 89% of its total annual discharge is discharged in April, May and June.

Water from Labbane Spring is conveyed to Chabrough dam and into an irrigation canal.

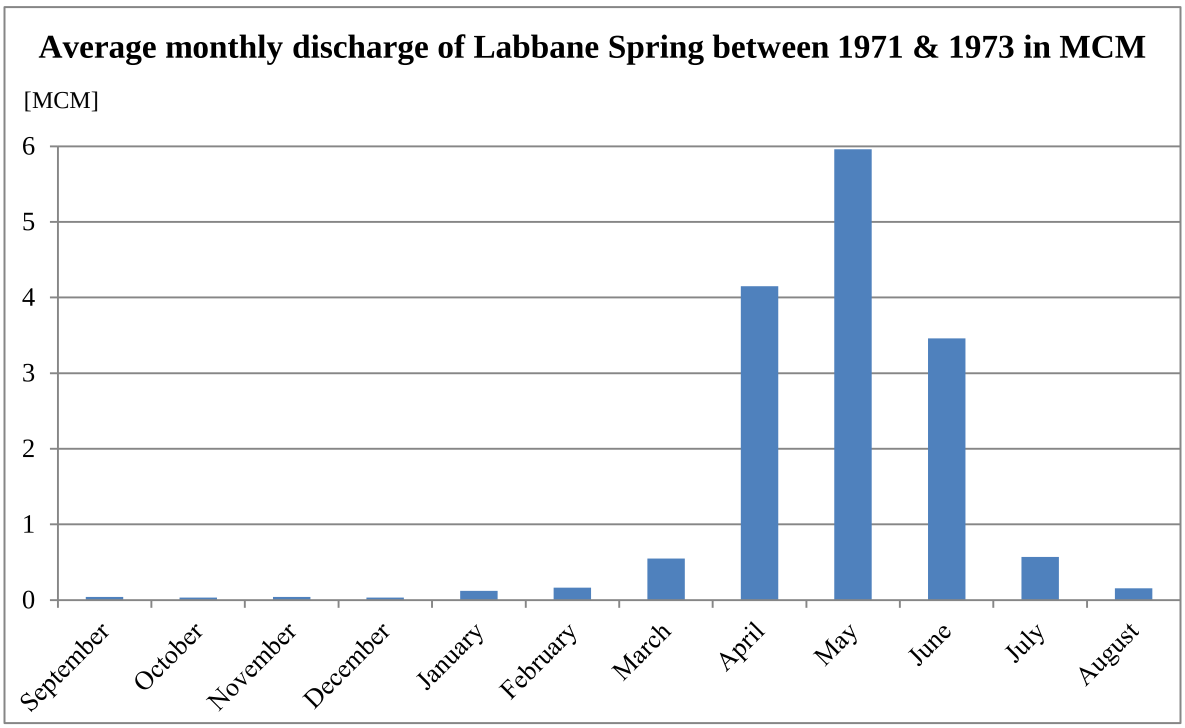


Figure 17: Average monthly discharge of Labbane Spring between September 1971 and August 1973 in MCM; source of data: LRA 2011.

4.5. Jeita Spring

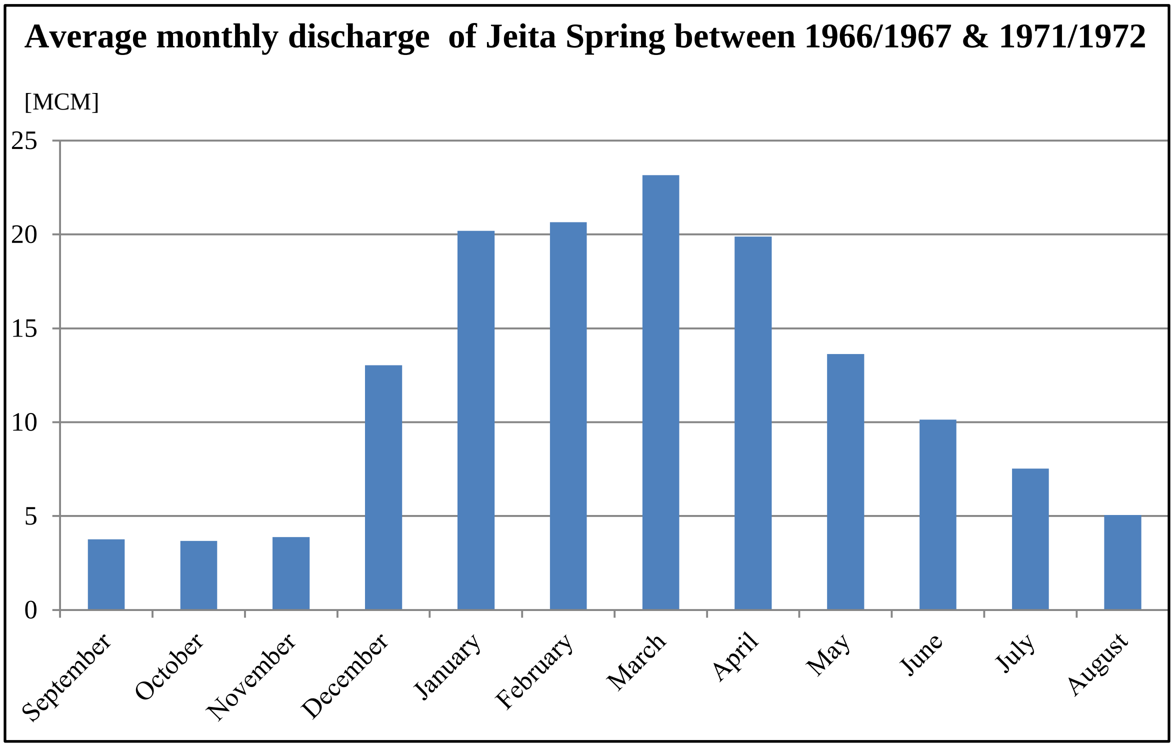


Figure 18: Average monthly discharge of Jeita Spring between September 1966 and August 1972 in MCM; source of data: LRA 2011.

Jeita Spring is located on 60 m.s.l. For the water years between 1966 and 1972, discharge records are presented in Table 5 and average monthly records for this period are shown in Figure 18. Between 1966 and 1972, average annual discharge is approximately 144.59 MCM, which corresponds to an average flow of 4.60 m³/sec. Highest discharge occurs in March, with an average of 23.16 MCM (8.65 m³/sec.), as response to the rainy season that starts mid of November. According to all documented records, the highest ever measured discharge is 80 m³/sec., recorded on February 21, 2011 (MARGANE [a] 2011). Lowest monthly discharge occurs in October, with a total flow of 3.68 MCM (1.37 m³/sec.). Jeita is directly fed by groundwater, which is stored within the J4 aquifer. J4 receives water input through infiltrated and percolated rainfall on top of its relief, and through water that is discharged by Afqa spring and re-enters JSC (J4) via Nahr Ibrahim. Only a little share of groundwater flows from the aquitard (J5-C3) to the J4. Therefore, Jeita's feeding space mainly consists of the surface of the J4 unit and the surface of Afqa Spring's sub-surface catchment.

Table 5: Average monthly discharge of Jeita Spring between 1966/1967 and 1971/1972 in MCM.

Water year	1966/ 1967	1967/ 1968	1968/ 1969	1969/ 1970	1970/ 1971	1971/ 1972	Average
September	3.63	4.30	3.76	4.45	2.68	3.71	3.76
October	3.75	4.48	3.54	4.00	2.84	3.48	3.68
November	3.63	5.23	3.16	5.11	2.81	3.34	3.88
December	8.29	15.08	22.00	10.31	12.16	10.36	13.03
January	17.62	28.84	33.49	13.37	11.76	16.03	20.19
February	26.56	27.64	26.14	16.96	11.15	15.46	20.65
March	37.06	26.39	25.55	18.15	18.50	13.33	23.16
April	29.83	15.29	19.99	16.05	25.65	12.50	19.89
May	15.82	11.64	14.14	11.81	18.17	10.18	13.63
June	11.86	9.41	10.89	8.01	12.43	8.24	10.14
July	9.31	6.94	9.11	5.40	9.49	4.97	7.54
August	6.89	4.31	6.62	3.82	5.45	3.23	5.05
Total	**174.24**	**159.55**	**178.40**	**117.43**	**133.10**	**104.84**	**144.59**

Source of data: LRA 2011.

In order to assess the relationship between surface runoff and spring discharge, Figure 19 shows the linear regression for the two variables 'average monthly discharges of Jeita Spring' and 'average monthly discharge of Nahr el Kalb', as measured at Mokhada station. For the average monthly discharge, Pearson product-moment correlation coefficient (PPMCC) is 0.93, which is high significant; R^2 is 0.87, which states that PPMCC is reliable and has a high variance. It can be concluded that discharge behavior of Jeita Spring is very similar to discharge behavior of Nahr el Kalb; thus, both of them may react similar towards rainfall events above the JSC.

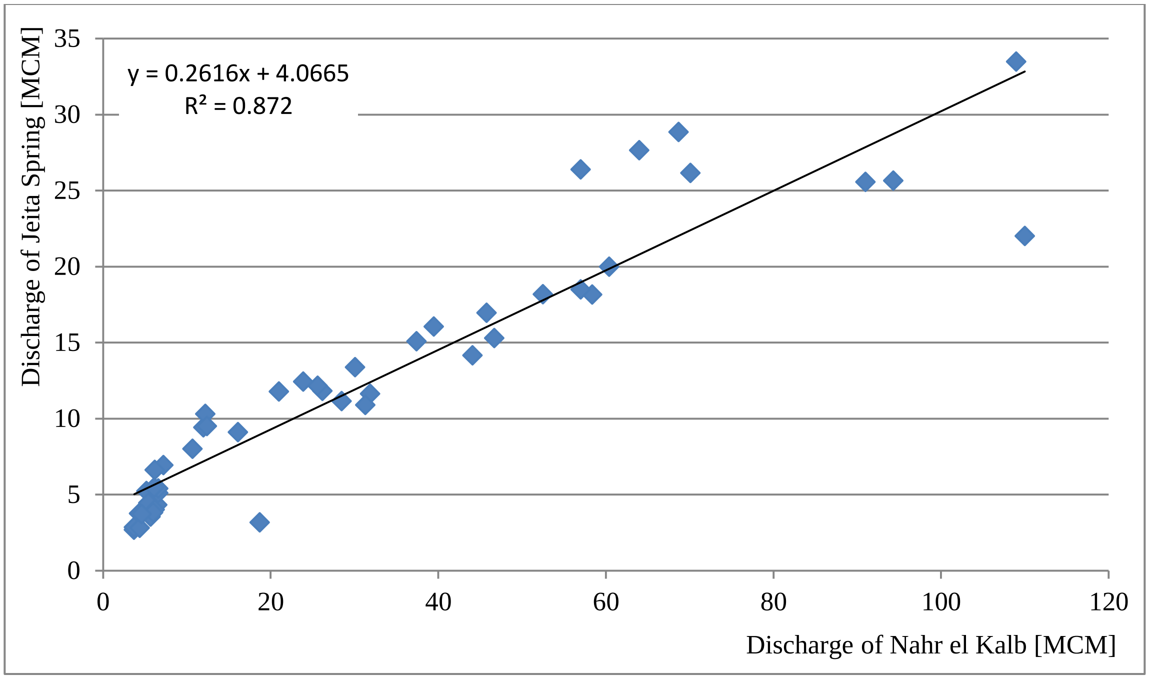


Figure 19: Linear regression between average total monthly discharge of Jeita Spring and Nahr el Kalb between 1967/1968 and 1970/1971.

4.6. Land-use

Total land-use, i.e. for humans' activities shaped surface, covers in total 3 363 ha, which corresponds to 10.8% of the whole catchment. Figure 20 shows the spatial distribution of land-use classes within the JSC and Figure 21 gives on overview about the absolute extent of each land-use class and each class's share on total land-use; Single land-use classes are aggregated to agriculture and impervious surfaces, as it will be further outlined within the following two sections.

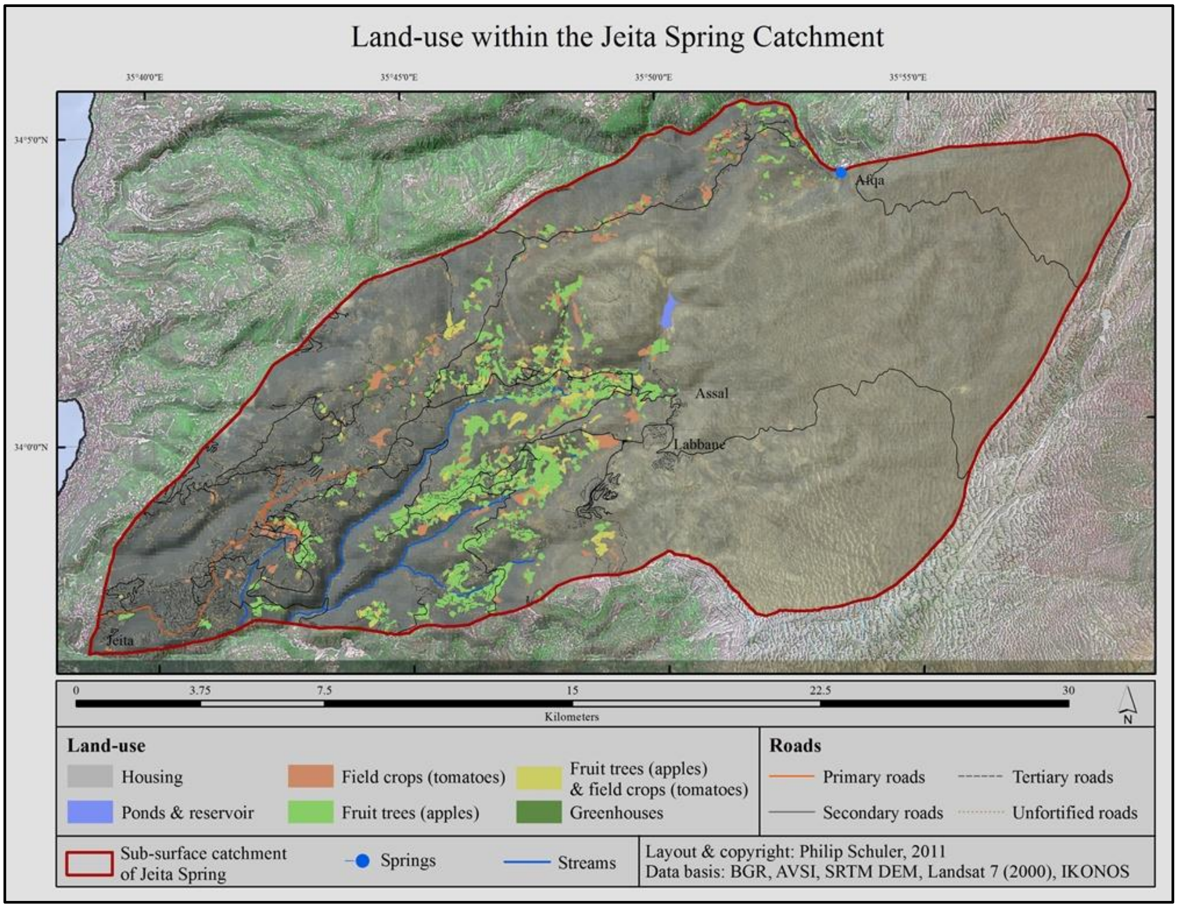


Figure 20: Land-use classes within the Jeita Spring Catchment: housing, ponds & reservoir, field crops, fruit trees, fruit trees & field crops and greenhouses.

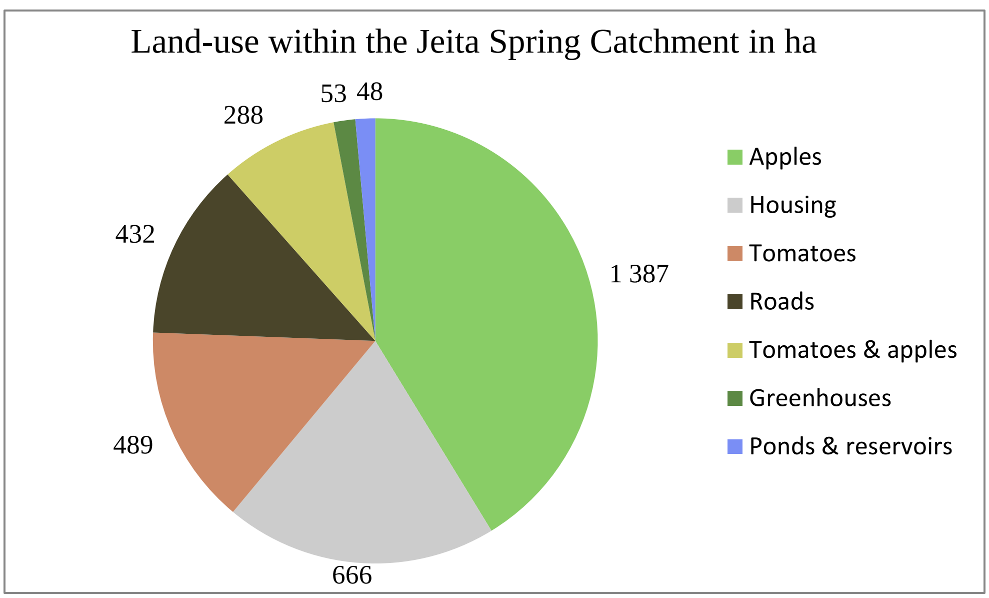


Figure 21: Land-use within the Jeita Spring Catchment in ha: apples, hosing, tomatoes, roads, tomatoes & apples, greenhouses and ponds.

4.6.1. Impervious surfaces

Impervious surfaces consist of the land-use class ‘housing’ and ‘roads’. Both of them prevent rainfall from infiltrating into the soil. Rainfall that accumulates on impervious surfaces is subject to relatively high evaporation and runoff. The land-use class ‘housing’ extends mostly in the south-west of the catchment, along the Keserwan main road; this area includes the settlements Ballouneh, Aajaltoun, Raifoun, Ashkout and Faitroun (Figure 3), up to an altitude of approximately 1 200 m.s.l. Housing makes up 19.80% of total land-use, or 2.14% of whole JSC. ‘Roads’ account for 12.84% of land-use, which corresponds to 1.39% of the total catchment area. Width of roads changes, according to the road’s order: primary roads, i.e. Keserwan main road, has a width of 14 m, secondary roads, i.e. wider roads within and between settlements have a width of 9 meters and tertiary roads, i.e. roads within settlements, a width of 7 meters.

4.6.2. Agriculture

Agricultural land-use consists of crops, ‘greenhouses’ and ‘ponds & reservoirs’. Altogether, these classes make up 63.7% of total land-use, which corresponds to 7.29% of the whole JSC. For further specification, crops are disaggregated, as there are two major crops within the JSC: apples, i.e. ‘fruit trees’, and tomatoes, i.e. ‘field crops’. Apples account for the largest share, 41.2%, of total land-use; they are mainly grown in the center of the catchment, between 1 150 and 1 500 m.s.l. Tomatoes are grown wide spread throughout the catchment, below 1 800 m.s.l. Tomatoes account for 14.55% of land use, or 1.57% of the total catchment. Combined growth of the two crops, i.e. ‘fruit trees & field crops’, is done mainly in the center of JSC, where most of mapped land-use class ‘fruit trees’ is located. Figure 22 shows the two crop coefficients for apples and tomatoes.

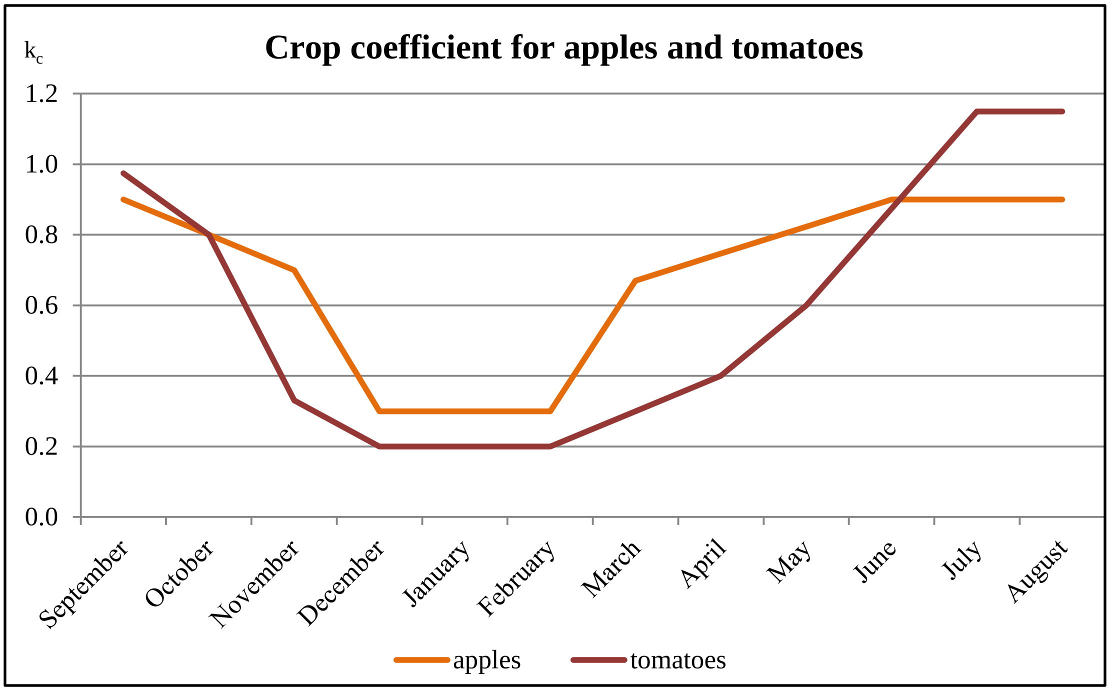


Figure 22: Crop coefficient for tomatoes (Mediterranean) and apples; source of data: ALLEN, ET AL. 1998.

‘Ponds & reservoirs’ and ‘greenhouses’ account only for a very little share of coverage. Since ponds are constructed elements, which are used to store irrigation water, they are attributed as land-use, and not land-cover. Due to practical reasons, Chabrough dam is also included in this class.

As irrigation technique, farmers apply surface irrigation and mainly drip irrigation (THE STUDY OF NAHR EL KALB WATERSHED 2009), which has been empirical validated by field research. BENLIL, ET AL. (2006) calculates that drip irrigation has 57% more efficiency than surface irrigation techniques; however, according to unpublished data, for this study, irrigation efficiency is expected to be 60%.

52% of all agricultural activity takes place above the aquitard. Almost all the remaining share of agricultural activity takes place above the J4 unit; there is almost no agricultural activity above the Cretaceous unit.

4.7. Land-cover

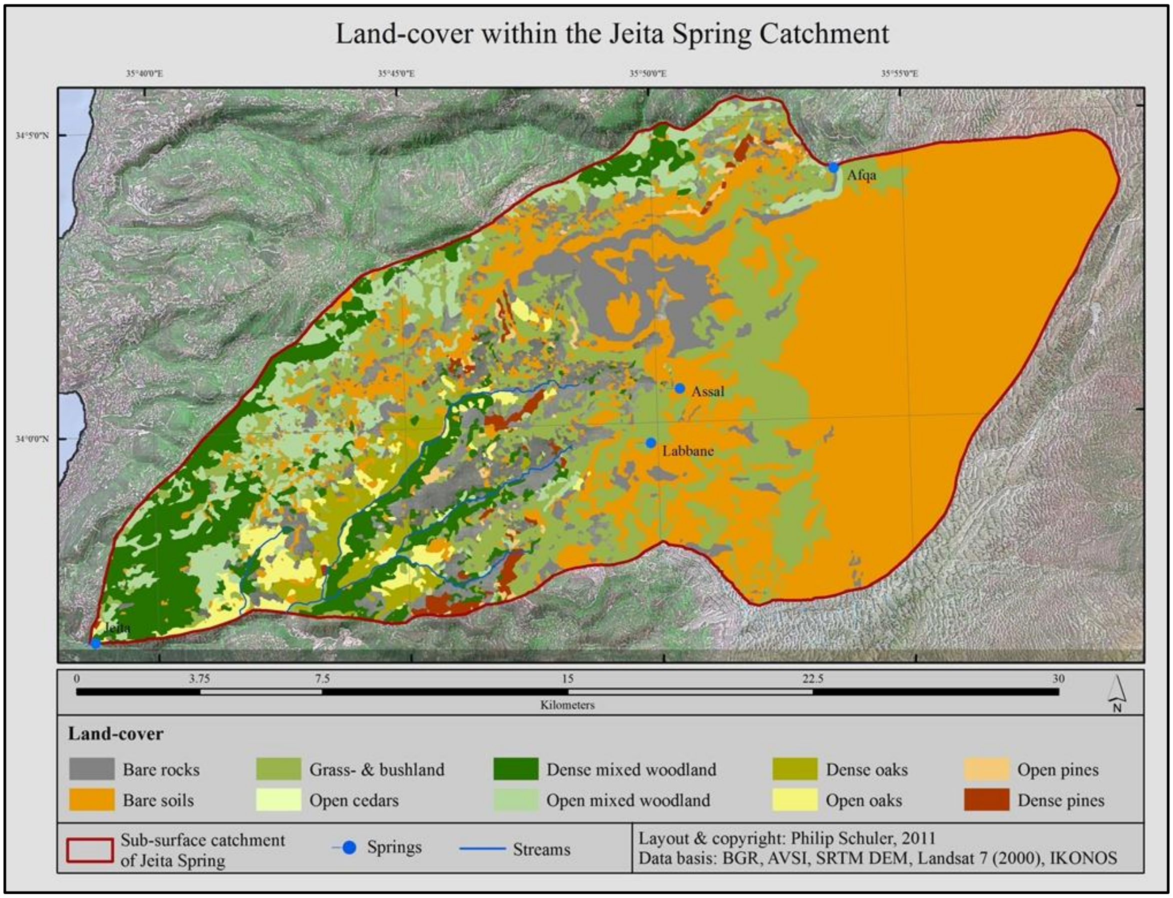


Figure 23: Land-cover-classes within the Jeita Spring Catchment: Bare rocks, bare soils, grass- & bushland, open cedars, dense- and open mixed woodland, dense- and open oaks, dense- and open pines.

Total land-cover, i.e. land that is not primarily shaped for human activities, covers in total 27 711 ha, which corresponds to 89.2% of the whole JSC. Figure 23 shows the spatial distribution of all land-cover classes within the JSC and Figure 24 gives an overview about the absolute extent of each land-cover class and each class's share on total land-cover; Single land-cover classes are aggregated to vegetation and soil and bare rocks, as it will be outlined within the following chapters.

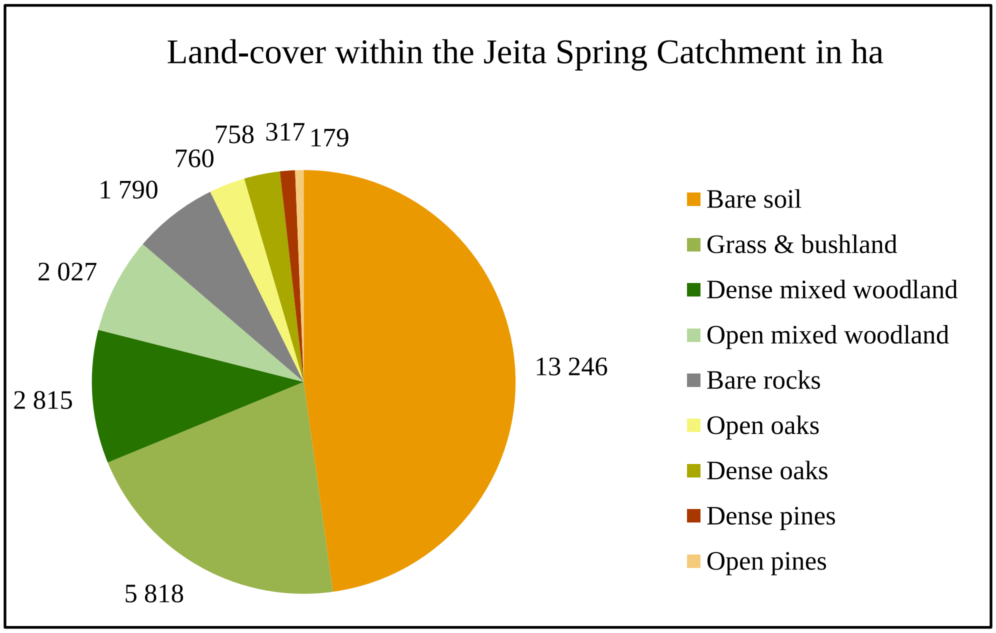


Figure 24: Land-cover within the Jeita Spring Catchment in ha: Bare soil, grass- & bushland, dense mixed woodland, open mixed woodland, bare rocks, open oaks, dense oaks, dense pines and open pines.

4.7.1. Vegetation

Vegetation is represented by all land-cover classes, except 'bare soils' and 'bare rocks'. Classification of vegetation, e.g. forests, is a challenging issue because of the subjective judgment of the researcher. According to FAO (2000), "*Forests are lands of more than 0.5 hectares, with a tree canopy cover of more than 10 percent, which are not primarily under agricultural or urban land use*". With respect to this study, it is necessary to stress that classification of vegetation bases on FRA 2000; however, in this study, classification it is slightly modified. As it is indicated in Figure 23, 'forest land' is mapped as 'dense-' or 'open' tree-vegetation cover, regardless the minimum area of 0.5 hectares. Classification of 'open-' and 'dense-' tree-vegetation is applied on the classes of 'mixed woodland', 'oaks' and 'pines'. The attribute 'open' implies canopy cover of <10% over the ground (with respect to FRA classification 'Forest'/'Other wooded land'); the attribute 'dense' implies > 10% canopy cover (with respect to FRA classification 'Forest').

Within the JSC, there exist mainly drought tolerant trees, either coniferous or broadleaved ones.

As part of coniferous woodland, a negligible share of cedars (genus: *cedrus*; species: *cedrus libani*) of approximately 5 ha (< 0.02% of vegetation) is located in the center of the catchment on the geological C3 unit (Figure 23). However, for practical purpose, cedars are integrated into the land-cover class 'open mixed woodland'. Pines (genus: *pinus*; species: *pinus brutia, pinus pinea)* constitute for 4% of vegetation cover, or 1.60% of total land-cover, located almost exclusively on the low permeable C1 unit. *Pinus brutia* grows between 0 and 1 700 m.s.l. and reaches approximately 25 m in height and becomes up to 120 years old (CABI 2002). Interception rate for maritime pines ranges between 13% and 20% of total rainfall, with respect to a relatively low leaf area index (LAI), which ranges between 1.5 and 4.0. A low LAI leads to relatively low canopy storage of precipitation and low stem flow rates; therefore, it is mainly the rainfall regime that leads to variation in total interception (LOUSTAU, ET AL. 1992, SILVA AND RODRIGUEZ 2001). Oaks (*quercus calliprinos; quercus infectoria*) constitute for 12% of vegetation cover, or 4.89% of total land-cover. *Quercus calliprinos* is the most common species in Lebanon; it thrives up to an altitude of 1 500 m.s.l., followed by *quercus infectoria* that thrives between 200 and 1 700 m.s.l. (BEYDOUN AND ESTEPHAN n.d.). SILVA AND RODRIGUEZ (2001) estimates average interception loss for oaks (*quercus spp.)* on 13.6% of total rainfall; for *quercus ilex*, DAVID, ET AL. (2006) calculates an interception rate of 22% of gross rainfall. 'Mixed woodland', i.e. mainly pines and oaks constitute for approximately 38% of the catchment's covering vegetation or 15.60% of total land-cover. Mixed woodland is predicted to have higher rates of interception than vegetation classes that consist of only one genus. According SILVA AND RODRIGUEZ (2001), average interception rate for pine- and oak woodland is approximately 23% of total rainfall.

Besides the above mentioned vegetation classes, 'grass- and bushland' constitutes for the highest share on vegetation; approximately 46% of vegetation, or 18.72% of total land-cover, is classified as 'grass- and bushland. It corresponds to FRA's classification of 'other land'.

4.7.2. Soil & rocks

'Bare rocks' and 'bare soils' constitute for 54% of total land-cover (15.0 ha), which corresponds to 48.3% of the whole JSC. As shown in Figure 24, 'bare soils' is the major land-cover class; this class makes up to 47.8% of all land-cover, which corresponds to 42.6% of the whole JSC. Bare soils cover almost all the C4 unit, while bare rocks expand mainly in the north-western share of the C4 unit.

Bare rocks and bare soils are predicted to have no vegetation layer, and thus, no interception loss.

4.8. Population

Lebanon's last census dates back to 1932. Population records that used in this study are either derived from registered apartments per municipality, from municipality records or from estimations from representatives. Population figures add uncertainty about municipalities' water consumption rates and their wastewater discharge rates. Wastewater is either discharged out of the JSC via Nahr el Kalb or other streams, or it is discharged directly into the underground, via leaking cesspits, from where it may contribute to groundwater recharge to the underlying hydrogeological unit.

As previously mentioned, JSC has been exposed to severe urban growth. Between 1963 and 2005, urban space has increased by 230% (THE STUDY ON THE NAHR EL KALB WATERSHED 2009). Today, expansion is still continuing; construction sites of new housing are ubiquitous within the catchment, mainly along existing roads. It can be surmised that urban growth develops according population growth and vice versa. In mountainous located villages, like Faqra or Faraya, number of population in winter exceeds number of population in summer. Thus, JSC is exposed to additional pressure by people spending only a limited amount of time within the catchment. In turn to this, in agriculture-dominated villages, like 'Lassa' or 'Ouate Ej Jaouz', approximately 80-90% of the total population leaves during winter. This seasonal variation leads to changing demand for drinking water – and, in turn, seasonal variation of discharged wastewater.

Table 13-15 in chapter 5.3.3. present municipalities/villages of JSC and their available total population records for winter and summer. Winter is defined as the period between January and March. Average per/capita water demand is estimated to be 140 liters/year, which corresponds to 51.1 m^3. This figure is lower than estimations of daily 200-250 liters per capita (FAO AQUASTAT) and projections on 230 liters (FADEL, ET AL. 2000). However, for this study, a rather passive and careful per/capita demand is surmised.

4.9. Agricultural- & domestic water supply

Demand sites within the JSC are exclusively supplied with fresh water that originates from rainfall, which enters the hydrological system of the JSC. There is no water import from an attached catchment. Withdrawn fresh water is distributed by Beirut & Mount Lebanon Water Establishment (WEBML) to the domestic sector. At the present, there are no records about water consumption and water-use rates for the JSC because water supply is not metered. This leads to uncertainty regarding quantities of supplied water, as well as uncertainties regarding non-revenue water. For the water supply district 'Beirut and Mount Lebanon', MOE/UNDP (2010) estimates agricultural water demand by 33.2% and domestic water demand by 54.0%. Potable water source is distinguished from irrigation water, as it is for example defined within the 'North Lebanon Water and Wastewater Establishment Exploitation Regulation' (DECREE NO 14603, ARTICLE 1, 56-86). Regulations of other Lebanese water operators, and thus WEBML, are comparable to each other. Farmers subscribe for irrigation water, based on the extent of the certain area, as it is […] *fixed in the subscription act* (Article 63), while irrigation water is distinguished from other water resources, as it is claimed that it […] *does not meet the sanitary conditions related to the potable water* (Article 68). Theoretically, water fees can be charged through different tariff systems (e.g. lump sum, per supplied unit), whereas decision for applied system depends on the Water Establishment's infrastructure (e.g. available meters) (Article 71); this does also apply to potable water (Article 31). However, in reality, households pay a lump sum for a defined amount of supplied water, including costs for installation, which vary, depending on the diameter of the tube (Article 31). According to unpublished data, within JSC, households pay approximately 150 USD per year for drinking water supply. Households below a size of 200 m² have the right of minimum supply of 1 m³/day, households between 200 and 300 m² 2 m³/day and households above 300 m² 3 m³/day (Article 30). This way of lump-sum payment puts no water saving incentives on households.

Water, which is supplied by WEBML, is either tapped from springs or abstracted via wells. It is then conveyed through its network and stored in 50 closed reservoirs and the open Chabrough dam (Figure 25). It is surmised that consumption rate of the domestic sector is

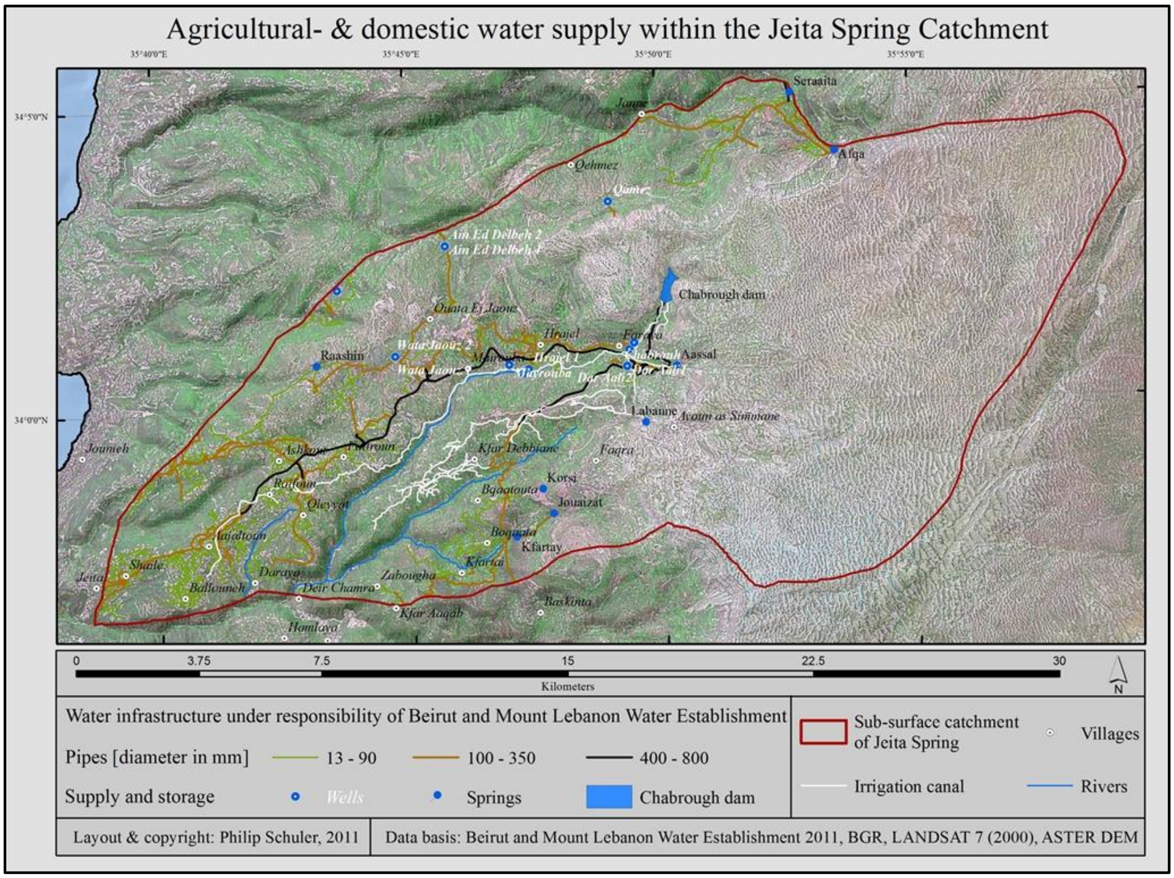


Figure 25: Irrigation canal network and domestic water Supply infrastructure of Beirut & Mount Lebanon Water Establishment.

50%; 50% of supplied water evaporates and 50% returns to the hydrological system through wastewater return flow. Return flow occurs mainly via leaking cesspits.

Untreated fresh water is used for agricultural purpose; Figure 25 shows the major irrigation canal network, which is fed by Assal- and Labbane Spring; according to WEBML, only a negligible share of Chabrough dam is used for irrigation (approximately 0.15 MCM per year).

4.9.1. Springs

Table 6: Springs, which are used by WEBML for fresh water conveyance.

WEBML Springs							
Labbane	Assal	Afqa	El Korsi	Raashin	Kfartay	Seraaita	Jouaizat

Source of data: WEBML 2011.

According to Figure 25 and Table 6, there are 8 springs, including Afqa, Assal and Labbane, which are connected to the public water distribution network that is run by WEBML. Due to their major importance, which is caused by their quantity of discharge, it is only the discharge of Afqa, Assal and Labbane that is integrated within the WEAP model (discharge from springs, fed by through SC 2 are modeled as one generalized discharge, see Figure 28). Seraaita and Afqa Spring are tapped for supply of irrigation- and drinking water within the very north-eastern area of the JSC. Labbane Spring is connected to the irrigation canal network and to the supply network of WEBML; most of the discharge of the spring is conveyed to Chabrough dam. Discharge of Assal Spring is conveyed into different directions. One share is distributed to the agricultural sector via the irrigation network and one share is conveyed directly to the domestic sector.

Treatment of fresh water is done below Chabrough dam only; no tapped water from local springs is treated.

4.9.2. Wells

Table 7: Public wells, used for drinking water supply by Beirut & Mount Lebanon Water Establishment, including min.-, max. - and average abstraction rates.

Wells	max. abstraction [m³/d]	min. abstraction [m³/d]	average abstraction [m³/d]
Dar Aali2	1 728	864	*1 296*
Dar Aali1	1 728	864	*1 296*
Ain Ed Delbeh 1	2 592	2 592	2 592
Ain Ed Delbeh 2	2 592	2 592	2 592
Coint Vert	1 037	1 037	1 037
Chabrough	1 037	1 037	1 037
Hrajel 1	1 728	1 728	1 728
Hrajel 2	950	950	950
Mayrouba	864	864	864
Ouata Jaouz 1	950	950	950
Ouata Jaouz 2	950	950	950
Chahtoul	1 296	1 296	1 296
Qamez	0	0	0
Sum	**17 452**	**15 724**	**16 588**

Source of data: WEBML 2011.

Table 7 shows all public wells within the JSC that are run by the Beirut & Mount Lebanon Water Establishment for the supply of fresh water and their minimum and maximum abstraction rates. For all wells, maximum abstraction rate is equal to the minimum abstraction rate.

4.9.3. Chabrough dam

Chabrough dam is the major source for the supply of potable water within the JSC. Figure 26 visualizes records of the reservoir for the water year 2010/2011, with a minimum storage of 0.116 MCM in November and a maximum storage of 9.28 MCM in May and June. Between June and September, 73.6% (5.8 MCM) of the total annual discharge (7.9 MCM) is released from the dam. This variation in discharge matches to the variation of staying population within the JSC; it also might be caused by irrigation demand, which may be higher than the officially declared annual 0.15 MCM.

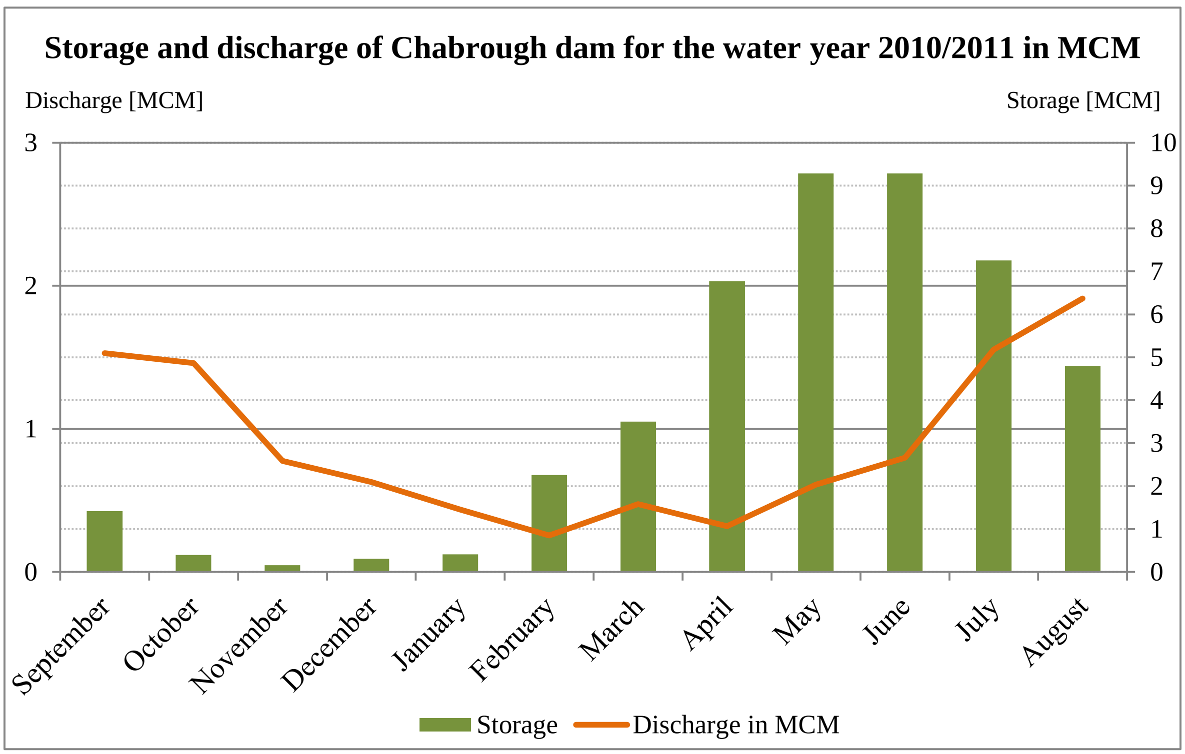


Figure 26: Monthly discharge and storage volume of Chabrough dam from September 2010 to August 2011; source of data: WEBML 2011.

5. WEAP model

5.1. Conceptual model of WEAP

The sub-surface catchment of Jeita Spring is sub-divided into nine sub-catchments (SC), as they are delineated in Figure 27. Within WEAP, each sub-catchment needs average input data (average precipitation, average reference evapotranspiration) that are representative for the whole catchment. Thus, sub-division of the whole catchment increases precision of the modeling process because by decreasing the reference space for input data, this data is less generalized, and therefore, contributes to a higher precision and reliability. Division into

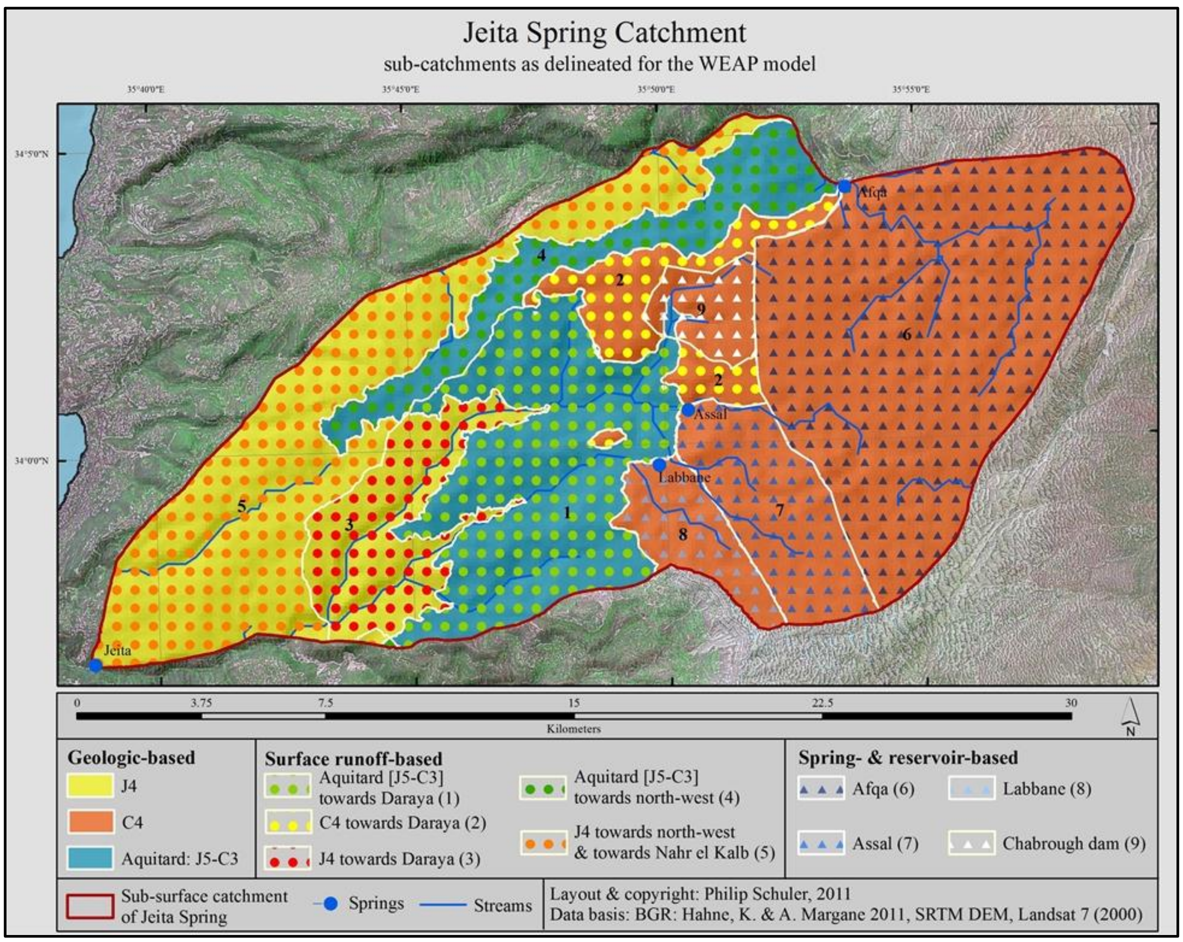


Figure 27: 9 WEAP sub-catchments according to 1. Geology, 2. Spring- & reservoir sub-surface catchments and 3. Concentration of surface runoff.

different SCs is done according to hydrogeological characteristics; since Assal-, Afqa- and Labbane Spring show different seasonal discharge, it is assumed that they are fed through different aquifers. Thus, each spring is represented as an own catchment with an own groundwater node (Figure 28). Another criteria for definition of the SCs is surface runoff and its concentration within specific surface catchments; surface runoff is an important calibration parameter for the model. Therefore, structure of the WEAP model should allow the researcher to attribute surface runoff to its specific surface catchment.

For delineation of SC, three criteria are used, according to their significance: 1. Geology, 2. Spring- & reservoir catchments and 3. Surface runoff catchments. The geologic setting (Figure 13) and the geological units' attributed *k*-values (Table 4) are the primary criteria for defining SCs. According to Figure 27, the geological unit of J5-C3 (aquitard) is regarded as one generalized unit, including the geological unit C2b and J6. Due to simplicity of the modeling process, C2b and J6 are clustered together with J5, C1, C2a and C3, even though these two units don't show the low hydraulic conductivity as the other units. However, since C2b and J6 account for only 3.6% of the whole JSC's extent, this generalization is surmised to be acceptable. The aquitard lies between the J4 and the C4 and separates them. J4 and C4 are both kept as single geological unit.

The secondary criteria for defining SCs, is based on the extent of sub-surface catchments of springs and reservoir, i.e. Assal-, Afqa-, Labbane Spring and Chabrough dam, as it is done for SC 6-9. Each of SC 6-9 is surmised to have an own, distinguishable hydrogeological system. Therefore, each one shall be represented by an own groundwater- and catchment node. Output records, representing spring discharge and released discharge from Chabrough dam, is used for calibration of these single catchments (ARRANZ AND MCCARTNEY

2007). Due to high karstification, almost all effective precipitation infiltrates above this Cretaceous unit; a small share is available for evaporation while surface runoff is surmised to account for 0% of effective precipitation.

The tertiary criteria for definition of SCs, is the extent of surface runoff catchments, i.e. surface runoff contribution spaces. SCs 1- 3 contribute to runoff towards Nahr es Salib and Nahr es Zirghaya, Nahr el Kalb respectively; the rivers' discharge is recorded at Daraya gauging station (see Figure 14). According to the underlying geologic setting, SCs 1-3 show different characteristics regarding their contribution to surface runoff. SC 1 lies above the aquitard (J5-C3); this fact implies relatively high surface runoff, which is surmised to be 92% of effective precipitation. SC 3 expands above the J4 unit and has moderate surface runoff; surface runoff is expected to account for 40% of effective precipitation. Modeled surface runoff of SC 1 and 3 is calibrated by using records from Daraya.

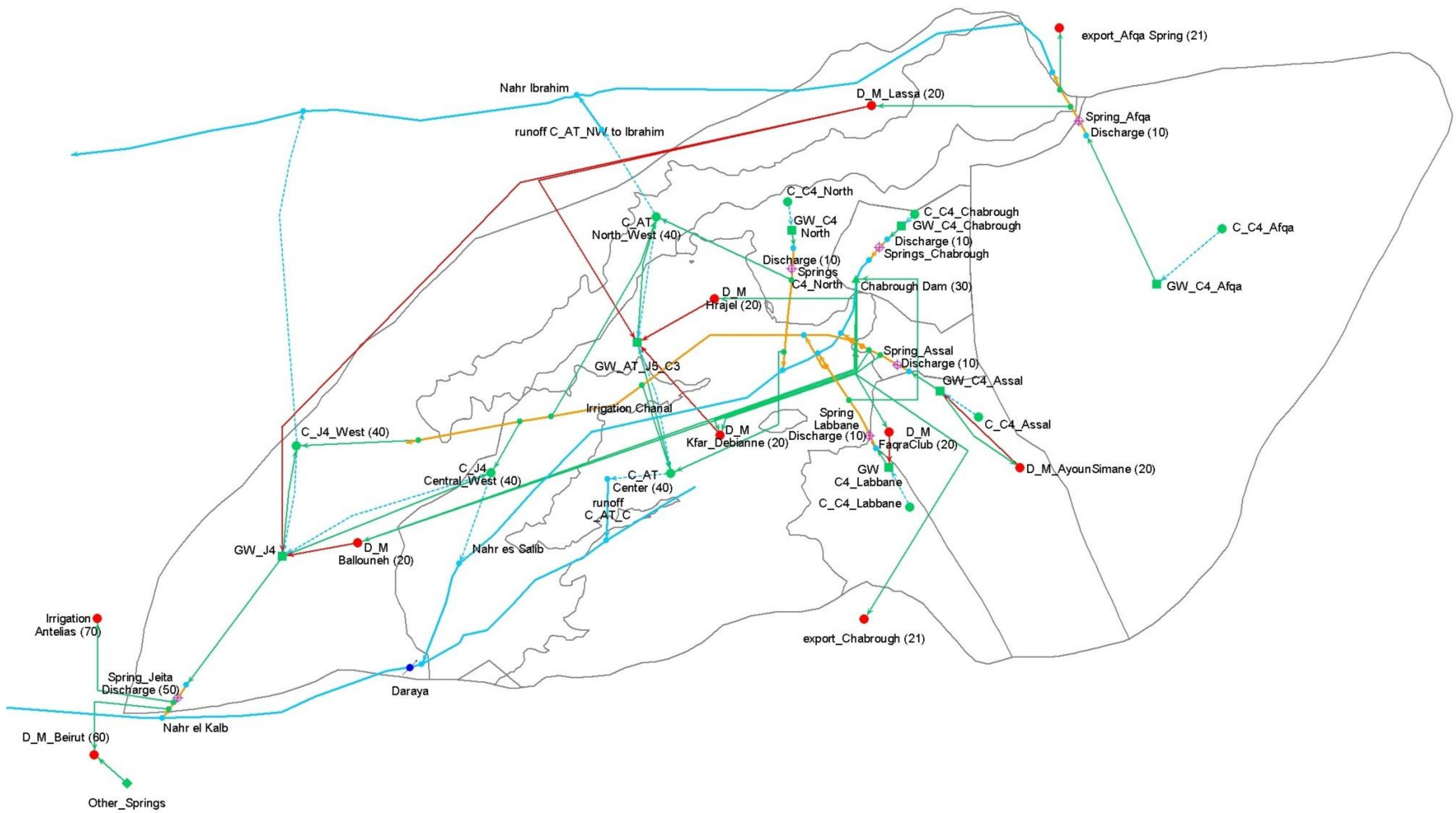
SC 2 lies, same as SC 6-9, above the C4, which implies a negligible share of surface runoff that is modeled as 0% of effective precipitation.

SC 4 and 5 contribute to surface runoff that leaves JSC via its north-western border and via Nahr el Kalb. Since surface runoff from these areas is not measured, quantity of surface runoff must be derived from modeled surface runoff from SC 1 and 3.

A comparison between Figure 27 with Figure 7, 11 and 13, indicates correlation between topography and geology of the SC on the one hand and distribution of rainfall on the other. SC 3 and 5, located above the J4 unit, expand on the lowest altitude of JSC; thus, SC 3 and 5 receive the least amount of monthly average precipitation (P) but the highest rates of average monthly reference evapotranspiration ($ET_{0)}$). On the other side, SC 1 and 4, expanding above the higher elevated aquitard (J5-C3), receive more amount of average monthly P while showing lower rates of average monthly ET_0. Due to the high elevated extent of C4, SC 2 and 6-9 receive most amount of average monthly P and least amount of average monthly ET_0.

Figure 28 shows the WEAP structure, consisting of all transmission links, return flows, rivers, diversion links, flow requirements (springs), catchment-, groundwater- and demand site nodes.

Figure 28: WEAP schematic for the Jeita Spring sub-surface catchment.



5.2. Overview of specific areas

Table 8: Absolute extent of each land-use and land-cover class for each of the 9 sub-catchments of the WEAP model in ha.

	Land-use							Land-cover								
				Agriculture						Vegetation						
										Oaks		Pines		Mixed Woodland		
Sub-catchments	Roads	Housing	Ponds	Apples	Tomatoes	Tomatoes & apples	Green-houses	Bare soil	Bare rock	Open	Dense	Open	Dense	Open	Dense	Grass & bush
1 Total area	120.9	166.9	16.2	1 028.5	205.4	206.0	1.3	642.8	157.3	84.7	38.9	117.1	268.9	78.2	350.1	1 694.7
2 Total area	0.5	0.3	0.2	3.9	0.9	0.2	-	497.7	686.1	-	-	-	-	48.9	-	313.0
3 Total area	47.9	63.1	0.4	128.4	22.5	24.8	3.9	151.0	24.9	324.7	641.0	7.4	7.1	51.7	592.9	214.7
4 Total area	43.0	32.6	8.8	143.5	170.1	39.4	41.4	979.3	72.1	-	0.1	55.0	37.8	120.7	10.2	528.1
5 Total area	188.7	370.8	0.5	83.3	90.2	17.3	6.1	497.6	272.6	351.0	78.4	-	3.6	1 697.5	1 862.0	837.4
6 Total area	19.3	-	-	-	-	-	-	8 377.0	62.9	-	-	0.0	0.0	30.4	-	828.3
7 Total area	5.1	9.0	-	-	-	-	-	1 252.5	73.4	-	-	-	-	-	0.1	812.2
8 Total area	6.3	23.2	0.1	-	-	-	-	646.0	98.6	-	-	-	-	-	-	363.6
9 Total area	-	0.0	22.2	-	-	-	-	201.7	342.0	-	-	-	-	-	-	225.5
JSC total area	**431.9**	**665.8**	**48.4**	**1 387.5**	**489.2**	**287.7**	**52.7**	**13 245.5**	**1 789.9**	**760.3**	**758.3**	**179.4**	**317.3**	**2 027.5**	**2 815.3**	**5 817.6**

Table 9: Relative extent of each land-use and land-cover class in each of the 9 sub-catchments of the WEAP model in %.

	Land-use							Land-cover								
				Agriculture						Vegetation						
										Oaks		Pines		Mixed Woodland		
Sub-catchments	Roads	Housing	Ponds	Apples	Tomatoes	Tomatoes & apples	Green-houses	Bare soil	Bare rock	Open	Dense	Open	Dense	Open	Dense	Grass & bush
1																
Total area	2.33	3.22	0.31	19.86	3.97	3.98	0.03	12.41	3.04	1.64	0.75	2.26	5.19	1.51	6.76	32.73
2																
Total area	0.03	0.02	0.01	0.25	0.06	0.01	-	32.07	44.21	-	-	-	-	3.15	-	20.17
3																
Total area	2.08	2.74	0.02	5.57	0.97	1.07	0.17	6.55	1.08	14.08	27.79	0.32	0.31	2.24	25.71	9.31
4																
Total area	1.89	1.43	0.38	6.29	7.46	1.73	1.81	42.91	3.16	-	0.00	2.41	1.66	5.29	0.45	23.14
5																
Total area	2.97	5.83	0.01	1.31	1.42	0.27	0.10	7.83	4.29	5.52	1.23	-	0.06	26.70	29.29	13.17
6																
Total area	0.21	-	-	-	-	-	-	89.90	0.67	-	-	0.00	0.00	0.33	-	8.89
7																
Total area	0.24	0.42	-	-	-	-	-	58.19	3.41	-	-	-	-	-	0.00	37.74
8																
Total area	0.56	2.04	0.01	-	-	-	-	56.78	8.67	-	-	-	-	-	-	31.95
9																
Total area	-	0.00	2.81	-	-	-	-	25.49	43.21	-	-	-	-	-	-	28.49
JSC total area	**1.39**	**2.14**	**0.16**	**4.47**	**1.57**	**0.93**	**0.17**	**42.63**	**5.76**	**2.45**	**2.44**	**0.58**	**1.02**	**6.52**	**9.06**	**18.72**

5.3. Catchment elements

5.3.1. Groundwater nodes

According to Figure 28, there are 7 groundwater nodes within the WEAP. Table 10 shows all 7 groundwater nodes, their storage capacity and natural recharge. Natural recharge rates are based on hydrogeological assessments and unpublished data of BGR; groundwater recharge rates are used for calibration of runoff and k_c-values. Storage capacity is calculated by the thickness of the geological unit, multiplied by the areal extent and hydraulic conductivity.

Table 10: Storage capacity natural recharge of WEAP groundwater nodes.

GW node	Storage capacity [MCM]	Natural recharge [% of total rainfall]
GW_J4	4 665	50
GW_AT	4 036	8
GW_C4_North	93	92
GW_C4_Afqa	559	92
GW_C4_Assal	129	92
GW_C4_Labbane	68	92
GW_C4_Chabrough	47	92

5.3.2. Catchment nodes

For the current WEAP model, land-use and land-cover classes, as shown in Figure 21 and 24, are further generalized in order to simplify the modeling process. ‘Scarce vegetation’ includes the land-cover classes ‘bare soils’, ‘bare rocks’ and ‘grass- and bushland’; ‘woodland’ contains all classes for ‘pines’, ‘oaks’ and ‘mixed woodland’; ‘agriculture’ contains all agricultural fields, including greenhouses. Attributed Kc-values are 0.1 for scarce vegetation, 0.1 for sealed surfaces, 0.2-1.15 for crops (see Figure 22) and 0.8 for woodland. Table 11 shows all generalized land-use and land-cover classes and their share on each SC.

Table 11: Generalized land-use and land-cover classes for the WEAP model: Scarce vegetation, sealed surfaces, agriculture and woodland in %.

SC ID	WEAP SC	Scarce vegetation	Sealed	Agriculture	Woodland
1	C_AT_Center	53.6	6	22.4	18
2	C_C4_North	97			3
3	C_J4_Central_West	18.6	5	6.4	70
4	C_AT_North_West	73.4	3	13.6	10
5	C_J4_West	25.6	9	2.4	63
6	C_C4Afqa	100			
7	C_C4_Assal	100			
8	C_C4_Labbane	97	3		
9	C_C4_Chabrough	100			

Table 12: Average monthly precipitation for the JSC and for the 9 WEAP sub-catchments, scaled by JSC Mean for the period 1931-1960 in mm.

	JSC Mean	% of total JSC	SC 1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9
Jan	321.9	22.2	326.3	343.2	287.0	326.3	287.0	364.7	380.0	368.0	343.2
Feb	244.1	16.8	247.4	260.2	217.6	247.4	217.6	276.5	288.2	279.1	260.2
Mar	240.2	16.6	243.5	256.1	214.2	243.5	214.2	272.2	283.6	274.7	256.1
Apr	95.4	6.6	96.7	101.7	85.1	96.7	85.1	108.1	112.6	109.1	101.7
May	37.2	2.6	37.7	39.7	33.2	37.7	33.2	42.2	43.9	42.5	39.7
Jun	1.4	0.1	1.4	1.5	1.2	1.4	1.2	1.6	1.7	1.6	1.5
Jul	0.5	0.0	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Aug	0.5	0.0	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Sep	7.7	0.5	7.8	8.2	6.9	7.8	6.9	8.7	9.1	8.8	8.2
Oct	74.3	5.1	75.3	79.2	66.2	75.3	66.2	84.2	87.7	84.9	79.2
Nov	148.7	10.3	150.8	158.6	132.6	150.8	132.6	168.5	175.6	170.1	158.6
Dec	278.1	19.2	281.9	296.5	248.0	281.9	248.0	315.1	328.3	317.9	296.5
Total	1 450	100	1 470	1 546	1 293	1 470	1 293	1 643	1 712	1 658	1 546

Source of data: ATLAS CLIMATIQUE DU LIBAN (1977).

Table 12 shows average monthly precipitation rates for the JSC and for all 9 WEAP sub-catchments. Average records for the 9 sub-catchments are derived from monthly percentage of JSC's total annual rainfall. As indicated, quantity of rainfall of the SCs increases with increasing mean altitude of the SCs.

5.3.3. Demand nodes

Table 13-15 present all demand sites, located within the JSC, their summer- and winter population and their respective water demand, based on a per capita use of 51,1 m³ per year. Water consumption is assumed to be 50%, which means that 50% of total delivered water evaporates while 50% returns to groundwater nodes. Since a share of water, delivered from Chabrough dam and Afqa Spring is conveyed outside of the JSC, two additional demand sites are added. 'Export_Afqa Spring' and 'export_Chabrough' represent demand sites outside the JSC (Figure 28); both of them are necessary to equal the water balance of supplied and demanded water resources.

Table 13: Villages on top of the C4 unit. Summer- and winter population and respective water demand, based on annual 140 l/capita demand.

WEAP Demand site	Municipality/village	Population		Seasonal water demand	
		summer	winter	summer	winter
Cretaceous					
Faqra Club	Faqra	3 000	3 378	153 300	172 616
Aayoun Simane	Aayoun Al Simane*	1 689	3 000	86 308	153 300

Source of data: * INCEPTION REPORT (2011).

Table 14: Villages on top of the J4 unit. Summer- and winter population and respective water demand, based on annual 140 l/capita demand ('-' not available).

WEAP Demand site	Municipality/village	Population		Seasonal water demand	
		summer	winter	summer	winter
J4 North-West					
Lassa	Afqa	-	-	-	-
	El Ghabat	3 000	600	153 300	30 660
	Lassa	3 000	300	153 300	15 330
	Saraaita	-	-	-	-
J4 West					
Ballouneh	Aajaltoun*	12 000	6 000	613 200	306 600
	Ashkout	8 024	5 617	410 026	287 029
	Beqaatet Aachqout	2 800	1 200	143 080	61 320
	Bzommar	500	250	25 550	12 775
	Daraya*	1 500	1 500	76 650	76 650
	Delbta	900	450	45 990	22 995
	Ein el Delbe	400	20	20 440	31 324
	Ein el Rihane	4 000	4 000	204 400	204 400
	Faitroun*	3 400	1 800	173 740	91 980
	Ghosta	3 500	2 500	178 850	127 750
	Hiyata	-	-	-	-
	Jeita	5 000	5 000	255 500	255 500
	Kfar Debianne*	12 000	12 000	613 200	613 200
	Qahmez	1 200	50	61 320	2 555
	Qlaiaat*	11 000	5 500	562 100	281 050
	Raashine	6 000	4 500	306 600	229 950
	Raifoun	5 000	1 000	255 500	51 100
	Shaile	6 000	6 000	306 600	306 600

Source of data: * INCEPTION REPORT (2011).

Table 15: Villages on top of the aquitard. Summer- and winter population and respective water demand, based on annual 140 l/capita demand ('-' not available).

WEAP Demand site	Municipality/village	Population		Seasonal water demand	
		summer	winter	summer	winter
Aquitard North					
Hrajel	Faraya	-	-	-	-
	Hrajel	8 000	4 000	408 800	204 400
	Mairouba	-	-	-	-
	Ouata Ej Jaouz	3 000	600	153 300	30 660
Aquitard South					
Kfar Debianne	Baskinta (10%)	1 600	1 568	81 760	80 125
	Boqataa	2 800	1 200	143 080	61 320
	Bqaatouta	2 400	2 400	122 640	122 640
	Kfar Debianne	12 000	12 000	613 200	613 200
	Kfartai*	1 000	1 000	51 100	51 100
	Ouadi al Karm	-	-	-	-

Source of data: * INCEPTION REPORT (2011).

5.3.4. Flow requirements

Within the WEAP model, all springs are represented by flow requirements. This is related to the fact that monthly discharge of springs is not modeled but defined by records that are presented in chapter 4.4. and 4.5. Thus, real spring discharge is represented as flow requirement. Annual discharge records are entered as 'minimum flow requirement', which is proportional dispensed on months through the 'monthly time-series wizard'.

5.3.5. Reservoir

Chabrough dam has a total storage capacity of 9.3 MCM. Modeling of discharge of the reservoir is done according to real discharge records of WEBML by calibration. According to data from WEBML and due to the fact of increased discharge of local springs since operation of the dam, leakage from Chabrough dam is supposed to exist. Leaking water recharges the aquifer of sub-catchment 2. Within the WEAP model, a water loss of 0.3 MCM is defined if storage of the dam is above 1.5 MCM.

6. Scenario analysis

Scenario analysis aims to expose the quality of modeling results of the WEAP model. As one benchmark, modeled surface runoff at Daraya gauging station is compared to observed records from LRA. In addition to this, balance of modeled groundwater in- and outflow, groundwater storage and unmet demand is used. During calibration, groundwater storage is modeled as being the same in September 2010 as in August 2011, according to the surmise that total annual groundwater inflow is equal to total annual groundwater outflow. All modeled records refer to the 'Reference Scenario'.

6.1. Runoff at Daraya

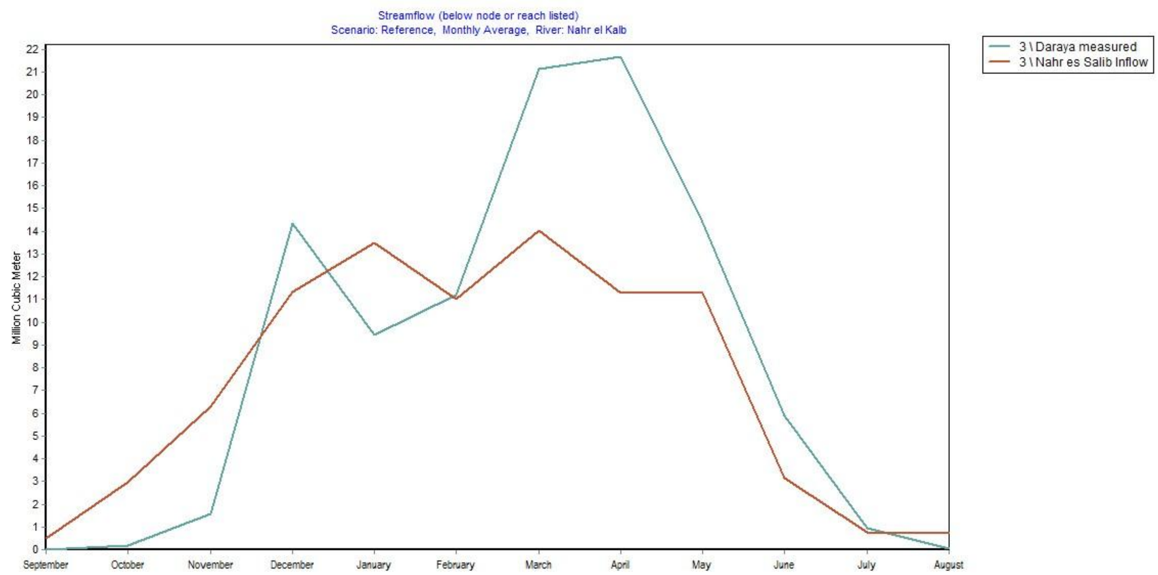


Figure 29: Modeled and observed discharge of Nahr el Kalb at Daraya gauging station in MCM.

Figure 29 shows modeled and measured discharge of Nahr el Kalb at Daraya. Modeled runoff has lower peaks than the measured runoff and is generally lower. The measured run-off's high peak in March and April may be explained by melting of accumulated snow, generating high rates of surface runoff, which concentrates in delay to actual precipitation events; water, i.e. snow, is stored during winter on top of the mountains and released in spring through melting. However, storage of snow cannot be considered within the present WEAP model; thus, modeled surface runoff occurs in direct response to actual precipitation, and thus, modeled runoff may tend to be lower than measured runoff. Total measured annual runoff at Daraya is 101 MCM, whereas on the other side, total modeled runoff is 87 MCM, which corresponds to a difference of 12%; keeping all uncertainties of this model in mind, this difference is surmised to be within an acceptable range.

6.2. Groundwater in- & outflow

Figure 30-36 show average monthly groundwater in- and outflow for all groundwater nodes for the water years 2010/2011 to 2011/2012. Inflow and outflow varies throughout the year; however, on an annual scale, input is almost equal to output, and so, groundwater storage (Figure 37).

Decrease in storage (outflow) is either related to spring discharge (Figure 30, 32-35) or to groundwater abstraction for irrigation, shown as outflow to a catchment node (Figure 30 and 31). As derived from Figure 35, flow from Chabrough's catchment into the reservoir is modeled as spring discharge, i.e. flow requirement. This is done to compute inflow to Chabrough. The groundwater node of the aquitard contains a decrease in storage of 0.18 MCM water per month, which is modeled according to surmised groundwater leakage towards the J4 unit, labeled as 'overflow'. In principal, variation of groundwater outflow is mainly subject to spring discharge and crops' water demand, i.e. water abstraction for irrigation.

Increase in storage (inflow) is mainly related to runoff/infiltration from catchment nodes to groundwater nodes. Besides this, there are several other flow paths for groundwater re-charge. One way of groundwater recharge is return flow, originating from demand sites (villages) (Figure 30, 31, 34 and 35). Another source is leakage from Chabrough dam to groundwater of SC 2 (Figure 32) and leakage from the aquitard to the groundwater node of the J4 (Figure 30). J4 also receives input through bank infiltration from Nahr Ibrahim (Figure 30).

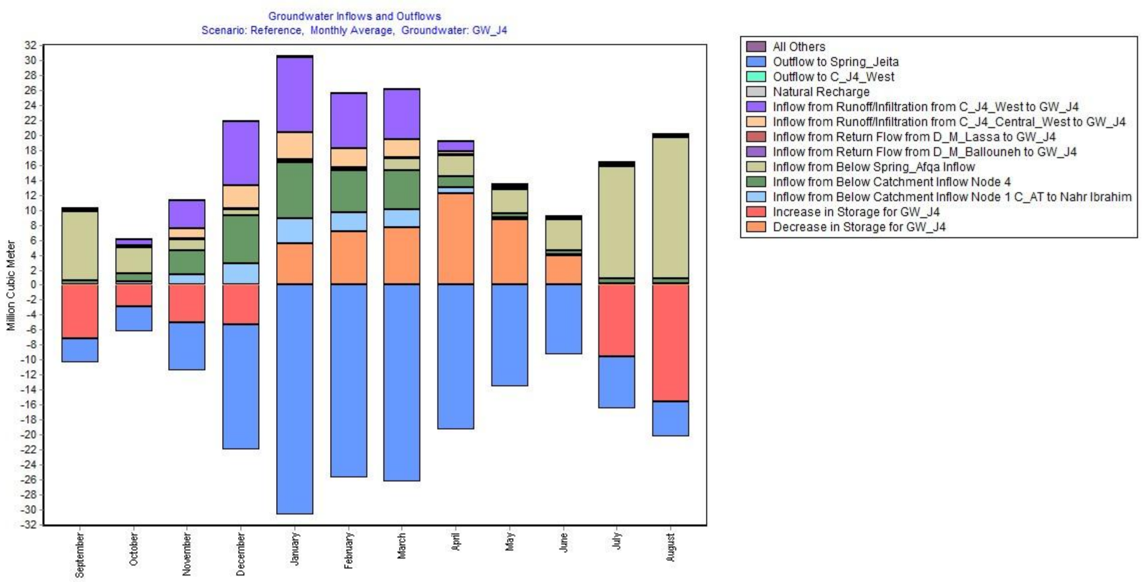


Figure 30: Average monthly inflow and outflow from the J4 aquifer between September 2010 and August 2012 in MCM.

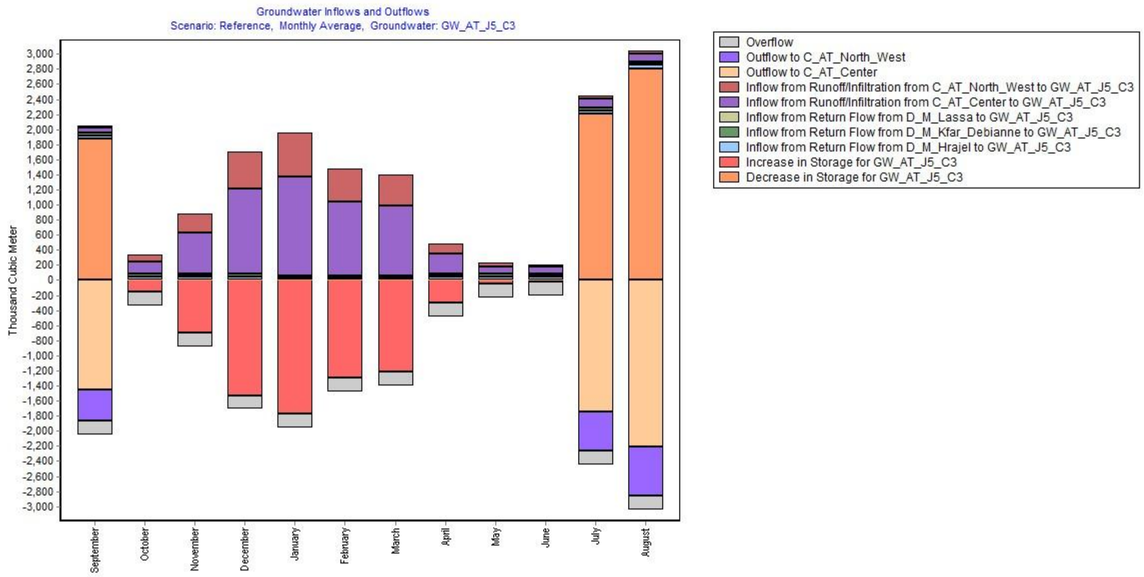


Figure 31: Average monthly inflow and outflow from the aquitard between September 2010 and August 2012 in TCM.

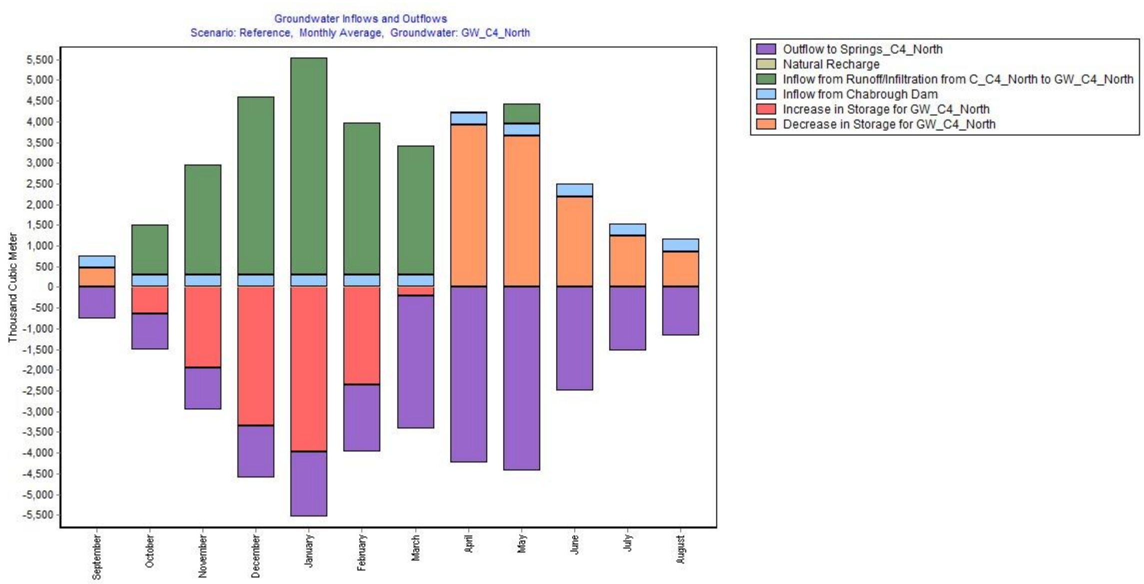


Figure 32: Average monthly inflow and outflow from the SC 2 aquifer between September 2010 and August 2012 in TCM.

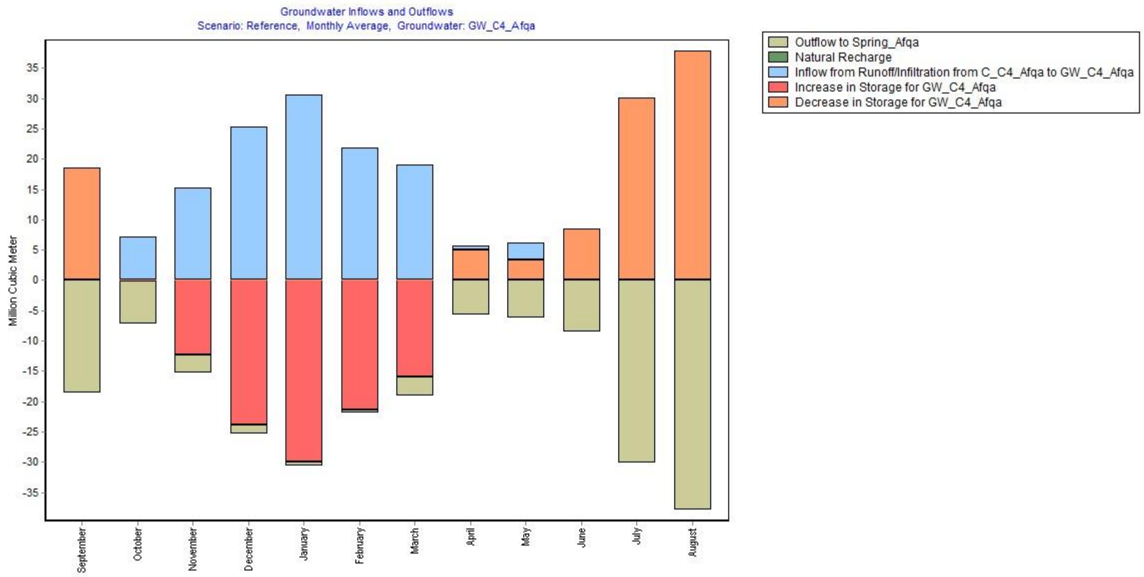


Figure 33: Average monthly inflow and outflow from Afqa Spring's aquifer between September 2010 and August 2012 in MCM.

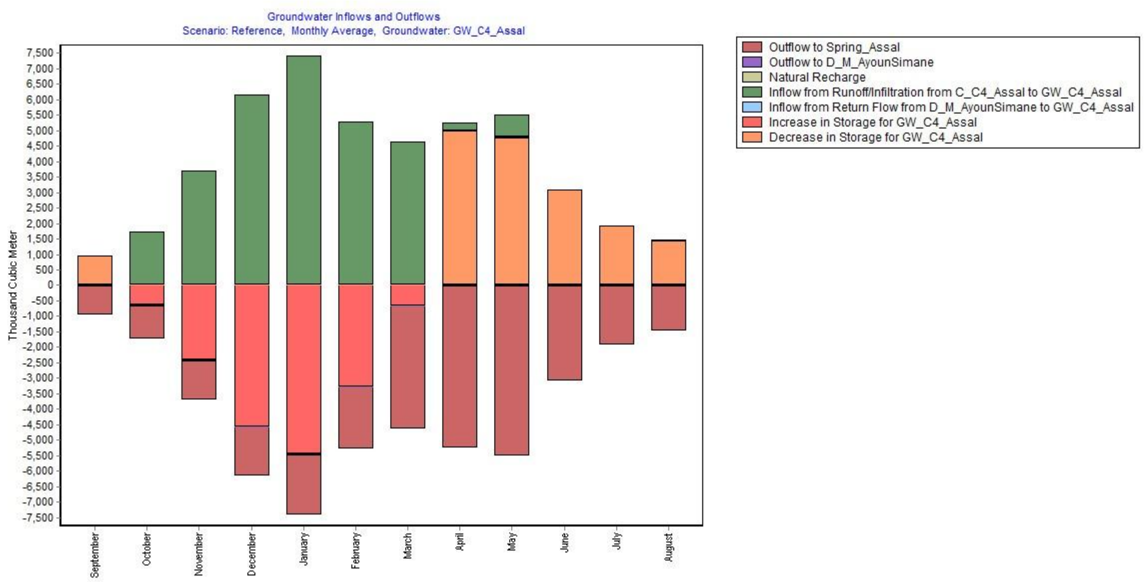


Figure 34: Average monthly inflow and outflow from Assal Spring's aquifer between September 2010 and August 2012 in TCM.

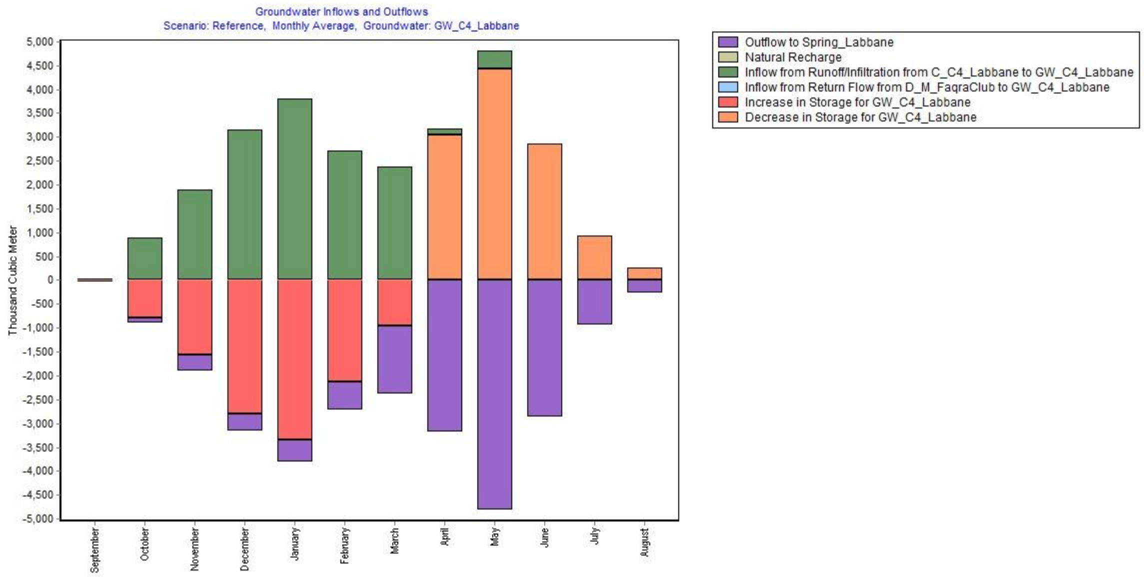


Figure 35: Average monthly inflow and outflow from Labbane Spring's aquifer between September 2010 and August 2012 in TCM.

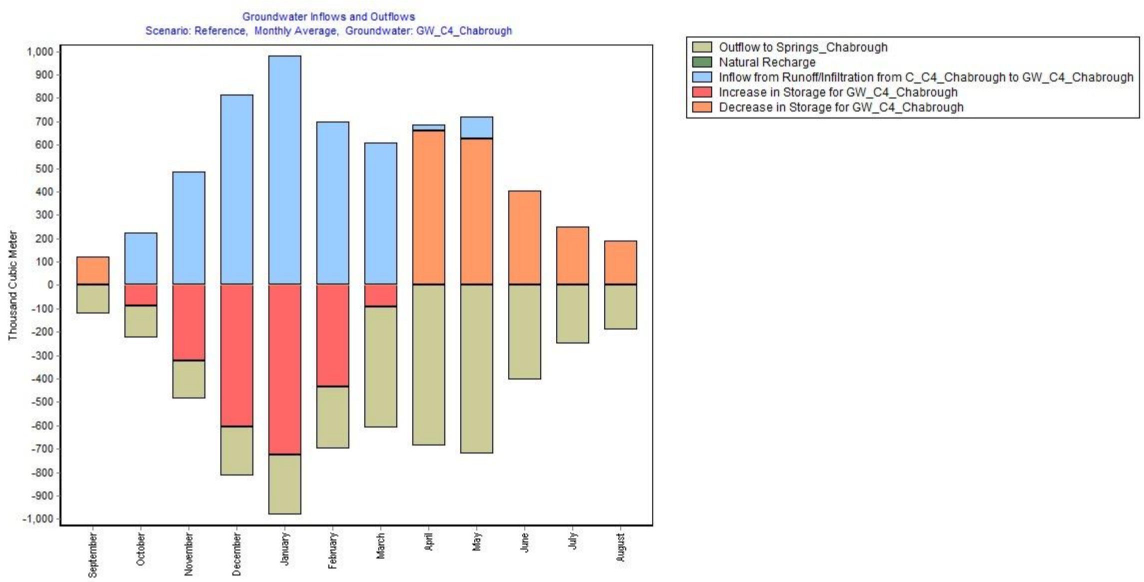


Figure 36: Average monthly inflow and outflow from Chabrough's aquifer between September 2010 and August 2012 in TCM.

6.3. Groundwater storage

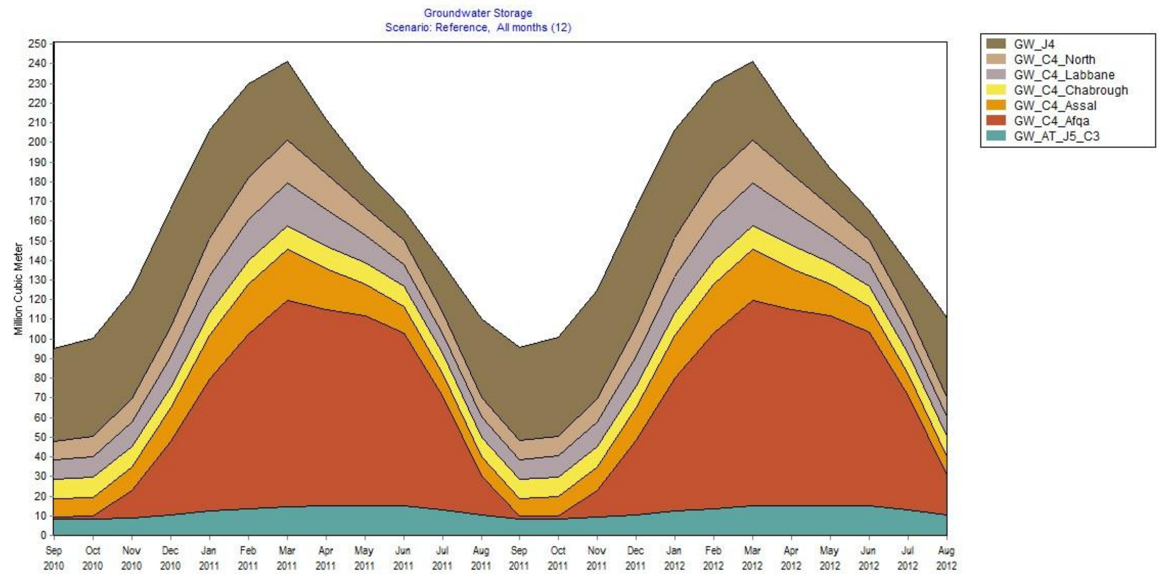


Figure 37: Monthly variation of groundwater storage for all groundwater nodes between September 2011 and August 2011 in MCM.

Groundwater storage, as shown in Figure 37, has a high seasonal variation, with a maximum in March and a minimum in September.

6.4. Unmet demand

As shown in Figure 38, there is no unmet demand within the catchment (appearance of bars are related to rounding errors in WEAP); all demand sites receive their needed share on water resources.

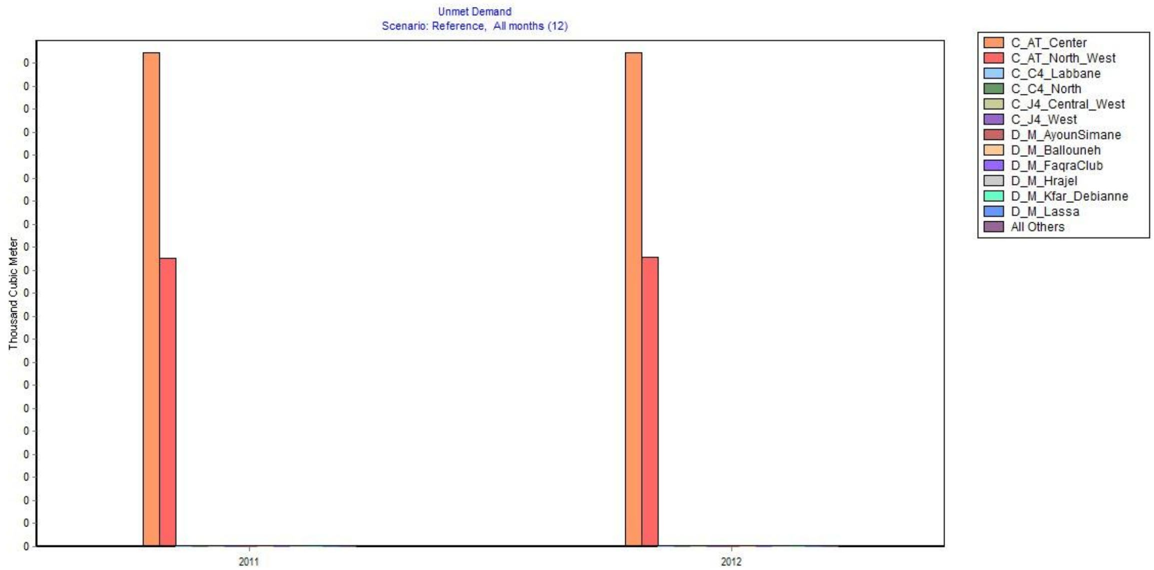


Figure 38: Unmet demand within the WEAP model in thousand cubic meter.

7. Results

7.1. Inflow and outflow

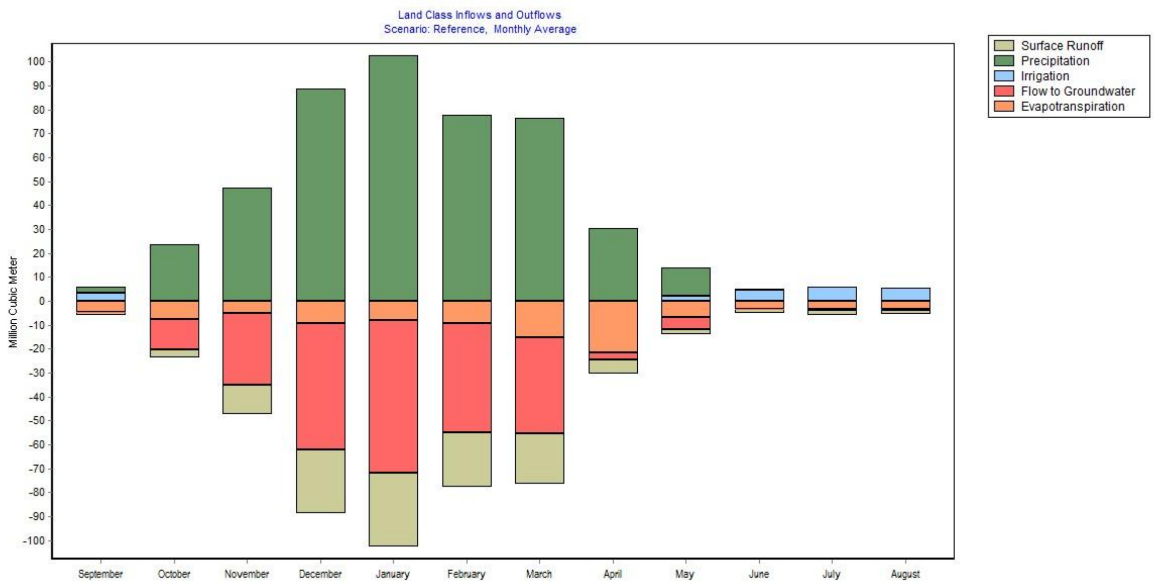


Figure 39: Average monthly surface runoff, precipitation, irrigation, groundwater recharge and evapotranspiration for the JSC between September 2010 and August 2012 in MCM.

Total annual precipitation is 462.5 MCM with the maximum in January. Within the same month, generated surface runoff and groundwater recharge reach their monthly maximum; in January, surface runoff accounts for 30.9 MCM (132.1 MCM per year), groundwater recharge accounts for 63.5 MCM (254.2 MCM per year). Maximum monthly evapotranspiration, including both, irrigated crops and vegetation, is 15.1 MCM, which accounts for 22% of total annual evapotranspiration (97.6 MCM). Occurrence of this peak in April is caused by relatively high reference evaporation, which occurs parallel to still moderate rainfall of 30.4 MCM. Water for irrigation is demanded between May and September, summing up to 21.3 MCM per year.

7.2. Agricultural water demand

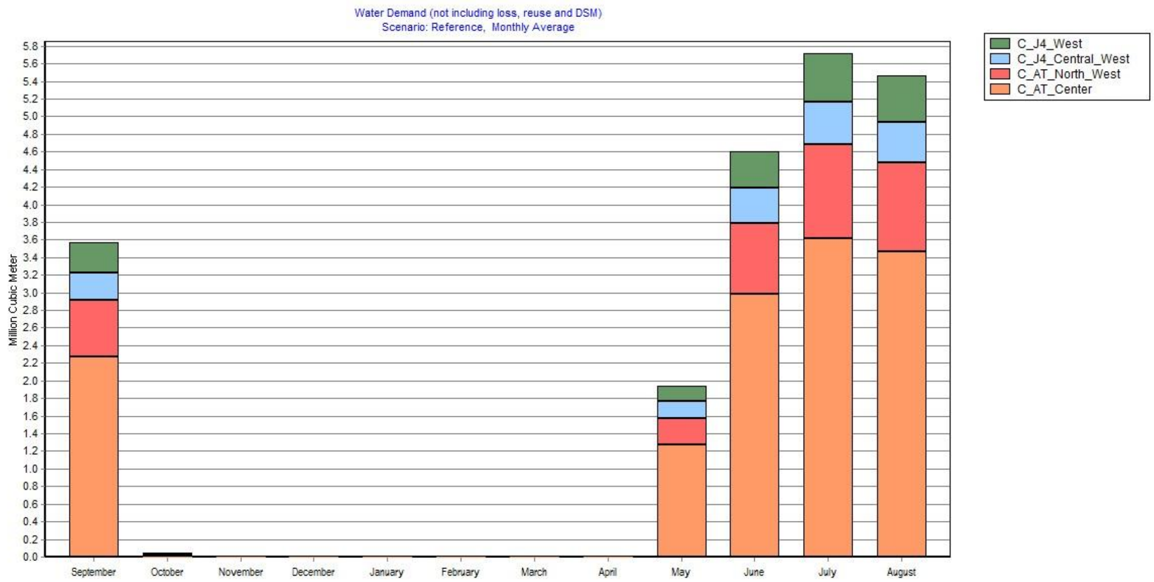


Figure 40: Average monthly agricultural water demand within the JSC between September 2010 and August 2012 in MCM.

As mentioned before, agricultural water demand makes up 21.3 MCM, which corresponds to 4.6% of annual precipitation; thus, irrigation demand is a relatively small share in the overall water budget of the Jeita Spring catchment. As presented in Figure 40, most agricultural water is demanded by activities in sub-catchment 1; annual agricultural demand within SC 1 sums up to 13.62 MCM, which corresponds to 64% of annual agricultural water demand within the JSC (Table 16). In terms of irrigation demand, SC 1 and 4, located above the aquitard, are the main agricultural reference spaces; in turn, crop water demand above the J4 unit is relatively low. Fruit trees, i.e. apples, account for 68%, and field crops, i.e. tomatoes, for 32% of the total crop water demand.

Table 16: Average monthly crop water demand for SC 1, 3, 4 and 5 between September 2010 and August 2012 in MCM.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sum
SC1													
Field Crops	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.63	0.94	0.90	**3.16**
Fruit Trees	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	2.35	2.68	2.56	**10.46**
SC3													
Field Crops	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.12	0.11	**0.40**
Fruit Trees	0.24	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.32	0.36	0.35	**1.46**
SC4													
Field Crops	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.43	0.64	0.61	**2.15**
Fruit Trees	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.37	0.43	0.41	**1.66**
SC5													
Field Crops	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.22	0.32	0.30	**1.10**
Fruit Trees	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.21	0.23	0.22	**0.93**
Sum	**3.57**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.94**	**4.61**	**5.71**	**5.46**	**21.33**

7.3. Domestic water demand

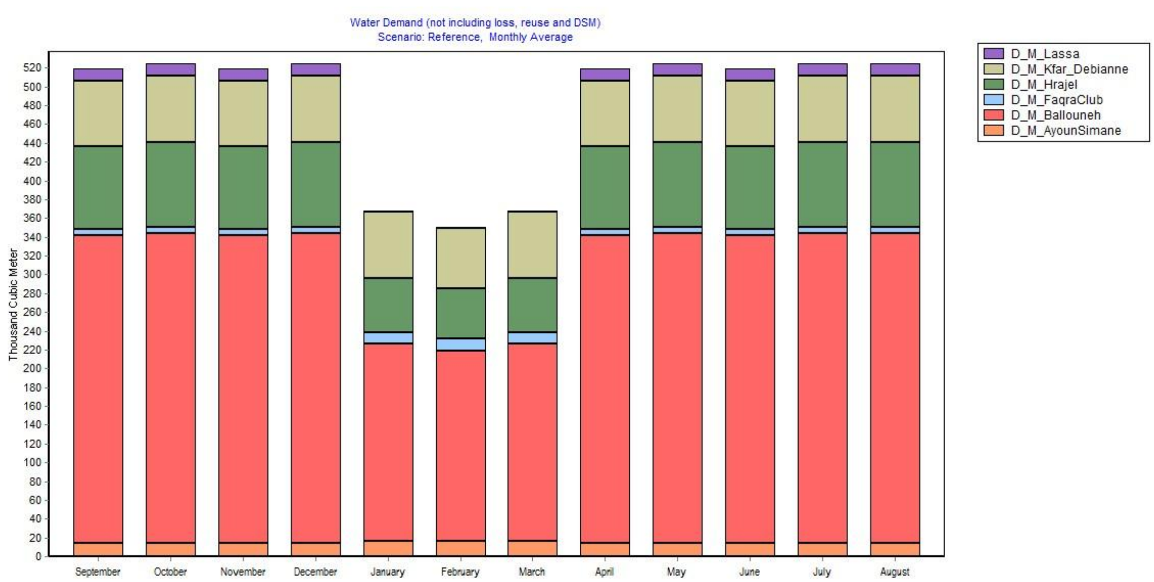


Figure 41: Average monthly domestic water demand between September 2010 and August 2012 in TCM.

Figure 41 shows the average monthly water demand of all 6 demand nodes within the JSC. Total annual water demand is approximately 5.8 MCM; average monthly demand during winter months (January-March) is 0.362 MCM. During the remaining 9 months, this figure increases by 44%, to an average monthly demand of 0.522 MCM. It is the demand site 'Ballouneh', which represents villages in the south-west of the catchment that has the highest total water demand. This implies also highest rates of total discharged wastewater.

7.4. Chabrough dam

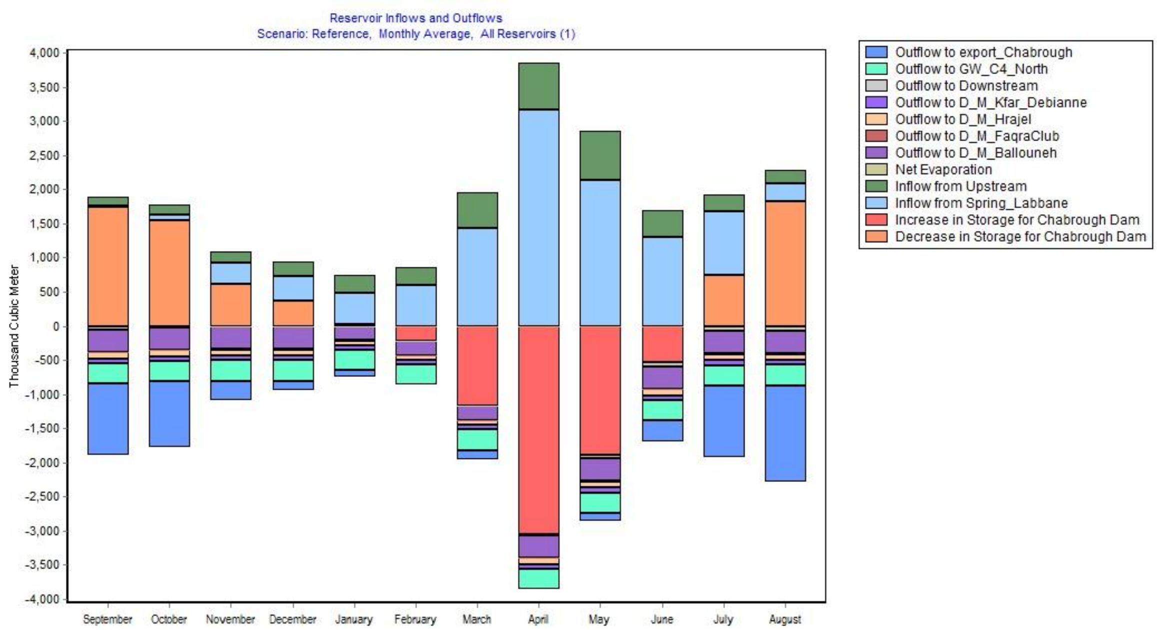


Figure 42: Average monthly inflow and outflow of Chabrough dam between September 2010 and August 2012 in TCM.

Figure 42 shows average monthly inflow and outflow of Chabrough dam. On an annual scale, input equals output; as presented in Table 17, increase in storage occurs between February and June. Chabrough receives 73.9% of its total input from Labbane Spring, especially during the period of high discharge of the spring. Between March and May, 72% of Labbane's discharge (9.4 MCM) is conveyed to Chabrough. In June, this share drops to 45%, despite the relatively high discharge of Labbane (2.9 MCM). The low rate of conveyance can be related to full storage capacity of the dam and demand of agriculture in SC 1, 3-5, which is partly supplied by Labbane Spring via an irrigation canal. The remaining share of input, which is 26.1%, Chabrough receives from its catchment.

Decrease in storage occurs between July and January, with highest discharge rates between August and October. Most of Chabrough's discharged water (36.8%) is conveyed outside the JSC; on an annual scale, approximately 24% of Chabrough's stored water leaks towards sub-catchment 2; this amount is almost equal to the amount of fresh water that is conveyed to the demand site Ballouneh in one year.

Table 17: Average total and relative annual in- and outflow of Chabrough dam between September 2010 and August 2012 in MCM.

	flow in MCM	% of in-/output
Inflow from Spring_Labbane	11.1	73.9
Inflow from Upstream	3.9	26.1
Total inflow	**15.0**	
Net Evaporation	-0.4	2.7
Outflow to D_M_Ballouneh	-3.6	23.8
Outflow to D_M_FaqraClub	-0.1	0.7
Outflow to D_M_Hrajel	-1.0	6.5
Outflow to D_M_Kfar_Debianne	-0.8	5.6
Outflow to Downstream	0.0	0.0
Outflow to GW_C4_North	-3.6	24.0
Outflow to export_Chabrough	-5.5	36.8
Total outflow	**-15.0**	

7.5. Evaporation from sealed surfaces

Table 18: Average monthly actual evaporation from sealed surfaces between September 2010 and August 2012 in TCM.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sum
SC1	2.43	23.42	16.58	12.17	10.95	12.15	18.79	26.13	11.73	0.44	0.16	0.16	**135**
SC2	-	-	-	-	-	-	-	-	-	-	-	-	**-**
SC3	0.79	7.64	6.75	5.12	4.78	5.15	7.76	9.81	3.83	0.14	0.05	0.05	**52**
SC4	0.53	5.16	3.74	2.77	2.51	2.77	4.25	5.85	2.58	0.10	0.03	0.03	**30**
SC5	3.93	37.94	34.61	26.53	25.00	26.74	39.94	48.71	19.00	0.71	0.26	0.26	**264**
SC6	-	-	-	-	-	-	-	-	-	-	-	-	**-**
SC7	-	-	-	-	-	-	-	-	-	-	-	-	**-**
SC8	0.30	2.65	1.62	1.14	0.97	1.12	1.80	2.65	1.46	0.05	0.02	0.02	**14**
SC9	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Sum	**6**	**53**	**47**	**36**	**33**	**36**	**54**	**67**	**27**	**1**	**0**	**0**	**360**

Table 18 presents total figures on monthly evaporation from sealed surfaces. According to the results, annual rate of evaporation from sealed surfaces accounts for 0.36 MCM; evaporation occurs according to the amount of rainfall and reference evapotranspiration.

8. Discussion

This study, elaborated within the TC project ‘Protection of Jeita Spring’, presents the first WEAP model for a spring catchment in Lebanon. As it has been previously outlined in chapter 3.2., availability of secondary data was the main constraint for this study; and still, assessment of existing data quality is difficult because there is barely any documentation about methodology of how data is collected. Thus, assessment of the output of modeled records in terms of how good the model does represent the ‘reality’ is difficult. However, the Jeita Spring catchment is certainly the best hydrogeological documented space in Lebanon. Therefore, for the elaboration of a WEAP model in Lebanon, the JSC offers the best conditions in Lebanon.

For two main reasons, it is important to stress the importance to develop such a model within a TC project. First, reasons for this are practical related; by conducting this study within a hydrogeological TC project, access to exclusive primary data is allowed. Research findings and primary data about the hydrogeological setting of JSC from BGR are the premise for this model. However, what makes this data valuable is its connection to the knowledge and experience of the researcher who is responsible for collection of this data. Knowledge about this data, which is used for the WEAP model, helps to identify the importance of each variable or parameter, and to define the ‘search space’ for parameters during calibration; knowledge about data helps to deconstruct the ‘black box WEAP model’. This is important for a ‘trial and error method’ in setting up a model, and in turn, increases importance of carefully documentation of working progress. For setting up such a model, support from WEAP-experienced staff is mandatory because during calibration, comprehending changes of parameters and their specific impact on other variables is a challenge for its own. This knowledge is also important to bridge some gaps of missing data because in these cases, assumptions about data have to be made.

So it is both, experience in collection of primary data and processing of this data, as well as handling a model, which is needed to balance out uncertainties related to existing secondary data. Some of this secondary data has been obtained from Lebanese project counterparts, mainly from WEBML. It only can be assumed that access to some of the data has only been granted through this technical cooperation project.

The other reason for the importance of development of such a model within a TC framework is related to the long-term sustainability of the established WEAP model. A WEAP model offers a theoretical-based evaluation that shall serve for practical planning of future water resources management. By developing such a model within a TC project, the model may be used later on within the project; it is a practical tool for illustration of seasonal supply and demand, as well as for persuasion of water related actions that have been elaborated within the project. In doing so, it may not only be the project actions that are illustrated, but the model itself. Such an approach implies identification of advantages of using WEAP for water planning and also a possible integration of the software to responsible levels of decision makers for the future.

Despite gained access to data from Lebanese counterparts, exchange of data and communication between ministries outside the project has been difficult, even though there exist an agreement on this technical cooperation project that has been signed by the government, representing all ministries. Updated climate data, for example, could not been procured free of charge even though it is a governmental institution that is in charge for the meteorological service. The reason for this might be related to the fact that the Lebanese Meteorological Department is under responsibility of the MoPW, which is not a counterpart within this project.

9. Conclusion & recommendations

9.1. Conclusion

According to the modeling results, surface runoff exceeds evapotranspiration between November and March; within this period, 45% of total annual evapotranspiration occurs, but on the other side, 85% of total annual precipitation. Rates of evapotranspiration are governed by both, reference evapotranspiration or potential evapotranspiration (PET). Application of UNEP (1992) aridity index, which is the quotient of mean annual rainfall and PET, on the JSC indicates a value of 3.2, which is far beyond the least dry class of 'dry subhumid' that ranges between 0.5-0.56. This fact highlights the annual overshoot of rainfall, corresponding to the calculation of LAWRENCE, ET AL. (2002). On an annual scale, there is no water shortage within the JSC and so, on the first glance, also no inter-sector conflicts between different water users. From an annual precipitation of 462.5 MCM, approximately 53% contribute to groundwater recharge. Recharge rates are not subject to limited potential storage volume of the aquifers; the J4 aquifer and Afqa's aquifer, which are the most important that (in-) directly feed Jeita Spring, have a potential storage of 5 224 MCM.

Surface runoff accounts for the largest share of water loss from the hydrological system JSC; approximately 27% of total rainfall leaves the JSC unused, before it flows into the Mediterranean Sea. This share of runoff, however, is subject to an increase, which is caused by urban development, sealing of surfaces and deforestation. Reservoirs are one possibility to store shares of this runoff; Chabrough dam does already allocate almost all of the 5.8 MCM water that is demanded by the domestic sector within the catchment, even though the reservoir is mainly supplied by Labbane Spring. However, additional reservoirs within the

JSC could contribute to capture runoff, which is then conveyed to Beirut. Especially between August and November, when Jeita Spring discharges only 11% of its annual discharge, stored resources would increase water availability.

Constructed reservoirs would increase storage capacity within the Jeita Spring catchment, and therefore, improve the water balance in terms of humans' interests. Since currently, all demands within the JSC are supposed to be covered, water shall be conveyed outside the catchment. Therefore, conclusions and recommendations of this study are based on the fact that it is mainly the application of supply management that shall have priority for the Jeita Spring catchment.

9.2. Recommendations

According to previous discussion and conclusions, recommendations for future water strategies and actions aim to improve the cooperation between different counterparts within the technical cooperation project, to improve data availability for further research and to increase total water availability for Beirut during summer months.

Referring to the conclusion of 27% water loss through surface runoff, construction of dams is recommended in order to capture and store this runoff. Stored water shall buffer water shortage in Beirut, which mainly appears between August and November, when discharge of Jeita Spring is lowest. Suitable locations for dams are in unsettled areas on top of the aquitard. Due to low hydraulic conductivity of the aquitard, potential leakage is expected to be very low. WEAP shall be used to identify recharge potential for proposed dams and evaporation loss, according to surface extent and ET_0; each proposed dam shall be modeled according to its specific sub-surface catchment and its hydrological balance. Therefore, delineated sub-catchments of proposed dams shall be integrated within the current WEAP model.

For more accurate modeling of domestic sector's demand, precise population records and water-use rates are needed. Currently, population figures and water-use rates are often estimated. Therefore, it is recommended to establish decentralized population registers for all municipalities. These registers shall be connected to a central database, from where all ministries and their subordinated institutions shall have access to it. Regarding water-use rates, installation of water meters is strongly recommended; by doing so, also water loss within the supply network become comprehensible.

A central, inter-ministerial data base shall be used also for storage of existing hydrogeological data; currently, ministries and subordinated institutions are highly separated from each other, which may be one reason for limited exchange of data. Access to this database, which is granted to ministries and institutions, would also imply better accessibility of foreign counterparts to present data. It is also recommended to provide data and research results, elaborated by the foreign counterpart, within this database. Responsible actors within ministries and institutions shall be subject to evaluate research results by the foreign counterpart. This institutionalizing of evaluation aims to force all actors to actively deal with the project; understanding of relevant problems and designing strategies to cope with them shall be improved by this. With respect to the ending of a project, this understanding is the basis for sustainability of the technical cooperation project because after the project phase it is the local partners that shall continue with tackling the problems.

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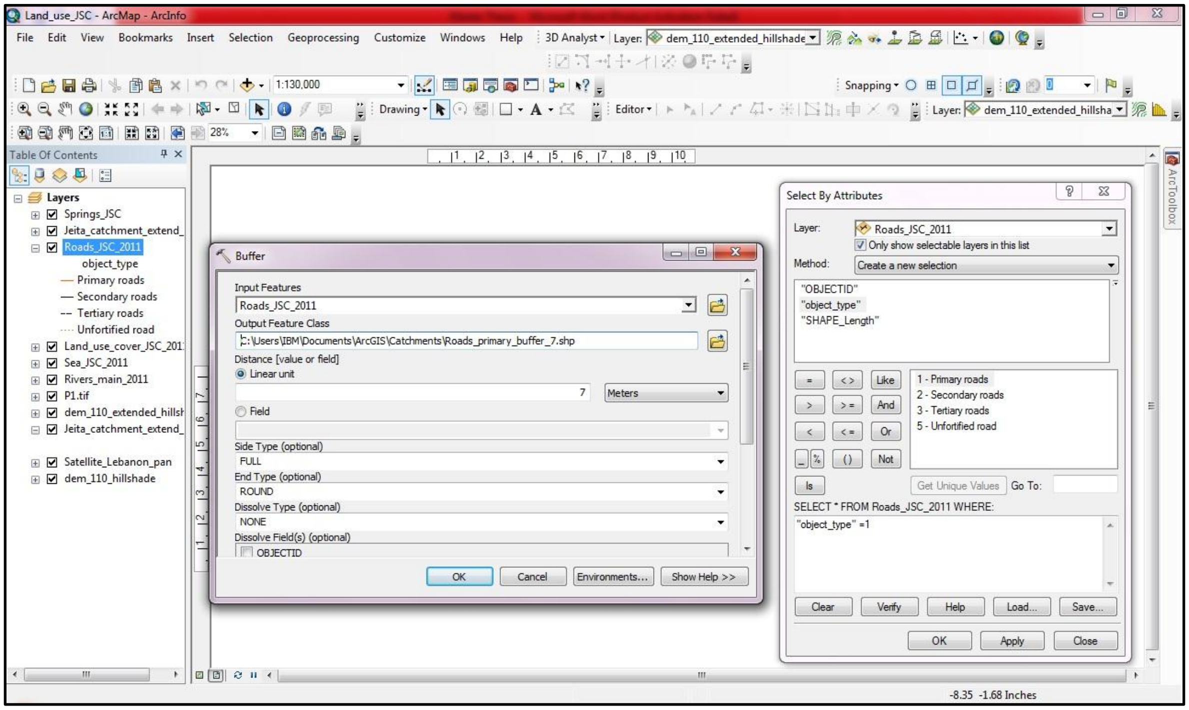
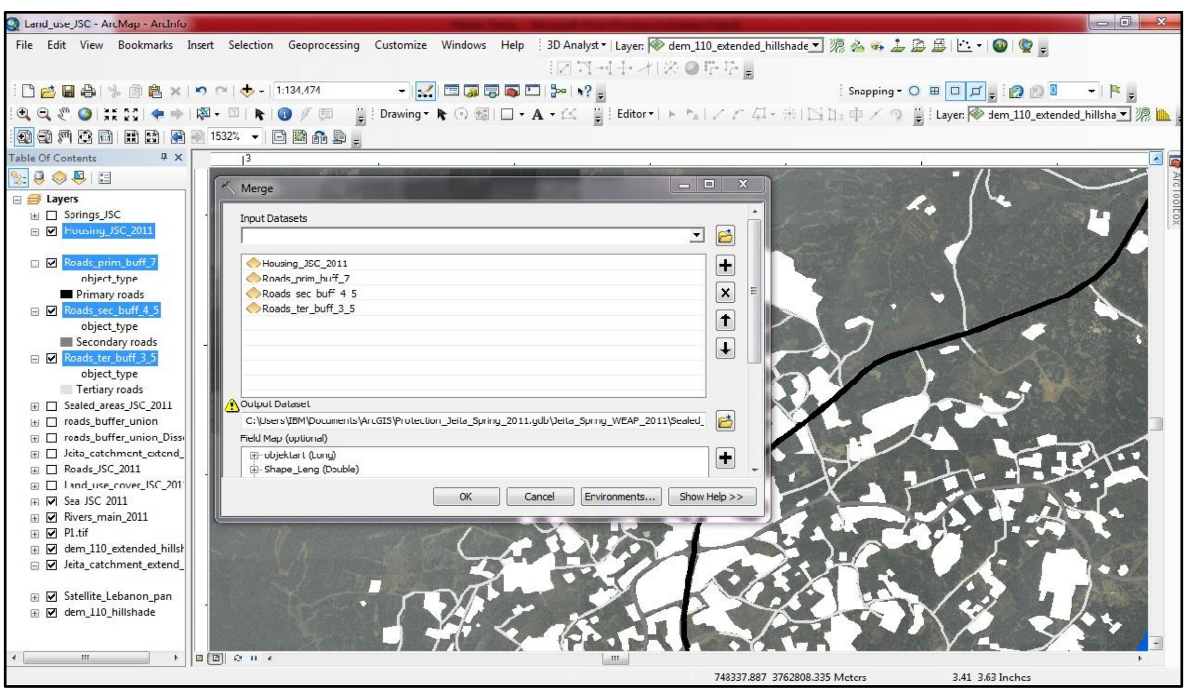
Appendix

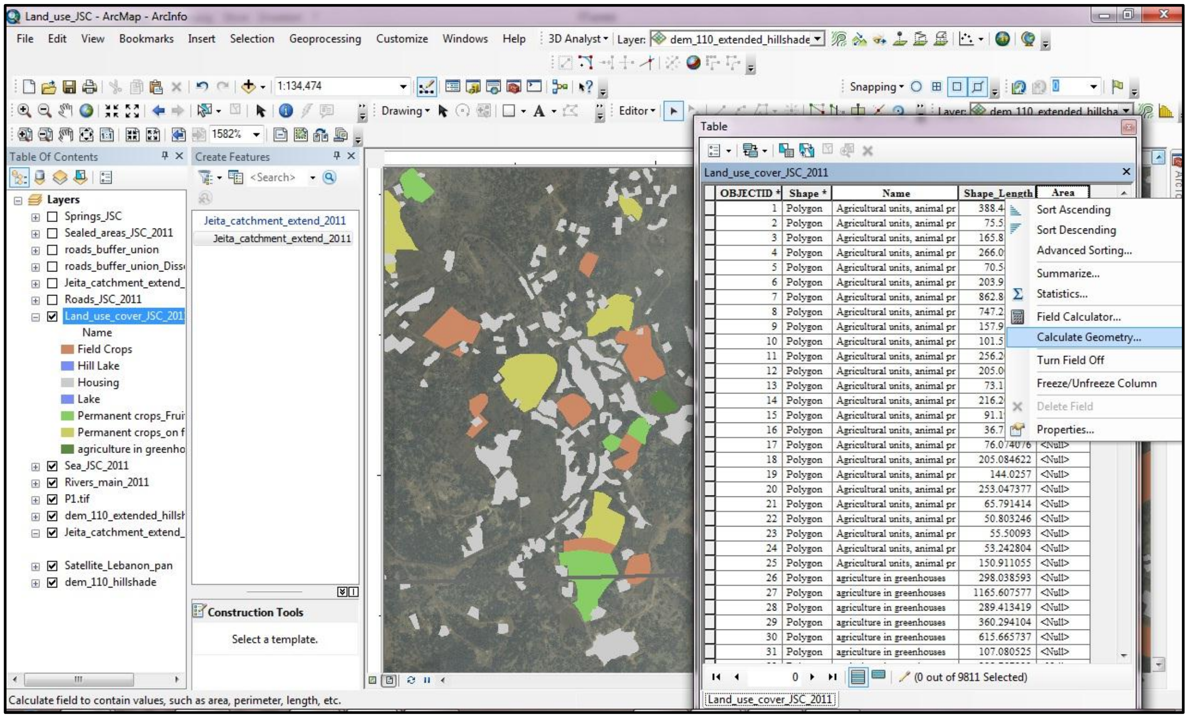
Appendix A: Buffering, merging and calculating geometry in ArcGIS



Appendix A 2: Buffer of 7 meters around primary roads.

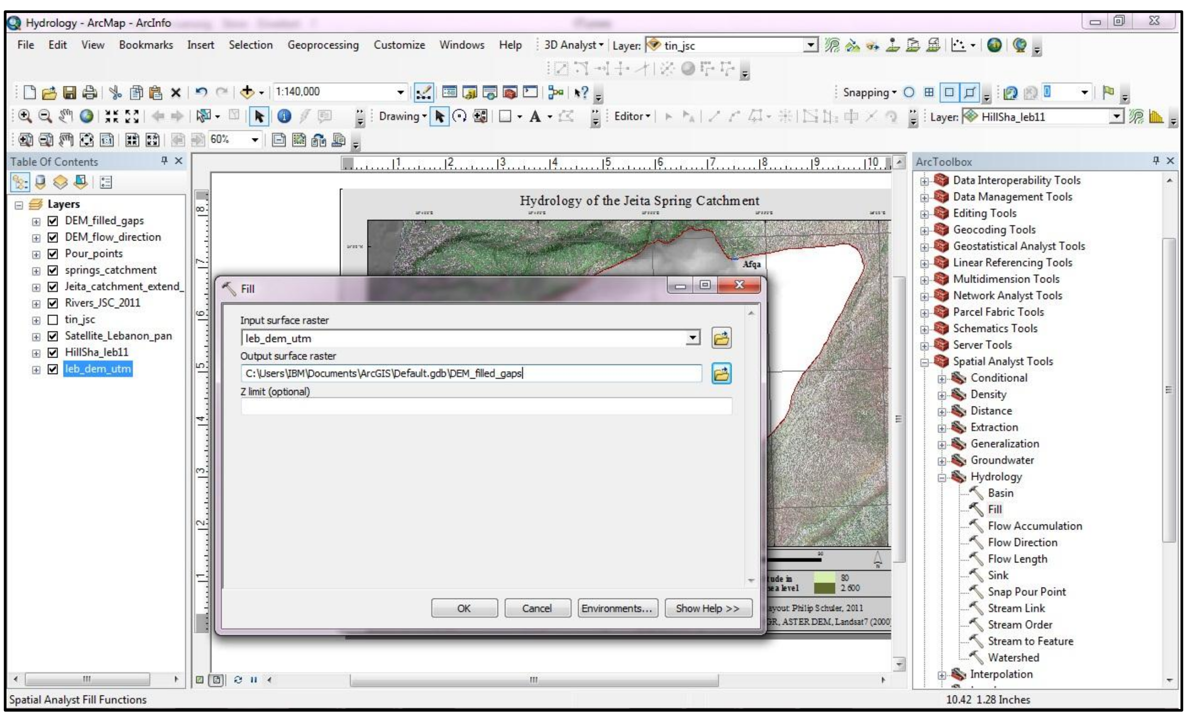


Appendix A 1: Merging of road-buffer with housing layer.

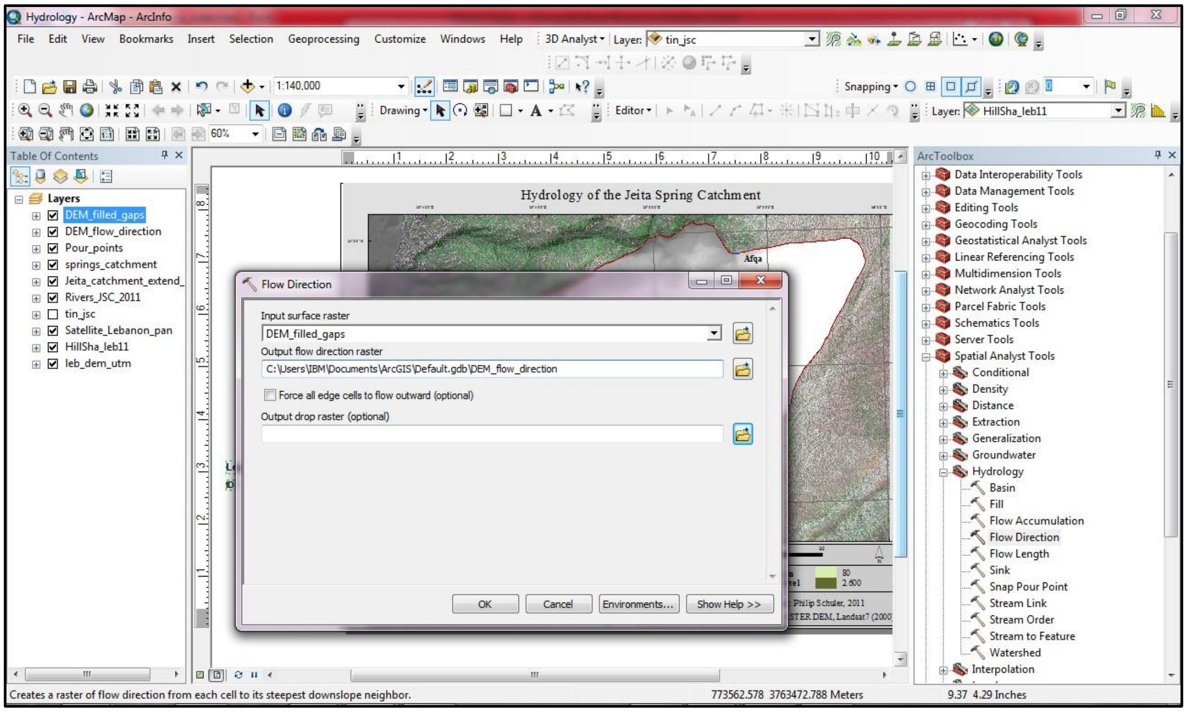


Appendix A 3: Calculation of polygons' geometry.

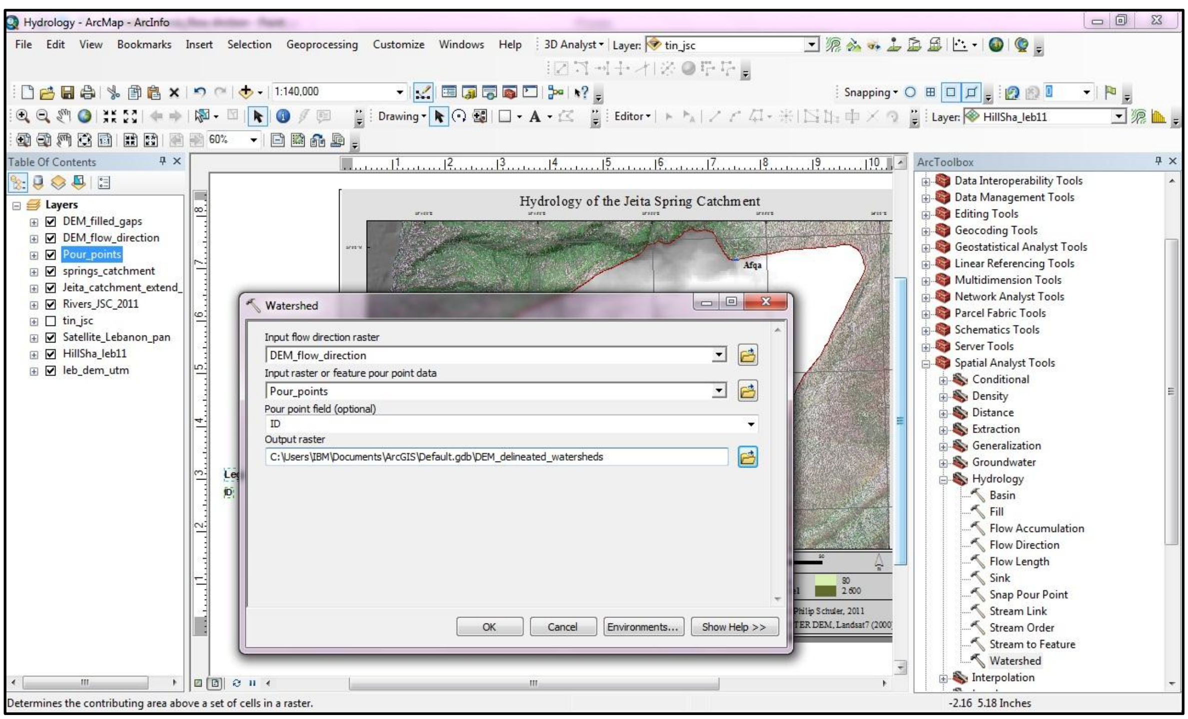
Appendix B: Filling gaps, flow direction and delineation of a watershed in ArcGIS



Appendix B 1: Filling gaps of the Digital Elevation Model



Appendix B 2: Calculation of flow direction



Appendix B 3: Delineation of catchments.

Appendix C: Arabic abstract

ملخّص

ما يقارب 63% من حاجات بيروت لمياه الشرب يتم تأمينه من نبع جعيتا، ما يعطي أهمية عظمى لهذا النبع بالنسبة ل1,9 مليون من أصل 4,1 مليون لبناني(CIA FACTBOOK 2011). كمية المياه المؤمّنة لبيروت تعتمد على نبع جعيتا الكارستي مع تغيرات تصريفه الموسمية، التي تختلف بين المعدل اشهري الأدنى 1,55 متر مكعب بالثانية خلال الأشهر بين آب وتشرين الثاني، والمعدّل الأعلى 8,65 متر مكعب بالثانية في شهر آذار. هذا الاختلاف الموسمي بالتصريف يسببه الشكل الطوبوغرافي للحوض الجوفي لنبع جعيتا (JSC)، والشروط الجيولوجيّة والمناخية. يتراوح ارتفاع الحوض مابين 90 الى 2,611 متر فوق سطح البحر، كما تغطيه اختلافات في معدّل المتساقطات (P) والتبخُّر (ET_0). وبالاعتماد على كمية تصريف نبع جعيتا، تحتل مساحة الجوراسي الكارستي J4 الاهمية الكبرى لانه المغذي المباشر للنبع. جرت هذه الدراسة من ضمن مشروع التعاون التقني "حماية مياه نبع جعيتا" تحت اشراف المعهد الفدرالي الالماني لعلوم الارض والموارد الطبيعية (BGR): هذه الدراسة هي تجربة تطبيقية لاقامة تقييم وتخطيط مائي (WEAP) لحوض تغذية نبع جعيتا بهدف تمثيل مقومات الموازنة المائية لهذا الحوض خلال سنة واحدة, مع الاخذ بعين الاعتبار وجهة استعمال الاراضي (سكن أو زراعة) و الغطاء الموجود (نبات أو تربة أو صخور)، ضمن هذا الحوض.

من أجل تمثيل دقيق لاختلاف المجالات في الحوض، تم تقسيم الحوض الى تسع أحواض ثانوية، لا تسمح بتحديد معدّلات متساقطات وتبخُّر شهرية لكل حوض ثانوي فحسب، بل تأخذ بعين الاعتبار مختلف الطبقات الجيولوجية ذات اختلاف التصريف المائي، ونسبة التسرّب والتخزين والجريان السطحي أيضاً.

، بناءً على مجموع المتساقطات السنوي 462,5 مليون متر مكعب موزّع على المياه الجوفية WEAP أظهرت نتائج ال تقريباً 53%، 20% تبخّر ونتح، 27% جريان سطحي. وبما ان المثال يعتمد على أن حاجات المياه ضمن مساحة الدراسة متوفّرة، إذا لا يوجد استعمال مفترض لمياه الجريان السطحي في المنطقة، أي أنّ 27% من مدخول المياه الى المنطقة يحسم "خسارة". بناءً على ذلك، تقترح الدراسة التركيز على استعمال مياه الجريان السطحي ضمن ادارة التوزيع. وبالتحديد اقتراح بناء سدود على الطبقات الجيولوجية قليلة التسريب، في المناطق الغير مستغلّة، لتخزين مياه الجريان السطحي خلال فصل الامطار. تُجرّ المياه المخزّنة باتجاه بيروت، وبخاصّةٍ بين شهري آب وتشرين الثاني، عندما تكون كميات تصريف نبع جعيتا منخفضة.