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Protection of Jeita Spring

TECHNICAL REPORT NO. 6

Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP

Including Water Resources Management Options & Scenarios

Raifoun
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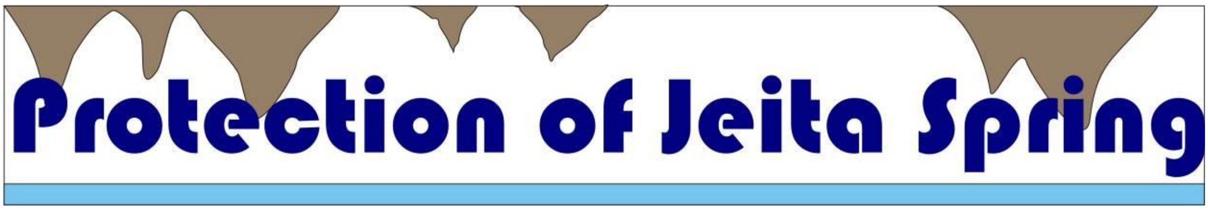

Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP

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List of Abbreviations

a	Year
ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
ADCP	Acoustic Doppler Current Profiler
asl	Above mean sea level
AVSI	Associazione Volontari per il Servizio Internazionale
AT	Aquitard
C4	Cretaceous 4
Cap	Capita
CDR	Council for Development and Reconstruction
d	Day
DAG	Directorate of Geographic Affairs
DSS	Decision Support System
D_M	Demand site
EC	Electrical conductivity
ET	Evapotranspiration
ET_{actual}	Actual evapotranspiration
ET_o	reference evapotranspiration
ET_{pot}	Potential evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GW	Groundwater
GWR	Groundwater recharge
GWCZ	Groundwater contribution zone
J4	Jurassic 4
k_c	Crop coefficient
l	Liters
LRA	Litani River Authority
MAR	Managed aquifer recharge
MCM	Million cubic meters
MENA	Middle East and North Africa
mm	millimeter
MoE	Ministry of Environment
MoEW	Ministry of Energy and Water
NMS	National Meteorological Service
NTU	Nephelometric turbidity unit
NWSS	National Water Sector Strategy
P	Precipitation
PRECIS	Providing REgional Climates for Impacts Studies
P_{eff}	Effective precipitation
PEST	Parameter Estimation Tool
SC	Sub-catchment
SEI	Stockholm Environment Institute
SR	Surface runoff
T	Temperature
TCM	Thousand cubic meters
UNDP	United Nations Development Programme
WEAP	Water Evaluation And Planning
WEBML	Water Establishment Beirut and Mount Lebanon

List of Reports prepared by the Technical Cooperation Project Protection of Jeita Spring

Report No.	Title	Date Completed
Technical Reports		
1	Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment General Recommendations from the Perspective of Groundwater Resources Protection	January 2011
2	Best Management Practice Guideline for Wastewater Facilities in Karstic Areas of Lebanon with special respect to the protection of ground- and surface waters	March 2011
3	Guideline for Environmental Impact Assessments for Wastewater Facilities in Lebanon Recommendations from the Perspective of Groundwater Resources Protection	November 2011
4	Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring	September 2011
5	Hydrogeology of the Groundwater Contribution Zone of Jeita Spring	July 2013
6	Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP including Water Resources Management Options and Scenarios	August 2013
7	Groundwater Vulnerability Mapping in the Jeita Spring Catchment and Delineation of Groundwater Protection Zones using the COP Method	February 2013
7b	Vulnerability Mapping using the COP and EPIK Methods	October 2012
Special Reports		
1	Artificial Tracer Tests 1 - April 2010*	July 2010
2	Artificial Tracer Tests 2 - August 2010*	November 2010
3	Practice Guide for Tracer Tests	Version 1 January 2011
4	Proposed National Standard for Treated Domestic Wastewater Reuse for Irrigation	July 2011
5	Artificial Tracer Tests 4B - May 2011*	September 2011
6	Artificial Tracer Tests 5A - June 2011*	September 2011
7	Mapping of Surface Karst Features in the Jeita Spring Catchment	October 2011
8	Monitoring of Spring Discharge and Sur-	May 2013

Report No.	Title	Date Completed
	face Water Runoff in the Groundwater Contribution Zone of Jeita Spring	
9	Soil Survey in the Groundwater Contribution Zone of Jeita Spring	First Draft November 2011
10	Mapping of the Irrigation System in the Jeita Catchment	First Draft November 2011
11	Artificial Tracer Tests 5C - September 2011*	February 2012
12	Stable Isotope Investigations in the Groundwater Contribution Zone of Jeita Spring	~July 2013
13	Micropollutant Investigations in the Groundwater Contribution Zone of Jeita Spring*	May 2012
14	Environmental Risk Assessment of the Fuel Stations in the Jeita Spring Catchment - Guidelines from the Perspective of Groundwater Resources Protection	June 2012
15	Analysis of Helium/Tritium, CFC and SF6 Tracers in the Jeita Groundwater Catchment*	June 2013
16	Hazards to Groundwater and Assessment of Pollution Risk in the Jeita Spring Catchment	June 2013
17	Artificial Tracer Tests 4C - May 2012*	~June 2013
18	Meteorological Stations installed by the Project	~September 2013
Advisory Service Document		
1	Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley	May 2012
1 - 1	Addendum No. 1 to Main Report [Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley]	June 2012
2	Locating the Source of the Turbidity Peaks Occurring in April - June 2012 in the Dbayeh Drinking Water Treatment Plant	June 2012
3	Locating the Pollution Source of Kashkoush Spring	September 2012
4	Preliminary Assessment of Jeita Cave Stability	April 2013
5	Preliminary Assessment of the Most Critical Groundwater Hazards to Jeita Spring	June 2013

Reports with KfW Development Bank (jointly prepared and submitted to CDR or with BGR contributions)		
1	Jeita Spring Protection Project Phase I - Regional Sewage Plan	October 2011
2	Jeita Spring Protection Project - Feasibility Study - Rehabilitation of Transmission Channel Jeita Spring Intake – Dbaye WTP	May 2012
3	Jeita Spring Protection Project - Environmental Impact Assessment for the Proposed CDR/KfW Wastewater Scheme in the Lower Nahr el Kalb Catchment	June 2013 (BGR contribution)
4	Design Report on-site Sanitation Industrial and Commercial Wastewater Treatment	June 2013 (BGR contribution)

* prepared in cooperation with University of Goettingen

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0 Executive Summary

This report presents the first WEAP model for the groundwater (GW) contribution zone (GWCZ) of Jeita spring, with a total size of 406 km^2, as finally delineated by the project in June 2013. The model shall serve as a practical tool for water management options in the Jeita catchment. Options include integration of dams that model potential storage/managed aquifer recharge (MAR).

In a first step, a static model with defined spring discharges was developed (Model 1) to reach a first calibrated and balanced model. Based on this, a flexible model with variable spring discharge was established (Model 2). The presented results in Chapter 9 refer to Model 2.

To model the water balance, the entire catchment was sub-divided into 13 sub-catchments. Sub-division was done according to: 1. Geology (rate of infiltration of precipitation), 2. Direction of surface runoff and 3. Spring and reservoir catchments. Sub-division was done in order to decrease the reference space of climate data because each sub-catchment (SC) is assigned respective climate data. The result is less generalized data with a higher precision and reliability of the modeling output.

SCs 1.1 to 2.3 are located on the Lower Aquifer (J4) and the Aquitard Complex and were modeled by the Rainfall Runoff Method (simplified coefficient). SCs 3.1 to 3.6 extend on the Upper Aquifer (C4) and were modeled by the Rainfall Runoff Method (soil moisture model). The latter methodology has the ad-vantage of integrating snow into the modeling process, which plays only a minor role in the lower part of the catchment.

Hydrological and climatic input data relate, if possible, homogenously to the period between the water years 1967 and 1975. Each variable was used to establish a respective average water year on a monthly time step.

Calibration was done based on subjective criteria, including adjusting modeled to observed spring discharge, infiltration/groundwater recharge (GWR) rates, as well as streamflow of Nahr el Kalb at Daraya gauging station.

The results show, that from a total annual precipitation of 620 MCM (404.5 MCM rain; 215.3 MCM snow), 110 MCM are subject to direct evapotranspiration (ET) (incl. crops without applied irrigation), 141 MCM to direct surface runoff (SR) and 370 MCM to direct groundwater recharge (GWR) (154.4 MCM from rainfall; 215.3 MCM from snowmelt). Annual irrigation demand between May and September is 17 MCM (with an irrigation efficiency of 75%) while domestic water demand sums up to 10 MCM (incl. 35% network losses and 50% GW return flow).

Annual modeled discharge of Jeita sums up to 171.4 MCM. 23% of discharge originates from rainfall on the Aquitard Complex, 38% from the J4 and 39%

from the C4. Approximately 46% of Jeita’s discharge originates from riverbed infiltration of Nahr es Salib, Nahr es Zirghaya and Nahr Ibrahim. In Ibrahim valley, 23% of streamflow infiltrates towards the J4 Aquifer, making this infiltration of high importance to Jeita spring.

Due to the high infiltration along streams in karstified valleys, the project recommends MAR (Managed aquifer recharge). In Nahr es Salib Valley, MAR could increase the annual discharge of Jeita Spring by 17.5 MCM to 188.9 MCM.

MAR may become more crucial if climate change predictions turn out to become real. For an optimistic outlook (Scenario 2), a decrease of precipitation by 10%-15% and an increase of temperature by 1.5 °C -1.75 °C during a water year in 2040 will reduce discharge of Jeita by 19% to 140 MCM per year.

This study emphasizes the need to the Lebanese government to invest in data collection, in a monitoring and maintenance system, and into an inter-ministerial database. A lack of data puts a question mark behind hydrological studies in Lebanon, which are used as the planning basis for expensive infrastructure projects.

1 Introduction

The work presented in this report was conducted in the framework of the German-Lebanese Technical Cooperation project Protection of Jeita Spring. This written report bases upon the master thesis Hydrological Balance of the Jeita Spring Catchment (SCHULER, 2011).

In contribution to a sustainable water supply for Beirut and for the study area within the Jeita groundwater catchment, a Water Evaluation And Planning (WEAP) model is established. This model is addressed to academia, water management experts, national decision makers and partners of the Protection of Jeita Spring project, i.e. Water Establishment Beirut and Mount Lebanon (WEBML), Council for Development and Reconstruction (CDR) and Ministry of Energy and Water (MoEW). Project partners are of major importance because this model shall serve as a decision support system (DSS) for the practical application of regional water management by the mentioned institutions.

WEAP is developed by the non-profit research and policy institute Stockholm Environment Institute (SEI). The software is free of charge for non-profit users in developing countries, while users in industrialized countries pay for the use. Thereby, they support research in developing countries (SEI, 2012). So far, within the MENA region, WEAP models have been established for river catchments in Morocco, Tunisia, Palestine, Syria and Jordan (HADDAD et al., 2007; DROUBI et al., 2008; GHALLABI et al., 2010; HOFF et al., 2011). The presented WEAP model for Jeita spring is the first catchment-based WEAP model for Lebanon, which is based on extensive field monitoring.

Among the other MENA countries, Lebanon faces intra-annual water shortages that occur during the end of summer and autumn, between the period of September to December. During this time, limited access and availability of natural resources are too constricted to cover a disproportional water demand of 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: AVSI, 2009). On the other hand, between November and end of March, there is a high input of precipitation. During this period, 85% of the total precipitation of a water year (September to August, named according to the ending year) occurs, with a maximum of average monthly rainfall of 328 mm at Faraiya (1,325 m asl), for the period 1931 to 1960 (ATLAS CLIMATIQUE DU LIBAN, 1977).

Water resources that are not used by humans and partly by the ecosystem leave the hydrological system of the Jeita catchment via evapotranspiration (ET) but mainly via surface runoff (SR). Unused resources can be considered as physical loss. WEAP was used to establish a water balance for the Jeita catchment for one water year on a monthly basis, including the relevant components of a hydrological balance (Chapter 5). SR is of major interest because it may be turned into an additional water resource for human activities. SR may be stored in dams from where resources infiltrate and recharge the respective aquifer (Managed Aquifer Recharge), in which flow velocities are generally slower than on the surface. In this way, spring discharges will be increased and the Jeita catchment may be further integrated in the national supply management as it is already envisaged within the National Water Sector Strategy (NWSS) (MoEW, 2010). Stored water shall be used to decrease natural losses from the hydrological system and thus, to increase availability of resources for the regional water supply during the period of water shortage.

Supply management may become even more a necessity, if climate change predictions will turn to be true. A decrease of 20% of precipitation and an increase of 2 °C until 2040 will have a tremendous impact on the regional hydrogeological system (MoE, 2011).

This report presents the chronological development from Model 1 to Model 2. The final model shall be regarded as a continuous and iterative tool. Based on the present conceptual structure, input data shall be frequently updated in the future. Due to the lack of updated data, the current WEAP model represents one water year while it is mainly built on historical data for a long enough period between 1931 and 1975. For this timespan, available data is generally broader than it is today (rainfall data, spring discharge). In order to ensure reliability, used data originates homogenously from the same period of time.

WEAP Model 1 contains defined spring discharges (Afqa, Assal, Jeita, Labbane and Rouaiss), according to historical data and results of the calibration. By defining monthly spring discharges, i.e. groundwater outflows, previous flow paths of spring discharges (ET, GWR, SR) can be calibrated according to the output of the aquifer. Thus, the aquifer becomes a reference system for surface water calibration. Model 2 is based on Model 1. The major difference between the two models is the flexibility of spring discharges. In Model 2, each monthly spring discharge was modeled according to a regression curve between P and spring discharge of Model 1.

2 Extent of the Jeita Catchment

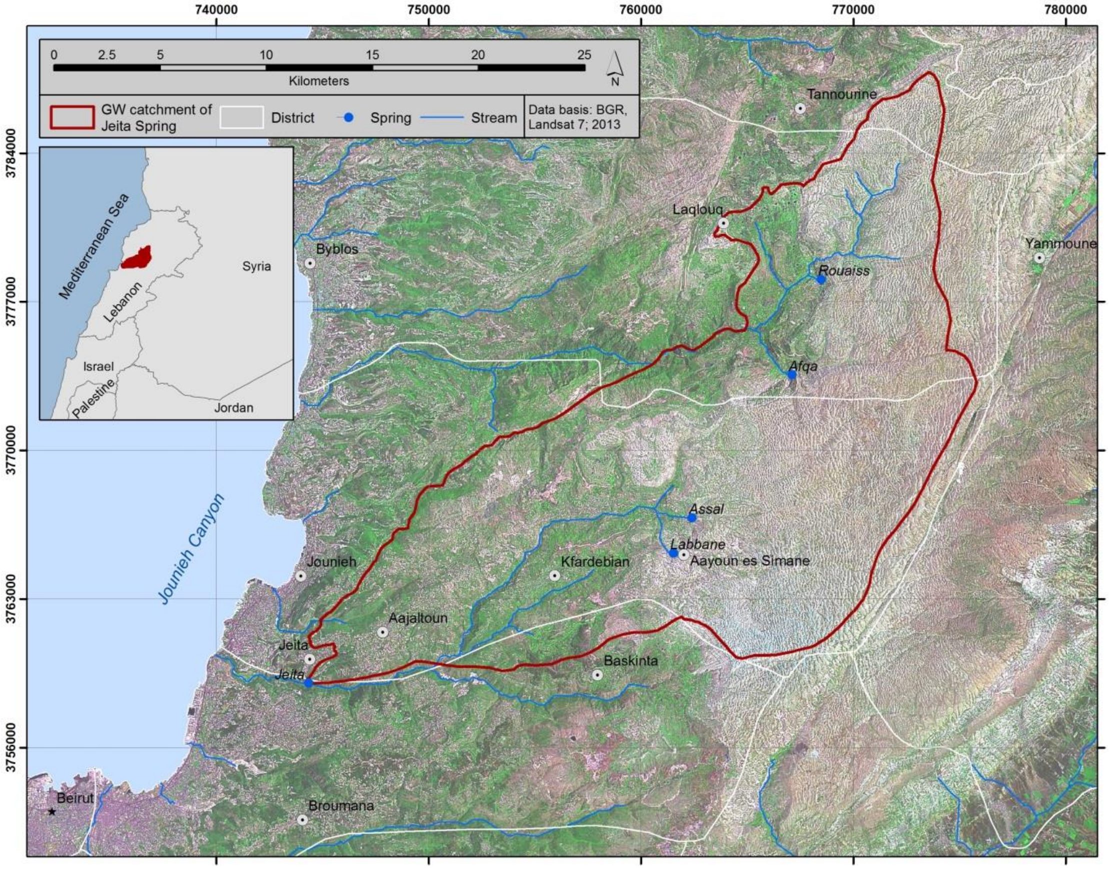

Figure 1: Extent of the GW Catchment of Jeita Spring

The groundwater catchment of Jeita spring (Figure 1) has a total size of 405.6 km². It is located in the center of Lebanon, starting 15 km northeast of Beirut, on the western exposed side of the Lebanon Mountains. It ranges north-south between the geographic coordinates 34°11’45’’ and 33°56’30’’, east-west between 35°59’10’’ and 35°38’30’’. These coordinates are located on UTM zone 36 of the northern hemisphere.

3 Methodology

3.1 WEAP

BGR has used Water Evaluation And Planning (WEAP) as a strategic tool within technical cooperation projects in the MENA region. Together with the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), a WEAP model was developed for the Zabadani basin in Syria and for the Berrechid basin in Morocco (DROUBI et al., 2008). On an institutional level, WEAP is acknowledged as a DSS tool for water management in Jordan, Lebanon, Morocco, Syria and Tunisia.

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 have to be defined. Boundaries are represented by river- or spring catchments. Based on this definition, elements (demand- and supply sites, reservoirs, etc.) of the system are identified, integrated into the model and connected to each other via natural or *man-made conduits*, e.g. transmission links or diversions. This built up structure is called *schematic* (Appendix I). Data is attributed to the elements of the system. After data input, assessment of quantification of flows and calibration of the model can be conducted. In this stadium, the model represents a conceptual representation 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 the Current Accounts, a reference or *business-as-usual* scenario is established. The reference scenario may include a variety of additional economic, demographic, hydrological and technological trends. After definition of this, simulations of the model lead to the assessment and interpretations concerning water distribution, supported by visualized output, through diagrams, maps or through data 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, such as the water year method, a tool that takes into consideration the temporal variability of input of the hydrological system. This is done through scenario analysis. Seasonal variation of streamflow, precipitation or groundwater recharge can be established and defined as different climate regimes (dry-wet, hot-cold), relative to the Current Accounts (MOUNIR et al., 2011).

Another important tool is the Rainfall Runoff Method (simplified coefficient) that is based on the methodology of FAO, taking into account the variability of rainfall. The Rainfall Runoff Method (simplified coefficient) 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, the Rainfall Runoff Method (simplified coefficient) was used to calculate crop water requirements and runoff/infiltration processes in Model 1 and partly in Model 2.

The Rainfall Runoff Method (soil moisture) integrates a one dimensional, two-layer soil model for advanced surface water/groundwater modeling. By using this method, the user can specify soil properties and advanced climate data (temperature, humidity, wind speed, etc.). Based on these data, WEAP calculates interflow, deep water percolation and ET_0. One major advantage of this methodology is the possibility of modeling snow accumulation and snowmelt. In turn, the disadvantage is the need for relatively complex data, especially to specify soil properties. This, however, can be neglected in this WEAP model because the Rainfall Runoff Method (soil moisture) was only applied in sub-catchments that have almost no soil layer. Thus, properties for the soil layer could be set respectively. The resulting benefit of this methodology, modeling of snow accumulation and snowmelt, has more advantages in case of this WEAP model, which is the reason why this method was partly applied in Model 2.

3.2 Model Calibration

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. According to COOPER et al. (2007), 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. 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.

Due to lack of data, within this study, the hydrological balance was modeled for one year. This fact eases the intra-annual calibration whereas inter-annual changes were not modeled and therefore, not calibrated.

For calibration of the present WEAP model, a trial and error method was used to adjust estimated parameters to observed ones (ARRANZ & MCCARTNEY, 2007). Observed records from Daraya gauging station were used to adjust modeled runoff of SC 1.2, 1.3, 2.3 and 2.4. In addition, also the rate of total infiltrating precipitation (GWR) was used to adjust modeled runoff, as well as crop coefficients (k_c-values). Table 1 gives an overview about the parameters that were used for calibration.

Table 1: Parameters for the best Fit Simulation, including their Range of Search Space

Parameter	Unit	Range/search space
Crop coefficient (k_c)	-	k_c (sealed surfaces): 0.1 k_c (apples): 0.1-1 k_c (tomatoes): 0.1-1.2 k_c (scarce vegetation): 0.1-0.4 k_c (woodland): 0.7-1 k_c (ponds & lakes): 1
Reference evapotranspiration (ET_0)	mm	Defined/limited
Infiltration rate	% of precipitation	C4: ~80 J4: 50-60 Aquitard: <10
Precipitation	MCM/mm	Defined/limited
Spring discharge	MCM	Defined/limited
Surface runoff Nahr el Kalb	MCM	Defined/limited

Even though WEAP contains the Parameter Estimation Tool (PEST), an inbuilt calibration tool, this feature has not been used for calibration because results have not proven to be more satisfying than the results of a subjective calibration.

3.3 Sources of Data

Climate data, used in this study, consist of precipitation (P), reference evapotranspiration (ET_0), relative humidity and temperature (T). ET_0 is extracted from FAO’s climate database CLIMWAT. This database contains long-term (period not known) average monthly ET_0 records (established using the Penman-Monteith method) available for three suitable stations, as they are considered to be representative for this region: Al-Arz (1,916 m asl), Beirut, American University (35 m asl) and Beirut, Airport (19 m asl). T and humidity are obtained from the TUTIEMPO NETWORK internet climate database.

Annual average rainfall distribution for the period between 1939 and 1970 is based on UNDP & FAO (1973). However, these isohyetes do not match with the reality in the north-east. According to UNDP & FAO (1973), average annual precipitation increases towards north-east and Afqa spring. This fact, however, is not consistent with empirical assessments of satellite images that display the spatial distribution of snow cover. This is why isohyetes were modified, according to MARGANE et al. (2013) (Figure 7).

Average monthly rainfall records for the following four climate stations were adapted for the climate stations of ATLAS CLIMATIQUE DU LIBAN (1977): Raifoun (1,050 m asl), Qartaba (1,140 m asl), Faraiya (1,325 m asl) and Laqlouq (1,700 m asl).

Hydrological data were obtained from Litani River Authority (LRA), Water Establishment Beirut and Mount Lebanon (WEBML), UNDP (1977) and BGR.

- Average monthly discharge of Jeita spring (1966/1967-1970/1971): UNDP (1972); MARGANE et al. (2013)
- Average monthly discharge of Afqa spring (2000/2001-2009/2010): LRA, 2011
- Average monthly discharge of Assal spring (1968/1969-1972/1973): LRA, 2011, MARGANE & STOECKL (2013)
- Average monthly discharge of Labbane spring (1971/1972-1972/1973 and 2002/2003-2008/2009): LRA, 2011; BGR, 2013
- Average monthly discharge of Rouaiss spring (2000/2001-2010/2011): LRA, 2012; BGR, 2013
- Average monthly flow of Nahr el Kalb at Daraya gauging station (1967/1968-1973/1974): LRA, 2011
- Average monthly discharge and storage volume of Chabrouh dam (September 2010-August 2011): WEBML (2011)
- Maximum possible well abstraction rates of public wells: WEBML
- Average annual rainfall distribution (1939-1970): UNDP & FAO (1973), modified, according to MARGANE, et al. (2013)
- Average monthly rainfall of Raifoun, Qartaba, Faraiya and Laqlouq (1931-1960): ATLAS CLIMATIQUE DU LIBAN (1977)

- Average monthly reference evapotranspiration (period not specified): FAO, CLIMWAT
- Average daily temperature and humidity (1973/1974-1974/1975): TUTIEMPO NETWORK

GIS data were obtained from:

- IKONOS satellite image (2005): DAG. Cell size 0.8 m. Coverage: Jeita GWCZ
- Landsat 7 satellite image (2000): NASA. Cell size 14.25 m. Coverage: Lebanon
- SRTM DEM (2000): BGR, 2011. Corrected cell size 110 m. Coverage: Lebanon
- Boundaries of the GW catchments of Afqa, Assal, Jeita, Labbane and Rouaiss spring and Chabrouh dam (shapefile): BGR, 2013. Coverage: Jeita GWCZ
- Boundaries of the catchments of Kfardebian dam (shapefile): GITEC & BGR, 2011. Coverage: Jeita GWCZ
- Administrative boundaries (shapefile): DAG, 2011. Coverage: Jeita GWCZ
- Landuse and landcover (shapefile): SCHULER (2011). Coverage: Jeita GWCZ, based on: AVSI (2009). Coverage: Nahr el Kalb surface water catchment
- Water supply network (reservoirs, wells, pipes) (shapefile): WEBML, 2011. Coverage: Jeita GWCZ
- Geology (shapefile): BGR, 2013. Coverage: Jeita GWCZ
- Streams (shapefile): SCHULER (2011), BGR, 2013. Coverage: Jeita GWCZ

Other data:

- Population records: modified after GITEC (2011b) and SCHULER (2011)

3.4 Data Processing

3.4.1 Quantification of Landuse and Landcover

Roads (line features) and housing (polygons) were digitalized in ArcMap 10.0, based on 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 buffers around line features were used. Width of primary roads was defined as 14 meters, of secondary roads as 9 meters and of tertiary roads as 7 meters. Therefore, respective buffers around roads are 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 were merged to one shapefile.

Present landuse and landcover is based on AVSI (2009), covering the extent of the surface catchment of Nahr el Kalb. These data were empirically assessed, modified and extended to the coverage of the Jeita GWCZ, based on the IKONOS satellite image and on the geology layer. Landuse and landcover classes of AVSI (2009) were generalized and aggregated to the 8 present landuse and landcover classes (Figure 11). For the WEAP model, the landuse class *apples & trees* and *greenhouses* were proportional divided up into the landuse class *apples* and *tomatoes*. Each class was assigned a specific crop coefficient (k_c) in order to model the specific ET from this surface.

All boundaries of surface water catchments within the Jeita GW catchment were delineated by using the Spatial Analyst-Hydrology-Tool in ArcMap 10, based on the SRTM DEM with a corrected cell size of 110 m. The process of delineation includes following steps: Firstly, gaps of the DEM are filled in order to have a raster layer without any depressions. Afterwards, this raster layer was used to calculate the flow direction, which would be the input raster for the calculation of surface catchments. A surface water catchment has one specific drainage location, which was used (raster or vector file) to finally calculate the geometry of the extent of the catchment.

3.4.2 Climate Data

Rainfall input data originate from ATLAS CLIMATIQUE DU LIBAN (1977) and from UNDP & FAO (1973), which were modified by MARGANE et al. (2013). In order to obtain specific records of mean annual rainfall for each sub-catchment, a modified rainfall distribution map of mean annual records between 1939 and 1970 UNDP & FAO (1973) (raster layer) was used and clipped by the specific extent of each sub-catchment in ArcMap. The mean annual records of each sub-catchment were then disaggregated to obtain mean monthly records. This was done by using a monthly reference dataset, consisting of the mean monthly variation of rainfall of the stations Raifoun (1,050 m asl), Qartaba (1,140 m asl), Faraiya (1,325 m asl) and Laqlouq (1,700 m asl).

ET_0 records originate from three climate stations, i.e. Beirut Airport (19 m asl), Beirut American University (35 m asl) and Al-Arz (1,916 m asl). The climate stations of Beirut American University and Beirut Airport were used to calculate an average value (Beirut Mean, 27 m asl). To obtain ET_0 records for specific elevations (mean altitude of WEAP catchment nodes), monthly data from Beirut Mean and Al-Arz were interpolated, extrapolated for elevations above Al-Arz respectively.

Temperature records and relative humidity records originate from TUTIEMPO NETWORK internet climate database. This database contains daily climate data for the station at Beirut Airport, starting in 1957, free of charge. In order to obtain respective records for specific elevations (mean altitude of WEAP catchment nodes), average monthly temperature records were projected on the mean altitude of the respective elevation, using a temperature gradient of -0.7 °C/+100 m.

3.4.3 Other Data

Secondary population data were modified after GITEC (2011b) while primary records were obtained from municipalities interviews with municipality representatives (SCHULER, 2011). In case of none existing population records, figures were derived from registered apartment-unit records per municipality. In this case, total numbers of apartment units were multiplied with an average number of 4 persons per unit (GITEC, 2011b).

4 General Characteristics of the Jeita Catchment

4.1 Topography

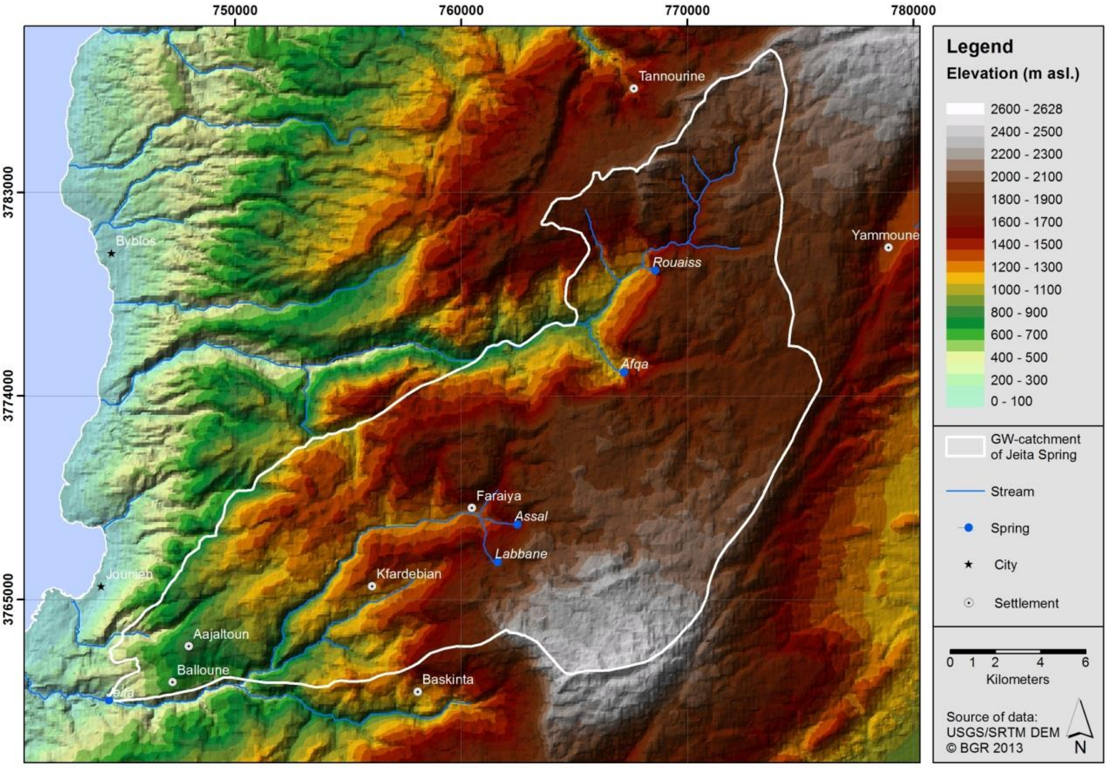

Figure 2: Elevation of the Jeita GW Catchment in m asl

The catchment of Jeita spring covers a total area of 405.6 km². It ranges between 60 m asl at Jeita spring, and 2,628 m asl at Mt Sannine, located in the south-eastern corner of the GWCZ (Figure 2). The relief of the study area, located on the western exposed side of the Lebanon Mountains, is dominated by a high plateau in the east and a change between very high and very low slopes in the center. Mean records of the slope raster in Figure 3 (cell size 110 m x 110 m) is 12.4°, with maximum records reaching 57.8°.

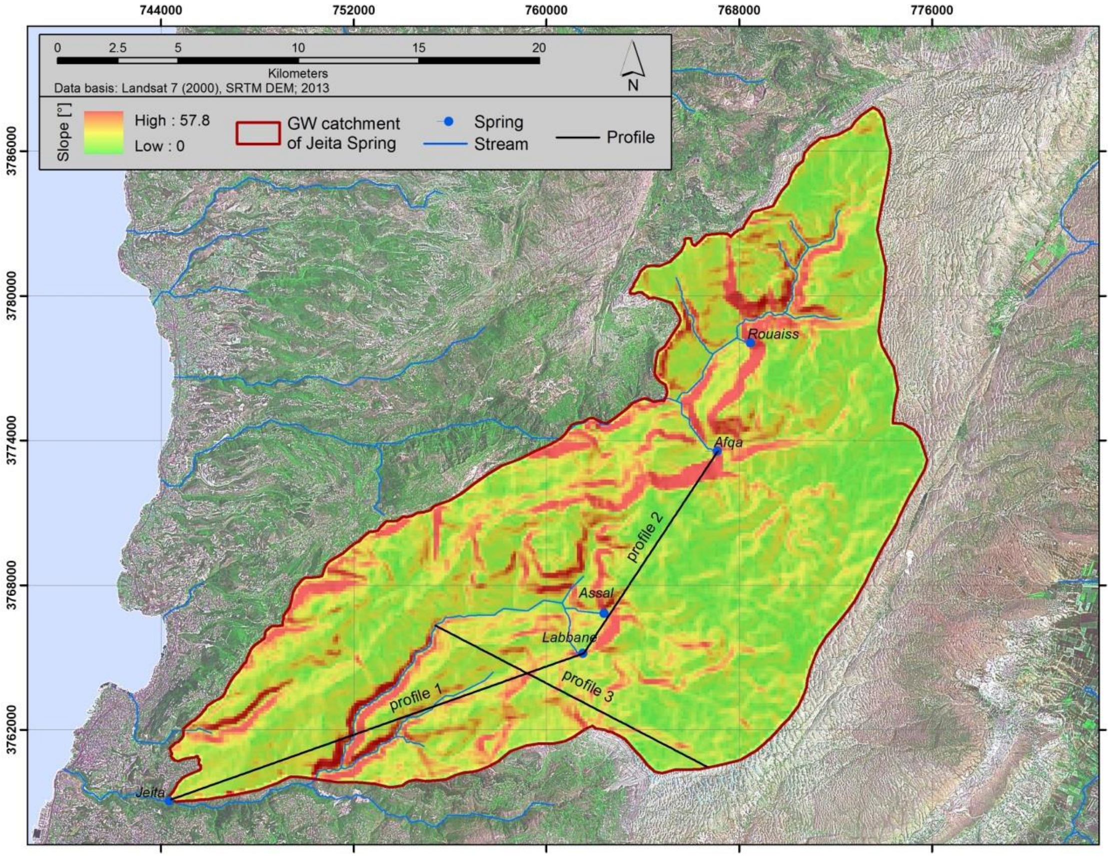

Figure 3: Topography of the Jeita Spring Catchment and three Profiles

Steepest reliefs occur along the hillside of fluvial shaped valleys in the southern center of the catchment (Figure 4: between the distance of 7,000 and 9,000 m from Jeita; Figure 6: in 12,000 m distance from Mt Sannine) and along the catchment's northern boundary, on the geological J4 unit (Figure 10). 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 4: in distance of 15,650 to 16,120 m from Jeita spring; Figure 6: in distance of 8,240 to 8,500 meters from Mt Sannine). Parallel to this bank, it is the lowest part of the C4 unit that has a very steep relief (Figure 6: in distance 8,570 to 10,130 m from Mt Sannine). High slopes lead to high velocities of surface runoff.

High rates of groundwater recharge occur in the eastern part of the catchment, on the C4 unit. Above approx. 1,850 m asl, the relief becomes flat towards the east, forming a plateau that covers the whole eastern part of the catchment (Figure 5: in distance of 3,330 and 8,570 m from Labbane spring).

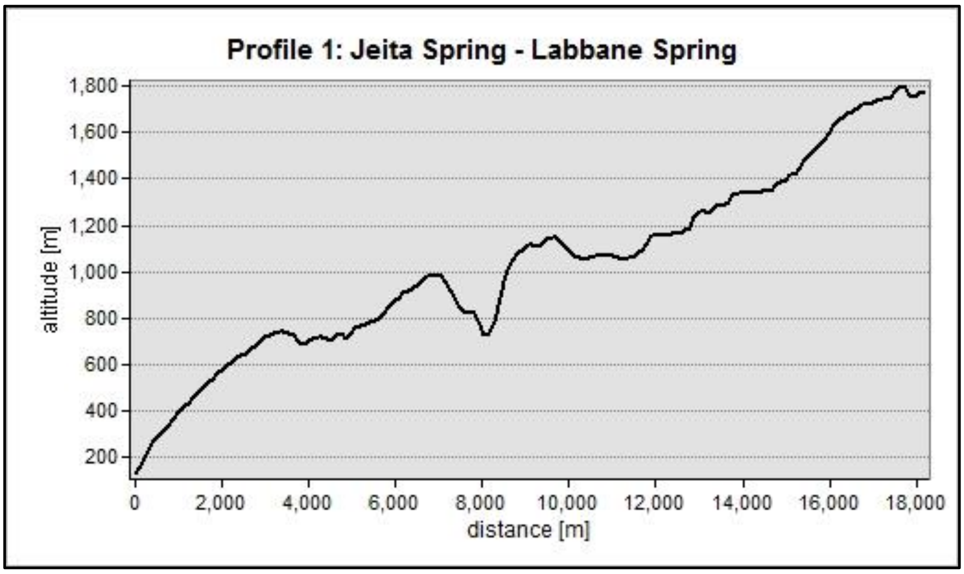

Figure 4: Profile between Jeita Spring (l) and Labbane Spring (r), ranging between 130 and 1,785 m asl

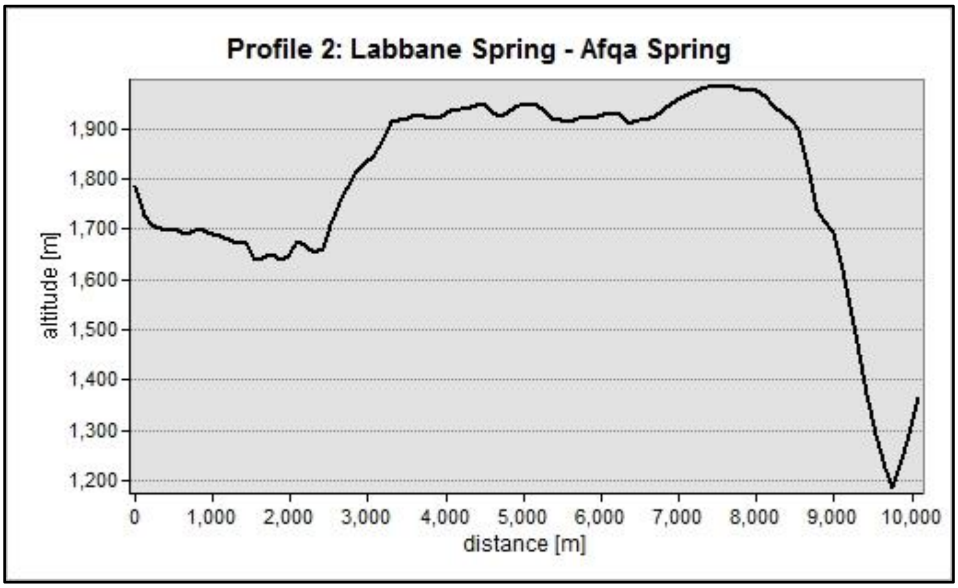

Figure 5: Profile between Labbane Spring (l) and Afqa Spring (r), ranging between 1,785 and 1,365 m asl

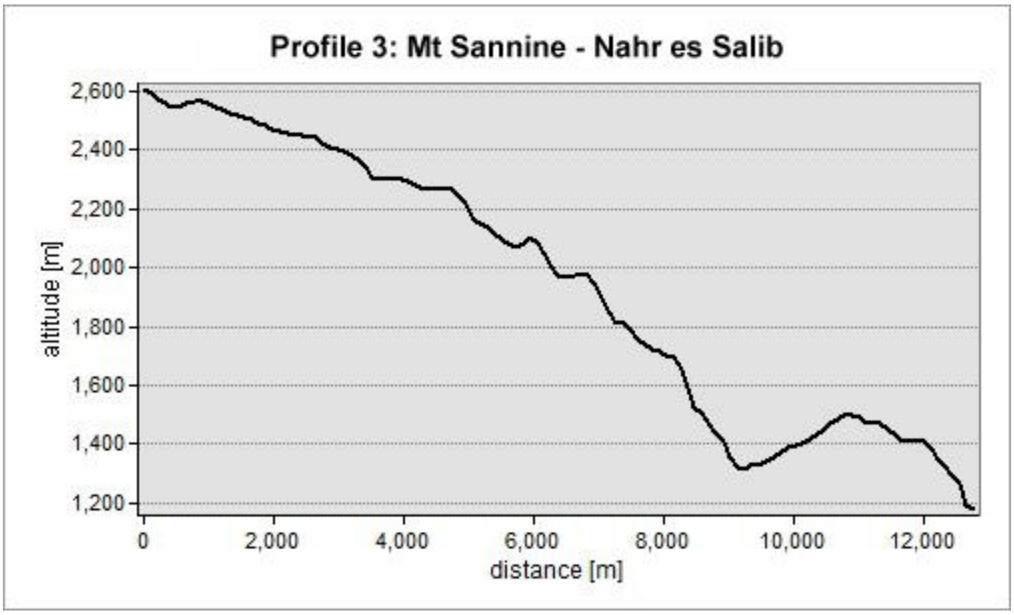

Figure 6: Profile between Mt Sannine (l) and Nahr es Salib (r), ranging between 2,628 and 1,190 m asl

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, while 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 in summer; on the other side, due to the ascending altitude, conditions in the Lebanon Mountains are increasingly cooler and increasingly humid. In April conditions are classified as semi-humid, as arid from May to the end of October, as humid in March and November and as wet from December until the end of February (UNDP, 1972). At Laqlouq (1,700 m asl), 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: between 1931 and 1960, average annual rainfall ranges between 1,200 mm at Raifoun (1,050 m asl), 1,435 mm at Qartaba (1,140 m asl) and 1,500 mm at Faraiya (1,325 m asl) (Figure 7).

Minimum monthly average precipitation for the three stations occurs in July and August (1 mm) while the maximum is reached in January (275 mm, 313 mm, 328 mm) (ATLAS CLIMATIQUE DU LIBAN, 1977). For an estimated size of Jeita spring's GW catchment of 288 km^2, UNDP (1972) calculates 1,415 mm of average annual rainfall, which is lower than the average annual rainfall of 1,529 mm, as calculated for the present catchment size of 405.6 km^2. Quantity of rainfall correlates with increasing altitude while spatial variation of precipitation reflects the effect of orographic lifting along the relief of the Lebanon Mountains.

Based on the available water resources through precipitation, reference evapotranspiration (ET_0), humidity and temperature (T) are the variables that drive actual ET. Figure 8 shows the inverted seasonal peaks of ET_0 and P. ET_0 ranges between a minimum of 28.2 mm in January in Al-Arz and a maximum 182.6 mm in Beirut in July.

Average monthly temperatures range between a minimum of -1.8 °C for the entire C4 outcrop area in January and a maximum of 19.3 °C for the entire J4 outcrop area in August (Figure 9).

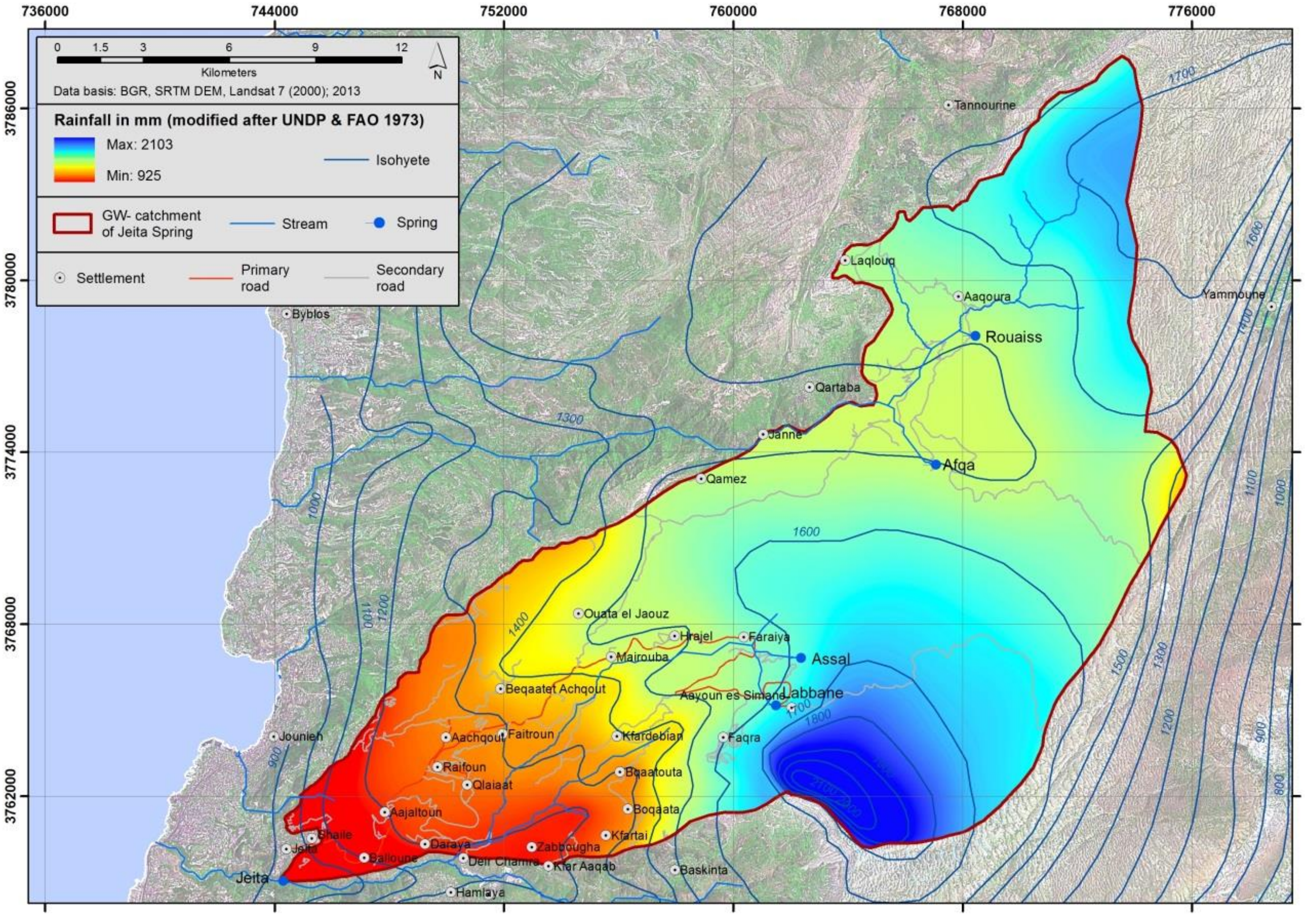

Figure 7: Average annual Precipitation between 1939 and 1970, modified according to MARGANE et al. (2013)

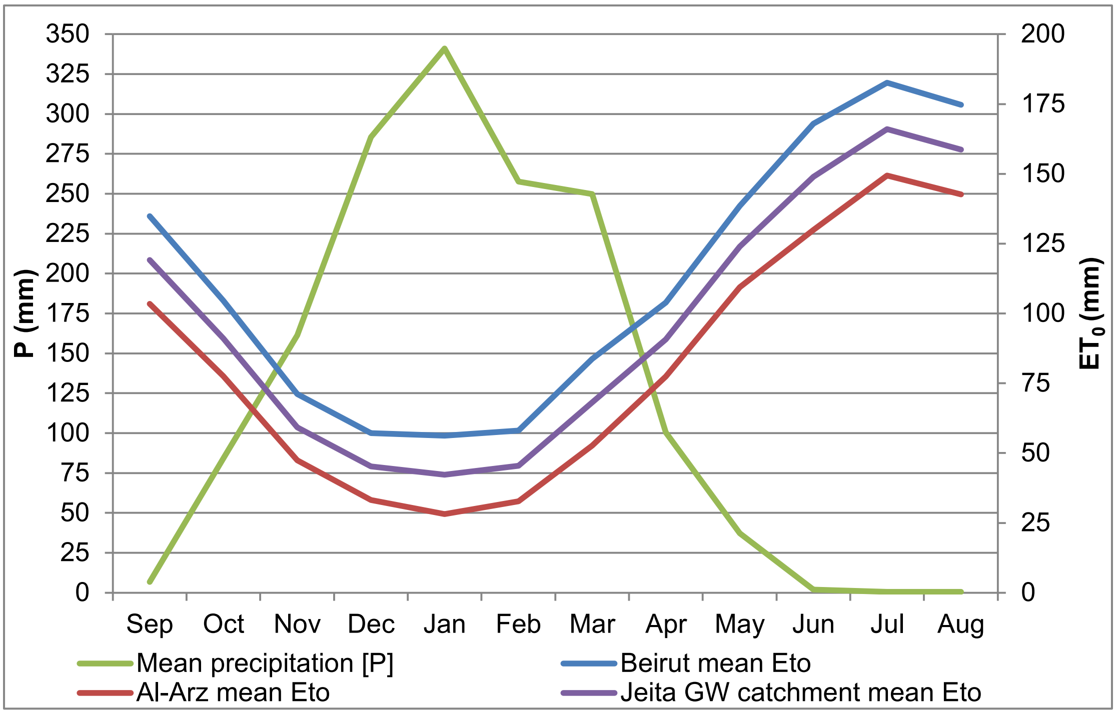

Figure 8: Average monthly P for Faraiya, Laqlouq, Qartaba and Raifoun between 1931 & 1960 and average monthly ET_0 for Al-Arz and Beirut Mean in mm; Source of Data: ATLAS CLIMATIQUE DU LIBAN (1977); FAO CLIMWAT Database

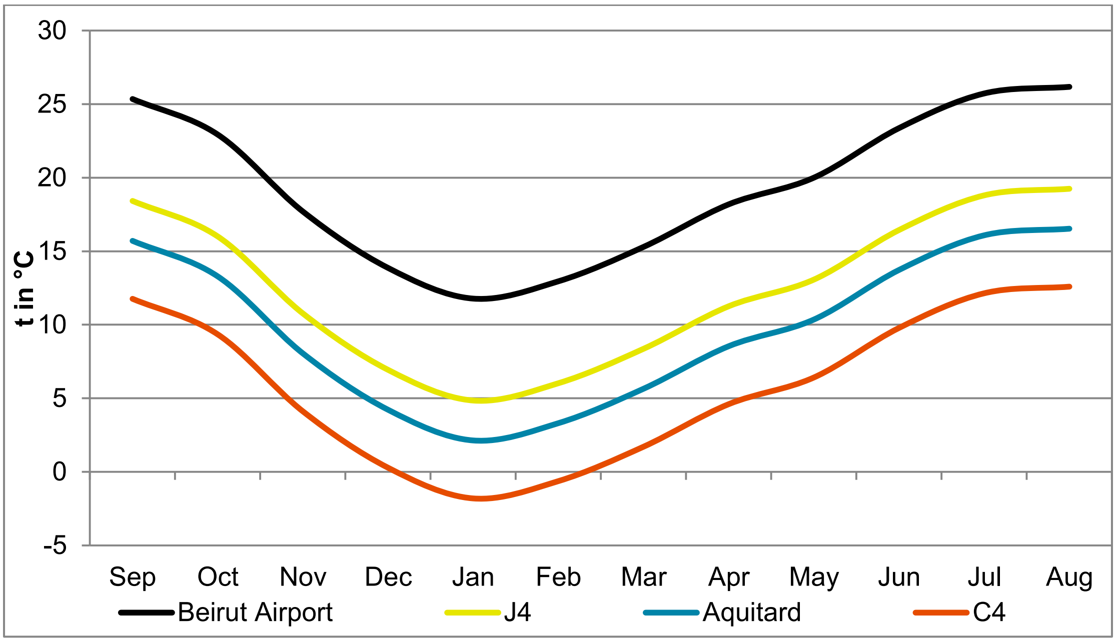

Figure 9: Average monthly Temperature in °C of the Water Years 1974 & 1975; Source of Data: TUTIEMPO NETWORK

4.3 Geology

Figure 10 displays the updated geological map (July 2013) of the Jeita GW catchment. For a detailed description, see Technical Report No 4 (HAHNE, 2011).

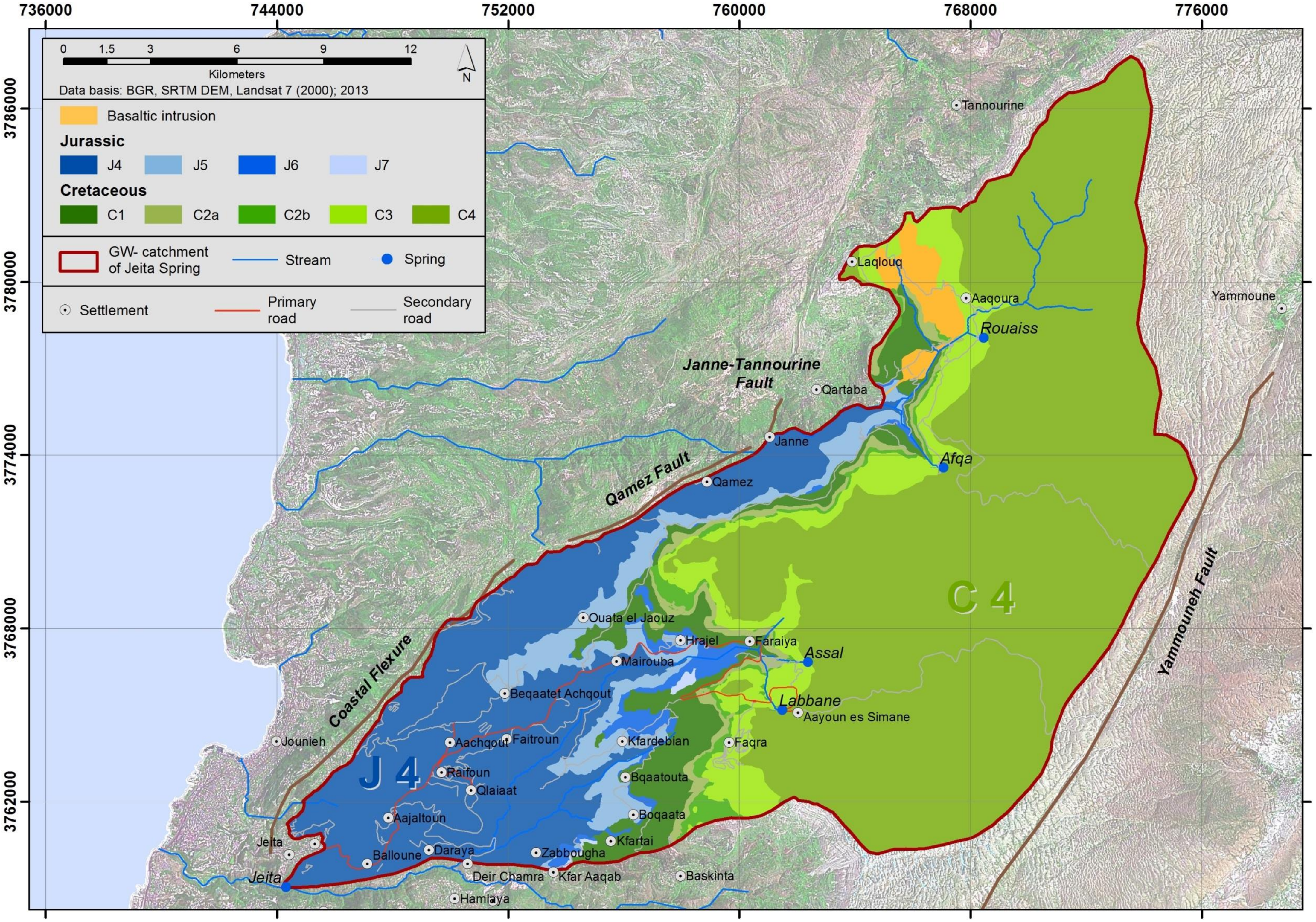

Figure 10: Geological Setting of the Jeita Spring GW Catchment

4.4 Landuse and Landcover

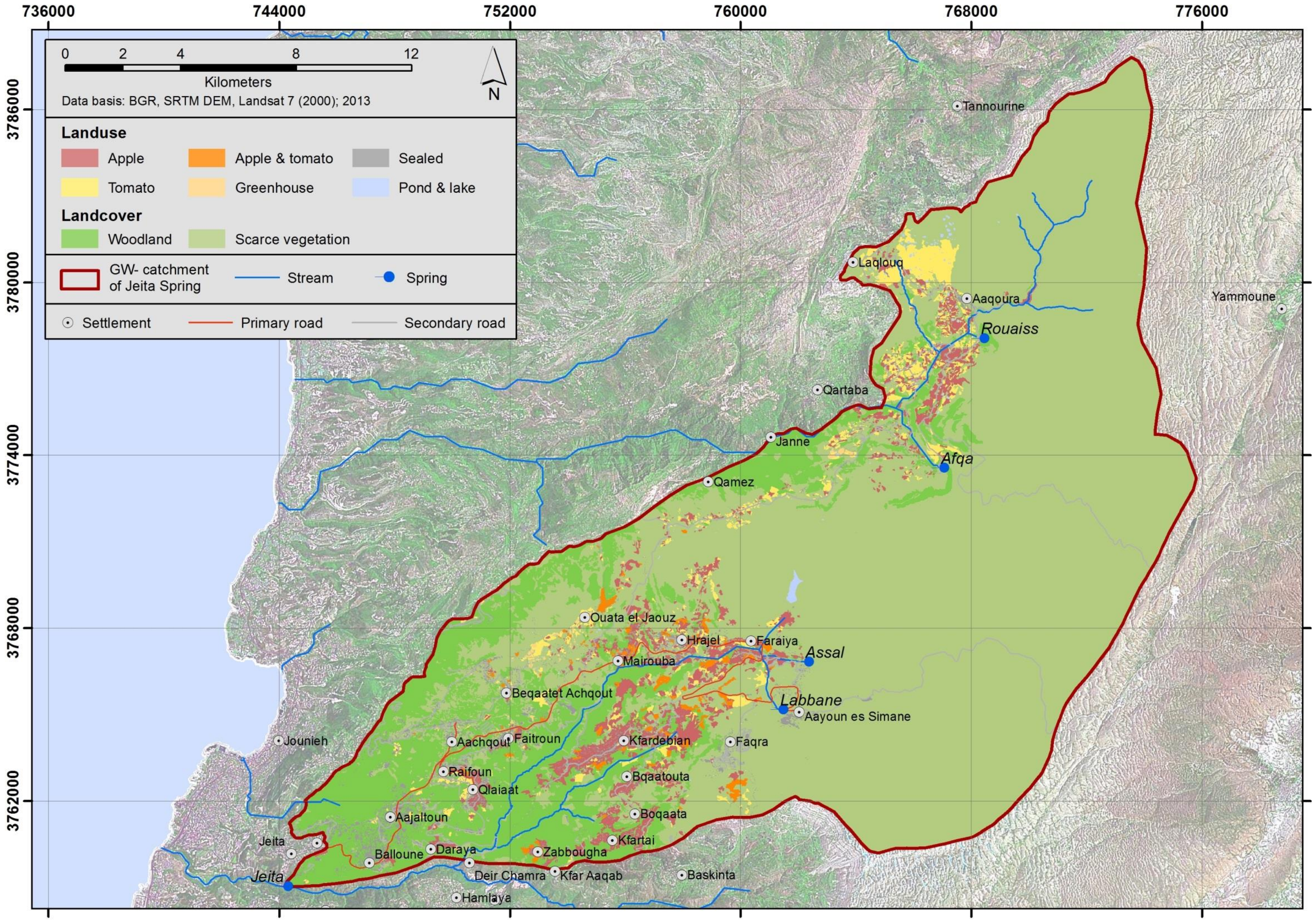

Figure 11: Landuse and Landcover Classes within the Jeita Spring GW Catchment

Total landuse, i.e. for and by human activities shaped surface, covers in total 4,364 ha, which corresponds to 10.8% of the whole catchment. In turn, total landcover, i.e. land that is not primarily shaped for human activities, covers in total 36,191 ha, which corresponds to 89.2% of the entire catchment area. Figure 11 shows the spatial distribution of all 8 landuse and landcover classes and Figure 12 presents the share of the generalized classes of the whole catchment.

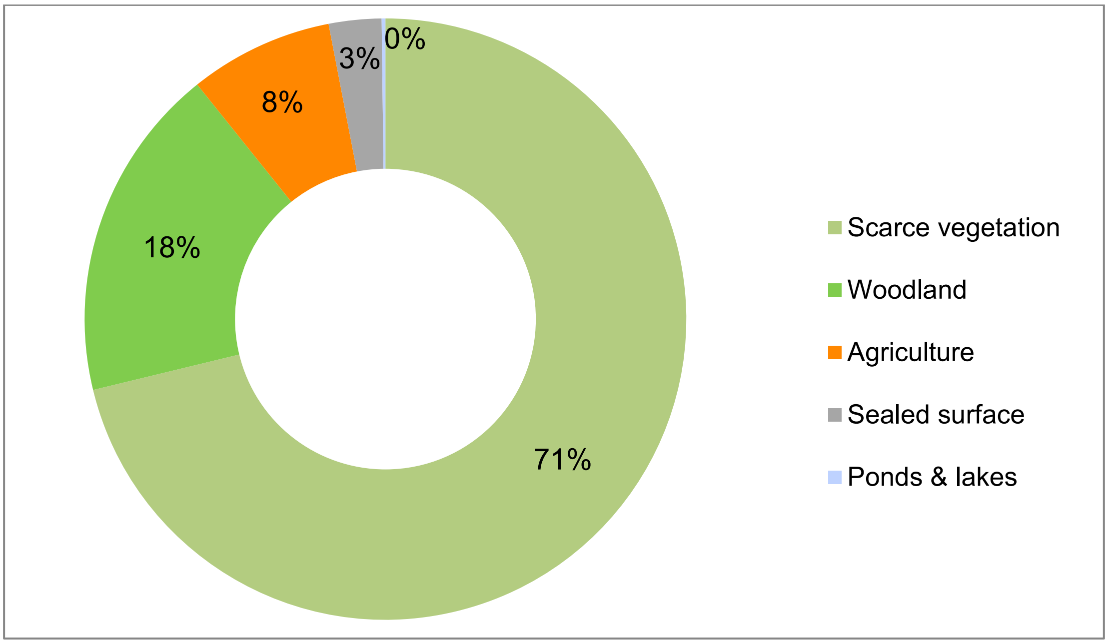

Figure 12: Landuse & Landcover within the Jeita Spring Catchment in % of the total Area

1,147 ha (3%) of the Jeita catchment is covered by *sealed surface* i.e. roads and housing. Sealed surfaces are mainly concentrated in the southwest of the catchment, in the dense populated agglomerations of Jeita, Balloune, Aajaltoun and Raifoun. On sealed surfaces, runoff is relatively high and storage of water very low. Thus, this class was assigned a k_c-value of 0.1.

3,136 ha (8%) of the Jeita catchment is covered by agriculture, i.e. *tomatoes*, *apples* and *ponds & lakes*. The smallest share, about 82 ha (0.2%) is covered by *ponds & lakes*. This landuse class was only integrated in SC 2.1 and 3.3, assigned a k_c-value of 1. *Apples* account for 62% of all spatial agricultural activity. Apples are mainly grown in the center of the catchment, between 1,150 and 1,500 m asl. Tomatoes are grown wide spread throughout the catchment but below 1,800 m asl. *Tomatoes* account for 38% of agricultural activity.

88% of all agricultural activity takes place on the Aquitard Complex. The remaining share of agricultural activity takes place on the J4 unit, while there is practically no agricultural activity on the Upper C4 unit.

Woodland accounts for 7,311 ha (18%) of total cover. Within the catchment, there exist mainly drought tolerant trees, either coniferous (cedar: *cedrus libani*, approx. 5 ha; pines: *pinus brutia, pinus pinea*) or broadleaved (oak: *quercus calliprinos; quercus infectoria*). For the aggregated landcover class *woodland*, the k_c-value was estimated at 0.8.

Scarce vegetation accounts for the largest share, which corresponds to 28,880 ha (71%), covering mainly the eastern part of the catchment. Due to very low storage capacity of rainfall, the landcover class *scarce vegetation* was assigned a k_c-value of 0.2.

4.5 Population

Lebanon’s last census dates back to 1932. Population records used in this study were either derived from registered apartments per municipality, taken from municipality records/estimations and extracted from GITEC (2011b) and modified. Population figures were used to model municipalities’ total water demand, ET, consumption and their total wastewater return flow.

In the Jeita catchment, there is currently no central wastewater collection and treatment system. Domestic wastewater is mainly injected and seeping into the underground, while only a relatively small share is discharged into Nahr el Kalb or other streams. Thus, within the WEAP model, domestic return flow (wastewater return flow) was modeled only as flow towards the groundwater system.

Between the summer (for the model defined as April to December) and winter season (for the model defined as January to March), total population size, which physically stays in the catchment, varies. During summer, the population reaches approx. 140,000 while during winter, population sizes drops to approx. 99,000. In agriculture-dominated villages like Lassa or Ouata el Jaouz, population size decreases by 80-90% in winter. This seasonal variation of population size results in changing demand for drinking water – and so, in a seasonal variation of total discharged wastewater.

Table 9-11 in Chapter 7.1.2 present municipalities/villages of the Jeita catchment and their population records during winter and summer. FAO AQUASTAT estimates the daily per capita water demand in Lebanon at 200-250 liters while projections from FADEL et al. (2000) estimate an approximate figure of 230 liters. Both figures are fairly high and don’t seem realistic. According to the knowledge of the authors, GIZ (2012) provide the only measured per capita water demand in Lebanon (for a district in Saida), which is 135 l/d. These records, however, could not be directly adopted from GIZ (2012) and applied on the WEAP model because the income and standard of living is higher in Keserwan, resulting in a higher expected water demand (BISWAS & TORTAJADA, 2009). Thus, the average per/capita water demand was increased at 140 l/d, which corresponds to 51.1 m^3/year. For D_M Faqra Club and D_M Ayoun es Simane, annual water demand/capita was estimated at be 60 m^3, corresponding to 164 l/d.

4.6 Water Supply

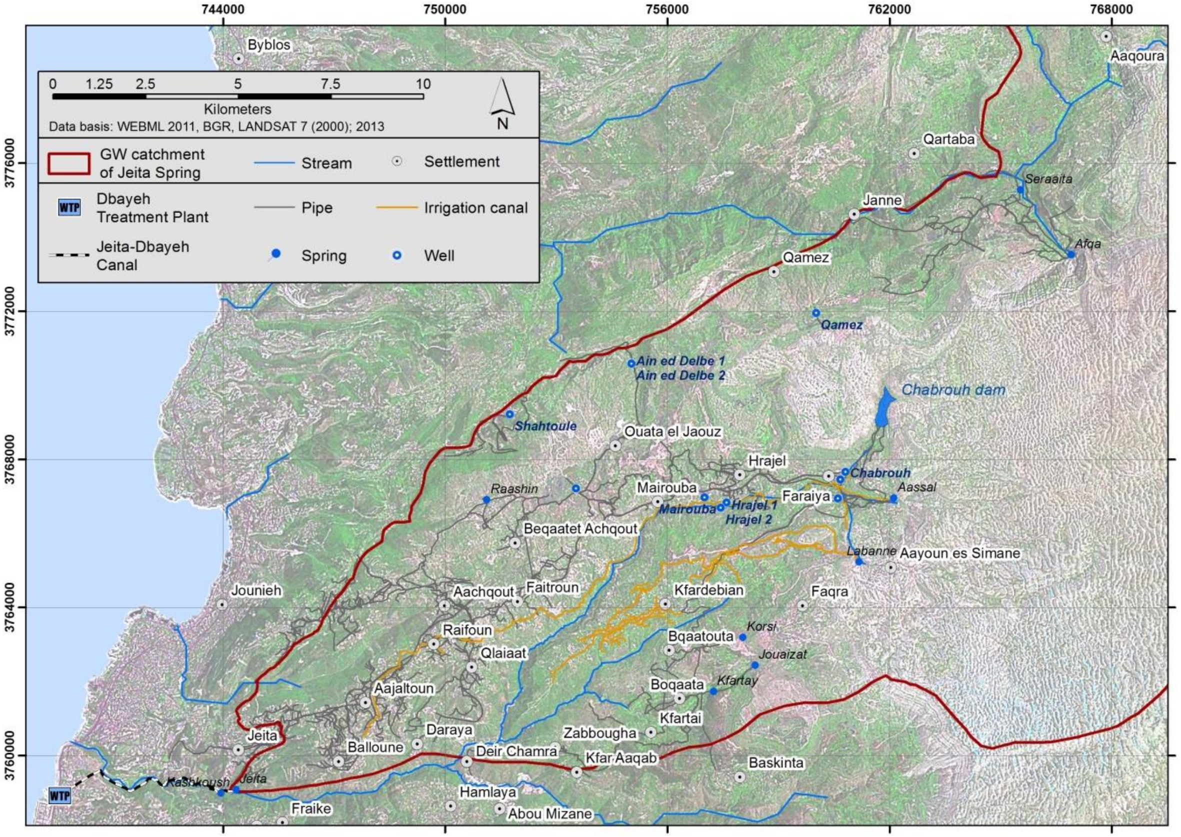

Figure 13: Irrigation Canal Network and domestic Water Supply Infrastructure of Water Establishment Beirut & Mount Lebanon

5 Water Balance Components

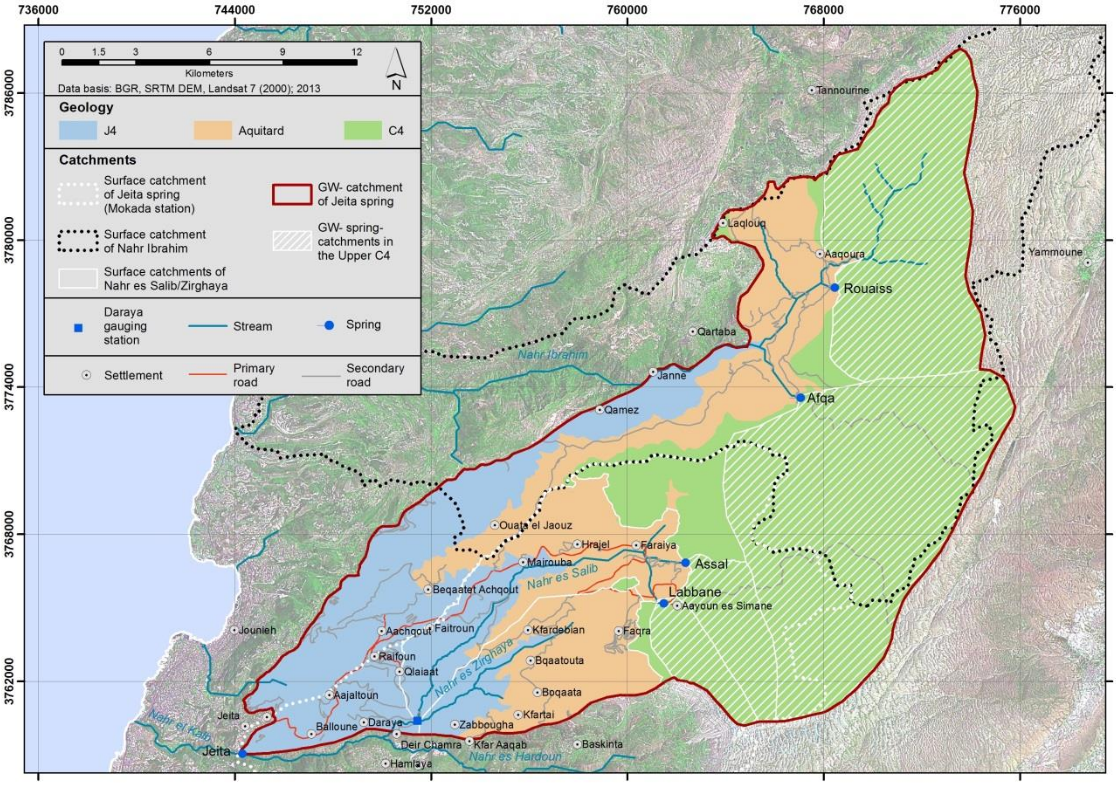

Figure 14: Hydrogeology of the Jeita Spring Catchment

5.1 *Surface Water*

For the present WEAP model, discharge records from Daraya gauging station were used to fit the model to observed data (Figure 15). Total annual discharge of Nahr el Kalb between the water years 1968 and 1974 sums up to 102.7 MCM. Average monthly discharge ranges between a minimum of 0 MCM in September and a maximum of 22.1 MCM (8.5 m³/s) in April.

The first peak of generated runoff of a water year appears in December and is related to the first rainfall events. Decrease in runoff in January and February is related to snowfall events above ~1,500 m asl and respective delay in GWR and spring discharge response. Thus, a second and higher peak of discharge occurs in April.

Daraya gauging station of Nahr el Kalb measures the streamflow below the conversion of Nahr es Zirghaya and Nahr es Salib. Both of the rivers' surface catchments extend between the J4 unit and until the outcropping base of the C4.

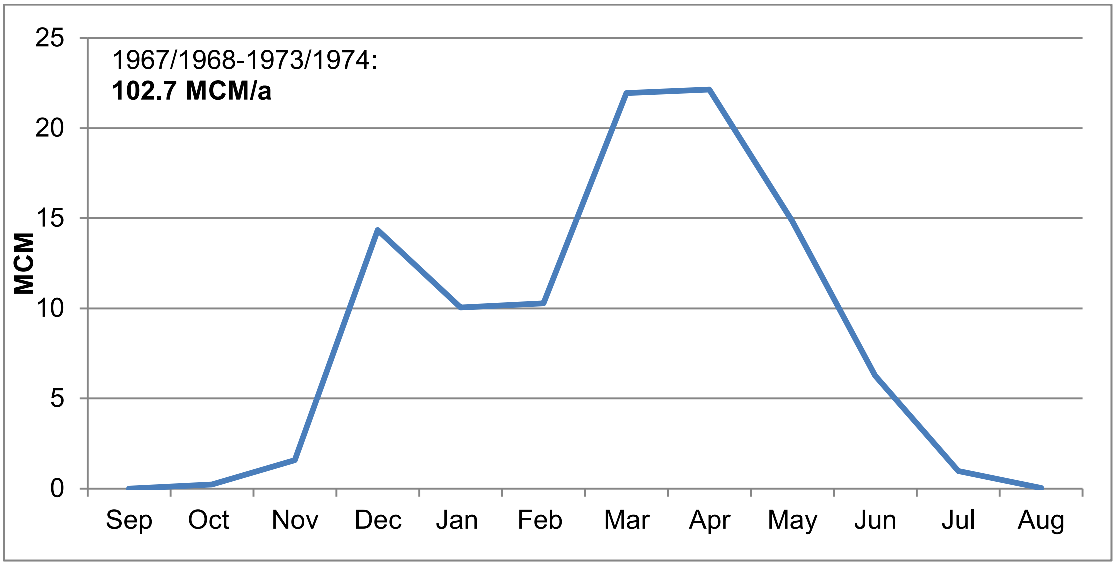

Figure 15: Average monthly Discharge of Nahr el Kalb in MCM at Daraya Gauging Station for the Water Years 1968 to 1974; Source of Data: LRA, 2011

Within the present WEAP model, runoff was modeled according to the FAO Rainfall Runoff Method (simplified coefficient) (CRITCHLEY & SIEGERT, 1991). WEAP uses following algorithm to calculate runoff (SEI, 2011):

$$R = MAX\ (0,\ PrecipAvailableForET - ET_{pot}) + (P \times (1 - P_{eff}))$$ [Equation 1],

where R is runoff (MCM), PrecipAvailableForET is the precipitation that is available for evapotranspiration (MCM), ET_{pot} the potential evapotranspiration (MCM), P precipitation (mm) and P_{eff} is the effective precipitation (%).

5.2 Evapotranspiration

Monthly actual ET depends on the availability of water (precipitation), the rate of reference evapotranspiration (ET_0) and the specificity of surface, which is expressed through the crop coefficient (k_c). Thereby, k_c-values were assigned to agricultural and non-agricultural landuse and landcover classes. To determine the actual evaporation on a specific surface, WEAP uses following algorithms (SEI, 2011):

$$ET_{actual} = Min\ (ET_{pot},\ PrecipAvailableForET)$$ [Equation 2],

where ET_{actual} is the actual evapotranspiration (MCM), ET_{pot} the potential evapotranspiration (MCM) and PrecipAvailableForET (MCM) is the precipitation that is available for evapotranspiration.

ET_{pot} is calculated by the equation:

$ET_{pot} = ET_o \times k_c \times area \times 10^{-5}$ [Equation 3],

where ET_0 is the reference evapotranspiration (mm), k_c the FAO crop coefficient and area is the area of landcover (ha).

PrecipAvailableForET (MCM) is calculated by the equation:

$PrecipAvailableForET = P \times area \times 10^{-5} \times P_{eff}$ [Equation 4],

where P is precipitation (mm), P_{eff} the effective precipitation (%) and area is the area of landcover (ha).

Figure 16 displays the contrary development of total annual P and ET_0 with reference to increasing altitude, as they are representative for the Jeita spring catchment.

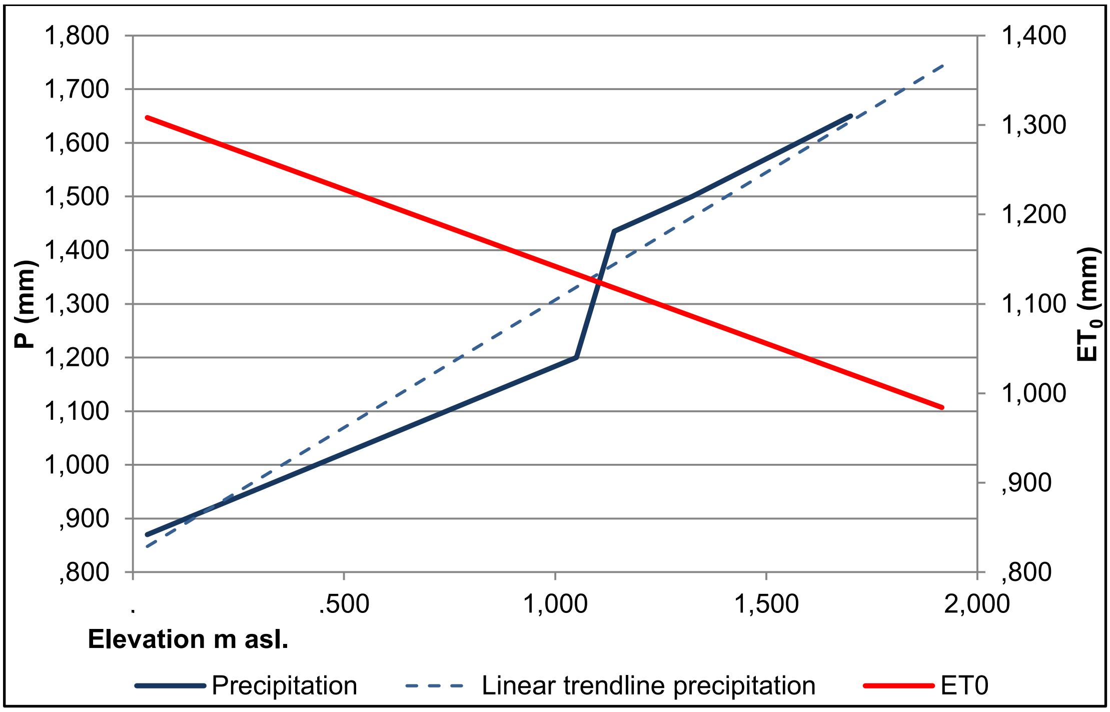

Figure 16: Mean annual P of American University Beirut (35 m asl), Raifoun (1,050 m asl), Qartaba (1,140 m asl), Faraiya (1,325 m asl) and Laqlouq (1,700 m asl) between 1931 & 1960 and total annual ET_0 between Al-Arz (1,916 m asl) and Beirut Mean (27 m asl); Source of Data: ATLAS CLIMATIQUE DU LIBAN (1977); FAO CLIMWAT Database

5.3 Groundwater Discharge

5.3.1 Jeita Spring

Jeita spring is located on 60 m asl. For the water years 1967 to 1968 and 1970 to 1971, average monthly records for this period are displayed in Figure 17 while discharge records are presented in Table 2 (the water year 1969 was excluded due to an unreliable annual discharge of 307 MCM). For this period, average annual discharge is 166.4 MCM, which corresponds to an average annual flow of 5.3 m³/s. Highest discharge occurs in February and March, with an average discharge of 27.8 MCM (11.5 m³/s), 27.6 MCM (10.3 m³/s) respectively, as response to the rainy season that starts mid of November. Lowest monthly discharge occurs in September, with an average flow of 3.6 MCM (1.4 m³/s).

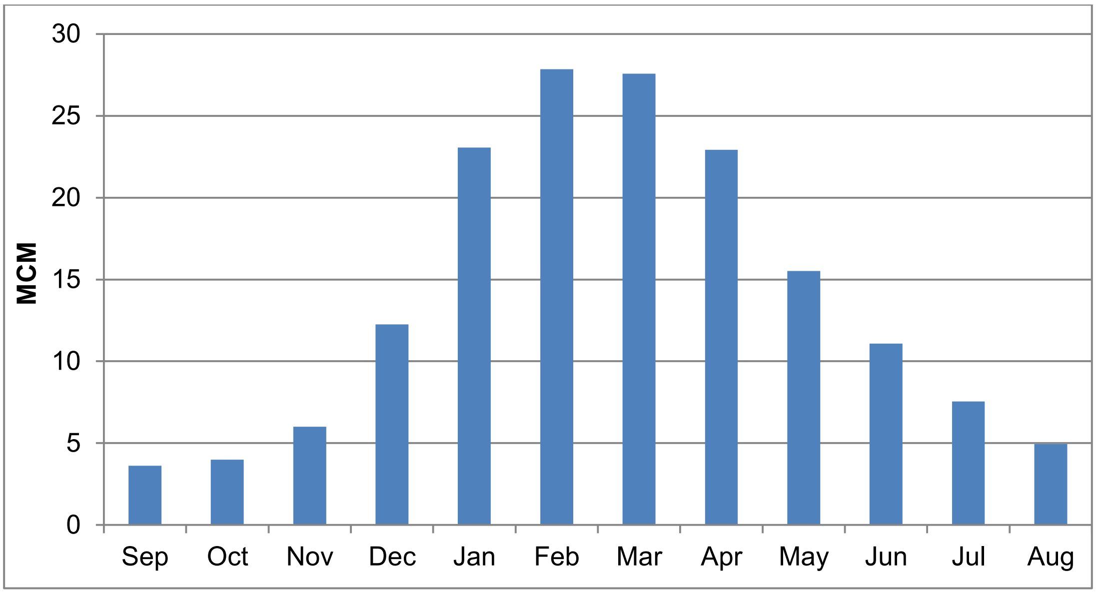

Figure 17: Average monthly Discharge of Jeita Spring between the Water Years 1967 to 1968 & 1970 to 1971 in MCM; Source of Data: UNDP (1972)

Jeita is directly fed by groundwater through the J4 Aquifer, which in turn mainly receives water via infiltration of rainfall on the land surface. In addition, the J4 is indirectly recharged by groundwater leakage through the Aquitard, irrigation and domestic return flows and through riverbed infiltration from Nahr Ibrahim and Nahr es Salib/Nahr es Zirghaya. In Ibrahim Valley between 40% and 51% of total streamflow infiltration was proven into the J4 Aquifer (MARGANE, 2012b). Due to this riverbed infiltration, the C4 becomes the main source of the J4.

Table 2: Average monthly Discharge of Jeita Spring for the Water Years 1967 to 1968 & 1970 to 1971 in MCM; Source of Data: UNDP (1972)

Water year	1967	1968	1970	1971	Total
Sep	4,2	3,7	3,2	3,4	**3,6**
Oct	3,4	4,5	5,0	3,1	**4,0**
Nov	6,8	7,1	6,2	3,9	**6,0**
Dec	16,6	15,0	6,5	11,0	**12,3**
Jan	29,2	37,6	15,3	10,1	**23,1**
Feb	39,5	36,0	23,2	12,7	**27,8**
Mar	34,2	26,8	27,3	22,0	**27,6**
Apr	22,6	14,2	19,4	35,5	**22,9**
Mai	15,3	10,8	14,4	21,7	**15,5**
Jun	12,4	9,5	9,0	13,5	**11,1**
Jul	8,7	6,9	5,5	9,2	**7,6**
Aug	6,8	4,0	3,7	5,3	**4,9**
TOTAL	**199,8**	**176,0**	**138,3**	**151,4**	**166,4**

5.3.2 Afqa Spring

Afqa spring is located on 1,300 m asl. Its GW catchment has a total size of 101.5 km² and a mean elevation of 2,012 m asl, reaching up to 2,500 m asl. Afqa is completely fed through the C4 unit, showing a high variation of discharge throughout the year. Figure 18 displays the average monthly discharge of Afqa between the water years 2001 and 2010 (no historic discharge records available). Average annual discharge is 123.2 MCM, with an average monthly minimum in October with 0.5 MCM (0.2 m³/s) and an average monthly maximum in April with 37.6 MCM (14.0 m³/s).

All of Afqa's discharge leaves he Jeita catchment via Nahr Ibrahim, which flows westwards, along the northern boundary of the Jeita catchment towards the Mediterranean Sea. It is proven that from Nahr Ibrahim, approx. 45% of surface water flow infiltrates through river bank infiltration into the J4 unit (MARGANE 2012b), whereas the actual rate of infiltration depends on the water level in the river and so, on the season. The period of infiltration starts after snowmelt in the Laqlouq area and spring discharge of Afqa and Rouaiss and lasts until September. Between September and spring, no major infiltration occurs.

Water from Afqa spring is used for domestic purpose in the north-east of the catchment, as well as for agricultural activity. For both purposes, an assumed figure of 0.5 MCM/year was conveyed out of the catchment in WEAP.

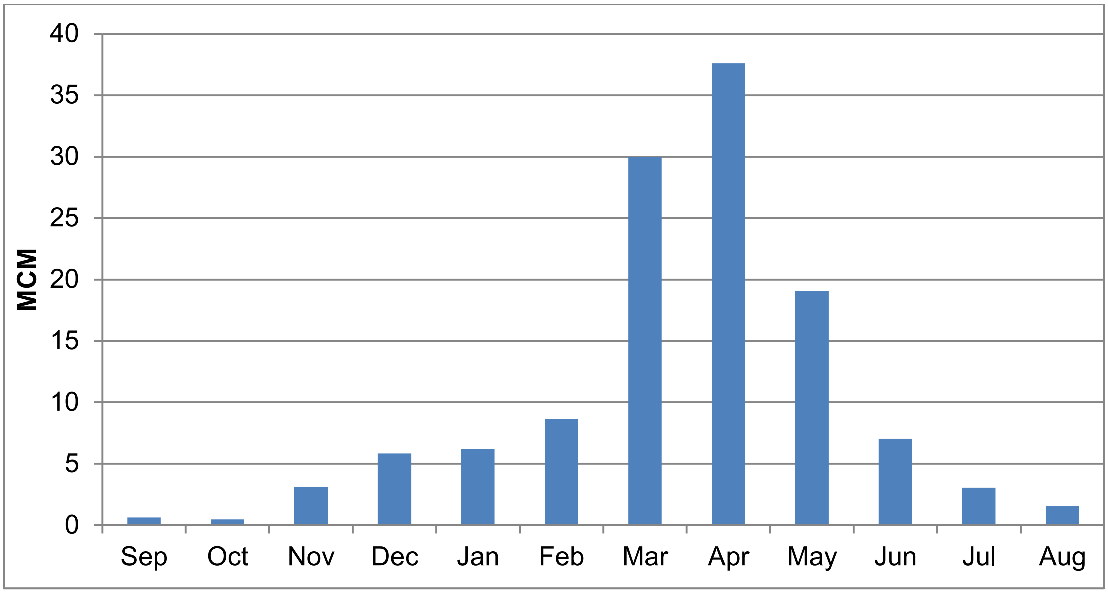

Figure 18: Average monthly Discharge of Afqa Spring between the Water Years 2001 & 2010 in MCM; Source of Data: LRA, 2011

5.3.3 Assal Spring

Assal spring is located on 1,570 m asl. Its GW catchment has a total size of approximately 14.6 km² and a mean elevation of 2,174 m. asl, reaching up to 2,628 m asl. Assal is completely fed through the C4 unit. For the average water year 1969 to 1973, discharge is 24.2 MCM. Based on he rojec 's easurements of spring discharge of Assal (ADCP), annual discharge was surmised to be at 21 MCM, which is 13% less of the LRA measurements. Calibration of Model 1 results in an annual discharge of 21.4 MCM (keeping the monthly distribution of measurements of LRA).

Figure 19 shows the monthly discharge records of Assal spring. Highest discharge occurs in May, with an average monthly discharge of 4.9 MCM (1.8 m³/s), in response to snowmelt in the C4 outcrop area. Lowest average monthly discharge is measured for November, with 0.7 MCM (0.3 m³/s).

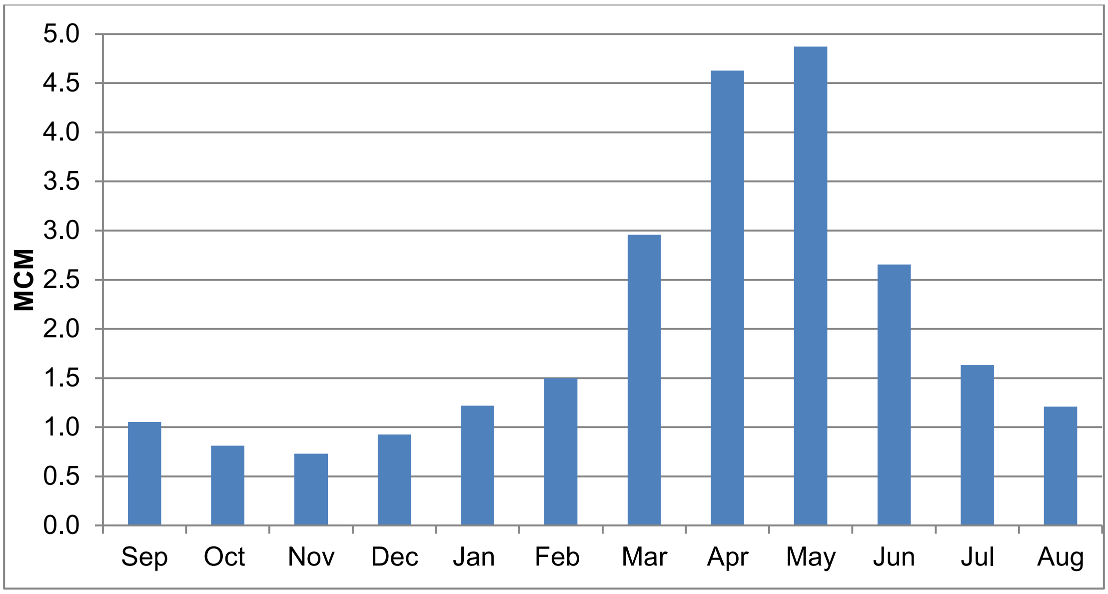

Figure 19: Average monthly Discharge of Assal Spring between the Water Years 1969 & 1973 in MCM; Source of Data: LRA, 2011; MARGANE & STOECKL (2013)

5.3.4 Labbane Spring

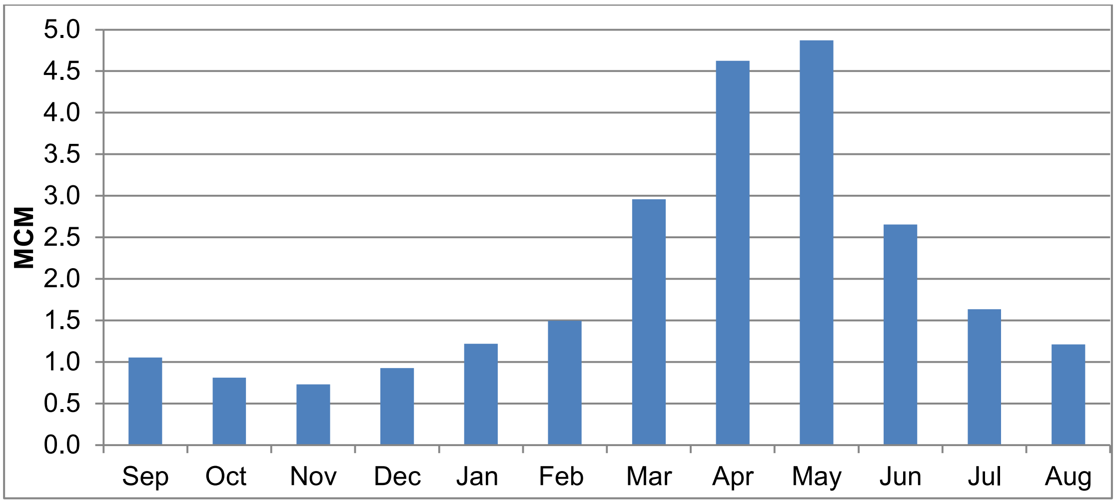

Figure 20: Average monthly Discharge of Labbane Spring, based on monthly Discharge between the Water Years 1972 & 1973 in MCM; Source of Data: LRA, 2011; BGR, 2013

Labbane spring is located on 1,785 m asl. Its GW catchment has a total size of approximately 9.5 km² and a mean elevation of 2,171 m asl, reaching up to 2,500 m asl. Labbane spring is completely fed through the C4 unit. For the average water year 1972 to 1973, discharge is 15.3 MCM. Based on the project's measurements of spring discharge of Labbane by dilution tests, mean annual discharge was surmised to be 6% less than LRA measurements. Within WEAP, annual discharge was defined as 14.4 MCM (keeping the monthly distribution of LRA, 2011).

Figure 20 shows the monthly discharge records of Labbane spring. Monthly discharge has been calculated by the mean monthly distribution of the water years 1972 to 1973. Highest discharge occurs in May, with an average discharge of 6.0 MCM (2.2 m³/s), in response to snowmelt in the C4 outcrop area. Lowest average monthly discharge occurs in September, with 0.03 MCM (0.01 m³/s).

Labbane spring indicates the highest variability in seasonal discharge of all springs; 71% of its total annual discharge is discharged between April and June.

Water from Labbane spring is conveyed to Chabrouh dam and into the irrigation canal system (Figure 13).

5.3.5 Rouaiss Spring

Rouaiss spring is located on 1,310 m asl. Its GW catchment has a total size of approximately 65.8 km² and a mean elevation of 1,919 m asl, reaching up to 2,275 m asl in the very north of the GWCZ. Rouaiss spring is completely fed through the C4 unit. For the average water year 2001 to 2011, according to LRA, discharge is 155.0 MCM, showing a very high inter-annual monthly scatter. Discharge records of Rouaiss are not reliable because the gauging station is in a fairly dilapidated condition and it is located ~1.4 km downstream the spring. This means that measured records include a share of surface runoff that is previously generated on the Aquitard. Therefore, annual discharge of Figure 21 is obtained during calibration of WEAP Model 1 (keeping the monthly dis-tribution of measurements of LRA), which results in 83.3 MCM. Highest dis-charge occurs in April, with an average discharge of 27.2 MCM (10.5 m³/s.), in response to snowmelt in the C4 outcrop area. Lowest average monthly dis-charge occurs in September, with 0.3 MCM (0.1 m³/s).

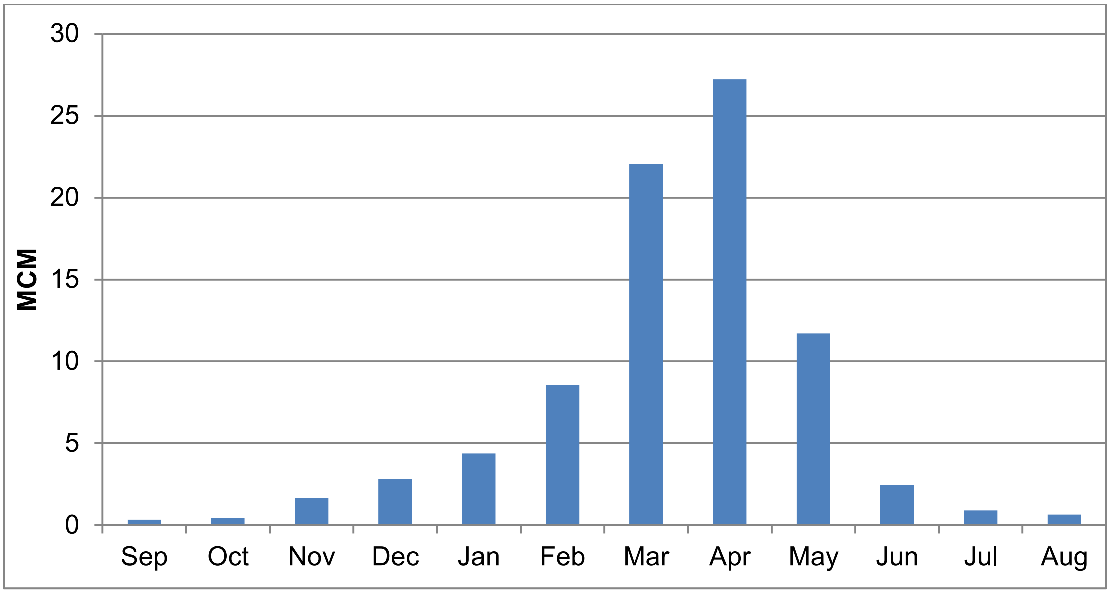

Figure 21: Average Monthly Discharge of Rouaiss Spring, according to Model 1 and based on the average monthly Discharge between the Water Years 2001 & 2011 in MCM; Source of Data: LRA, 2012; BGR, 2013

5.4 Groundwater Abstraction

5.4.1 Groundwater Uses

Within the catchment of Jeita spring, there are 9 official wells that are operated by WEBML. These wells serve for periodic supply to the domestic sector for the time when supply from Chabrouh dam is insufficient. Due to a lack of recording of abstraction, there is a high uncertainty concerning abstracted quantities from these wells.

Also, there is an unknown number of unlicensed wells. Total groundwater abstraction from these wells will most likely exceed the abstracted amount of the official wells. However, for the WEAP model, it was not differentiated between these two sources.

For the modeling period of Model 1, Chabrouh dam did not exist. Prior to the water supply from Chabrouh dam, Assal spring was the main supply source, which was insufficiently during the whole year. So, GW abstraction from the J4 must have been more commonly practiced than today in order to balance out the deficit in supply. It was estimated that in addition to the annual 166.4 MCM discharge of Jeita, ~6 MCM have been abstracted from the J4 throughout the year at that time. For the reference period of Model 2, however, Chabrouh dam exist, which reduces the need of GW abstraction. Thus, in Model 2, these 6 MCM were added for actual spring discharge of Jeita by calibrating the model according to an annual discharge of Jeita of 166.4 MCM + ~6 MCM = 171.3 MCM.

Annual GW abstraction by governmental wells was estimated at 0.5 MCM from the Mcheti/Chahtoul wells.

Within the model, groundwater is abstracted to cover irrigation demand and partially domestic demand (Demand site D_M Ayoun es Simane).

5.4.2 Physical Losses and Return Flow of Domestic Water Supply

Within the current Model 2, physical losses of the domestic supply network account 35%, recharging respective GW nodes. 35% estimated water loss may be in a realistic range, considering measured losses of 29% for a district in Saida (GIZ, 2012).

Domestic demand sites were defined to have a consumption rate of 50%. Thus, 50% of delivered supply is lost from the system through evaporation, while 50% constitutes return flow to groundwater.

5.5 Irrigation

5.5.1 Irrigation Water Uses

As outlined in Chapter 4.4, agricultural activity covers 3,136 ha. Irrigation water origins mainly from Assal, Labbane and Rouaiss spring but also from GW abstraction and ponds. The latter were modeled in SC 2.1.

Irrigation water is distributed via two irrigation canals (see Figure 13). Only a negligible share of irrigation water is contributed by Chabrouh dam (approximately 0.5 MCM per year).

As irrigation technique, farmers apply surface irrigation and mainly drip irrigation (AVSI, 2009), which has been empirical validated by field research. According to unpublished data, irrigation efficiency was expected to be 75%, as applied in the WEAP model.

Seasonal variation of crop water demand of apples and tomatoes is presented in Figure 22, based on ALLEN et al. (1998).

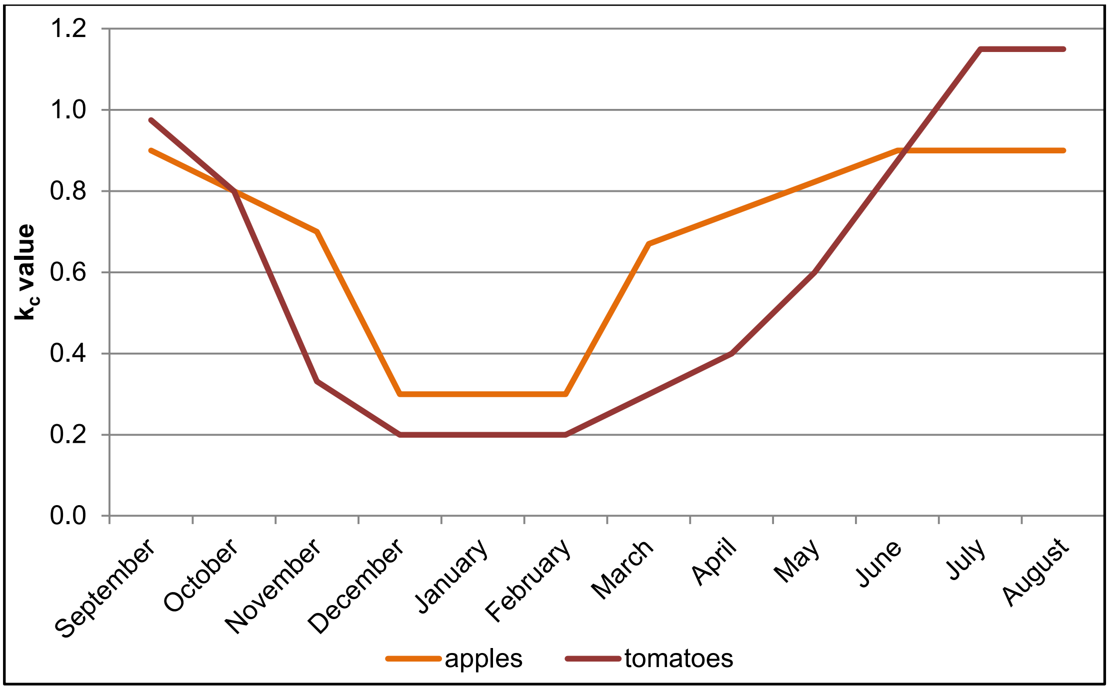

Figure 22: Crop Coefficient for Tomatoes (Mediterranean) and Apples; based on: ALLEN et al. (1998)

5.5.2 Irrigation Return Flow

Within the current model, irrigation return flow results through excess irrigation and was modeled according to the defined rate of irrigation fraction (irrigation efficiency). Irrigation fraction defines the share of supplied water that reaches the plant and is therefore available for ET. The difference between the irrigation fraction (in %) and 100 (%) needs to be additionally applied and is the remaining share that is available for surface runoff/groundwater recharge. Thus, absolute irrigation return flow depends on the irrigation fraction and on the defined proportion of groundwater recharge/surface runoff.

On the J4 Aquifer, GWR may be reaching 70% to 75% of total rainfall. Thus 18% -19% of total irrigation supply on the J4 is groundwater recharge.

On the Aquitard Complex, GWR may be 8% of total rainfall. Thus, irrigation return flow is 2% of total supplied irrigation water.

6 WEAP Model

6.1 Boundaries

Within this study, the GW catchment of Jeita spring was defined as an own hydrogeological system. On the input side, only precipitation, which reaches the surface within the boundaries of the GW catchment, was considered in the calculation of the total hydrological budget. It is only a share of this precipitation, which might infiltrate and flow towards Jeita spring because surface run-off concentrates towards rivers that leave the GW catchment. In fact, rivers constitute not only an output variable for resources of the catchment but also an input variable for the J4 Aquifer: Due to the high surface water/groundwater interaction, a large share of GWR to the J4 comes from riverbed infiltration (MARGANE, 2012a; MARGANE, 2012b).

It was not presumed that additional groundwater, recharged from precipitation outside the catchment, enters the Jeita GW catchment.

Delineation of the hydrogeological boundaries of the Jeita catchment was done using tracer tests and other hydrogeological investigations (MARGANE et al., 2013). The eastern boundary is defined by the GW catchment of Afqa, Assal, Labbane and Rouaiss spring. The southern boundary of the Jeita catchment, between Labbane spring and Daraya, follows the surface catchment of Nahr es Zirghaya (Figure 14). Between Daraya and Jeita spring, the southern boundary is defined by Nahr el Kalb, which follows a fault. The north-western boundary follows the coastal the flexure for approximately 15 km (see Figure 10). From the northern end of this flexure as far as the beginning of the surface catchment of Rouaiss spring, the boundary is defined by Amezh fault and Tannourine fault (MARGANE, 2012a; MARGANE, 2012b).

For a detailed description, see Technical Report No 5, Hydrogeology of the Groundwater Contribution Zone of Jeita Spring (MARGANE et al., 2013).

6.2 Model Concept

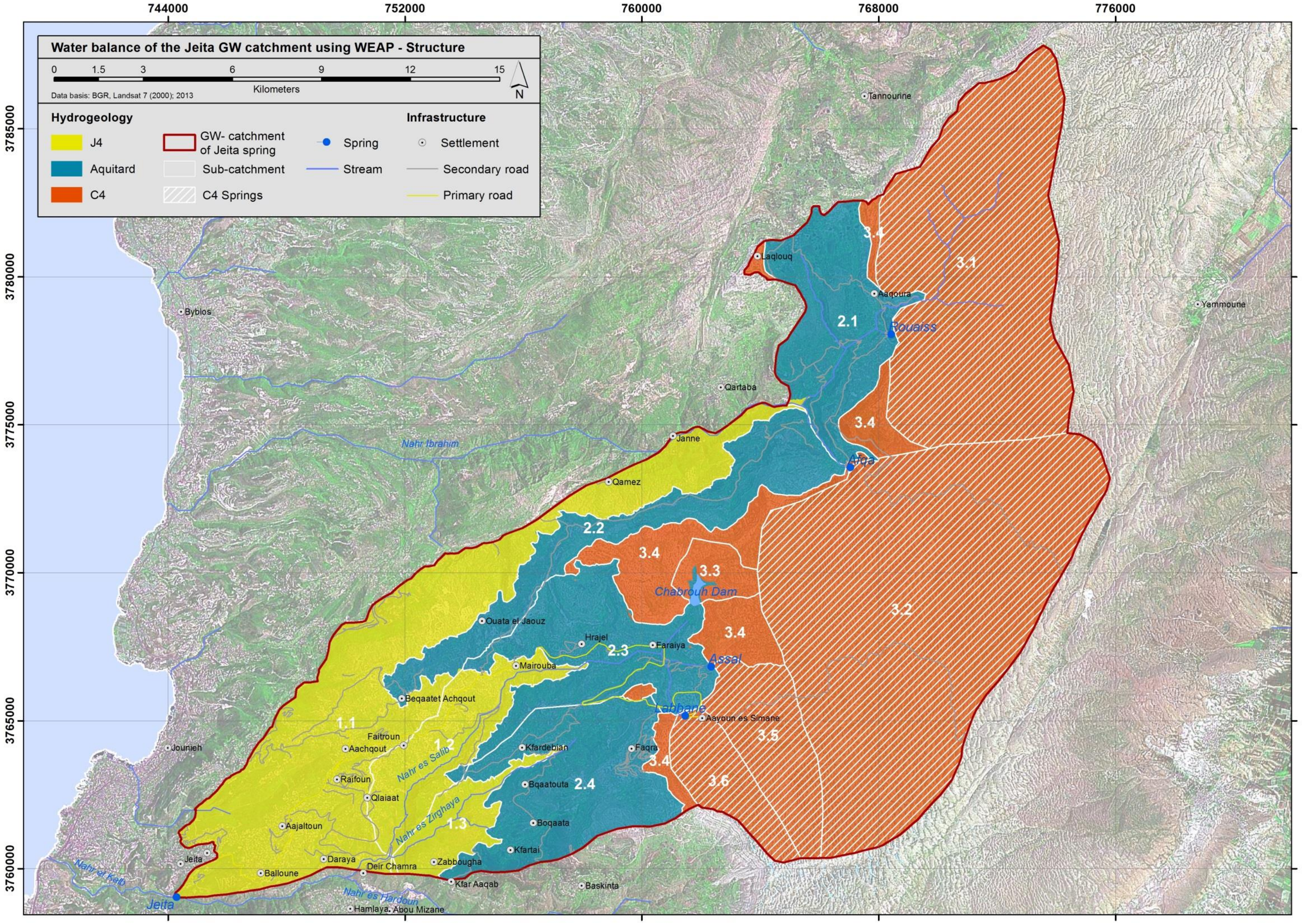

Figure 23: 13 Sub-Catchments (1.1 to 3.6) of the WEAP Model

The GW catchment of Jeita spring was sub-divided into 13 sub-catchments (SC), as they are displayed in Figure 23 for WEAP Model 1 and 2. Within WEAP, each sub-catchment has specific input data (average P, average ET_0, average T) that are representative for the climate of the entire SC.

Sub-division of the GWCZ of Jeita spring increases precision of the modeling process. By decreasing the reference space for input data, reference data becomes less generalized, and thus, input data become more representative for the reference space, which leads to a higher precision and reliability of the modeling output.

Division into different SCs was done according to hydrogeological characteristics. Afqa, Assal, Labbane and Rouaiss spring show different seasonal discharge characteristics and results of tracer tests indicate distinctive hydrogeological systems (MARGANE et al., 2013). Thus, each of these springs was represented by an own catchment node that is connected to a specific groundwater node. Another criterion for the definition of the SCs is surface runoff and its concentration within specific surface catchments. Generation of surface runoff volumes varies, depending on the underlying geological unit and its specific infiltration rate.

For delineation of SCs, three criteria were used, ordered downwards, according to their significance:

- 1. Geology,
- 2. spring- & reservoir catchments and
- 3. surface runoff catchments.

The geologic setting (Figure 10) was the primary criterion for definition of SCs. 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. Based on the methodology for the creation of a numerical expression (sf-value) for karst networks (MARGANE, 2003; MARGANE & SCHULER, 2013), geological units of the Jeita spring catchment were assigned sf-values, as listed in Table 3, based on an empirical approach. According to this classification, J4, J6, C2b and C4 show the highest degree of developed fractures and karst networks, i.e. the highest degree of karstification. According to Figure 23, the geological units J5-C3 (Aquitard Complex) were regarded as one generalized unit, which lies between the J4 and the C4 and separates them, as it comprises several units of low hydraulic conductivity. J4 and C4 were both kept as single geological units, as they represent the main aquifers.

There is no major hydraulic connection between units of the Aquitard Complex and the J4 unit below. The J5 unit, overlying the J4, prevents major downward leakage of GW. Thus, even highly karstified units, as the J6 and C2b, were clustered into the Aquitard Complex.

Table 3: sf-Values and Extent of the Geological Units within the Jeita GWCZ

Geological unit	Area km^2	Area in % of total GWCZ	Sf-value
C4	219.9	54.2	0.25
C3	28.1	6.9	0.50
C2b	5.5	1.4	0.25
C2a	7.5	1.8	0.75
C1	24.2	6.0	1.00
J7	0.6	0.1	0.50
J6	6.6	1.6	0.25
J5	20.1	5.0	1.00
J4	86.9	21.4	0.25
Basalt	6.3	1.6	1.00

The second criterion for definition of SC 3.1 to 3.6, was based on the extent of GW catchments of springs, i.e. Afqa (SC 3.2), Assal (SC 3.5), Labbane (SC 3.6) and Rouaiss (SC 3.1) spring, as well as the remaining minor springs (SC 3.4) and the one existing reservoir, Chabrouh dam (SC 3.3). Discharge from minor springs of the C4 (C4 Springs) and from Chabrouh dam was used for calibration of these single catchments (ARRANZ & MCCARTNEY, 2007).

The third criterion for definition of SCs was the extent of surface runoff (SR) catchments and their respective contribution to rivers. SCs 1.1 to 2.4 contribute to runoff towards rivers with respect to their underlying hydrogeological unit. On the J4, SC 1.1 to 1.3 generate SR towards Nahr Ibrahim and outside of the Jeita GW catchment (SC 1.1), Nahr es Salib (SC 1.2) and Nahr es Zirghaya (SC 1.3).

On the Aquitard Complex, SC 2.1 to 2.4 generate SR towards Nahr Ibrahim (SC 2.1 and 2.2), Nahr es Salib (SC 2.3) and Nahr es Zirghaya (SC 2.4).

On the Aquitard, SR, after covering ecosystem demands, constitutes ~92% of effective precipitation and on the J4 unit ~25% - 30%, respectively.

Modeled surface runoff of SC 1.2, 2.3, 1.3 and 2.4 was calibrated using historical discharge records of Nahr el Kalb at Daraya gauging station.

7 Model Versions

This chapter outlines the chronological development of the WEAP Model 1 to 2. Model 1 is the basis for Model 2, which is referred to for the presentation of the final results.

In a first step, Model 1 was set up in order to calibrate it according to streamflow of Nahr el Kalb, spring discharges and GWR rates. The differences of Model 1 and 2 are summarized in Table 4.

Table 4: Differences between WEAP Model 1 and 2

Different characteristics	Model 1	Model 2
Spring discharge	Defined, according to historical and modified records of LRA and UNDP (1972)	Modeled by regression formulas between spring discharge and precipitation input of Model 1
Catchment simulation method	Rainfall Runoff (simplified coefficient)	SC 1.1 to 2.4: Rainfall Runoff (simplified coefficient); SC 3.1 to 3.6: Rainfall Runoff (soil moisture model)
Total annual discharge of Jeita	Estimates an additional GW abstraction of 6 MCM/a from the J4	Estimates that discharge of Jeita is +6 MCM/a
Network losses	Excludes network losses to GW of 35%	Includes network losses to GW of 35%

The schematic of the WEAP setup is displayed in Annex I.

7.1 WEAP Model 1

The main difference between Model 1 and Model 2 is the way of modeling spring discharges. In Model 1, annual spring discharge and its monthly variation were defined according to historical data, and therefore, discharge is not flexibly modelled, as it was for a depending variable. By knowing the output of the GW system, input variables can be calibrated respectively despite the uncertainties that arise through missing data. Further differences are summarized in Table 4 and outlined in Chapter 7.2.

7.1.1 Catchment Nodes

Table 5 displays the size of each of the 13 sub-catchments and their coverage by landuse and landcover in km^2.

Table 5: Size of 13 WEAP Sub-Catchments (SC) and their Coverage by Landuse and Landcover (km^2)

Catchment	ID	Scarce vegetation	Woodland	Agriculture	Sealed	Ponds & lakes	Total
J4 West	1.1	15.9	40.2	1.9	5.3	0.0	63.3
J4 to Nahr es Salib	1.2	2.9	10.8	1.1	1.0	0.0	15.8
J4 to Nahr es Zirghaya	1.3	1.1	5.6	0.8	0.2	0.0	7.6
Aquitard Rouaiss	2.1	10.6	2.8	9.0	0.7	0.3	23.4
Aquitard North West	2.2	15.8	2.2	3.9	0.7	0.1	22.7
Aquitard to Nahr es Salib	2.3	12.6	3.3	7.2	1.4	0.1	24.5
Aquitard to Nahr es Zirghaya	2.4	12.8	6.2	7.3	1.5	0.0	27.9
C4 Rouaiss Spring	3.1	65.4	0.2	0.1	0.0	0.0	65.8
C4 Afqa Spring	3.2	100.5	0.7	0.0	0.2	0.0	101.5
C4 Chabrouh	3.3	4.3	0.0	0.0	0.0	0.2	4.5
C4 Springs	3.4	23.2	1.1	0.1	0.0	0.0	24.4
C4 Assal	3.5	14.5	0.0	0.0	0.1	0.0	14.6
C4 Labbane	3.6	9.2	0.0	0.0	0.3	0.0	9.5
J4		***19.9***	***56.6***	***3.8***	***6.4***	***0.0***	***86.7***
Aquitard		***51.7***	***14.5***	***27.4***	***4.4***	***0.6***	***98.6***
C4		***217.2***	***2.0***	***0.2***	***0.6***	***0.2***	***220.3***
Total		**288.8**	**73.1**	**31.4**	**11.5**	**0.8**	**405.6**

Table 6 displays the mean climatic parameters for each sub-catchment.

Runoff fraction defines the proportion of effective rainfall of a catchment that is diverted towards surface runoff/surface stream and groundwater recharge (GWR) after ET. The destinations of surface runoff of each sub-catchment are pre-sented in Table 7.

Table 8 gives an overview about the sub-catchments with irrigation and their specific supply sources, including maximum flow of each source (in %) and supply preferences (1 - highest; 3 - lowest).

Table 6: Characteristics of the WEAP Sub-Catchments

Catchment	ID	elevation (m asl)	rainfall (mm/a)	Mean ET_0 (mm/a)	SR/GWR fraction
J4 West	1.1	1,019	1,296	95.8	25/75
J4 to Nahr es Salib	1.2	1,124	1,333	94.2	25/75
J4 to Nahr es Zirghaya	1.3	1,003	1,232	96.0	30/70
Aquitard Rouaiss	2.1	1,422	1,525	89.5	92/8
Aquitard North West	2.2	1,385	1,501	90.1	92/8
Aquitard to Nahr es Salib	2.3	1,440	1,521	89.3	92/8
Aquitard to Nahr es Zirghaya	2.4	1,409	1,430	89.7	92/8
C4 Rouaiss Spring	3.1	1,919	1,613	82.0	0/100
C4 Afqa Spring	3.2	2,012	1,613	80.5	0/100
C4 Chabrouh	3.3	1,771	1,613	84.0	0/100
C4 Springs	3.4	1,771	1,585	84.0	0/100
C4 Assal	3.5	2,174	1,807	78.0	0/100
C4 Labbane	3.6	2,171	1,900	78.1	0/100

Table 7: WEAP Sub-Catchments and their Destinations of GWR and SR

Catchment	ID	GWR	SR
J4 West	1.1	GW J4	Nahr Ibrahim
J4 to Nahr es Salib	1.2	GW J4	Nahr es Salib
J4 to Nahr es Zirghaya	1.3	GW J4	Nahr es Zirghaya
Aquitard Rouaiss	2.1	GW AT Rouaiss	Nahr Ibrahim
Aquitard North West	2.2	GW AT	Nahr Ibrahim/C_J4 West
Aquitard to Nahr es Salib	2.3	GW AT	Nahr es Salib
Aquitard to Nahr es Zirghaya	2.4	GW AT	Nahr es Zirghaya
C4 Rouaiss Spring	3.1	GW C4 Rouaiss Spring	-
C4 Afqa Spring	3.2	GW C4 Afqa Spring	-
C4 Chabrouh	3.3	GW C4 Chabrouh	-
C4 Springs	3.4	GW C4	-
C4 Assal	3.5	GW C4 Assal	-
C4 Labbane	3.6	GW C4 Labbane	-

Table 8: Supply Preferences of Sub-Catchments 1.1 to 2.4 and maximum Inflow (% of Demand)

Catchment	ID	Supply preference 1	Supply preference 2	Supply preference 3
J4 West	1.1	Irrigation canal (30%)	GW J4	-
J4 to Nahr es Salib	1.2	Irrigation canal (40%)	GW J4	-
J4 to Nahr es Zirghaya	1.3	Irrigation canal (35%)	GW J4	-
Aquitard Rouaiss	2.1	Ponds	Rouaiss Spring	GW AT Rouaiss (35%)
Aquitard North West	2.2	Irrigation canal (45%)	C4 Springs	GW AT
Aquitard to Nahr es Salib	2.3	C4 Springs (50%)	Irrigation canal (50%)	GW AT
Aquitard to Nahr es Zirghaya	2.4	Irrigation canal (50%)	C4 Springs (30%)	GW AT

7.1.2 Demand Nodes

The domestic demand within the Jeita GW catchment is represented by six demand sites, D_M Faqra Club, D_M Ayoun Simane, D_M Hrajel, D_M Kfardebian, D_M Lassa and D_M Balloune, as they are presented in Table 9 to 11. Besides D_M Faqra Club and D_M Ayoun Simane, demand sites are aggregated by single municipalities/villages. Aggregation was done according to spatial proximity on one hydrogeological unit and according to their groundwater node that receives respective return flow.

D_M Faqra and D_M Hrajel are supplied only by Chabrouh dam. D_M Kfardebian and D_M Balloune are additionally supplied by Assal spring (Chabrouh: supply preference 1; Assal: supply preference 2) and D_M Ayoun Simane receives additional water from GW C4 Labbane. D_M Lassa is exclusively supplied by Afqa spring.

Table 9: Villages overlying the Aquitard Complex, their Summer and Winter Population and respective Water Demand, based on a Demand of 140/164 l/cap/d in Thousand Cubic Meters (TCM)

WEAP Demand site	Municipality/village	Population		Seasonal water demand (in TCM)	
		summer	winter	summer	winter
Aquitard North					
Hrajel	Faraiya	4,074	4,000	373.5	51.5
	Hrajel	9,270	4,635	700.8	97.3
	Mayrouba	4,074	4,000	373.5	51.5
	Ouata el Jaouz	3,803	760	249.2	35.1
Aquitard South					
Kfardebian	Boqaata Aachkout	1,222	1,200	112.1	15.5
	Bqaatouta	2,444	2,400	224.1	30.9
	Kfardebian	12,222	12,000	1120.6	154.6
	Kfartai	815	800	74.7	10.3

Table 10: Villages overlying the J4 Aquifer, their Summer and Winter Population and respective Water Demand, based on a Demand of 140/164 l/cap/d in Thousand Cubic Meters (TCM)

WEAP Demand site	Municipality/village	Population		Seasonal water Demand (in TCM)	
		summer	winter	summer	winter
J4 West - North					
Lassa	Lassa	3,109	104	186.3	26.5
J4 West					
Balloune	Aajaltoun	13,905	6,953	525.6	87.6
	Ashkout	8,795	6,156	332.5	77.6
	Balloune	16,009	12,808	605.1	161.4
	Beqaatet Aachqout	2,662	1,139	100.6	14.4
	Bzommar	579	290	21.9	3.7
	Daraya	1,528	1,500	57.8	18.9
	Dlebta	1,043	521	39.4	6.6
	Ein el Delbe	532	27	20.1	0.3
	Ein el Rihane	4,074	4,000	154.0	50.4
	Faitroun	3,908	2,067	147.7	26.0
	Ghosta	3,822	2,729	144.5	34.4
	Hiyata	509	500	19.3	6.3
	Jeita	5,093	5,000	192.5	63.0
	Qleyyat	12,746	6,373	481.8	80.3
	Raashine	6,489	4,867	245.3	61.3
	Raifoun	6,339	1,267	239.6	16.0
	Shaile	6,111	6,000	231.0	75.6

Table 11: Villages overlying the C4 Aquifer, their Summer and Winter Population and respective Water Demand, based on a Demand of 140/164 l/cap/d in Thousand Cubic Meters (TCM)

WEAP Demand site	Municipality/village	Population		Seasonal water demand (in TCM)	
		summer	winter	summer	winter
Cretaceous					
Faqra Club	Faqra	1,438	2,554	199.5	26.7
Ayoun Simane	Ayoun es Simane	3,462	3,899	334.6	45.5

7.1.3 Transmission Links

In WEAP, transmission links represent (Table 12) the water distribution network, connecting agricultural and domestic demand with their supply sources.

Total domestic supply delivered equals total domestic demand, which means that all domestic demand sites were modeled to be covered 100% - it was surmised that no water shortage/unmet demand exist.

Table 12: Transmission Links of Model 1: Demand Sites and their total Supply delivered (MCM) by Source and their Return Flow (MCM) by GW Destination

Demand Site	Demand in MCM/a	Supply source		Return flow (50% of demand)	
		Conveyed MCM/a	Source	Quantity MCM/a	to GW
D_M Balloune	4.3	6.7	Chabrouh/ Assal	2.2	J4
D_M Lassa	0.1	0.2	Afqa	0.0	Aquitard
				0.0	J4
D_M Faqra Club	0.1	0.2	Chabrouh/ Assal	0.1	C4 Springs
D_M Ayoun es Simane	0.2	0.2	GW Labbane/ Chabrouh	0.1	GW Labbane
D_M Hrajel	1.0	1.5	Chabrouh/ Assal	0.5	Aquitard
D_M Kfardebian	0.8	1.3	Chabrouh/ Assal	0.4	Aquitard
Total	**6.6**	**10.0**		**3.3**	

Total agricultural supply delivered equals total agricultural demand + 25% irrigation fraction (irrigation efficiency), which means that all agricultural demand was modeled to be 100% covered – no water shortage/uncovered demand was surmised to exist. Sources to cover agricultural demand are rainfall and irrigation water (ponds and Rouaiss spring: SC 2.1; C4 Springs: SC 2.2 to 2.4; irrigation canal: SC 1.1 to 1.3 and SC 2.2 to 2.4; GW: 1.1 to 2.4).

Table 13 displays the annual agricultural demand per SC and their sources of transmission links and respective share of irrigation supply.

Table 13: Agricultural Demand Sites, their Demand in MCM/a, Transmission (Irrigation) Sources and Share of Supply in %

Agricultural Demand Site	SC ID	Total demand in MCM/a	Transmission supply	
			Supply share of transmission main in %	Source
J4 West	1.1	1.2	24	Irrigation canal
			76	GW J4
J4 Nahr es Salib	1.2	0.6	29	Irrigation canal
			71	GW J4
J4 Nahr es Zirghaya	1.3	0.4	27	Irrigation canal
			73	GW J4
AT Rouaiss	2.1	5.4	28	Ponds
			19	GW Aquitard Rouaiss
			53	Rouaiss Spring
AT North West	2.2	2.2	35	Irrigation canal
			33	GW Aquitard
			32	C4 Springs
AT Nahr es Salib	2.3	3.8	40	Irrigation canal
			60	GW Aquitard
AT Nahr es Zirghaya	2.4	3.8	34	Irrigation canal
			44	GW Aquitard
			22	C4 Springs

7.1.4 Groundwater Nodes

Aquifers within the catchment are represented by 9 groundwater nodes. Table 14 shows all 9 groundwater nodes, their storage capacity and natural recharge rate. The natural recharge rate is the percentage that potentially can infiltrate after ecosystem demands are met, i.e. ET.

Table 14: Storage Capacity and Natural Recharge of WEAP GW Nodes

GW node	Storage capacity (MCM)	Natural recharge (% of P)
GW J4	4,036	25-30
GW AT	4,036	8
GW AT Rouaiss	421	8
GW C4	147	100
GW C4 Afqa	609	100
GW C4 Assal	88	100
GW C4 Chabrouh	27	100
GW C4 Labbane	57	100
GW C4 Rouaiss	395	100

Each groundwater node represents an own hydrological system that does not interact with other groundwater nodes, except GW J4 and GW AT. From GW AT, ~7% of GW storage leaks towards GW J4. Leakage was modeled via a demand site with 0% consumption rate.

Besides GWR through infiltration of precipitation, wastewater and irrigation return flow, as well as riverbed infiltration, contribute to recharge of aquifers/GW nodes.

7.1.5 GW Recharge

GWR was differentiated between natural GWR, i.e. infiltration from precipitation and losing streams, and anthropogenic GWR, i.e. irrigation and domestic return flow and network losses towards GW.

Table 15 displays natural and anthropogenic GWR sources of all GW nodes of the Jeita GW catchment WEAP model.

GW nodes of the C4 exclusively receive recharge through infiltration of precipitation. After accounting ET (and snow accumulation), all P (and snowmelt) was diverted towards GW nodes.

After covering ET demand, 8% of rainfall of catchments on the Aquitard infiltrates towards GW nodes. GWR of the total applied irrigation is 2%, considering that the largest share is used by the crop.

The J4 Aquifer is recharged by various sources. Leakage of the Aquitard accounts for 7% of GW storage of GW AT. As outlined before, return flow from domestic demand sites accounts for 50% of their delivered supply and 35% of total conveyed resources towards D_M Balloune. Riverbed infiltration from

Nahr es Salib, Nahr es Zirghaya and Nahr Ibrahim accounts for 20% to 23% of their annual streamflow. Infiltration from rainfall, after covering ET demand, was defined at 70-75%, leading to an irrigation return flow for 18-19% of total applied irrigation.

Table 15: Sources of Natural and Anthropogenic GWR and their respective Shares

GW node	Origin of GWR		GWR in %...	...of
GW J4	SC 1.1	Rainfall	75	effective P
		Irrigation	19	applied irrigation
	SC 1.2	Rainfall	75	effective P
		Irrigation	19	applied irrigation
	SC 1.3	Rainfall	70	effective P
		Irrigation	18	applied irrigation
	Nahr Ibrahim		23	streamflow
	Nahr es Salib		20	streamflow
	Nahr es Zirghaya		20	streamflow
	Leakage Aquitard		7	storage GW AT
	D_M Balloune		50	supply delivered
	Transmission to Balloune		35	conveyed resources
GW AT Rouaiss	SC 2.1	Rainfall	8	effective P
		Irrigation	2	applied irrigation
GW AT	SC 2.2	Rainfall	8	effective P
		Irrigation	2	applied irrigation
	SC 2.3	Rainfall	8	effective P
		Irrigation	2	applied irrigation
	SC 2.4	Rainfall	8	effective P
		Irrigation	2	applied irrigation
GW C4*	SC 3.1 - 3.6	Precipitation	100	effective P

*applied for all GW Nodes of the Upper C4 Aquifer

7.1.6 GW Discharge: Flow Requirements

Springs were represented by flow requirements within the Jeita GW catchment WEAP model. Total annual spring discharges and their monthly variations were defined, according to records in Chapter 5.3 and Table 16, using the monthly time-series wizard.

Flow requirements are located on diversions (WEAP conduit) from where discharge is divided according to Table 17.

Table 16: Defined annual Spring Discharges in MCM

Spring	Afqa	Assal	C4 Springs	Jeita	Labbane	Rouaiss
Discharge in MCM/a	123.2	21.4	34.9	166.4	14.4	83.3

Table 17: WEAP Flow Requirements (Springs) and their Outlet Recipients

Flow requirement/spring	Recipients	
Afqa	D_M Lassa	
	D_M Exported	
	Nahr Ibrahim	
Assal	D_M Kfardebian	
	D_M Balloune	
	Irrigation Canal	
	Nahr es Salib	
C4 Springs	C4 Springs North	SC 2.2
		SC 2.3
		Nahr es Salib
	C4 Springs South	SC 2.4
		Nahr es Zirghaya
Jeita	Nahr el Kalb	
Labbane	Chabrouh dam	
	Irrigation canal	
	Nahr es Salib	
Rouaiss	SC 2.1	
	Nahr Ibrahim	

7.2 WEAP Model 2

Model 2 is a more flexible version of Model 1 because spring discharges were modeled as a dependent variable. Total annual spring discharge (annual flow requirement) equals the annual GWR of the respective groundwater node because annual GW inflow was surmised to be equal to annual outflow. Thus, any changes in annual precipitation would affect GWR and so, monthly and annual spring discharges.

Monthly variation of annual discharge was modeled according to the monthly variation of precipitation, based on Model 1 because P was defined as the independent variable. For each spring, the relation between precipitation and spring discharge was expressed through a mathematical equation.

Further, the catchment nodes on the C4 unit (SC 3.1 to 3.6) were modelled by the Rainfall/Runoff (soil moisture) method, which includes modeling of snow accumulation/melting.

In reality, there is very little soil cover on the C4 unit. Thus, all soil parameters were set to a minimum. For the upper soil layer, soil water capacity was set to 30 mm and root zone conductivity was left as default (20 mm). Preferred flow direction was set to 0, which means that after ET is covered, all P and snowmelt is diverted vertically towards the GW node.

Model 2 also represents a temporal shift of the modeling period. Due to the existence of a central water supply system through Chabrouh Reservoir, the central transmission (supply) network was modeled more realistic by including water losses from the system towards GW nodes (35%). Due to the improved coverage of water supply, represented by Model 2, less GW abstraction of private wells was surmised to exist. In Model 1, additional abstraction of private wells was believed to be 6 MCM/a, due to the absence of this central supply network. This figure, however, is obsolete for Model 2, which results in a surge of discharge of Jeita spring by 6 MCM/a.

Modifications between Model 1 and Model 2 are outlined in the following Chapters.

7.2.1 Catchment Nodes

Figure 24 and Figure 25 display climate data, which were used for the subcatchments that were modeled with the Rainfall/Runoff (soil moisture) method. Mean monthly temperature ranges between a maximum of 13.9 °C in August (SC 3.3 and 3.4) and a minimum of -3.3 °C in January (SC 3.5). Wind speed is left as default value (2 m/s).

Monthly variation of relative humidity refers to the climate station at Beirut Airport. These records were directly transferred into the WEAP model. Cloudiness fraction was estimated, assuming higher records during the period of rainfall in autumn/winter.

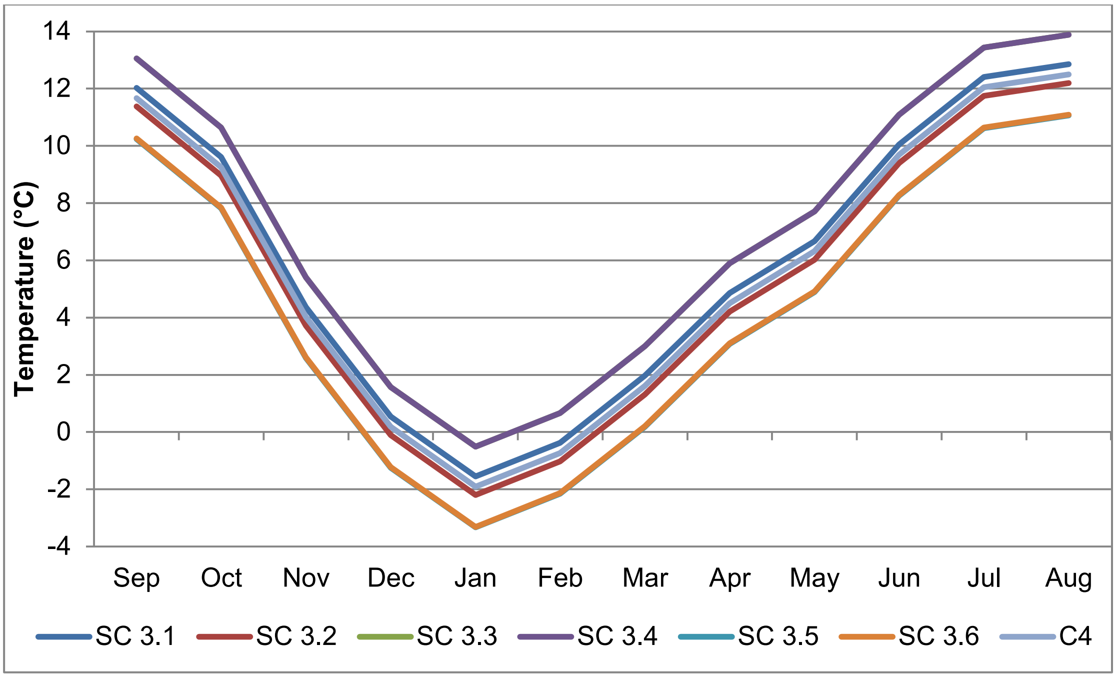

Figure 24: Mean monthly Temperatures in °C of SC 3.1 to 3.6 and the total C4 Outcrop Area

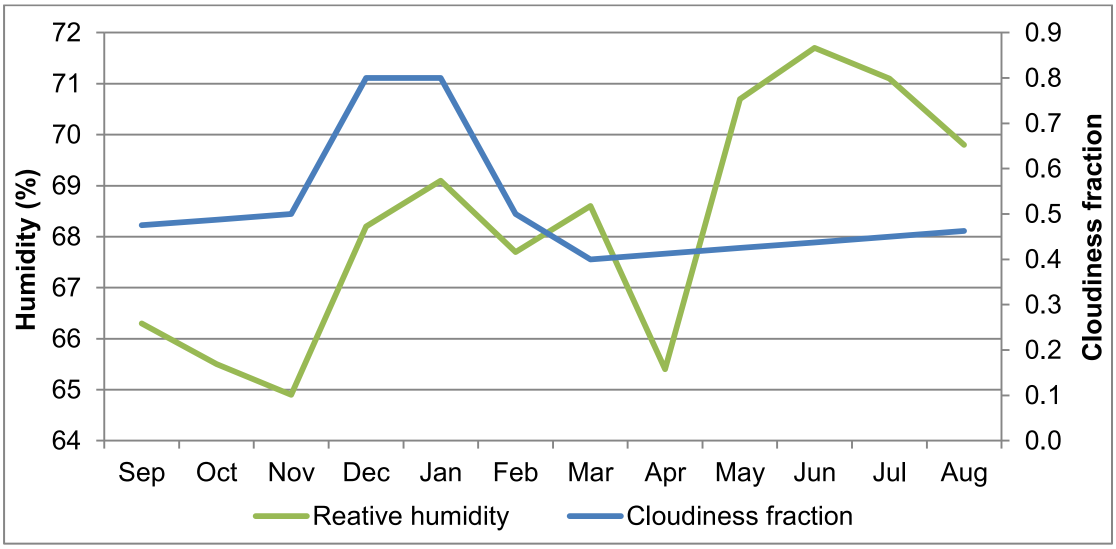

Figure 25: Monthly Relative Humidity (%) for Beirut Airport for the Water Years 1974 & 1975 and monthly Cloudiness Fraction; Source of Relative Humidity Data: TUTIEMPO NETWORK

7.2.2 Transmission Links

Table 18: Transmission Links of Model 2: Demand Sites and their total Supply delivered (MCM) by Source and their Return Flow (MCM) by GW Destination

Demand Site	Demand in MCM/a	Supply source		Network loss (35% of conveyed supply)		Return flow (50% of demand)	
		Conveyed MCM/a	Source	Quantity MCM/a	to GW	Quantity MCM/a	to GW
D_M Balloune	4.3	6.7	Chabrouh/Assal	2.3	J4	2.2	J4
D_M Lassa	0.1	0.2	Afqa	0.0	Aquitard	0.0	Aquitard
				0.0	J4	0.0	J4
D_M Faqra Club	0.1	0.2	Chabrouh/Assal	0.1	GW Labbane	0.1	C4 Springs
D_M Ayoun es Simane	0.2	0.2	GW Labbane/Chabrouh	0.0	Aquitard	0.1	GW Labbane
D_M Hrajel	1.0	1.5	Chabrouh/Assal	0.5	Aquitard	0.5	Aquitard
D_M Kfardebian	0.8	1.3	Chabrouh/Assal	0.5	Aquitard	0.4	Aquitard
Total	**6.6**	**10.0**		**3.4**		**3.3**	

7.2.3 GW Discharge: Flow Requirements

A comparison between the monthly variation of rainfall and the monthly variation of spring discharges (Figure 17-21) indicate a high correlation between the two variables, however, in time shifted (Figure 26).

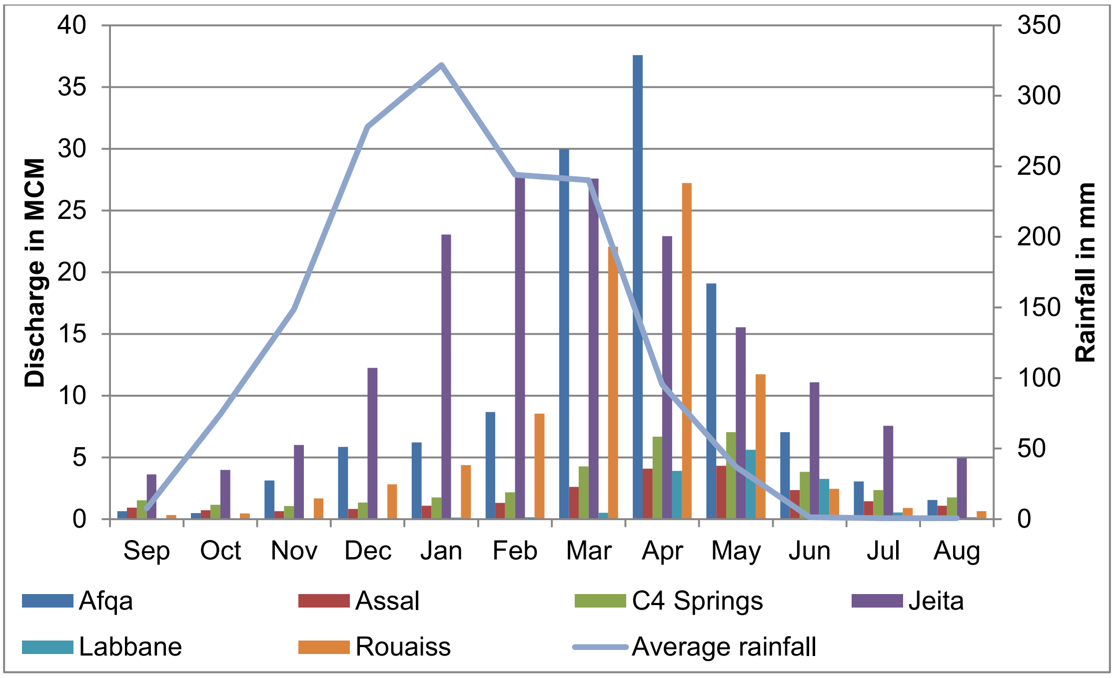

Figure 26: Monthly Spring Discharges of Model 1 in MCM and average monthly Rainfall between 1931 &1960 in mm

The peak of discharge of Jeita spring occurs approx. 1 month later than the peak of the average rainfall distribution in the GWCZ of Jeita spring. Springs of the C4 unit show all a later response towards precipitation due to snowmelt. The peak of Afqa and Rouaiss occurs 3 months later than the precipitation peak while the peak of discharge of Assal and Labbane occurs 4 months later. Within Model 2, these temporal shifts of monthly variation of spring discharge and rainfall were integrated. Based on the specific relation of rainfall and spring discharge, polynomial equations were derived for each spring (Table 19).

The quantity of total annual spring discharge depends on the quantity of total infiltration to the groundwater node. Since for each groundwater node input equals output, following equation represents annual discharge of springs of the C4 unit:

$$D_{annual} = P_{annual} - ET_{annual} + RF_{annual} - ABS_{annual} \quad \text{[Equation 5],}$$

where D_{annual} is the annual spring discharge, P_{annual} annual precipitation, ET_{annual} evapotranspiration, RF_{annual} the annual domestic return flow and ABS_{annual} the annual GW abstraction.

Table 19: Discharge Equation for Afqa, Assal, C4, Jeita and Labbane Spring, including R^2. Y = Spring Discharge, x = Precipitation

Spring	Equation	R^2
Afqa	$y = 0.040x^2 - 0.500x + 3.490$	0.88
Assal	$y = 0.025x^4 - 0.247x^3 + 0.776x^2 - 0.346x + 0.823$	0.85
C4 Springs	$y = 0.015x^4 - 0.163x^3 + 0.561x^2 - 0.160x + 1.004$	0.84
Jeita	$y = 0.001x^4 - 0.026x^3 + 0.323x^2 + 0.133x + 4.58$	0.92
Labbane	$y = 0.100x^4 - 0.700x^3 + 1.719x^2 - 1.004x + 0.307$	0.91

7.3 WEAP Model 2: Kfardebian Dam

Model 2 was used to establish a water resources management option. Kfardebian dam (Figure 27) was integrated as managed aquifer recharge (MAR) option, as proposed by GITEC & BGR (2011) (Table 20).

WEAP was used to assess the quantity of potential runoff/streamflow at the selected dam location in Nahr es Salib, to model the dam’s storage behavior and the potential recharge to the J4 Aquifer.

In this report, the results of Kfardebian dam are presented. According to the SRTM raster grid, Kfardebian dam has a potential static storage of 7.3 MCM, a surface catchment of 91.0 km^2 and a rain volume of 142.4 MCM/a.

These data, however, include the Upper C4 Aquifer in the calculation of the surface catchment, which is, according to the WEAP approach, not valid because the C4 does not generate surface runoff. Thus, the surface catchment was decreased/clipped according to the hydrogeological setting, considering only the Aquitard/J4 as surface water catchment (Table 21 and Figure 28).

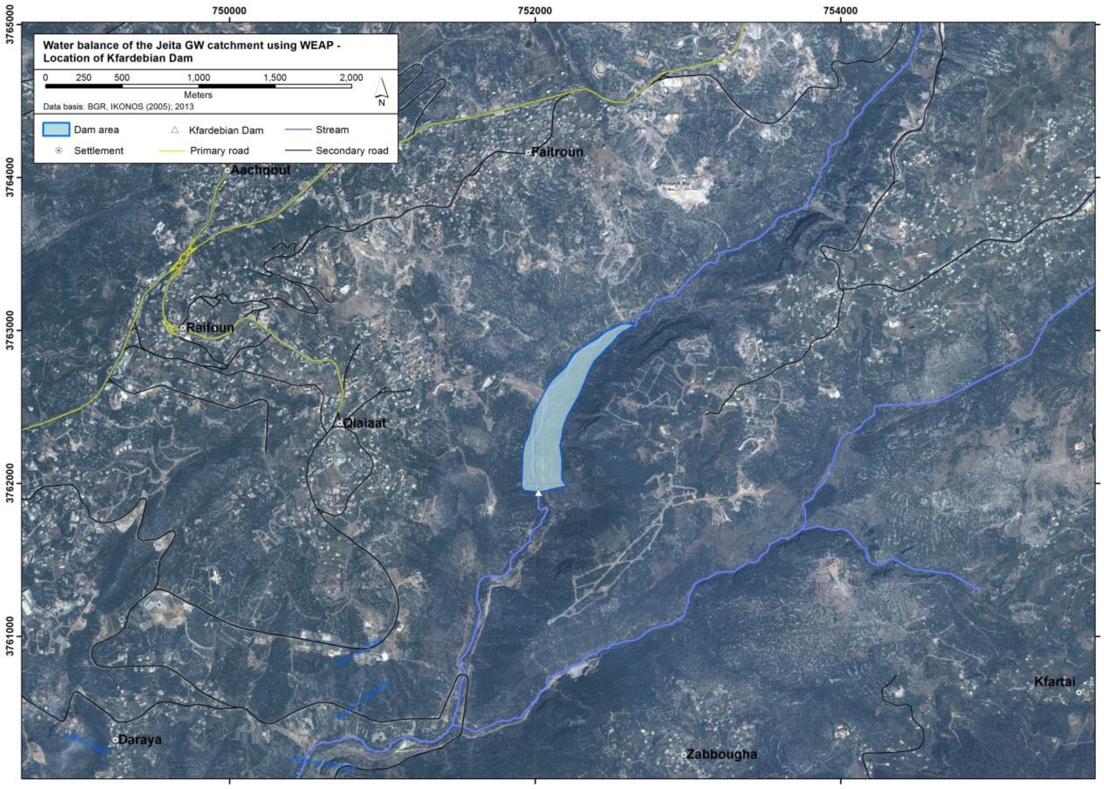

Figure 27: Location of Kfardebian MAR Dam

Table 20: Proposed Dams for MAR; Source of Data: GITEC & BGR (2011)

Dam	Elevation (m asl)	Dam crest (m)	Storage (MCM)	Surface area (m²)	Catch-ment (km²)	Rain volume (MCM/a)
Boqaata	900	80	4.1	198,025	16.8	24.2
Faitroun	1,115	65	6.6	459,963	80.1	127.8
Kfardebian	720	100	7.3	224,721	91.0	142.4
Zabbougha	635	100	3.0	104,976	46.9	68.2

Table 21: Characteristics of Kfardebian Dam, as integrated into the WEAP Model

Dam	Elevation (m asl)	Dam crest (m)	Storage (MCM)	Surface area (m²)	Catch-ment (km²)	Rain volume (MCM/a)
Kfardebian	720	100	7.3	224,721	15.8	54.0

According to Table 21, the surface water catchment of Kfardebian dam on the J4/Aquitard encompasses only 15.8 km^2 instead of the previous 91.0 km^2. However, due to contribution of spring discharges to the streamflow of Nahr es Salib, GW catchments of the C4 need to be taken into consideration when assessing the recharge potential of Kfardebian Dam. Thus, the GW catchment must be taken into consideration, resulting in a size of 70 km² (Figure 28).

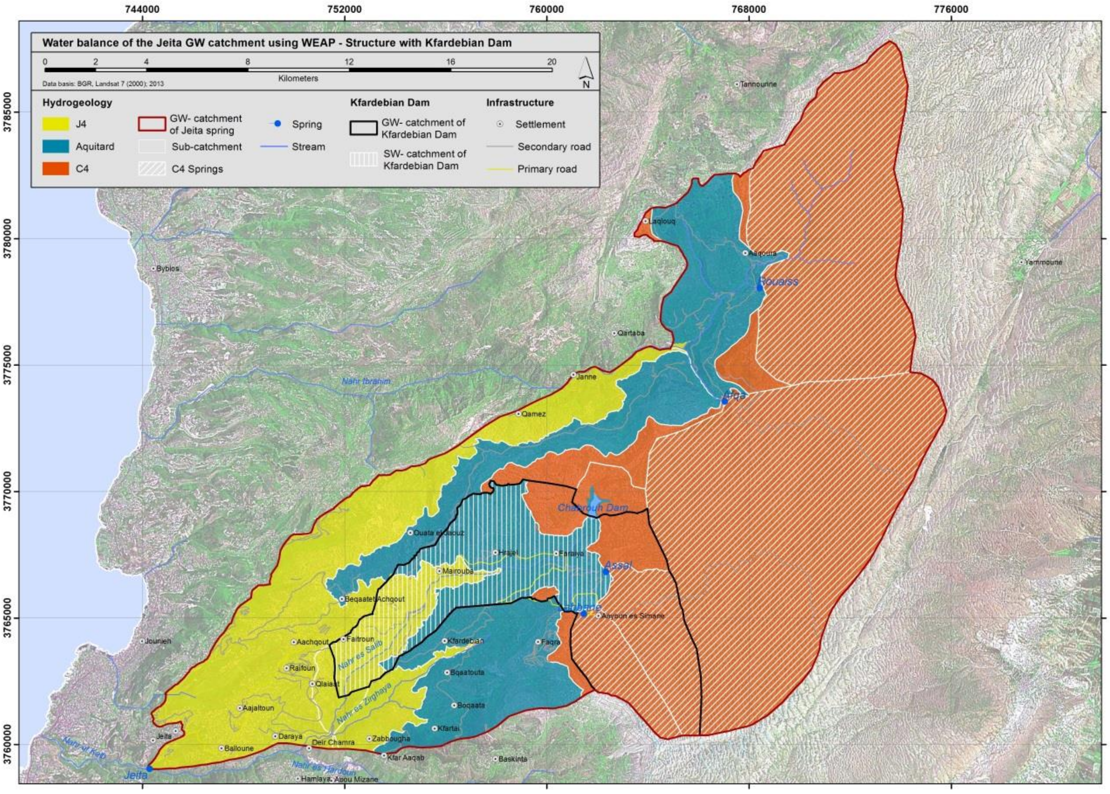

Figure 28: SW and GW Catchment of Kfardebian Dam within the existing WEAP Structure

17% (12.3 km²) of the GW catchment extends over the J4 and 35% (24.5 km²) over the Aquitard. 16% (9.5 km²) of the catchment is constituted by the GW catchment of Labbane spring and 24% (14.6 km²) by the GW catchment of Assal spring. Approx. 15% (9.4 km²) extends over a share of the C4 outcrop area.

For the integration of the GW catchment of Kfardebian Dam into the WEAP schematic, SC 1.2 was further disaggregated into two sub-catchments: J4 Kfardebian contributes SR upstream the reservoir while J4 Nahr es Salib contributes SR towards Nahr es Salib downstream the reservoir. SC 2.3 on the

Aquitard Complex complies with the SC of Nahr es Salib and therefore did not need to be modified.

Modifications with respect to the catchment nodes of the model are outlined in the following sections 7.3.1 and 7.3.2.

7.3.1 Catchment Nodes

SC 2.3 was divided into an upper part (J4 Kfardebian Dam), which has a total size of 12.3 km^2, and a lower part (J4 Nahr es Salib), which covers 3.5 km^2. Table 22 to Table 25 display the resulting changes in the structure of the model.

Table 22: Size of SC J4 Kfardebian Dam and J4 Nahr es Salib and their Coverage by Landuse and Landcover (km^2)

Catchment	Scarce vegetation	Woodland	Agriculture	Sealed	Ponds & lakes	Total
J4 Kfardebian Dam	2.5	8.2	0.8	0.7	0.0	12.3
J4 Nahr es Salib	0.4	2.6	0.3	0.3	0.0	3.5

Table 23: Characteristics of SC J4 Kfardebian Dam and J4 Nahr es Salib

Catchment	Elevation (m asl)	Rainfall (mm/a)	Mean ET$_0$ (mm/a)	SR/GWR fraction
J4 Kfardebian Dam	1,175	1,357	93.4	25/75
J4 Nahr es Salib	946	1,248	96.9	25/75

Table 24: SCs of Kfardebian Dam and their Destinations of GWR and SR

Catchment	GWR	SR
J4 Kfardebian Dam	GW J4	Nahr es Salib
J4 Nahr es Salib	GW J4	Nahr es Salib

Table 25: Supply Preferences of Sub-Catchments of Kfardebian Dam, including their maximum Inflow in % of Demand

Catchment	Supply preference 1	Supply preference 2
J4 Kfardebian Dam	Irrigation canal (40%)	GW J4
J4 Nahr es Salib	GW J4	-

7.3.2 Reservoir Node

Kfardebian dam has a static storage capacity of 7.3 MCM. The monthly variation of ET_0 was adopted from sub-catchment J4 Nahr es Salib, with a mean annual ET_0 of 97 mm.

Leakage of the reservoir, i.e. monthly loss to GW, was defined according to the calibrated loss to GW J4 of the losing streams Nahr es Salib and Nahr es Zirghaya, starting at a volume > 1.5 MCM. If the volume of the reservoir is > 1.5 MCM, the reservoir will lose 20% of this storage volume towards the J4 in the following month.

7.4 WEAP Model 2: Climate Change Scenario

A climate change scenario was established, modelling the period between the reference year of Model 2 and 2040, based on the regional climate change assessment, as published by MoE (2011) and summarized by (GITEC, 2011a). This assessment uses the results of the PRECIS (Providing REgional Climates for Impacts Studies) model on a 25 km x 25 km grid, sub-dividing Lebanon in 17 grid cells. PRECIS is based on the HadCM3 GCM model with a resolution of approx. 300 km x 300 km. A1B is the driving emission scenario used for PRECIS. The main output variables of the model are min and max temperature and precipitation by using data of the climate stations of Beirut, Cedars (Al Arz), Dahr el Baidar, and Zahleh of the National Meteorological Service (NMS) from 1971 on. Since PRECIS is built on historical data similar to the WEAP Model, the starting year for the climate change scenario was chosen to be the year of Model 2, without applying any modifications on the climate data of the model.

The A1B scenario lies between a pessimistic A2 and an optimistic B1 scenario, whereas results of global warming until 2040 are very similar for all simulations, making the selection of the scenario not a crucial one for the assessment of temperature rise. Uncertainties, however, are discussed in MoE (2011).

Results of high importance for human activities include the development of extreme weather events, which is not discussed here. Since the WEAP model runs on a monthly time step, extreme weather situations were not considered in the simulation of the monthly and annual water budget.

The main results of the PRECIS model, which are of relevance for this WEAP model, show that until 2040, maximum temperatures are likely to increase by 1 °C at the coast and by 2 °C in the mountainous inland, with a similar development for the minimum temperatures. Rainfall between the coastal and inland areas is likely to drop by -10% to -20% until 2040. Temperatures are likely to increase more in summer whereas rainfall is likely to decrease more in winter. Changes of humidity are very small until 2040. A change in wind speed and cloud fraction was not simulated, whereas the wind speed does not exceed 4 m/s within the PRECIS model.

Table 26 displays the climate change variables for the WEAP model. MoE (2011) refers to rainfall, rather than to precipitation (P). In this study, *rainfall predictions* were considered as *precipitation predictions*. Besides P and temperature (T), Table 26 shows the decrease of k_c values, derived from the decrease in temperature (-0.7 °C/+100 m asl). It is differentiated between two scenarios: scenario 1 is pessimistic, including higher decrease in P and higher increase in T, compared to scenario 2, which includes less increase/decrease of the respective variables.

Table 26: Climate Change Variables

Scenarios	Precipitation (%)		Temperature(°C)		ET_0 (mm)	
	Summer	Winter	Summer	Winter	Summer	Winter
Scenario 1	-15	-20	+2	+1.75	+4.4	+3.1
Scenario 2	-10	-15	+1.75	+1.5	3.1	2.6

For all variables it was differentiated between summer (May to end of October) and winter (November to end of April). As P is likely to decline mostly in winter, in scenario 1 the maximum prediction of -20% was used for this period while in summer, the drop of P was modeled at -15%.

Regarding T, the major increase is likely to occur in summer so that the maximum surge of predicted T of +2 °C was applied in the summer months while in winter, increase was modeled at +1.75 °C.

In scenario 2, increase of temperature is more moderate, ranging between +1.75 °C in summer and +1.5 °C in winter. Precipitation drops by -15% in winter and -10% in summer.

8 Model Calibration

This section analyzes the quality of modeling results of the WEAP model. For this assessment four benchmarks were used during calibration:

I. Surface runoff at Daraya gauging station: comparison between observed records from LRA and modeled output;
II. Groundwater in- and outflow: Evaluation of the intra-annual balance;
III. Annual spring discharges: Compliance with observed records from LRA and annual GWR;
IV. Unmet demand: Ensuring that all demands are met.

All modeled records refer to the Reference Scenario.

8.1 WEAP Model 1

8.1.1 Runoff at Daraya

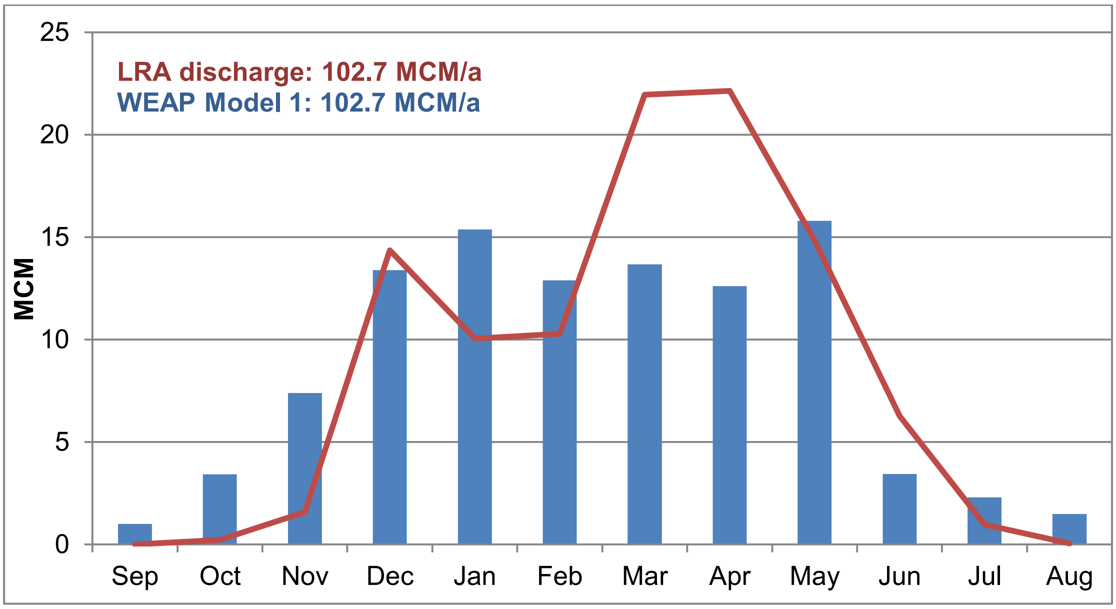

Figure 29: Modeled and observed Discharge of Nahr el Kalb at Daraya Gauging Station for WEAP Model 1

Figure 29 displays modeled and measured discharge of Nahr el Kalb at Daraya gauging station. Total measured annual runoff at Daraya is 102.7 MCM, total modeled runoff is 102.7 MCM, which shows the very good fit of the total annual discharge. Modeled runoff has lower peaks than the measured runoff and is generally lower. The correlation coefficient between the two data sets accounts for 0.84, being acceptably high (MORIASI et al., 2007).

8.1.2 Groundwater Inflow, Outflow & Storage

Figures 30-38 display the average monthly GW inflow and outflow for each of the nine groundwater nodes and their respective storages. Inflow varies throughout the year, however, inflow equals outflow to maintain an intra-annual balance.

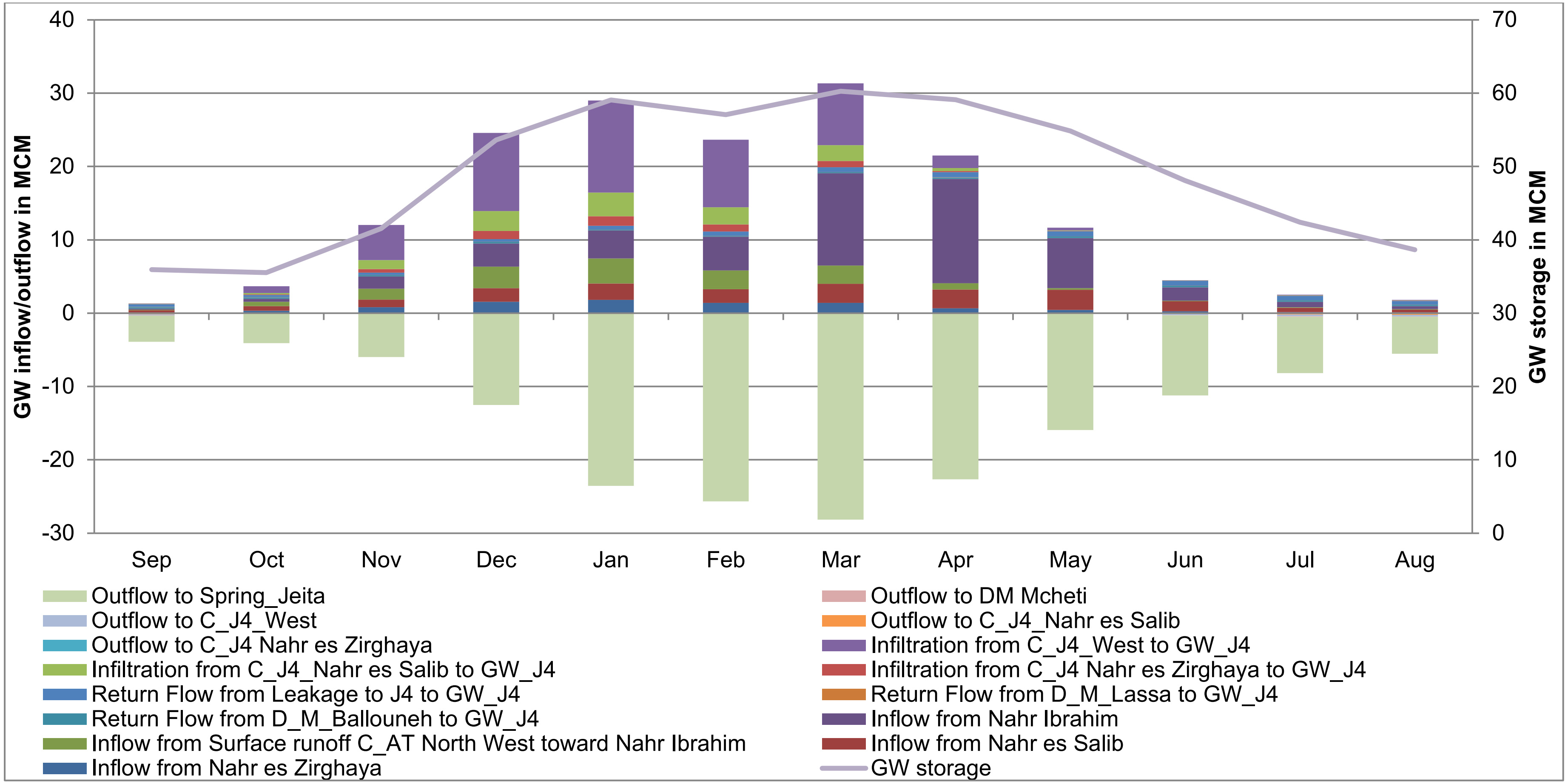

Figure 30: Average monthly Inflow and Outflow of GW J4 and GW Storage in MCM, according to Model 1

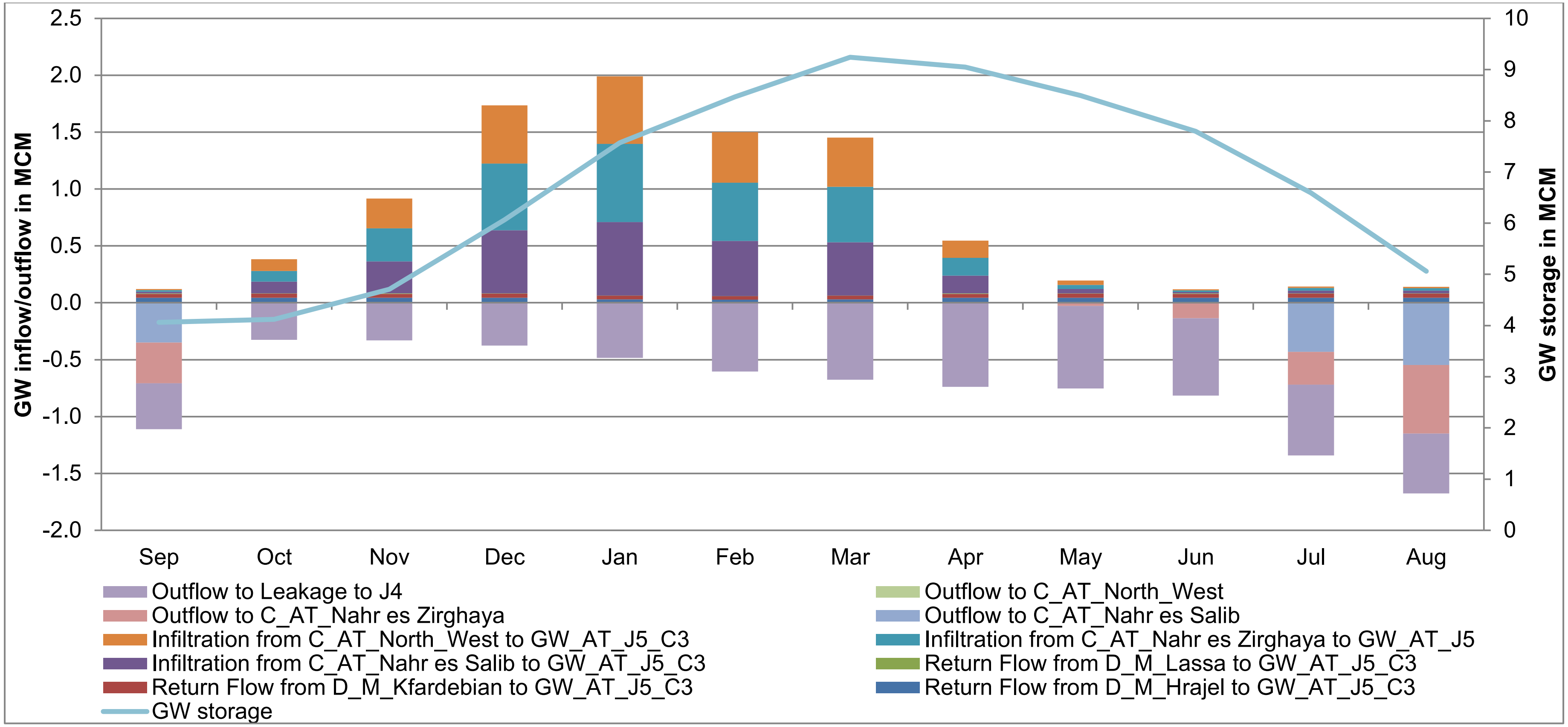

Figure 31: Average monthly Inflow and Outflow of GW AT and GW Storage in MCM, according to Model 1

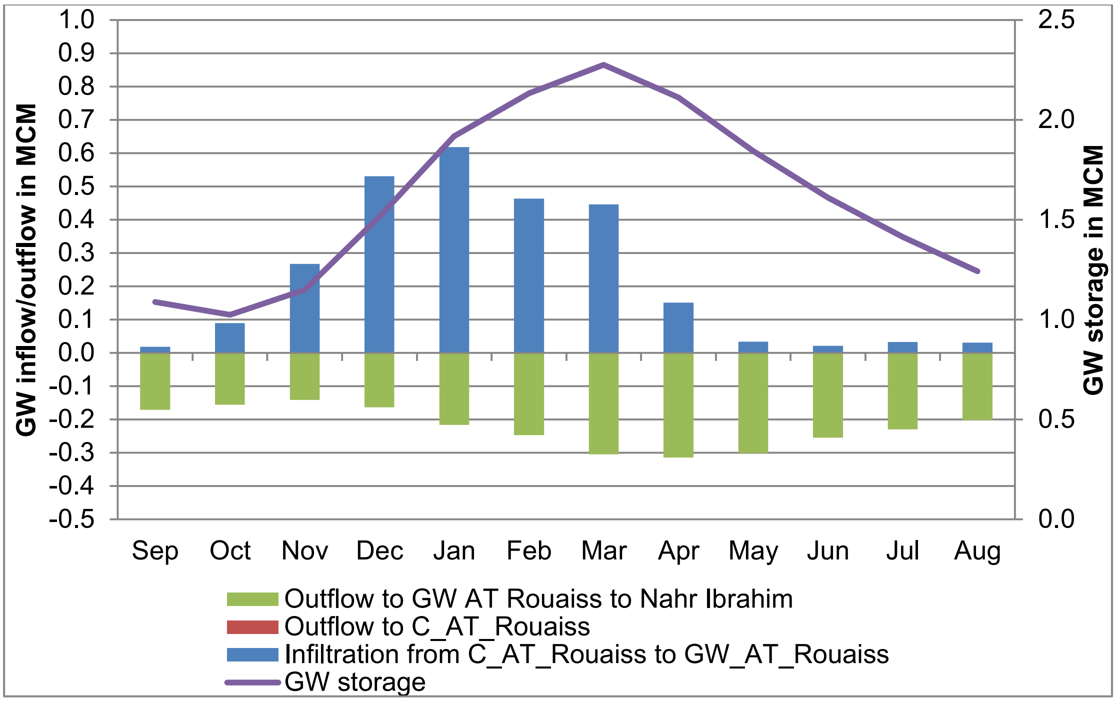

Figure 32: Average monthly Inflow and Outflow of GW AT Rouaiss and GW Storage in MCM, according to Model 1

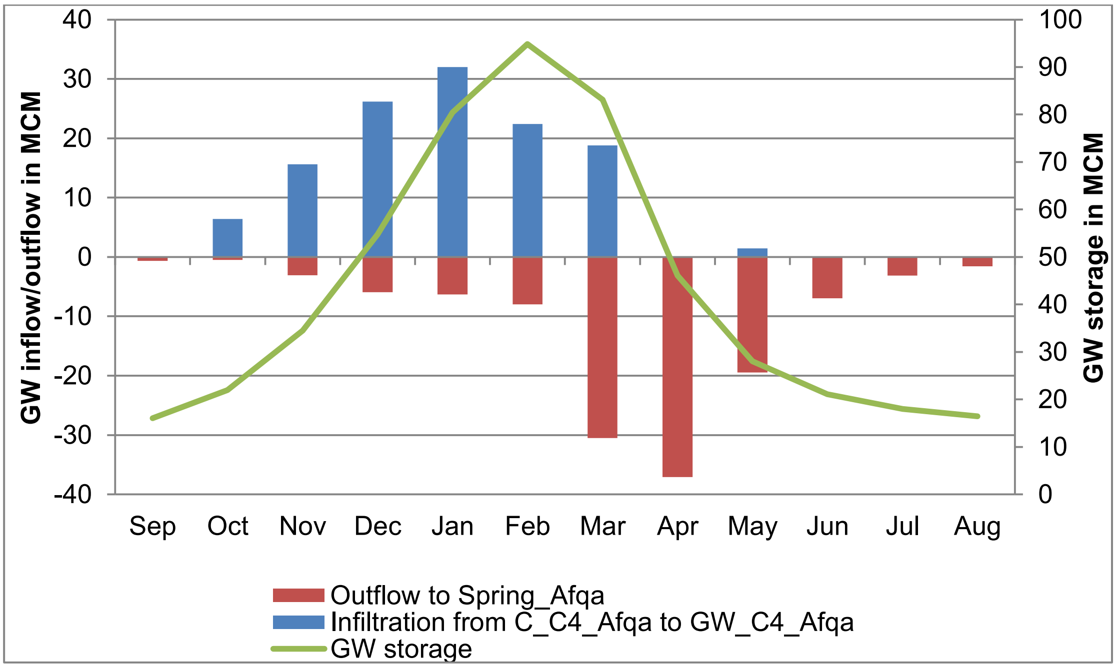

Figure 33: Average monthly Inflow and Outflow of GW C4 Afqa and GW Storage in MCM, according to Model 1

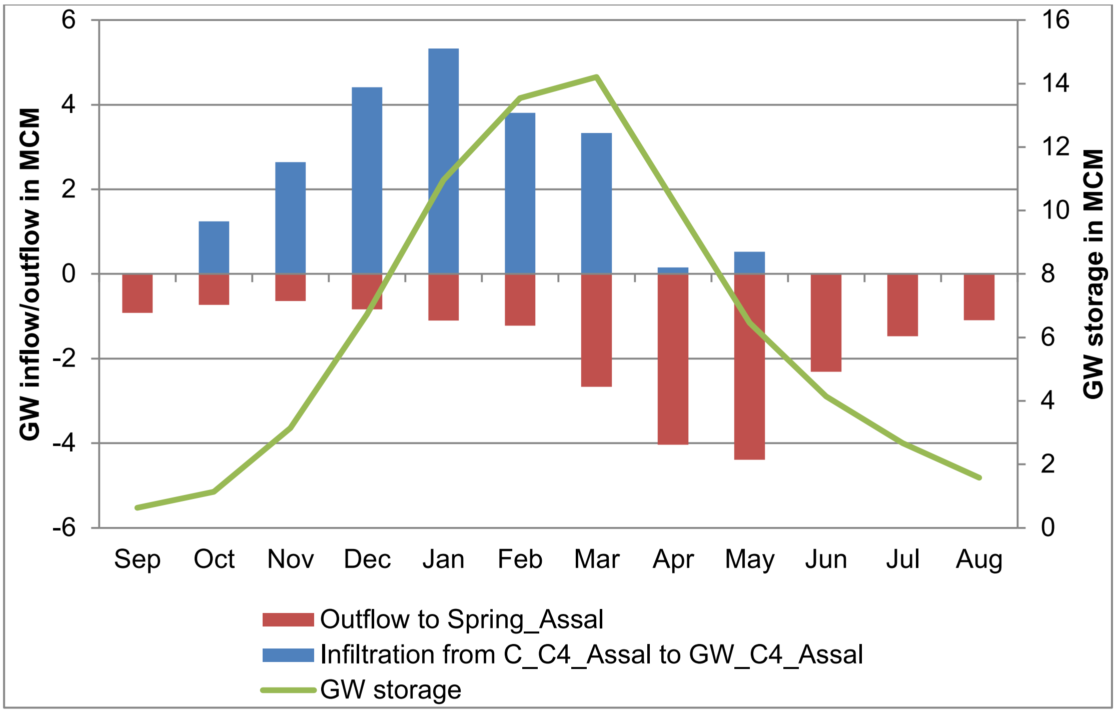

Figure 34: Average monthly Inflow and Outflow of GW C4 Assal and GW Storage in MCM, according to Model 1

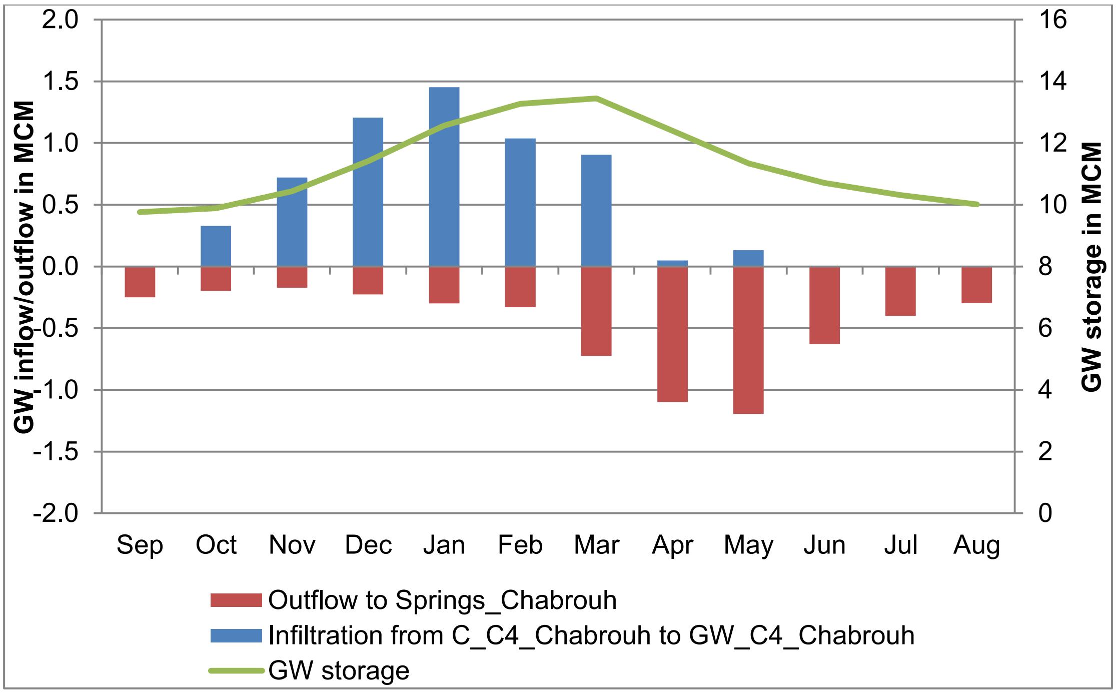

Figure 35: Average monthly Inflow and Outflow of GW C4 Chabrouh and GW Storage in MCM, according to Model 1

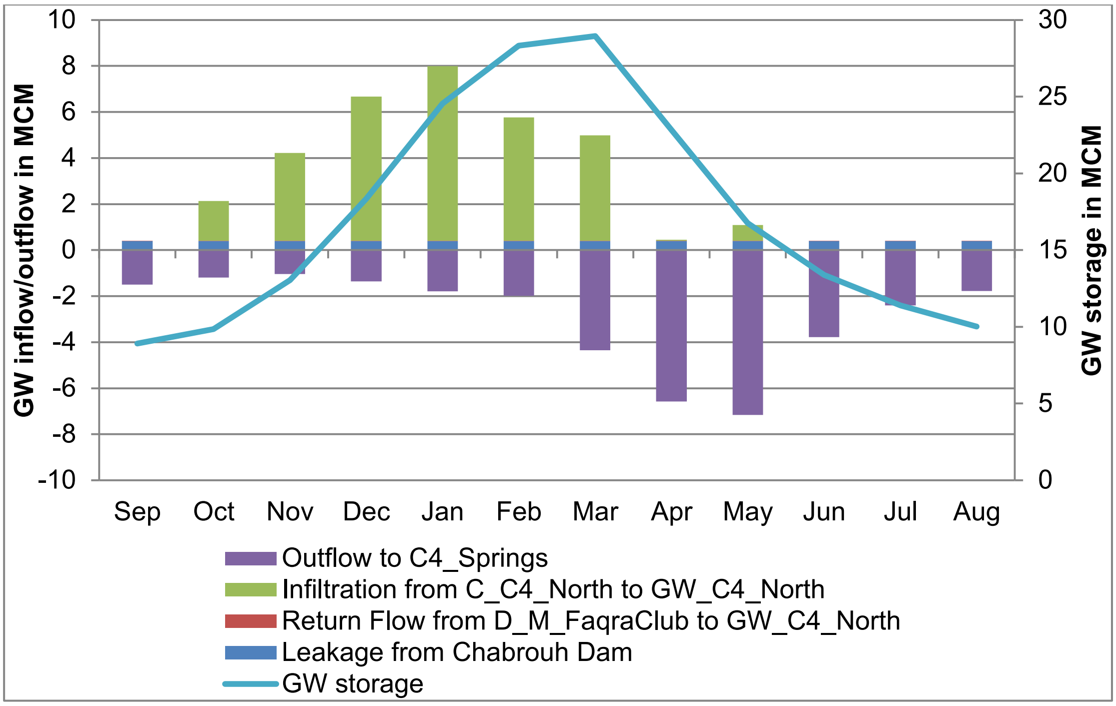

Figure 36: Average monthly Inflow and Outflow of GW C4 Springs and GW Storage in MCM, according to Model 1

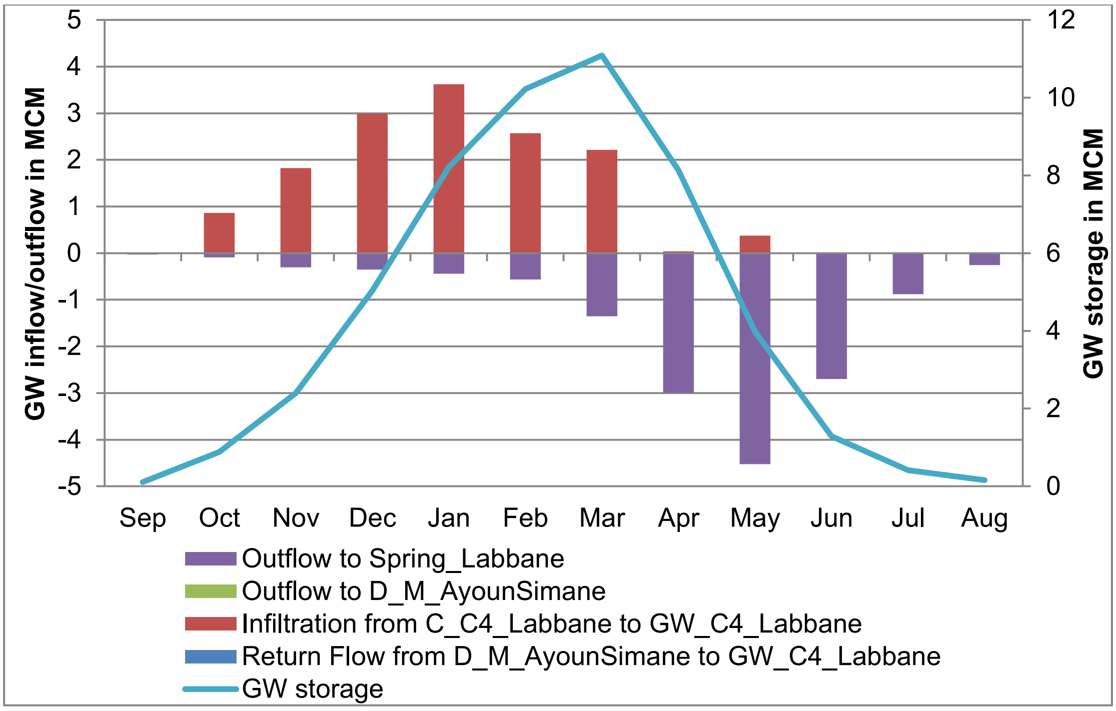

Figure 37: Average monthly Inflow and Outflow of GW C4 Labbane and GW Storage in MCM, according to Model 1

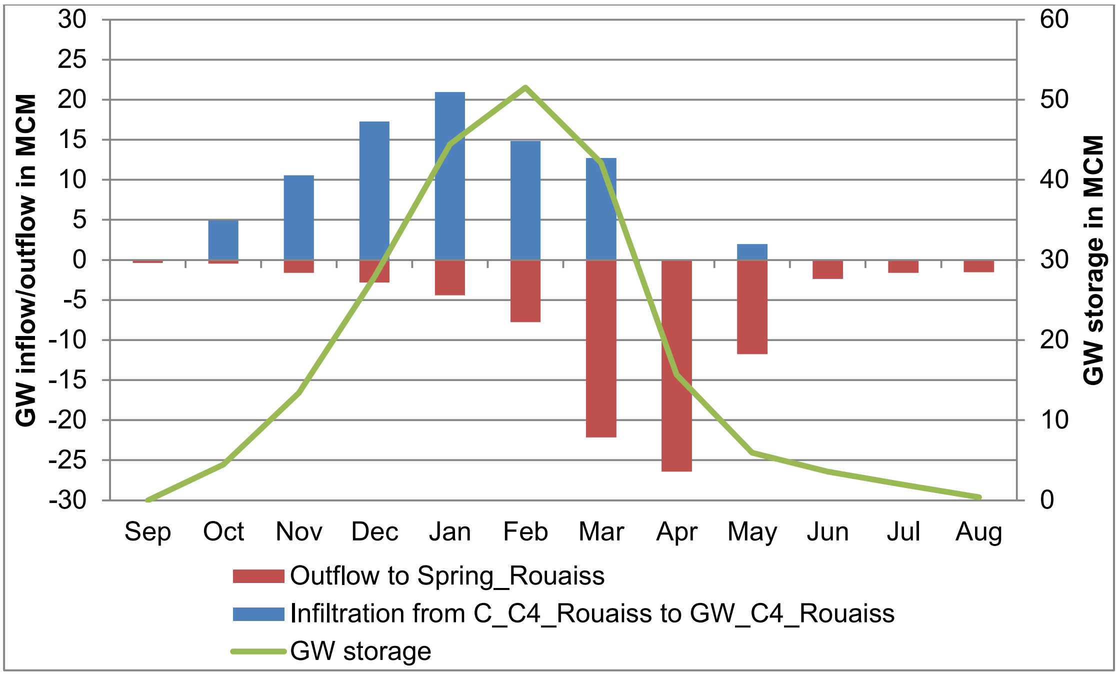

Figure 38: Average monthly Inflow and Outflow of GW C4 Rouaiss and GW Storage in MCM, according to Model 1

8.1.3 Unmet Demand

All demands are continuously satisfied and therefore 100% covered (Figure 39).

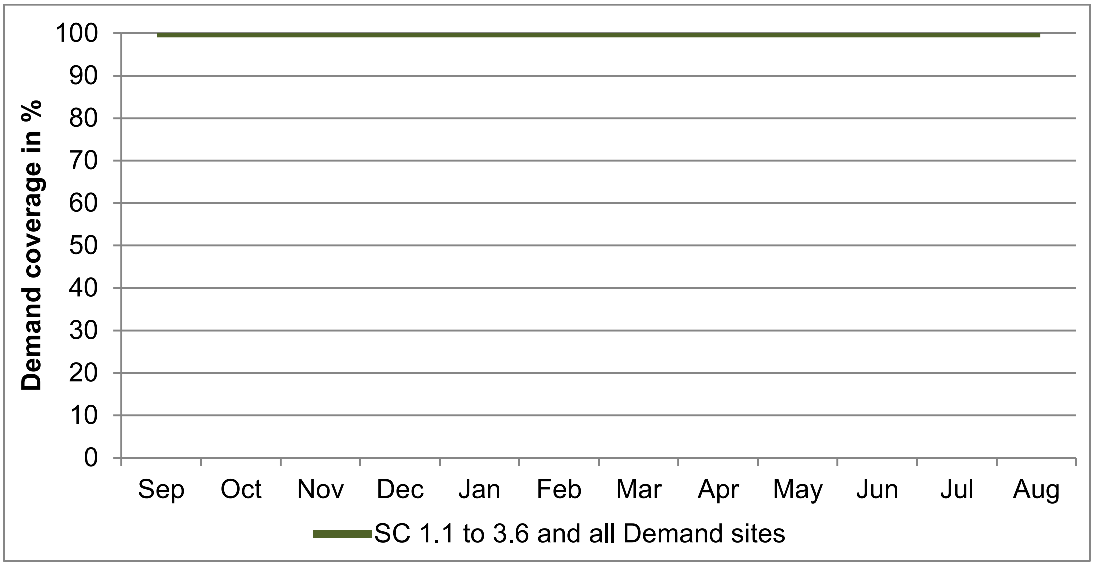

Figure 39: Demand Coverage of all Demand in %, according to Model 1

8.2 WEAP Model 2

8.2.1 Runoff at Daraya

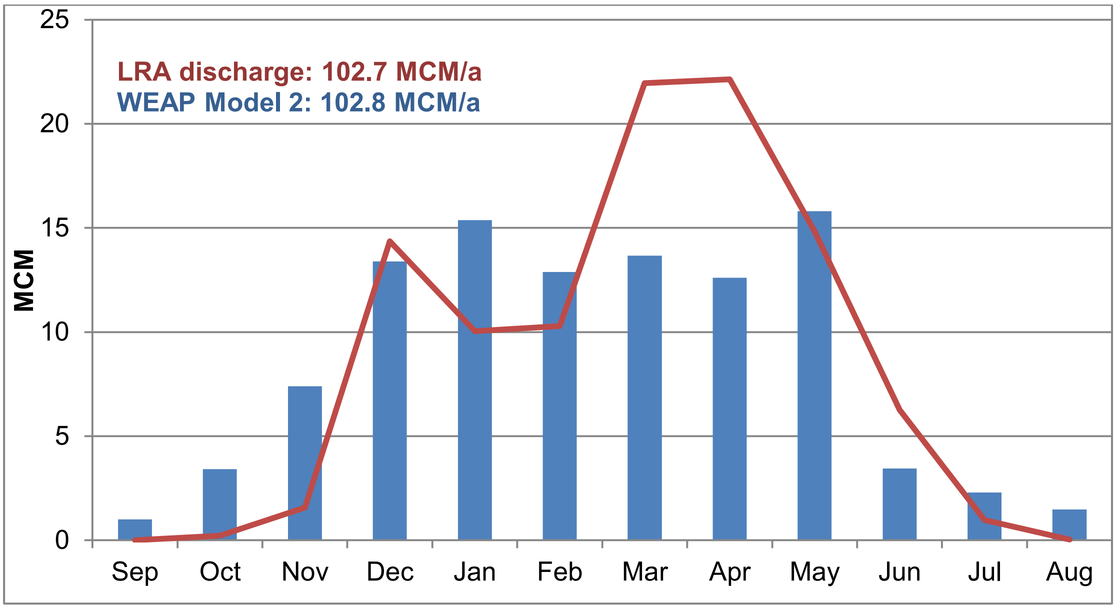

Figure 40: Modeled and observed Discharge of Nahr el Kalb at Daraya Gauging Station, according to Model 2

Figure 40 displays modeled and observed discharge of Nahr el Kalb at Daraya gauging station, according to Model 2. Total measured annual runoff at Daraya is 102.7 MCM, total modeled runoff is 102.8 MCM. The correlation coefficient between the two data sets accounts for 0.83, being acceptably high.

8.2.2 Groundwater Inflow, Outflow & Storage

Figures 41-49 display average the monthly GW inflow and outflow for each of the nine groundwater nodes and their respective storage. Inflow varies throughout the year, however, inflow equals outflow to maintain an intra-annual balance.

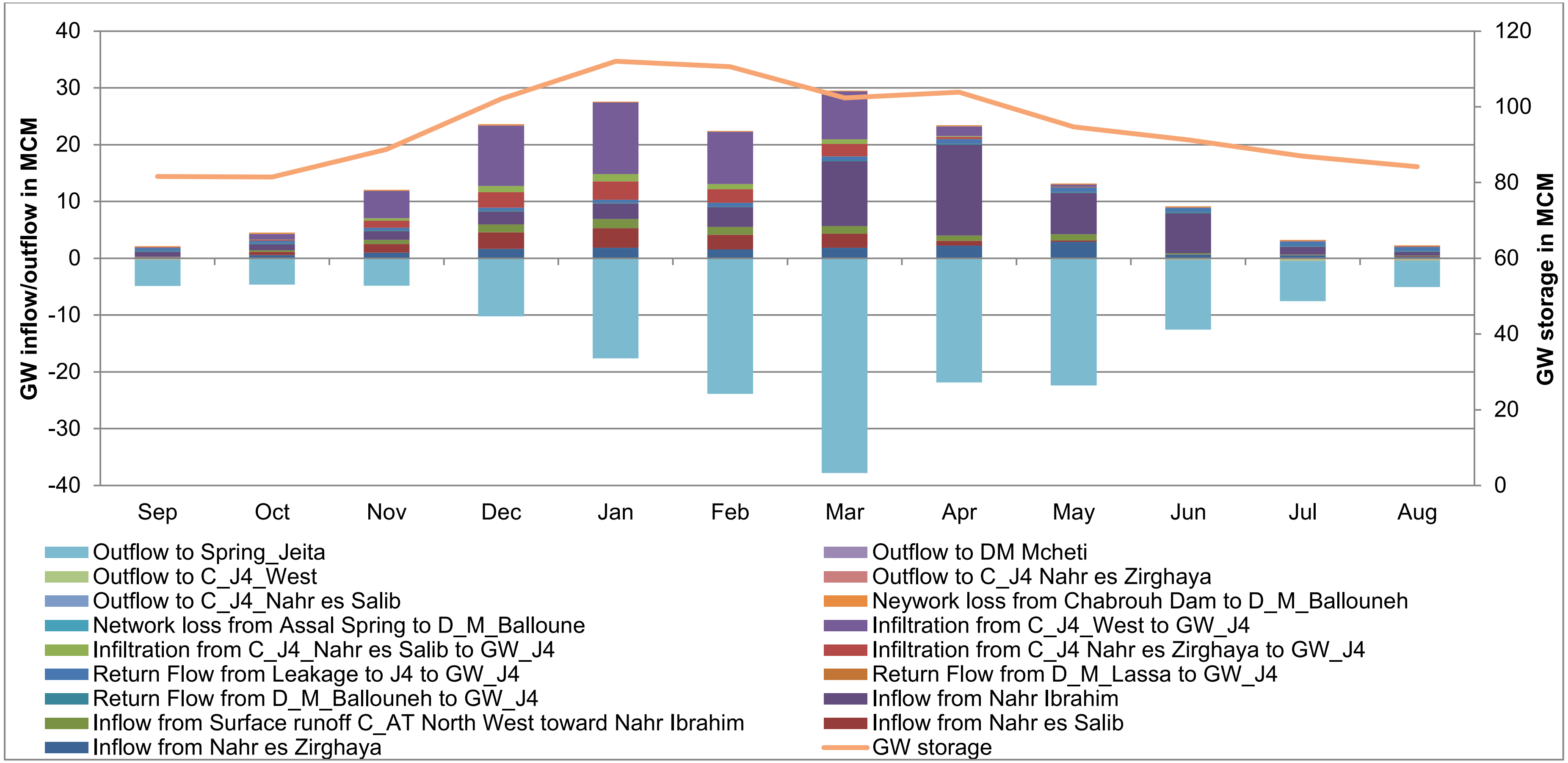

Figure 41: Average monthly Inflow and Outflow of GW J4 and GW Storage in MCM, according to Model 2

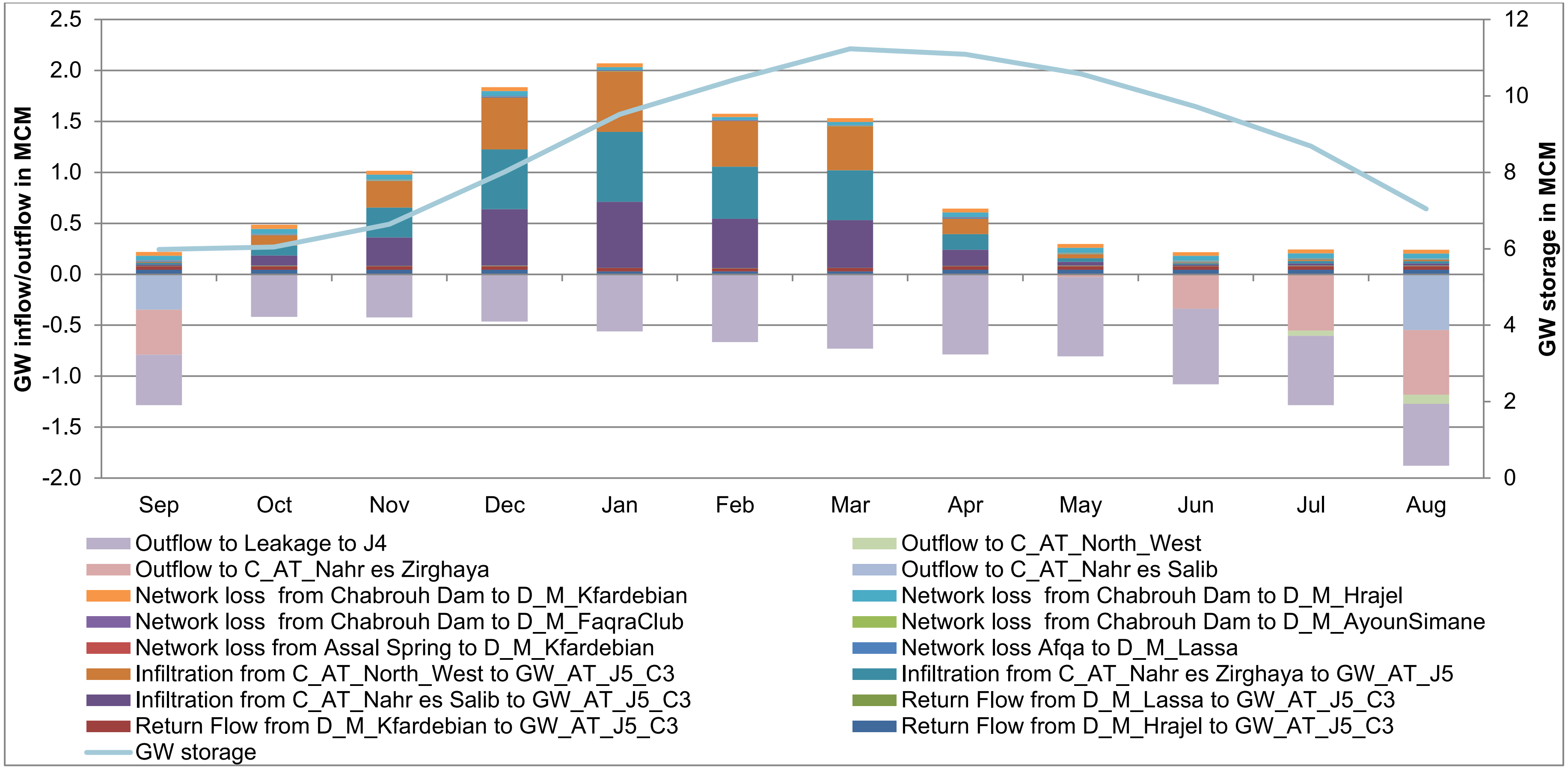

Figure 42: Average monthly Inflow and Outflow of GW AT and GW Storage in MCM, according to Model 2

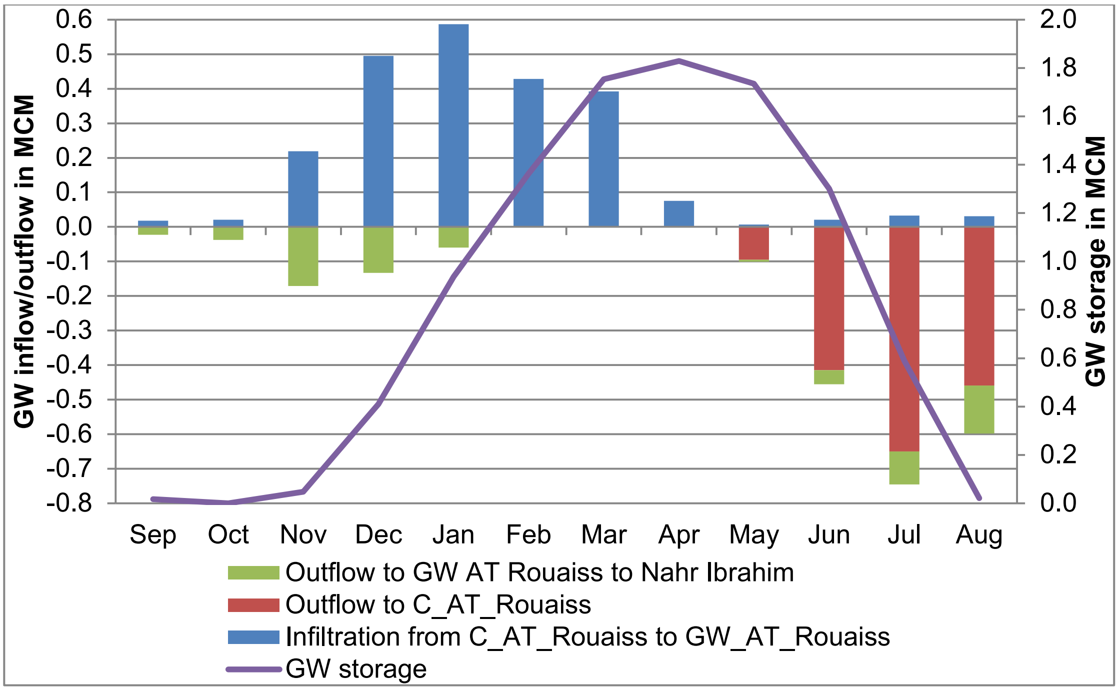

Figure 43: Average monthly Inflow and Outflow of GW AT Rouaiss and GW Storage in MCM, according to Model 2

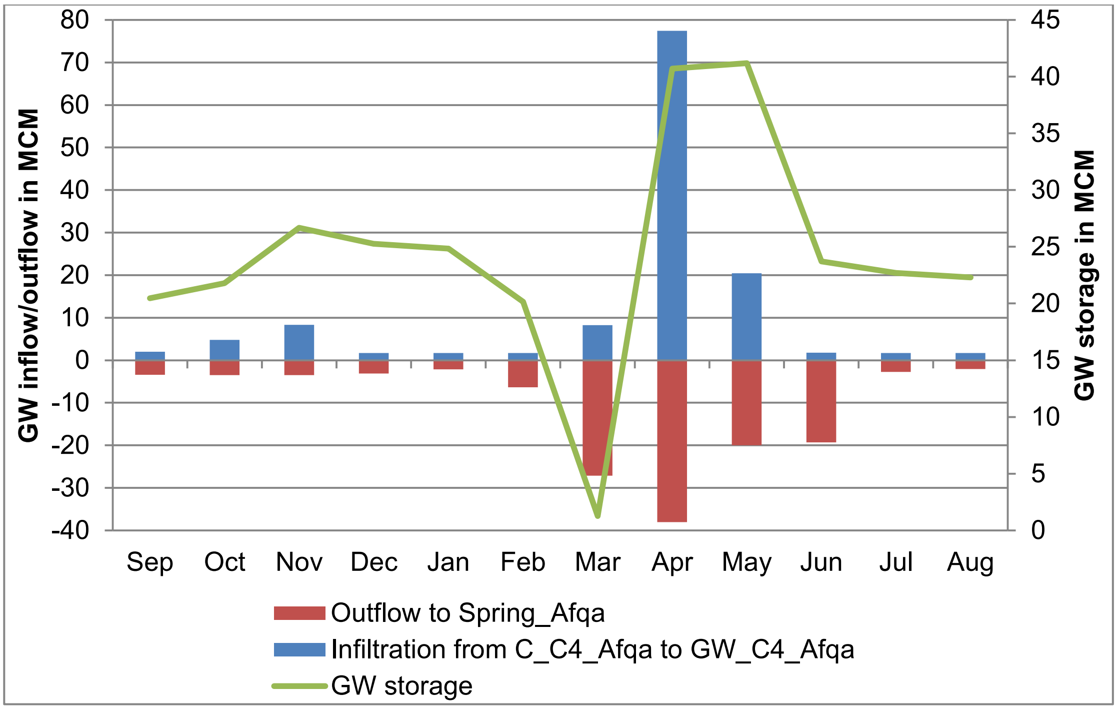

Figure 44: Average monthly Inflow and Outflow of GW C4 Afqa and GW Storage in MCM, according to Model 2

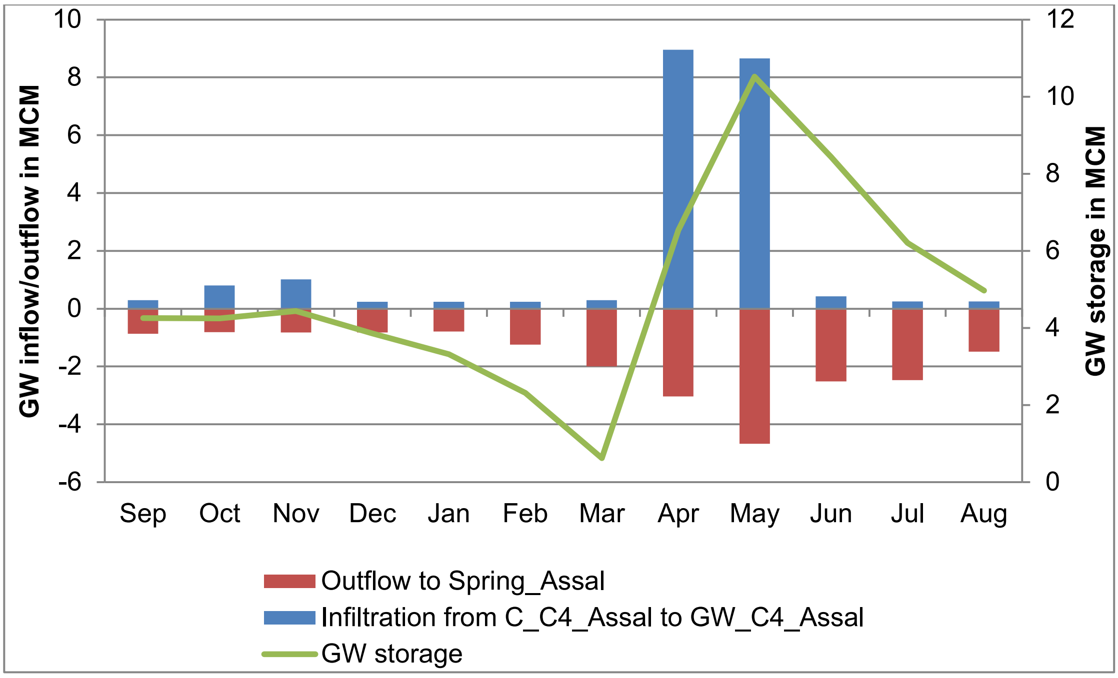

Figure 45: Average monthly Inflow and Outflow of GW C4 Assal and GW Storage in MCM, according to Model 2

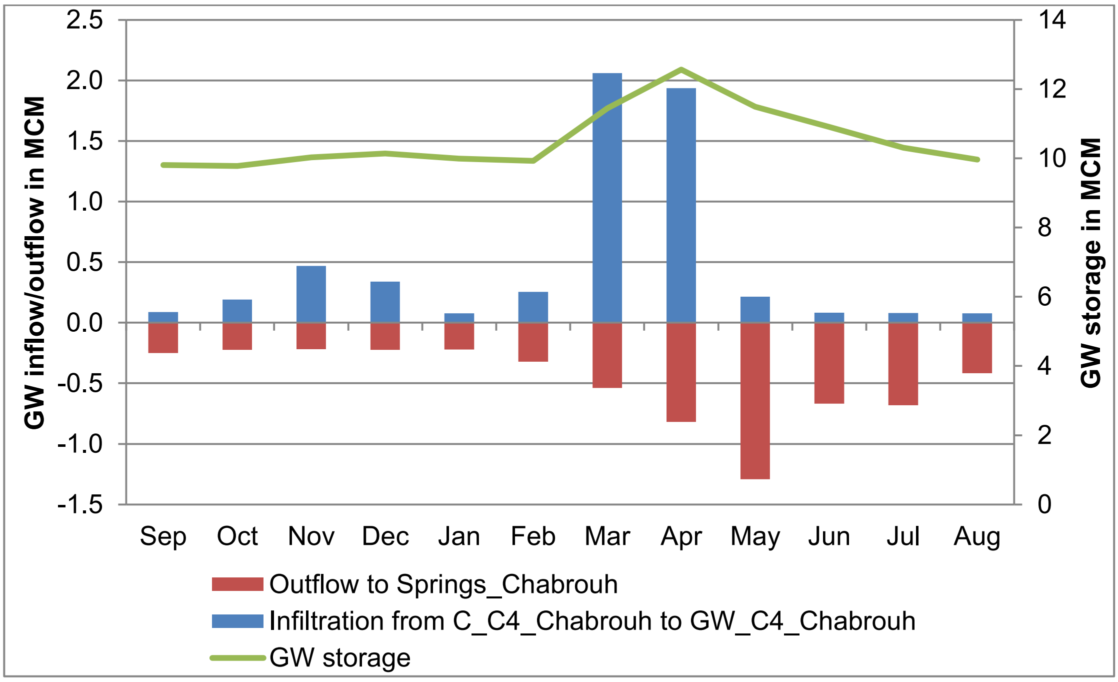

Figure 46: Average monthly Inflow and Outflow of GW C4 Chabrouh and GW Storage in MCM, according to Model 2

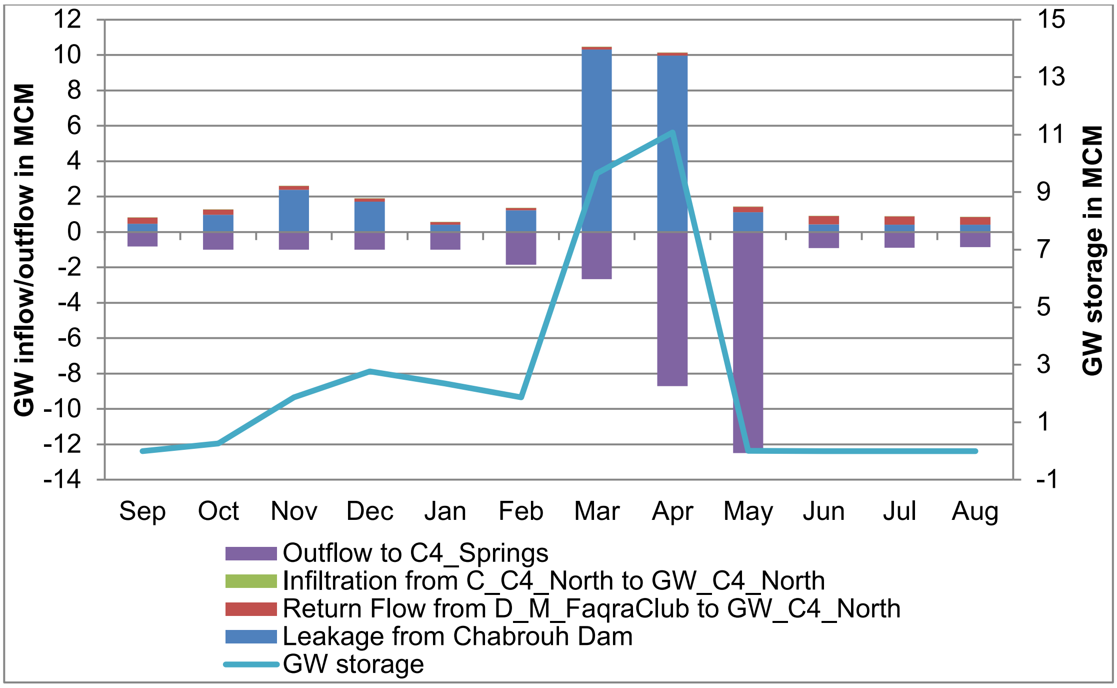

Figure 47: Average monthly Inflow and Outflow of GW C4 Springs and GW Storage in MCM, according to Model 2

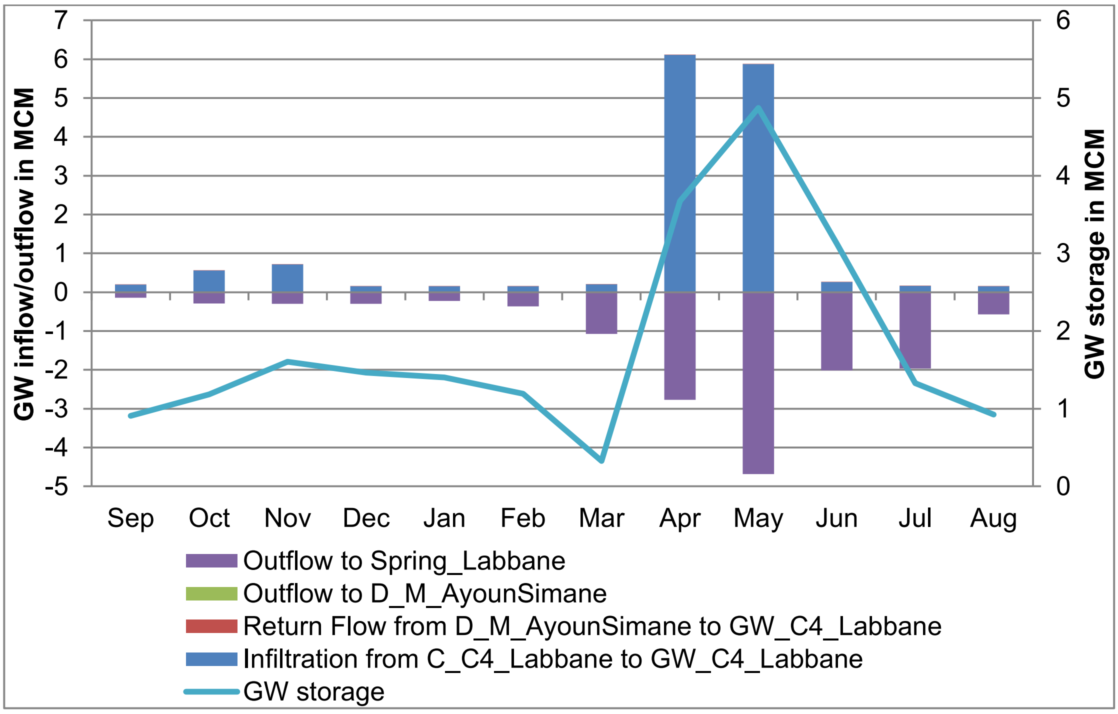

Figure 48: Average monthly Inflow and Outflow of GW C4 Labbane and GW Storage in MCM, according to Model 2

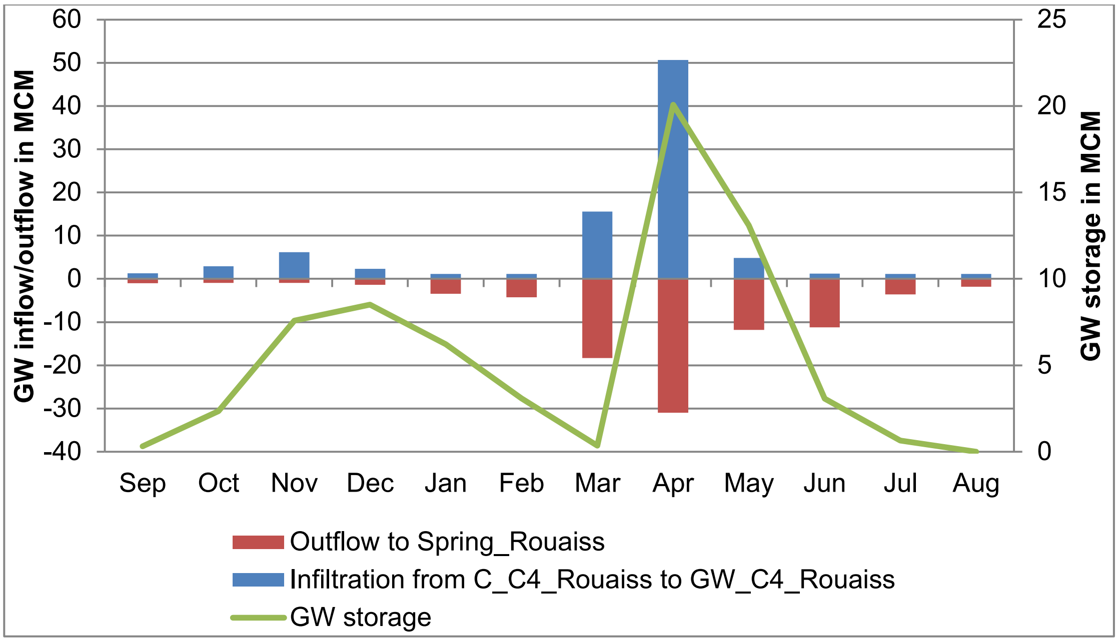

Figure 49: Average monthly Inflow and Outflow of GW C4 Rouaiss and GW Storage in MCM, according to Model

8.2.3 Unmet Demand

All demands are continuously satisfied and therefore 100% covered (Figure 50).

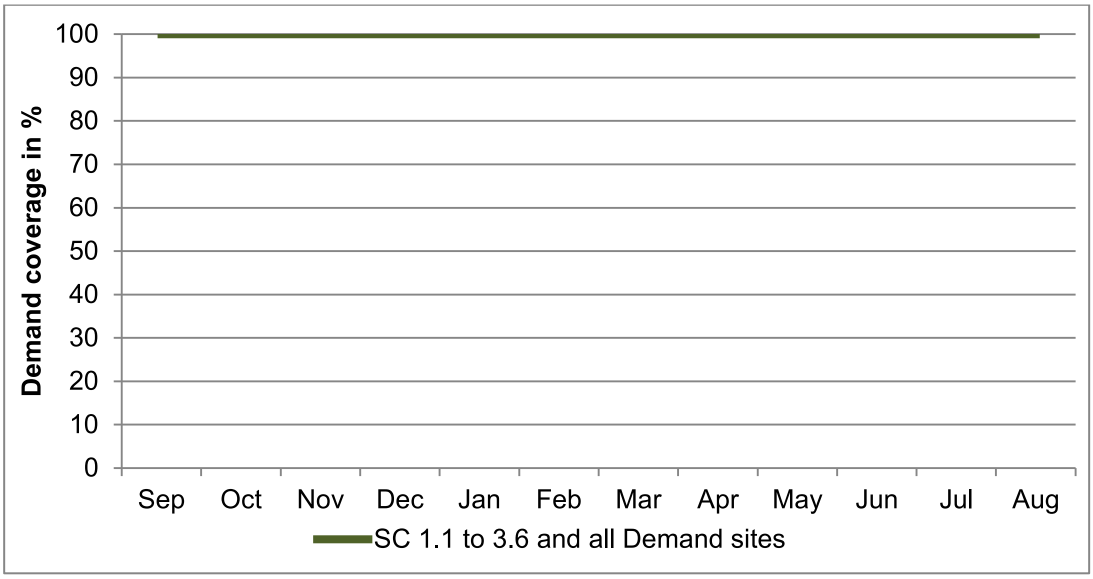

Figure 50: Demand Coverage of all Demand in %, according to Model 2

9 Results

All of the presented results refer to Model 2.

First, the *natural* water balance is presented (Figures 51 and Figure 52). The natural balance refers to the water balance, in which only the first catchment process (ET, SR, GWR) of a water drop, reaching the GW catchment through P, is considered. Thus, it assesses the direct SR, ET and GWR. Neither domestic nor agricultural supply nor GWR by riverbed infiltration or GW leakage is included because this would result in counting one water drop manifold. The natural water balance was established to assess the overall rate of GWR, ET and SR in % per hydrogeological unit.

Based on this balance, the *anthropogenic* water balance is presented. The anthropogenic water balance includes each catchment flow, which results in counting water drops manifold.

The presented records refer to rounded values, which may include rounding errors.

9.1 Natural Balance: Catchment Inflow and Outflow

Figure 51 displays the annual rate of direct catchment processes of the Jeita GW catchment. In total, the catchment receives 620 MCM precipitation per year of which 215 MCM (34.7% of total P) is snow on the C4 and 405 MCM (65.3% of total P) is rain over the entire catchment. The spatial variation of rainfall complies with the spatial variation and the mean elevation of the hydrogeological units: the J4, which has the lowest mean elevation, receives annually 1,297 mm per square meter, followed by the Aquitard Complex with 1,492 mm and the C4 with 1,635 mm. The C4 receives 58.1% of the total annual P, the J4 18.1% respectively.

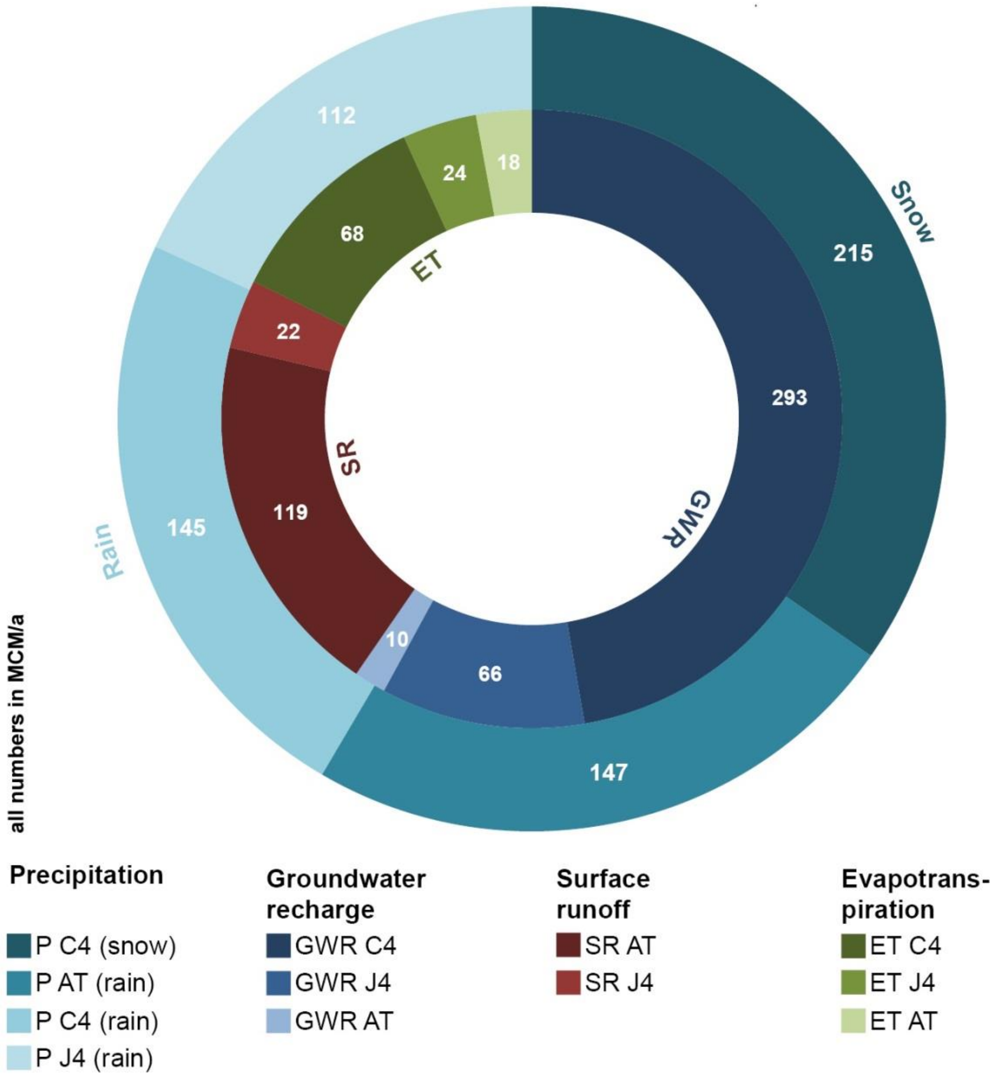

Figure 51: Natural annual Water Balance within the Jeita GW Catchment in MCM

P leads directly either to GWR, SR or ET. Total annual ET (excl. applied irrigation) sums up to 110 MCM (17.7% of total P). The lowest rate of ET per square meter occurs on the Aquitard Complex, with 182 mm per year, less than on the J4 where 277 mm evapotranspirate per year. This is contradicting to the availability of water, i.e. rainfall, which is higher on the Aquitard Complex. However, since mean temperatures/ET_0 records are lower on the Aquitard Complex than on the J4, and applied irrigation is excluded in this calculation, the Aquitard Complex shows a lower rate of ET than the J4. The highest annual rate of annual ET (329 mm/m^2) occurs on the C4, which can be explained by the large availability of water for ET. Another possible explanation for this large rate of ET on the C4 is the used modeling method for the catchment (soil moisture method in Model 2 and simplified coefficient method in Model 1). However, a comparison between the annual ET of the C4 sub-catchments between Model 1 and Model 2 shows actually higher ET results for Model 1 where all sub-catchments were modeled with the same method. Therefore, it is not the changed modeling method that explains the large rate of ET of Model 2 but rather the availability of precipitation on the C4 unit.

Total annual SR occurs only on the Aquitard Complex and on the J4, summing up to 141 MCM (22.8% of total P). The J4 generates 22 MCM of direct SR, which is equivalent to 259 mm/m^2/a. The Aquitard Complex, in turn, generates annually 119 MCM, equivalent to 1,205 mm/m^2/a.

GWR accounts for the largest share of direct catchment processes. Annually, 370 MCM (59.5% of total P) infiltrate towards the GW table. On the Aquitard Complex, 10 MCM recharge annually the GW system, which corresponds to a GWR rate of 105 mm/m^2/a. The J4 unit generates 66 MCM of GWR per year, which is equivalent to 761 mm/m^2/a. The C4 unit accounts for the largest share, generating 293 MCM of GWR, equivalent to 1,320 mm/m^2/a,

Table 27 displays the rate of GWR, SR and ET of P for each hydrogeological unit.

Table 27: Groundwater Recharge, Surface Water Runoff and Evapotranspiration as Share of Precipitation in each Hydrogeological Unit

Hydrogeological Unit	GWR in %	SR in %	ET in %
Upper Aquifer (C4)	81.3	0.0	18.7
Aquitard Complex	7.0	80.8	12.2
Lower Aquifer (J4)	58.7	20.0	21.3

The annual natural water balance per sub-catchment is displayed on the map in Annex III.

Figure 52 displays the monthly variation of the parameters of the natural balance.

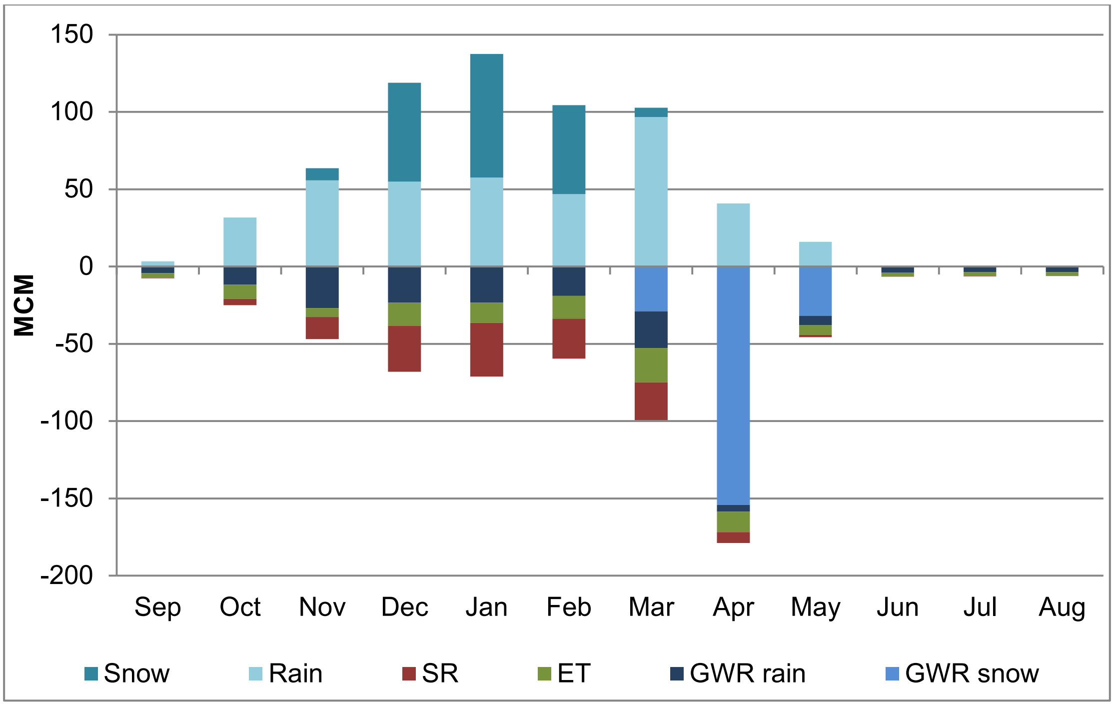

Figure 52: Natural monthly Water Balance within the Jeita GWCZ in MCM

Between October and the end of April, 96.7% of the annual P occurs, corresponding to 600 MCM. Annually, a maximum of 137.6 MCM occurs in January and a minimum of 0.2 MCM in July/August. Snowfall appears between November and March, whereas the maximum is reached in January with 80.0 MCM on the C4 unit. Respectively, 215 MCM of snowmelt recharge the C4 Aquifer, reaching the maximum of 154 MCM in April.

GWR through rainfall, ET and SR depend on actual occurring P. GWR through rainfall is very constant between November and March, varying between 27 and 19 MCM per month. ET reaches its maximum in March, when the relation between temperatures/ET_0 and availability of P are most favorable. The maximum of SR can be derived directly from the maximum of rainfall, which is January (34.7 MCM).

9.2 *Anthropogenic Balance: Catchment Inflow and Outflow*

Figure 53 displays the annual anthropogenic water balance of the Jeita GW catchment, differentiating between natural, i.e. direct (primary), catchment processes, as outlined in the previous chapter as well as the resulting (secondary) catchment flows. Annex II displays the monthly records.

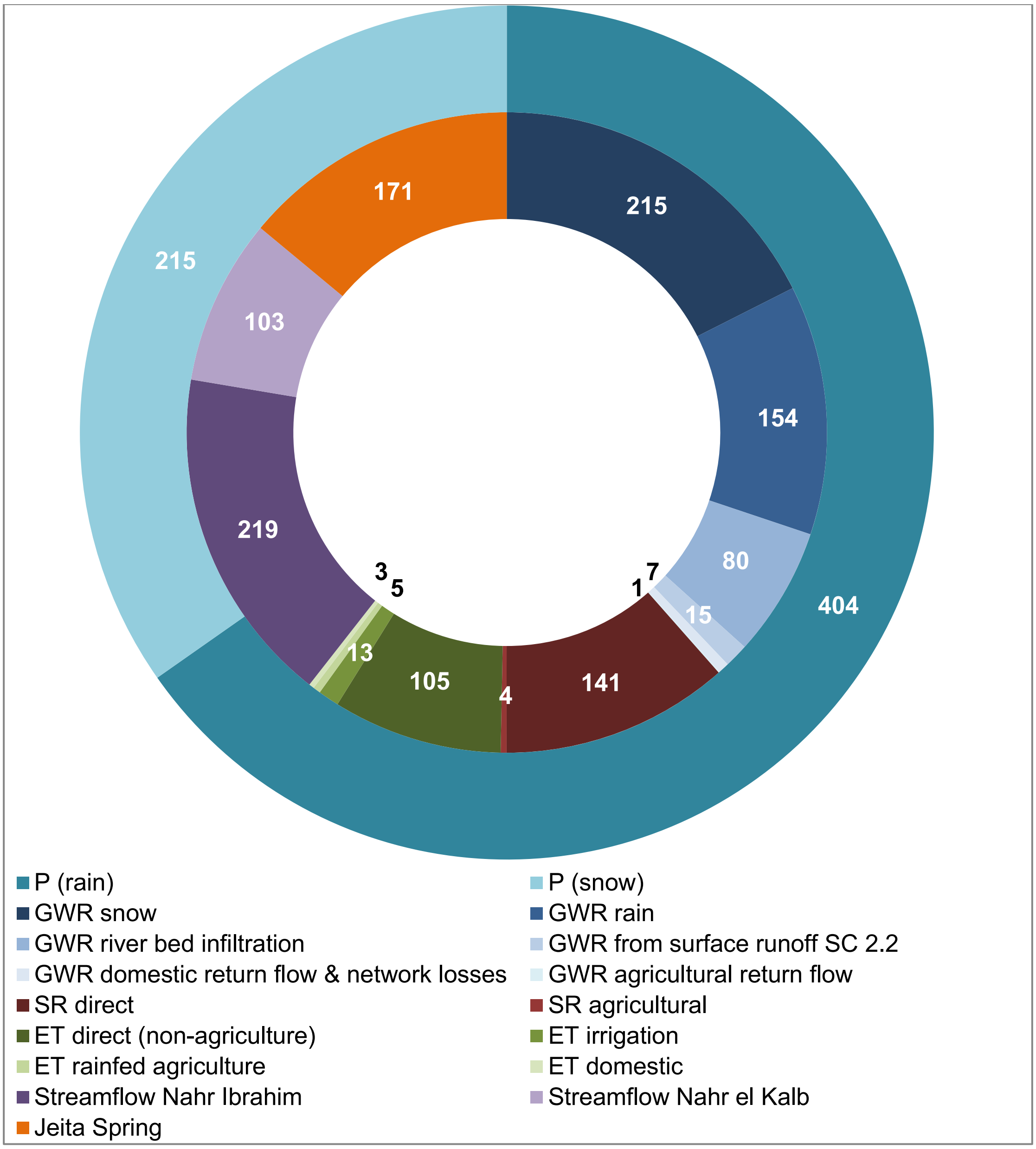

Figure 53: Annual anthropogenic Water Balance within the Jeita GWCZ in MCM

GWR and SR constitute flows within the boundaries of the Jeita GW catchment whereas ET, streamflow and discharge of Jeita spring account for flows that leave the boundaries of the catchment.

Discharge of Jeita spring accounts for more than 171 MCM per year, as outlined in the following Chapter 9.3.

Total streamflow that leaves the boundaries of the catchment sums up to 322 MCM. Nahr el Kalb discharges 103 MCM (Daraya gauging station) and Nahr Ibrahim 219 MCM. Nahr Ibrahim receives its major inflow from Afqa and Rouaiss spring, draining the C4 and summing up to 217 MCM/a (Figure 54).

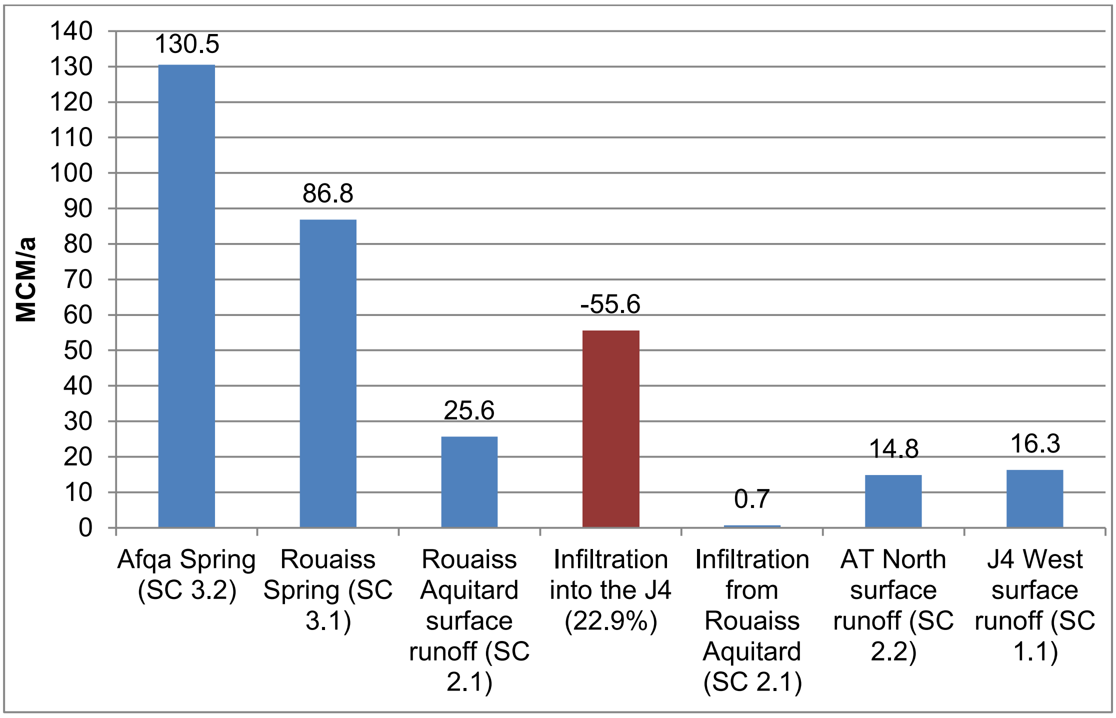

Figure 54: Annual Inflow and Outflow of Nahr Ibrahim in MCM

Total annual ET is 126 MCM (Figure 55). As mentioned, direct ET accounts for 110 MCM, whereas 105 MCM evapotranspirate from non-agricultural surfaces and 5 MCM evapotranspirate from agricultural lands and are therefore considered as rainfed agriculture. Annual ET from irrigation makes up 13 MCM and ET from domestic sites is 3 MCM (50% consumption rate, which is regarded as ET).

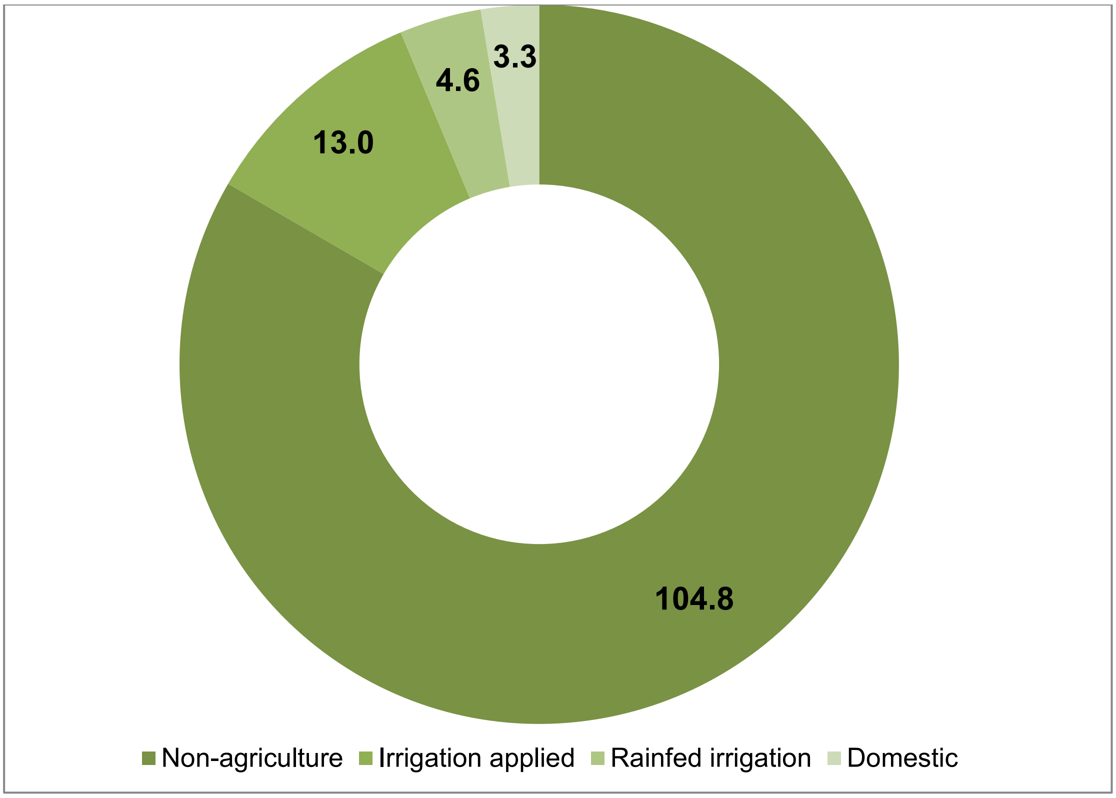

Figure 55: Annual ET in the Jeita GWCZ in MCM

Total SR sums up 145 MCM per year. In addition to the 141 MCM of direct surface runoff, agricultural excess irrigation generates 4 MCM of runoff per year.

Total annual GWR accounts for 475 MCM, including the 370 MCM of direct GWR (Figure 56). Additionally, 80 MCM of GWR originates from riverbed infiltration towards the J4 Aquifer. Nahr es Zirghaya loses 9 MCM, Nahr es Salib 15 MCM and Nahr Ibrahim 56 MCM, summing up to 80 MCM/a.

15 MCM of GWR are generated by SR, which concentrates in SC 2.2 towards the J4 Aquifer. The generated surface runoff passes over the highly karstified SC 1.1, from where approx. 50% of the SR infiltrate towards the J4.

7 MCM of GWR stems from the domestic sector, including 3.3 MCM from (wastewater) return flow and 3.4 MCM from network losses. Leakage of Chabrouh reservoir towards GW C4 Springs accounts for 3 MCM/a and less than 1 MCM of GWR is generated through agricultural return flow.

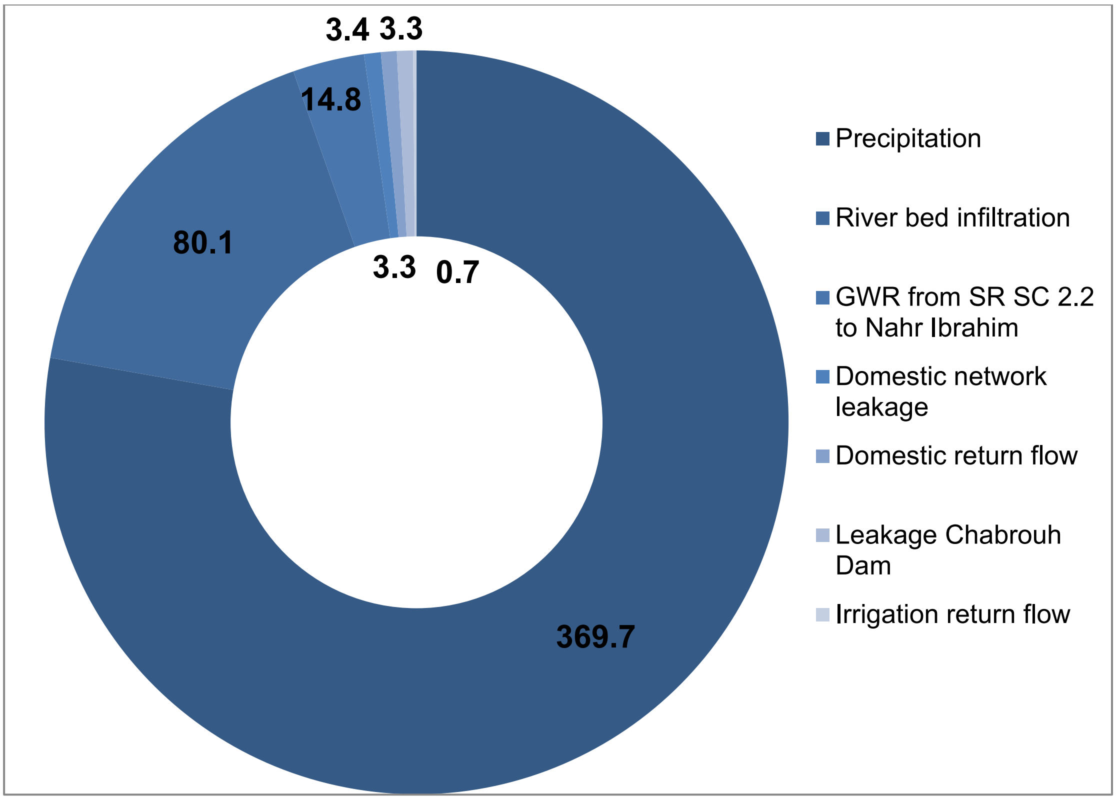

Figure 56: Annual GWR in the Jeita GWCZ in MCM

Figure 57 displays the monthly variation of the anthropogenic balance in MCM.

Irrigation is applied between May and September, whereas in May, crop demand is mainly covered by rainfall. In total, 17 MCM of irrigation water is supplied per year, with maxima of 5.2 and 5.0 MCM in July/August.

GWR by riverbed infiltration occurs according to the quantity of streamflow of respective rivers, with a maximum of 19 MCM in April.

Infiltration from SC 2.2 via surface runoff over SC 1.1 occurs according to the SR regime on the Aquitard, with a maximum of 3.4 MCM in January.

Monthly leakage of the domestic supply network and return flow varies between 0.4 MCM in winter and 0.6 MCM in summer. Agricultural return flow occurs according to the application of irrigation, same as the generation of SR from applied irrigation.

Monthly ET from non-agricultural land varies between 2.3 MCM in August and 21.7 MCM in March. ET from rainfed agriculture has its maximum in October, which is related to the planting season of crops and to the availability of water. The k_c value for crops is still relatively high in October so that a relatively large share of rainfall is providing water to the crops.

Monthly domestic ET ranges between 0.2 MCM in winter and 0.3 MCM in summer.

The two streams that leave the GW catchment of Jeita are constituted by Nahr el Kalb and Nahr Ibrahim. As displayed in Figure 40, annual streamflow of Nahr el Kalb accounts for 103 MCM with the respective seasonal variation and the peak flow in May. The peakflow of Nahr Ibrahim is reached one month earlier, in April. Annual streamflow of Nahr Ibrahim leaving the catchment sums up to 219 MCM. Both streams reflect the seasonal discharge characteristic of their feeding springs: the earlier discharge regime of Afqa and Rouaiss spring for Nahr Ibrahim and the later discharge regime of Assal, C4 Springs and Labbane Spring for Nahr el Kalb.

Finally, the modeled discharge of Jeita spring varies between a mean monthly minimum of 4.6 MCM (1.8 m^3/s) in October and a maximum of 37.8 MCM (14.1 m^3/s) in March.

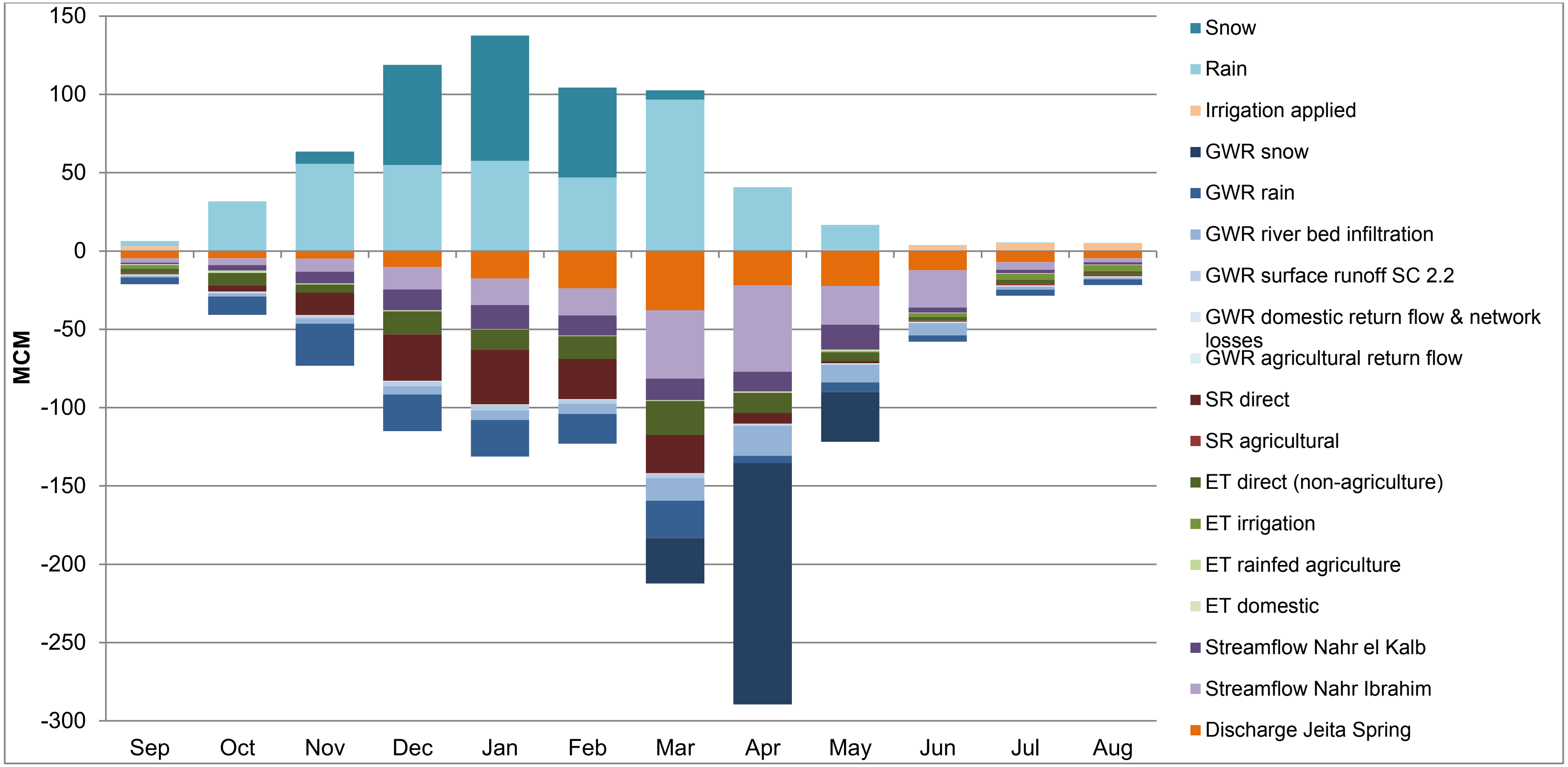

Figure 57: Anthropogenic monthly Water Balance within the Jeita GWCZ in MCM

9.3 Modeled Spring Discharge

Figure 58 and Table 28 display the comparison between the results of the defined discharge of Model 1 and the modeled discharge of Model 2.

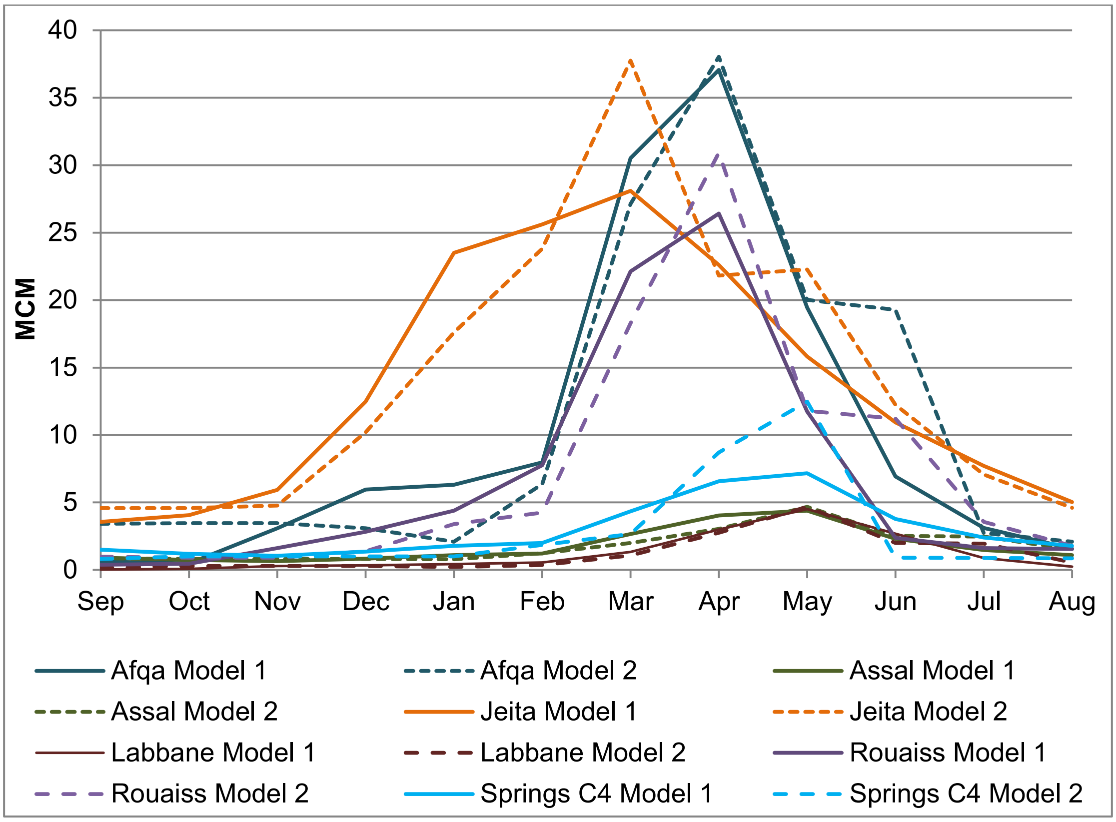

Figure 58: Monthly Discharge of Afqa, Assal, Jeita, Labbane, Rouaiss and C4 Springs in MCM, according to Model 1 and Model 2

Table 28: Annual Spring Discharge of WEAP Model 1 and 2 and Pearson's r

Discharge	Afqa	Assal	Jeita	Labbane	Rouaiss	C4 Springs
Total Model 1	123.1	21.4	165.4	14.4	83.3	34.9
Total Model 2	131.2	21.5	171.3	14.6	89.4	33.2
Pearson's r	0.94	0.92	0.92	0.95	0.93	0.90

Even though the monthly discharge may differ from Model 1 to Model 2, the occurrence of the maximum peak flows always complies with each other. The very good fit (MORIASI et al., 2007) is proven by a Person's r, which is ≥ 0.9

for all springs. The minor springs of the C4 outcrop (C4 Springs) show the lowest fit, with a correlation coefficient of 0.90. Labbane spring shows the best fit of all modeled springs, reaching 0.95.

9.4 Sources of Jeita

Each sub-catchment contributes to discharge of Jeita spring but the flow of a drop from a SC to Jeita may be very complex. A possible flow path, for example, is illustrated: a snowflake in SC 3.6 (GW catchment of Labbane) melts in spring and turns to a drop of water. This drop recharges the GW system, before it is discharged by Labbane spring, from where it is conveyed to Chabrouh dam. From Chabrouh dam, the drop leaks towards GW node C4 Springs, from where it is discharged again by C4 Springs. Water from C4 Springs is partly used for irrigation, so the water drop is used for irrigation of apples in SC 2.3. Because of the irrigation efficiency of 75%, 25% of applied irrigation doesn’ reach he cro and so, the traveling water drop becomes part of excess irrigation, which is further subject to SR GWR of GA AT. From there, it leaks downwards towards the J4 Aquifer from where it is finally discharged by Jeita spring.

The total annual recharge of the J4 is 173 MCM, the contribution of each sub-catchment to the recharge of the J4 Aquifer is displayed in Figure 59 and mapped in Annex III. The main flow paths and their quantities are shown in Annex V while the contribution per hydrogeological unit is summarized in Table 29.

Table 29: Sources of Flow to the Lower Aquifer (J4)

Hydrogeological Unit	Flow to J4 in MCM/a	Flow to J4 in %
Upper Aquifer (C4)	67.5	39.0
Aquitard Complex	39.5	22.8
Lower Aquifer (J4)	66.0	38.2

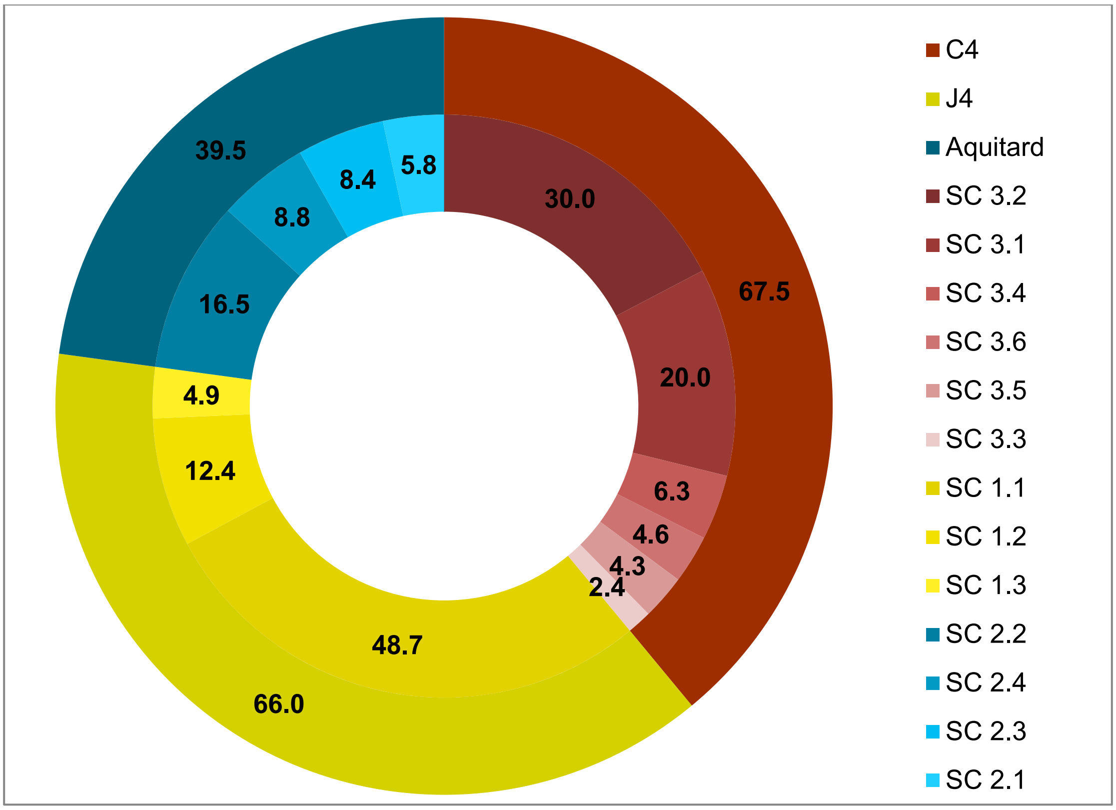

Figure 59: Annual Contribution of each Sub-Catchment to GWR of the J4 Aquifer in MCM

23% (40 MCM) of the annual recharge of the J4 originates from rainfall on the Aquitard Complex (SC 2.1 to 2.4). This share reaches the J4 indirectly either via GW leakage or generated surface runoff towards Nahr Ibrahim, Nahr es Salib or Nahr es Zirghaya (from the latter 20% infiltrate towards the J4). Riverbed infiltration makes up the major share of contribution.

38% (66 MCM) of Jeita's discharge is contributed by GWR of SC 1.1 to 1.3 on the J4 unit.

The largest share, approximately 39% (68 MCM) of Jeita's discharge, originates from GWR on the C4 unit. The major single source, originating from C4, is Afqa spring, which contributes 30 MCM (17% of the annual J4 recharge) per year. From this amount, 56% is generated through snowmelt and 44% through rainfall. Rouaiss spring contributes almost 20 MCM (11% of the annual J4 recharge) to the J4 per year. From the 20 MCM, 55% are generated through snowmelt and 45% through rainfall.

Assal spring contributes 4 MCM to the annual J4 recharge. From this amount, the major share reaches the J4 Aquifer via riverbed infiltration of Nahr es Salib.

Labbane spring contributes almost 5 MCM per year to the J4. 3 MCM are conveyed for irrigation via irrigation canals, 1 MCM reaches Nahr es Salib, from where 20% infiltrate towards the J4 and the major share, 10 MCM is conveyed to Chabrouh dam. From the reservoir, approx. 3 MCM infiltrate towards GW C4 Springs and 10 MCM are conveyed to cover domestic demand within the Jeita catchment, including 7 MCM for demand on the J4. Demand sites on the J4 generate 2.2 MCM return flow and 2.3 MCM network losses.

The minor springs of the C4 (C4 Springs) contribute 6 MCM to the annual recharge of the J4. The flowpath includes irrigation water supply for the J4 and Aquitard Complex, but mainly streamflow and riverbed infiltration from Nahr es Salib and Zirghaya.

9.4.1 Sources of Jeita & COP GW Vulnerability

The GW vulnerability of the aquifers of the Jeita GW catchment by using the COP method (VIAS et al., 2006) was established in MARGANE & SCHULER (2013).

Combining the GW vulnerability with the WEAP water balance serves two purposes: First, it is a way to validate the WEAP model and COP methods. Only catchments with a high infiltration rate, as modeled in WEAP, will contribute to major GW recharge. Karstification of the rock matrix, as is the case for the J4 and C4 units, allows rapid infiltration, passing the unsaturated zone and fast flow in the saturated zone. Sub-catchments with this characteristic, however, coincide with a high vulnerability of GW. Fast transport of pollutants from the land surface towards groundwater is therefore likely where intense GW recharge occurs. Therefore, comparing the spatial distribution of COP vulnerability with the spatial distribution of generated water resources allows the empirical identification of this spatial covariance.

Secondly, GW protection measures can be prioritized according to the quantity of generated resources or according to the flow paths (e.g. if groundwater-surface water interaction is existent). Therefore, the origin and contributing quantities of GW resources must be known. It could be argued, that the larger the storage of resources of a groundwater is, the less important GW protection measures become due to dilution of pollutants in the saturated zone (and in fact, this is considered in the COP method). However, this argument would not only be cynical and open way for continued GW contamination, it would also neglect that, due to the geological nature of the GW system, the aquifer rapidly depletes and GW flow reaches very low levels during the dry season so that the impacts of contamination become much more noted during this time period.

For the assessment of quantities that flow to Jeita spring with respect to GW vulnerability, the Spatial Analyst in ArcGIS was used.

Table 30 displays the respective quantities per vulnerability class and Annex IV illustrates the spatial distribution of origin by increasing darkness indicating increasing contributing quantities and their origin. It shows that only 20% of Jeita's discharge originates from low and very low vulnerable areas, which are located on the Aquitard Complex, outside the 500 stream buffers of Nahr es Salib and Nahr es Zirghaya (a buffer around streams was integrated into the COP method in order to reflect the surface water/groundwater interaction). 81% of Jeita's discharge originates from high and very high vulnerable areas, which highlights the importance of GW protection measures to prevent contamination.

Table 30: Sources of Flow in the Lower Aquifer and COP Groundwater Vulnerability in the Areas of Origin

COP vulnerability		Flow to J4 in MCM/a	% of total flow to J4
0-0.5	very high	111.0	64.1
0.5-1	high	29.1	16.8
1-2	moderate	1.8	1.1
2-4	low	0.6	0.3
4-10.0	very low	30.6	17.7

9.5 Agricultural Water Demand

Figure 60 displays the annual of agricultural demand covered through precipitation (rainfed, i.e. rainfall) and irrigation via canals, groundwater, springs and ponds, as well as excess irrigation (irrigation fraction, overshoot).

The J4 Aquifer accounts for 13% of agricultural demand, corresponding to 2.2 MCM of total agricultural demand. The Aquitard Complex is the main area of agricultural activity, demanding 87% or 15.3 MCM per year.

The total water demand for the agricultural sector, including rainfall and irrigation (75% efficiency), is 22 MCM, of which 18 MCM reach the crop (coverage 100%) (Table 31). Rainfall supplies 5 MCM, leaving a difference of 13 MCM that needs to be supplemented by irrigation. Due to the irrigation efficiency of 75%, 17 MCM must be supplied while 4 MCM of applied resources are subject to SR or GWR. Therefore, the total natural and anthropogenic expenditure for crops is 22 MCM.

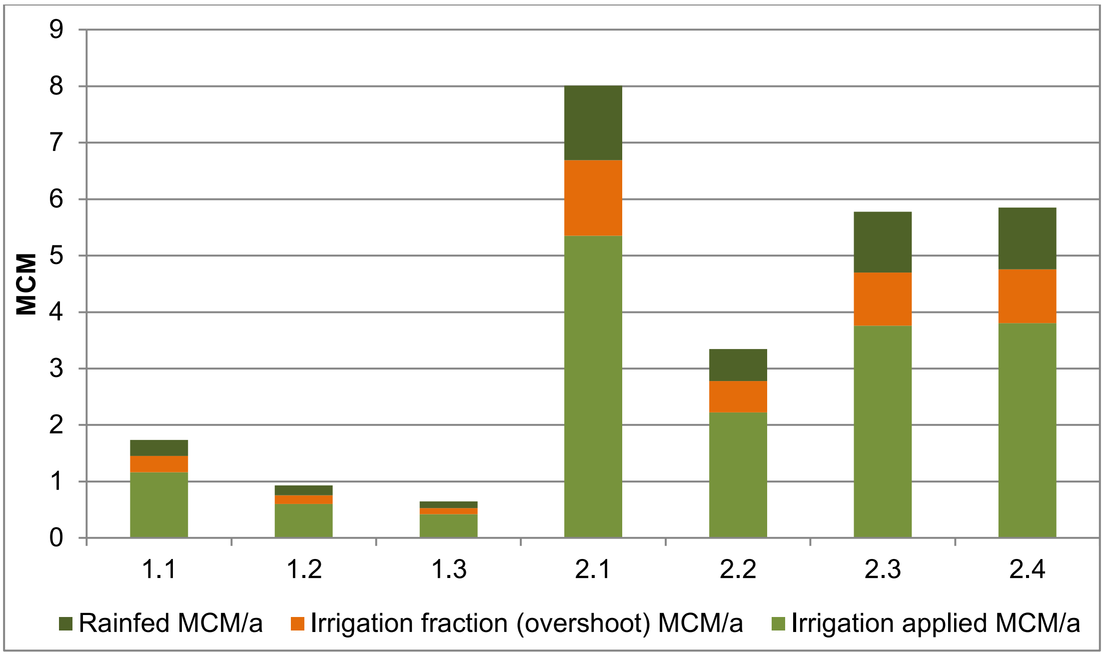

Figure 60: Annual Agricultural Demand per Sub-Catchment, covered by Rain, Irrigation and excess Irrigation due to Irrigation Efficiency (75%)

Table 31: Annual agricultural Water Demand in MCM

Agriculture		MCM/a
Demand		17.5
Supply by rain		4.5
Effective irrigation		13.0
Excess irrigation	GW recharge	0.7
	surface runoff	3.6
	Total	4.3
Irrigation applied		17.3
Total agricultural water expenditure		21.8

Figure 79 displays the share of excess irrigation per sub-catchment. Due to the karstification of the J4 and resulting high groundwater recharge rate, irrigation overshoot is much more prone to GWR than to surface water runoff. In turn, on the Aquitard Complex, GWR by irrigation overshoot is negligible in comparison to the high rate of surface runoff towards streams. Table 32 gives an overview about the total annual demand of each sub-catchment, as well as the specific sources of supply.

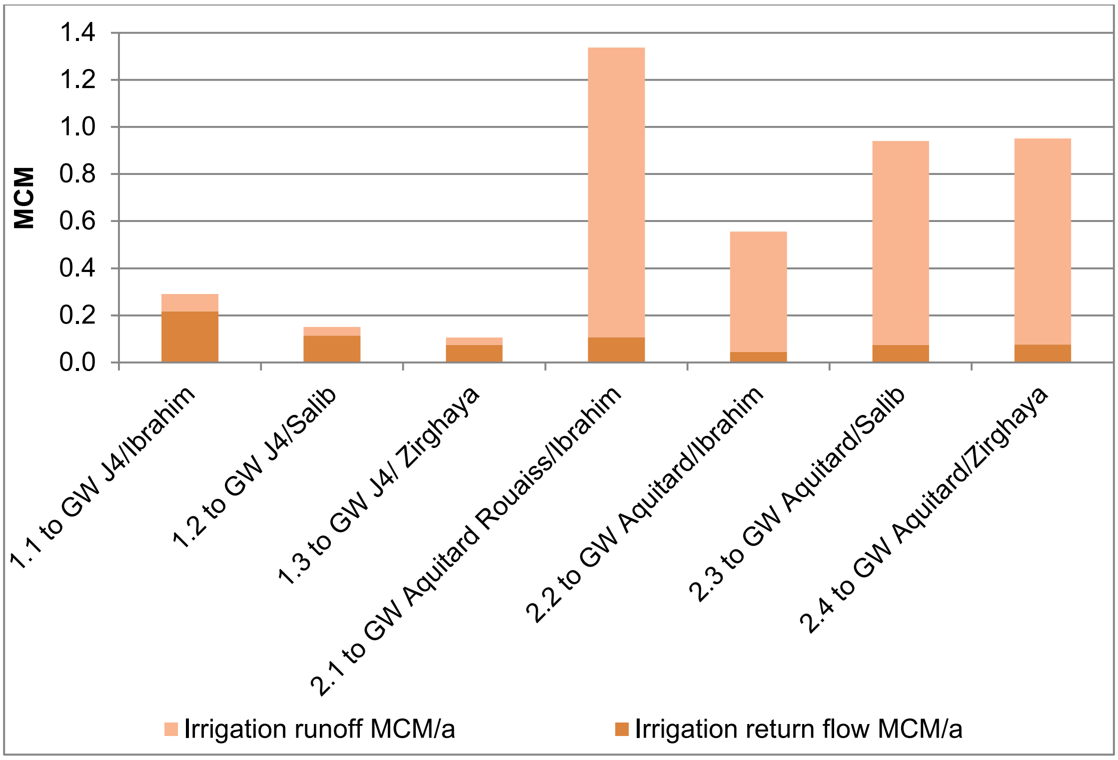

Figure 79: Annual Overshoot of Irrigation per Sub-Catchment and resulting Flow to Groundwater/Surface Water

Table 32: Annual agricultural Demand of each Sub-Catchment

Agricultural demand site (SC)	Demand in MCM/a	Source of supply
1.1	1.2	GW J4, irrigation canal
1.2	0.6	GW J4, irrigation canal
1.3	0.4	GW J4, irrigation canal
2.1	5.3	GW Aquitard Rouaiss, irrigation ponds, Rouaiss spring
2.2	2.2	GW Aquitard, irrigation canal, C4 Springs
2.3	3.9	GW Aquitard, irrigation canal, C4 Springs
2.4	3.8	GW Aquitard, irrigation canal, C4 Springs

All catchments receive resources from their connected groundwater node. Besides this, irrigation canals throughout the Jeita catchment provide 4.4 MCM per year, mainly by Assal and Labbane Spring and a minor share by

Chabrouh reservoir. All sub-catchments on the J4 and Aquitard Complex, except SC 2.1, are connected to the irrigation canal system. Sub-catchment 2.1 receives resources from irrigation ponds, which have altogether an approximate static storage capacity of 1 MCM. Also, Rouaiss spring provides water to SC 2.1.

Minor C4 Springs are providing water to the central sub-catchments of the Aquitard Complex, namely SC 2.2-2.4.

9.6 Domestic Water Demand

Villages in the Jeita GW catchment receive their supply almost exclusively by the governmental supply system, which is mainly fed by Chabrouh reservoir and Assal Spring.

To assess the flows for domestic supply and its return flow, villages in the Jeita GW catchment were aggregated to demand sites, according to their proximity in space and their shared return flow destination. Domestic demand was defined at 51.1 m^3/cap/a (140 l/cap/d), except for the demand sites Ayoun es Simane and Faqra Club, which are expected to have a higher demand of 60 m^3/cap/a (164 l/cap/d).

There is a high seasonal fluctuation of present population in the catchment. Due to the existence of many summer residents, population records are much higher in summer than in winter. Figure 61 displays the intra-annual water demand of the domestic demand sites.

Annual domestic water demand is 6.6 MCM. During the winter months, which are considered to be January to March, total demand is 1.3 MCM, which corresponds to 0.4 MCM per month. In summer, demand raises up to 0.6 MCM per month or 5.3 MCM for the respective period.

Since demand was expected to be met, the demand equals the supply that is delivered to the demand sites. However, network losses account for 35%, which leads to a GWR of 3.4 MCM per year. Table 33 shows all demand sites, their annual supply delivered from the respective source and their contribution to GWR by return flow and network leakage in MCM.

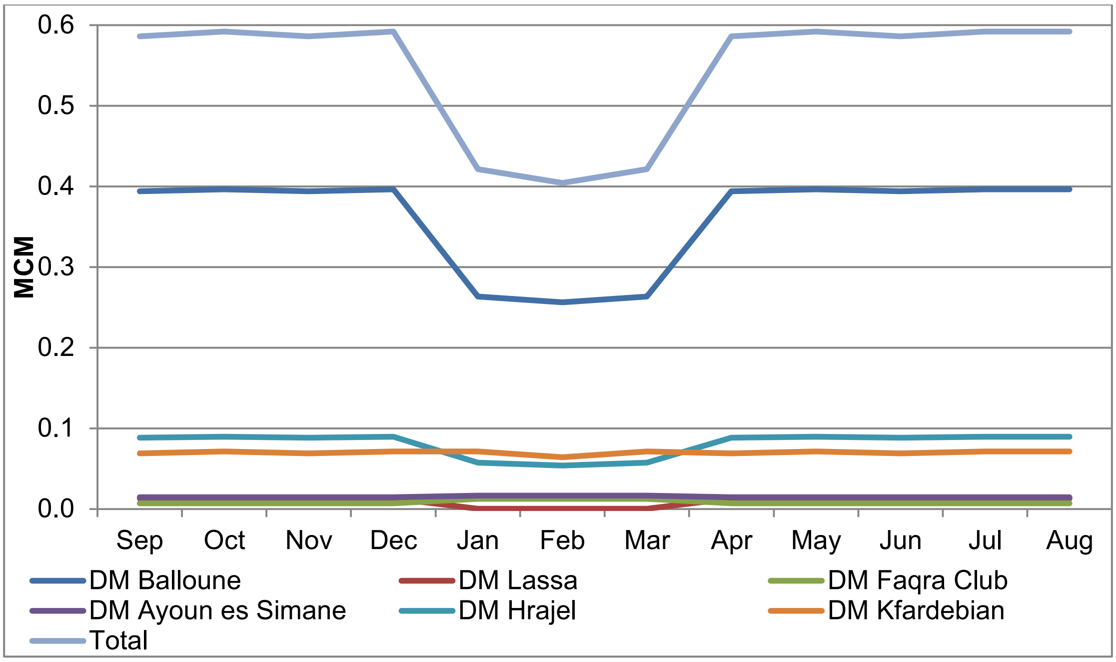

Figure 61: Monthly domestic Water Demand in MCM, according to Model 2

Table 33: Annual Inflow and Outflow of aggregated Demand Sites in the Jeita GW Catchment

Domestic demand site	Demand in MCM/a	Supply source		Network loss		Return flow	
		Conveyed in MCM/a	Source	MCM/a	to GW	MCM/a	to GW
D_M Balloune	4.3	6.7	Chabrouh/ Assal	2.3	J4	2.2	J4
D_M Lassa	0.1	0.2	Afqa	0.0	Aquitard	0.0	Aquitard
				0.0	J4	0.0	J4
D_M Faqra Club	0.1	0.2	Chabrouh/ Assal	0.1	GW Labbane	0.1	C4 Springs
D_M Ayoun es Simane	0.2	0.2	GW Labbane/ Chabrouh	0.1	Aquitard	0.1	GW Labbane
D_M Hrajel	1.0	1.5	Chabrouh/ Assal	0.5	Aquitard	0.5	Aquitard
D_M Kfardebian	0.8	1.3	Chabrouh/ Assal	0.4	Aquitard	0.4	Aquitard
Sum	**6.6**	**10.0**		**3.4**		**3.3**	

9.7 Ecosystem Demand

Within this WEAP model, ecosystem demand is considered as the sum of actual ET from the land classes woodland and scarce vegetation. ET was calculated by k_c-values, rainfall and ET_0. Thus, ecosystem demand is not directly related to plant physiognomy and its seasonal changing k_c-values, but rather a static result, which is mainly dependent on ET_0 and availability of precipitation input/availability.

Annually, 104 MCM are subject to ET from the land classes woodland and scarce vegetation. ET from the J4 accounts for 23 MCM, with peaks in October and April, same as on the Aquitard Complex, from where annually 14 MCM contribute to ET. As discussed before, higher rates of ET on the J4 than on the Aquitard Complex is related to higher ET_0 records (temperatures) of SCs 1.1 to 1.3. The C4 contributes 67 MCM ET per year, which constitutes the largest share, a fact that is related to the high availability of rainfall/show cover, as explained before in Chapter 9.1.

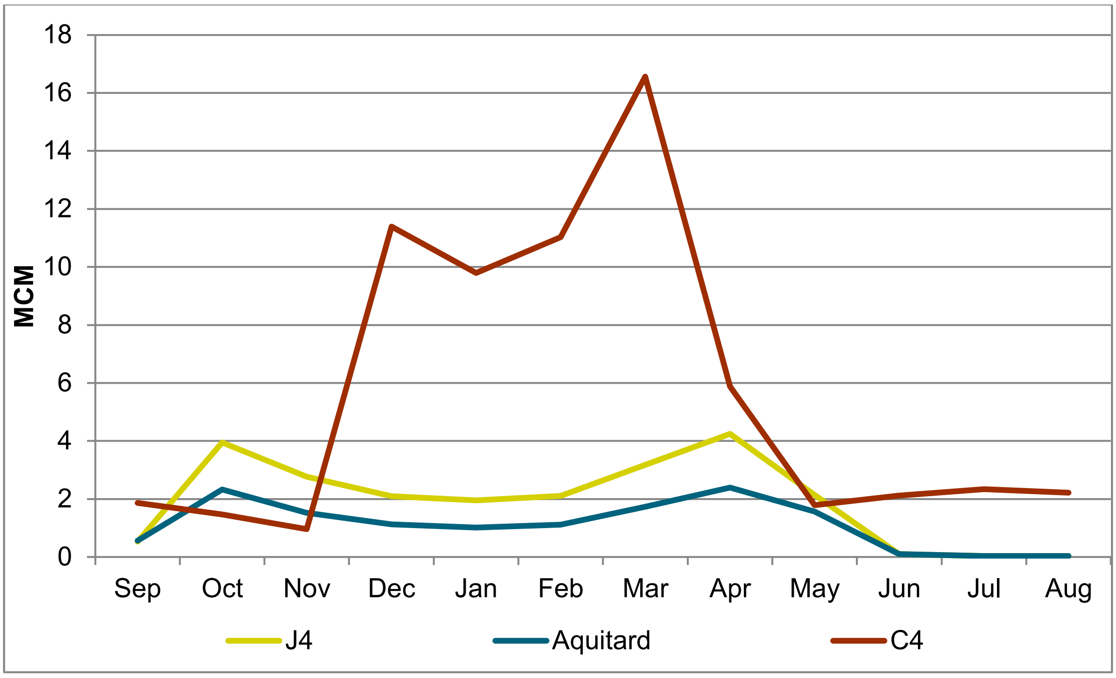

Figure 62: Monthly Evapotranspiration (ET) from the Landclass Scarce Vegetation and Woodland within the Jeita Spring Catchment in MCM, according to Model 2

9.8 MAR: Kfardebian Dam

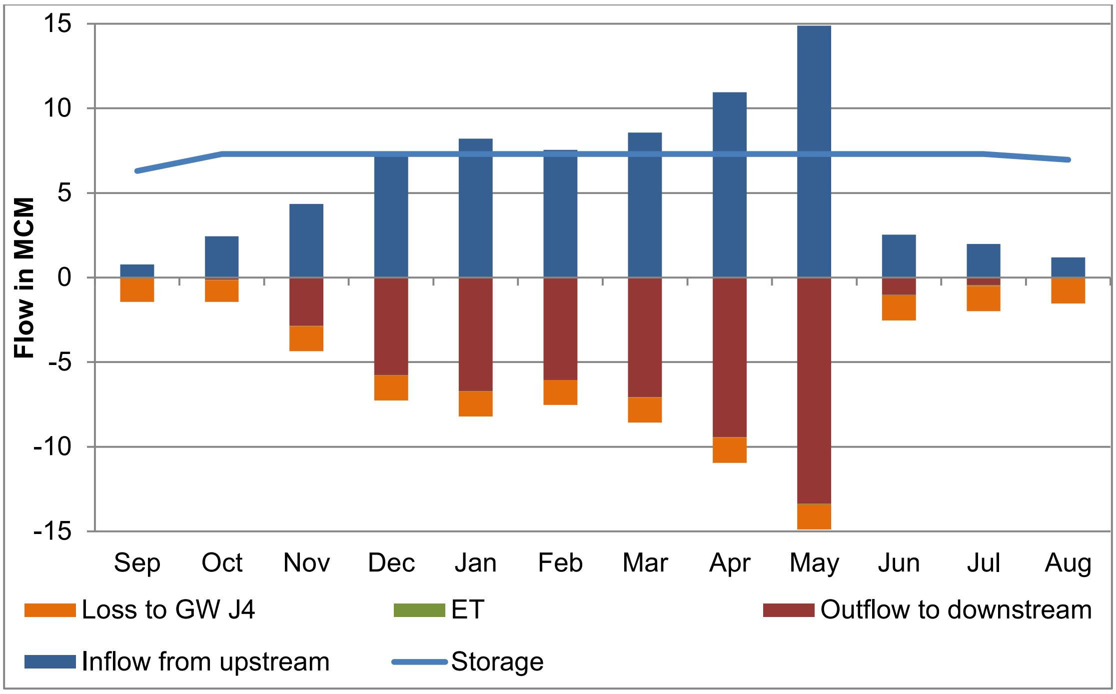

Figure 63: Monthly Inflow and Outflow of Kfardebian Dam, according to Model 2 in MCM

Kfardebian dam has a static storage capacity of 7.3 MCM, which shows to be charged during most of the year (Figure 63).

Total inflow from upstream is 71 MCM per year, reaching a maximum of 15 MCM in March (5.6 m^3/s) and a minimum of 0.8 MCM in August (0.28 m^3/s).

During the period of full storage, GW loss accounts for 1.5 MCM per month (20% of storage). This figure drops down to 1.3 MCM in October, summing up to an annual GW recharge capacity for the J4 Aquifer of 17.5 MCM.

ET losses from the reservoir account for 0.3 MCM per year, which is negligible.

Total outflow to downstream sums up to 53 MCM per year, which might indicate a high hydropower potential.

In reality, integration of Kfardebian Dam would certainly increase the discharge of Jeita spring. According to the simulation, annual discharge of Jeita Spring increases by 17.5 MCM to 188.9 MCM (Figure 64), which constitutes a surge of 10%. The seasonal variation of increased discharge of Jeita was, however, not assessed. Depending on the fast flow and slow flow components and GW flow velocities and its seasonal variation between the site of the dam and Jeita spring, infiltrating water from Nahr es Salib will reach Jeita spring. Currently, there is no knowledge about the flow mechanism in the GW system between the site of Kfardebian Dam and Jeita spring. Therefore, any assumption or even modeling is difficult to verify.

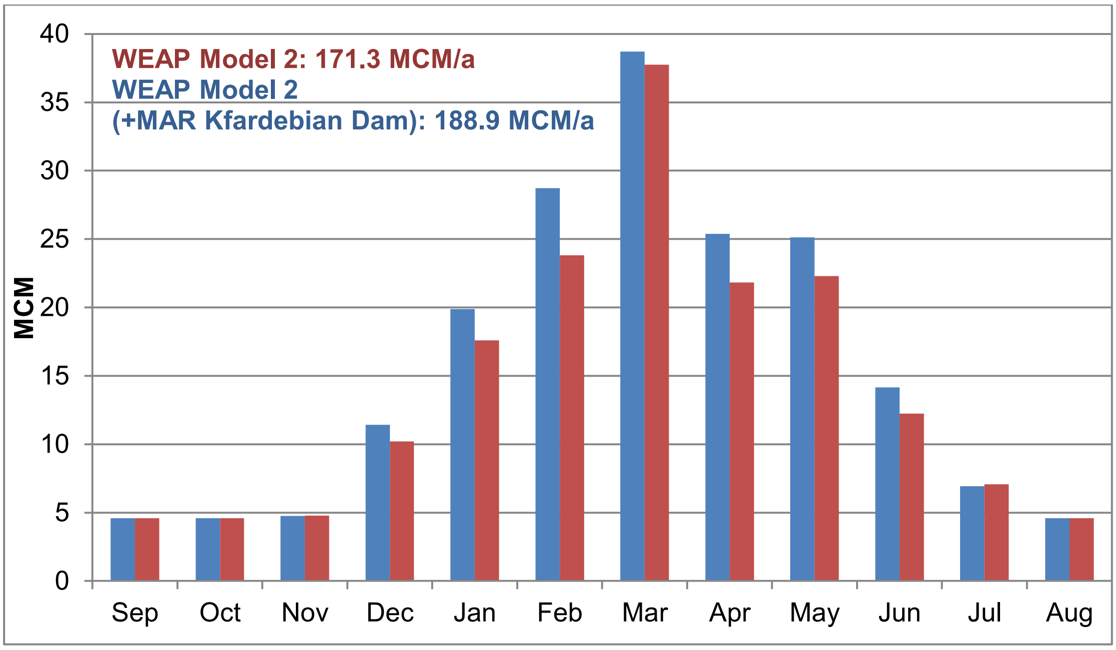

Figure 64: Monthly Discharge of Jeita Spring, incl. MAR Option Kfardebian Dam

9.9 Climate Change Scenario

9.9.1 Scenario 1

Table 34 displays the climate change variables for scenario 1.

Table 34: Climate Change Scenario 1: Variables

Precipitation (%)		Temperature (°C)		ET_0 (mm)	
Summer	Winter	Summer	Winter	Summer	Winter
-15	-20	+2	+1.75	+4.4	+3.1

According to scenario 1, in 2040 the GWCZ of Jeita spring receives 498 MCM of P, which is 20% less than in the reference scenario of Model 2. Snowfall decreases by 46%, leading to a drop of an annual snow accumulation from 215 MCM to only 116 MCM. Annual rainfall decreases by 6%, leading to an annual contribution of 382 MCM. Figure 65 displays the monthly distribution of precipitation and snowmelt records for the year 2040.

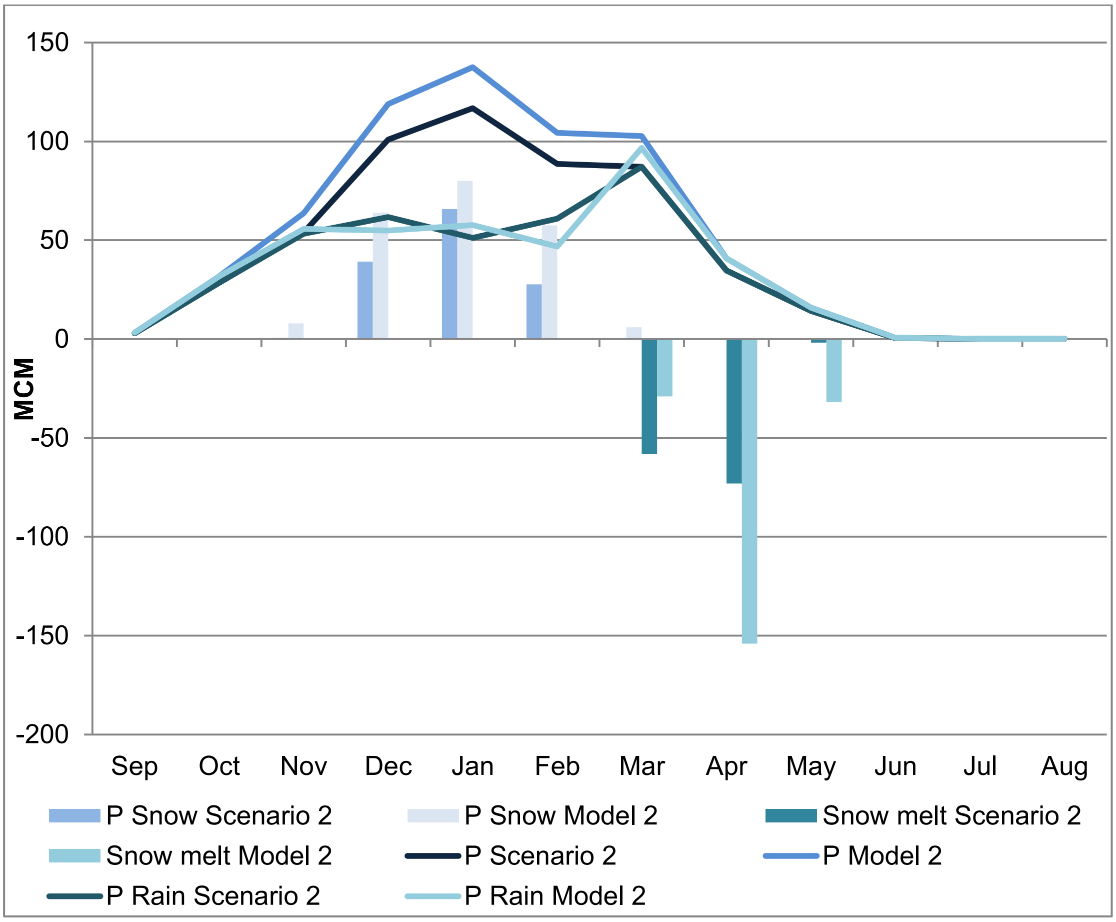

Figure 65: Monthly Precipitation Regime of Climate Change Scenario 1 in Year 2040 in MCM

Surface water flow, which is important for the recharge of the J4 Aquifer, decreases, according to the decrease in precipitation input (Figure 66). Streamflow of Nahr Ibrahim that leaves the GWCZ of Jeita spring drops by 23% to an annual flow of 169 MCM. The respective figure for Nahr el Kalb is 26% with an annual flow of 76 MCM that reaches Daraya gauging station.

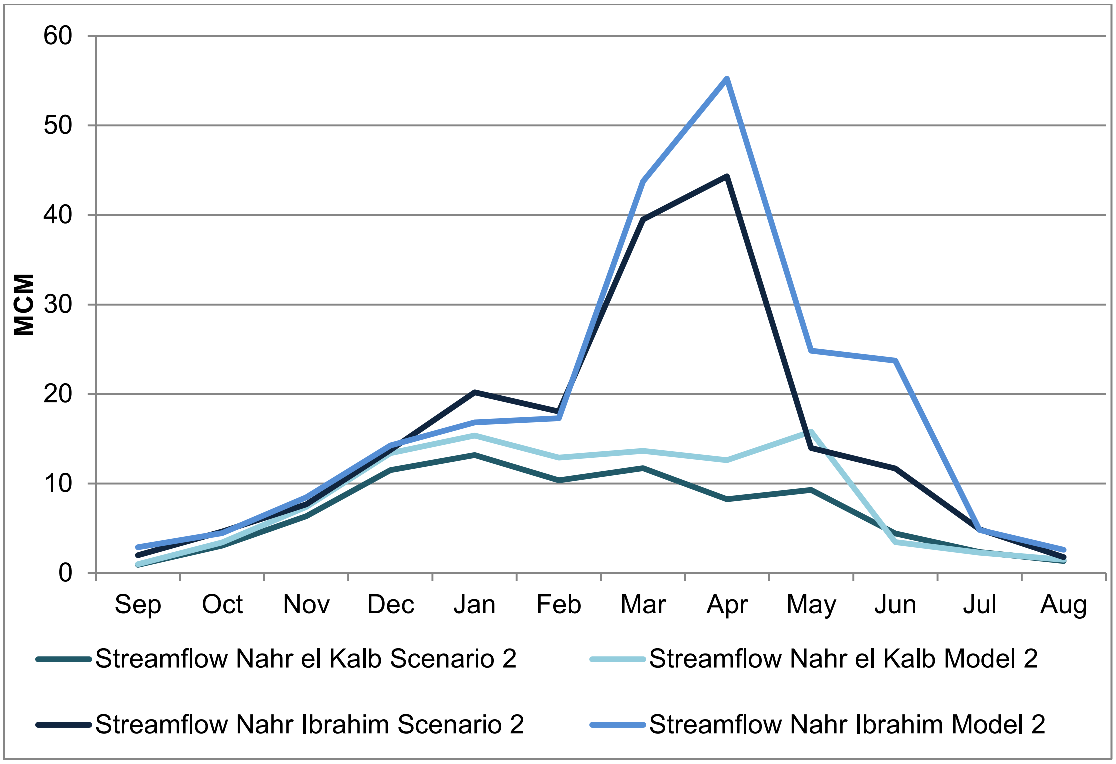

Figure 66: Monthly Surface Water Regime of Climate Change Scenario 1 in Year 2040 in MCM

According to scenario 1, annual spring discharges drop between 23% and 28%, as displayed in Table 35. Annual discharge of Labbane spring will decrease from 15 MCM to 11 MCM. Discharge of Afqa and Rouaiss spring decreases to 102 MCM, 70 MCM respectively. The respective decrease of streamflow of Nahr Ibrahim will lead to a drop of riverbed infiltration towards the J4 Aquifer from 66 MCM/a (reference Model 2) to 43 MCM/a. **Discharge of Jeita spring will drop from 171 MCM/a to 129 MCM/a.**

Table 35: Annual spring Discharges of Model 2 and Climate Change Scenario 1 in 2040 in MCM

Spring	Model 2 in MCM/a	Scenario 1 in MCM/a	Change in %
Afqa	131.2	101.7	-22.5
Assal	21.5	16.1	-25.2
Jeita	171.3	129.3	-24.5
Labbane	14.6	10.8	-26.3
Rouaiss	89.4	69.8	-22.0
Springs C4	33.2	23.9	-27.9

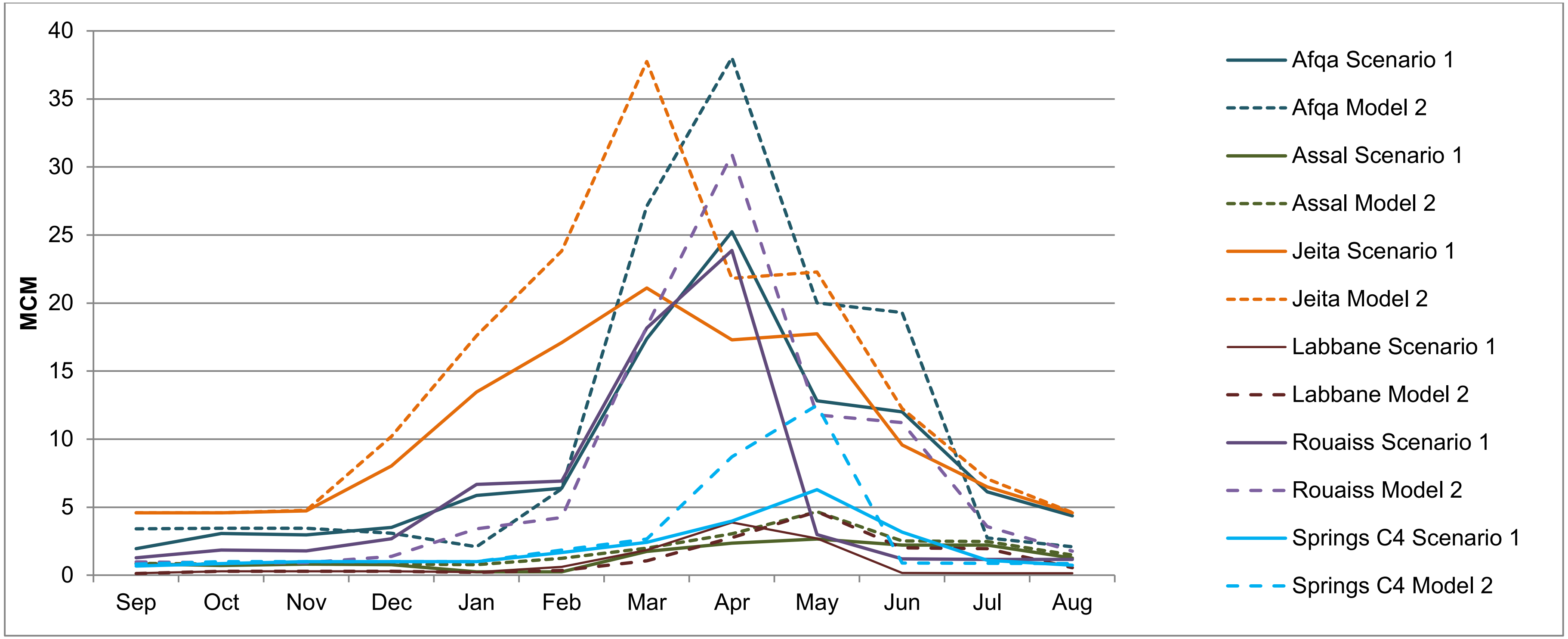

Figure 67: Monthly Spring Discharges of Model 2 and Climate Change Scenario 1 in Year 2040 in MCM

Figure 67 shows the monthly mean discharges of all springs according to scenario 1. The minimum of monthly discharge for Jeita spring is not different to Model 2, which is 4.6 MCM (1.8 m^3/s) in October. However, the maximum will reach only 21.1 MCM (7.9 m^3/s) in March.

9.9.2 Scenario 2

Table 36 displays the climate change variables for scenario 2.

Table 36: Climate Change Scenario 2: Variables

Precipitation (%)		Temperature (°C)		ET_0 (mm)	
Summer	Winter	Summer	Winter	Summer	Winter
-10	-15	+1.75	+1.5	+3.1	+2.6

According to scenario 2, in 2040 the GWCZ of Jeita spring receives 529 MCM of P, which is almost 15% less than in the reference scenario of Model 2. Snowfall decreases by 38%, leading to a drop of an annual snow accumulation from 215 MCM to 133 MCM. Annual rainfall decreases by 2%, leading to an annual contribution of 396 MCM. Figure 68 displays the monthly distribution of precipitation and snowmelt records for the year 2040.

The decrease of monthly surface water flow is shown in Figure 69. Streamflow of Nahr Ibrahim that leaves the GWCZ of Jeita spring drops down by almost 17% to an annual flow of 182 MCM. The respective figure for Nahr el Kalb is 20% with an annual flow of 83 MCM that reaches Daraya gauging station.

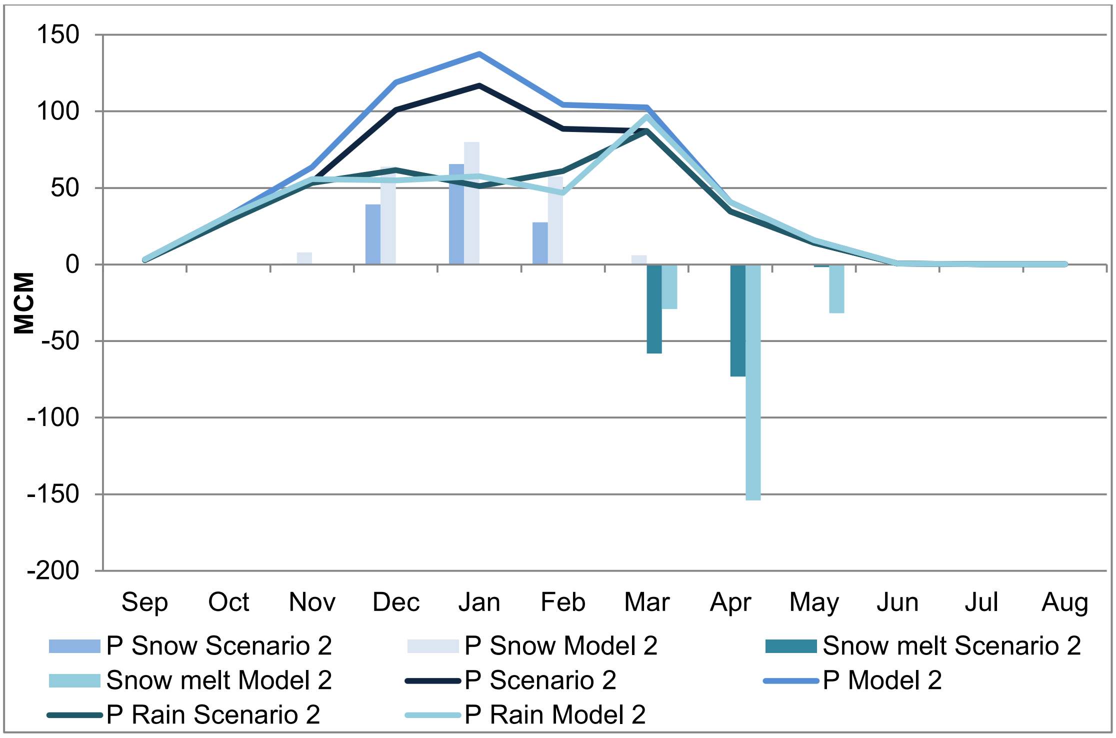

Figure 68: Monthly Precipitation Regime of Climate Change Scenario 2 in Year 2040 in MCM

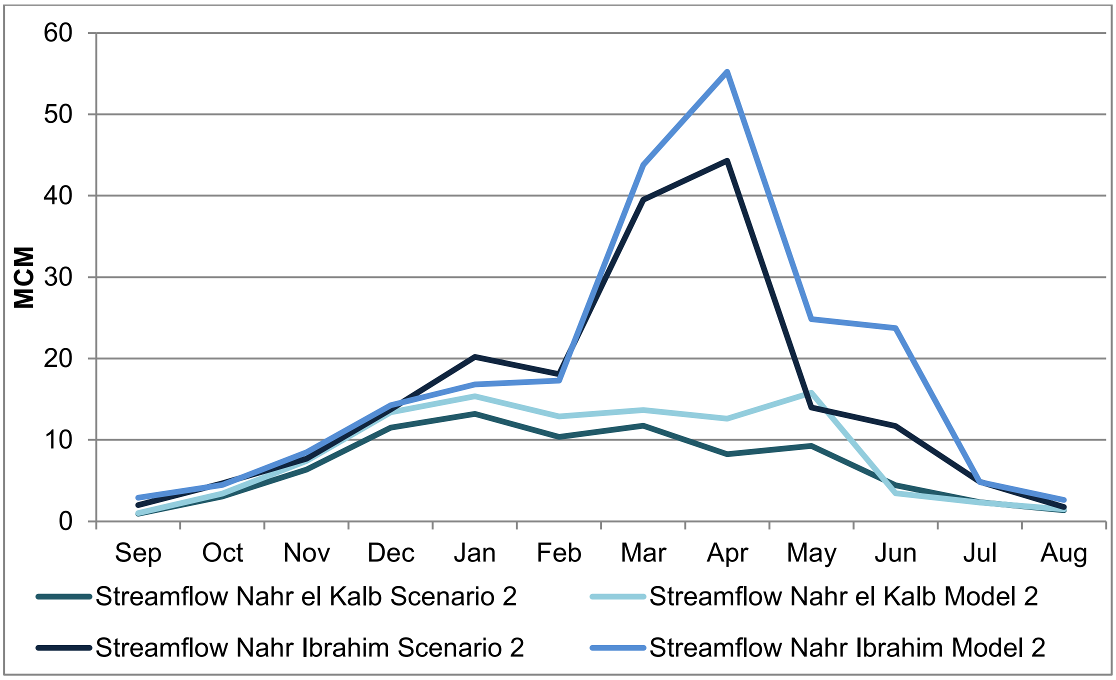

Figure 69: Monthly Surface Water Regime of Climate Change Scenario 2 in Year 2040 in MCM

According to scenario 2, annual spring discharges drop between 16% and 20%, as displayed in Table 37. Discharge of Labbane spring will drop from 15 MCM/a to 12 MCM/a, which is 1.3 MCM above the annual quantity of conveyed resources from the spring to Chabrouh dam. Discharge of Afqa and Rouaiss spring decreases to 110 MCM, 75 MCM respectively. The respective decrease of streamflow of Nahr Ibrahim will lead to a drop of riverbed infiltration towards the J4 Aquifer from 66 MCM/a (reference of Model 2) to 46 MCM/a. **Discharge of Jeita spring will drop from 171 MCM/a to 140 MCM/a.**

Table 37: Annual Spring Discharges of Model 2 and Climate Change Scenario 1 and 2 in 2040 in MCM

Spring	Model 2 in MCM/a	Scenario 1 in MCM/a	Scenario 2 in MCM/a	Change from Model 2 to Scenario 2 in %
Afqa	131.2	101.7	110.3	-15.9
Assal	21.5	16.1	17.5	-18.9
Jeita	171.3	129.3	139.6	-18.5
Labbane	14.6	10.8	11.7	-19.8
Rouaiss	89.4	69.8	75.3	-15.8
Springs C4	33.2	23.9	26.5	-20.0

Figure 70 shows the monthly mean discharges of all springs according to scenario 2. The minimum of monthly discharge for Jeita spring is not different to Model 2, which is 4.6 MCM (1.8 m^3/s) in October. However, the maximum will reach 24.1 MCM (9.0 m^3/s) in March.

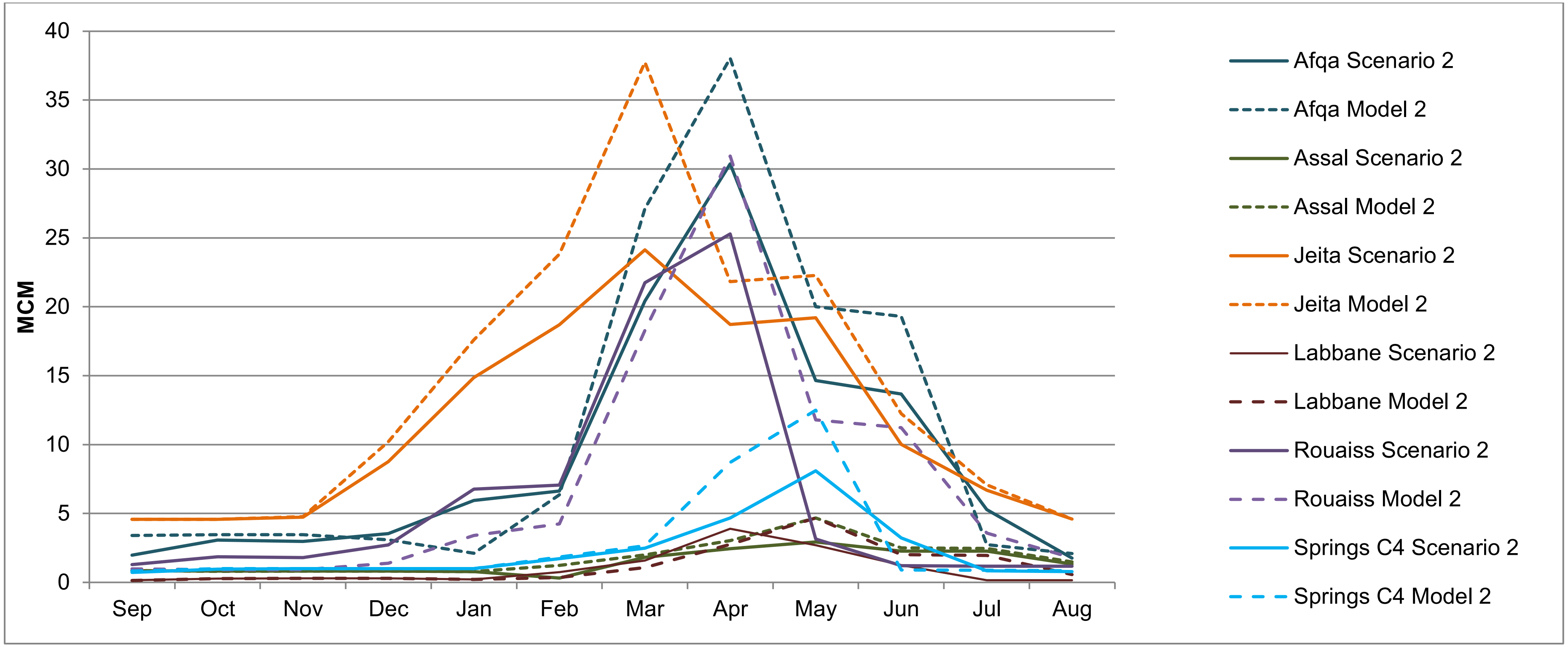

Figure 70: Monthly Spring Discharges of Model 2 and Climate Change Scenario 2 in 2040 in MCM

10 Discussion & Recommendations

The Jeita catchment is the best hydrogeologically documented area in Lebanon. Nevertheless, it is important to stress that data availability has been the major constraint for this study, a fact that adds uncertainty to the modeled output. Coupling of this WEAP model with a groundwater system via MODFLOW (MASSMANN et al., 2011) would add more certainty to the results.

In the study area where most water flow occurs in the GW system, at present, there is not a single groundwater observation borehole. This, however, would be important for the assessment and interpretation of groundwater levels and the preparation of a GW model. Besides this, spring discharges are not recorded sufficiently by LRA. Labbane spring is not measured at all; Afqa, Assal and Rouaiss spring are measured by LRA, despite neither the methodology (interval of measurements), nor the physical infrastructure (gauging stations, location of measurement), are sufficient. The monitoring station at Afqa shows very turbulent flow and some share of discharge flows around the gauging station during the period of high discharge. The monitoring station of Rouaiss spring is located 1.4 km downstream of the spring in a very poor condition. Thus, it records not only the spring's discharge but also surface runoff. Discharge of Jeita spring is not directly recorded by LRA but only monitored downstream in the Jeita-Dbayeh conveyor where a maximum of only 3.1 m^3/s can be diverted to the Dbayeh treatment plant.

Regarding climate data, there are currently 5 stations in the region, operated by NMS: Kaslik University (40 m asl), Hemlaya (790 m asl), Qartaba (1,102 m asl), Faqra Club (1,690 m asl) and Faraiya (1,885 m asl). However, snowfall in winter is not recorded because rainfall gauges are not heated. Wind speed and humidity are important variables for the calculation of ET_0. However, both parameters are currently only recorded at few stations.

Surface runoff is measured at Daraya and Hrajel through LRA. However, integration of more gauging stations (e.g. Nahr Ibrahim) and rehabilitation of existing stations would contribute to a more precise understanding of runoff/infiltration relations, and thus, to a more precise definition of runoff/infiltration fractions of single sub-catchments. Discharge records of Nahr Ibrahim (e.g. at Joe Marine) would be of importance. Firstly, for the assessment of quantities of surface runoff that leave the catchment towards the NW and secondly, for a continuous assessment of infiltration losses of Nahr Ibrahim towards the J4. Construction of surface runoff stations is relatively costly and could not be financially covered by this project. Thus, construction of them must be addressed by the Lebanese government.

Regarding meteo data, 5 stations were established within the BGR project (ABI-RIZK, 2013). Spring discharge of Assal, Kashkoush, Labbane and Jeita was continuously measured (EC, ORP, pH, RDO, temperature, turbidity, water level). Assal, Kashkoush and Labbane spring were periodically measured through dilution tests. Discharge of Assal and Jeita was continuously measured by an ADCP (Acoustic Doppler Current Profiler) (MARGANE & STOECKL, 2013).

For an improvement of the technical infrastructure, financial means need to be made available to establish GW observation wells and surface runoff stations. Together with all existing infrastructure, stations need to be operated and maintained, which adds another effort to the responsible institution. Operation includes storage of data, preferably in a central database. This database should be accessible to all Ministries and governmental entities (LRA, Water Establishments, etc.) at no charge.

This approach implies certainly large financial expenses. For the physical infrastructure, estimates are at minimum of 9 million USD, with an additional 640,000 USD per year for operation and maintenance, only in the Jeita catchment (MARGANE, 2012a). This amount, however, can be justified by the huge supply potential of this catchment. On the one hand, infrastructure improvements shall aim to improve the tapping of Jeita spring, since the existing infrastructure is very inefficient (GITEC & BGR, 2012). On the other hand, as is highlighted by this WEAP model, the catchment of Jeita offers large quantities of unused resources. Direct surface runoff within the catchment sums up to 141 MCM per year, which is close to the annual discharge of Jeita spring. Altogether, the entire catchment is drained by 322 MCM/a through Nahr el Kalb and Nahr Ibrahim. Considering ET, already one proposed MAR dam could divert 17.5 MCM/a from surface flow towards the GW system of the J4 Aquifer to increase discharge of Jeita at 188.9 MCM/a. This approach may become even more crucial if discharge of Jeita will drop due to climate change. Based on the PRECIS model, until 2040, annual precipitation in the GWCZ of Jeita could decrease by 20%, which would result in 25% less annual discharge of Jeita spring (129 MCM). Therefore, limited resources must be used as efficient and effectively as possible to reduce water losses and increase water use efficiency in all sectors of the country. And, most importantly, water management must start within the hydrogeological boundaries of a catchment. Currently, the lack of data and the shortage in hydrogeological research reflects the negligence of this subject. However, to assess the resources of a country for the development of proper management strategies, hydrogeological investigations are needed. In this context, it is strongly advised to carry out water balance models in other important catchments in Lebanon. By integrating socio-economic and climatic future predictions into these models, an early development of strategies to cope with related challenges will be facilitated.

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12 Annex

Annex I

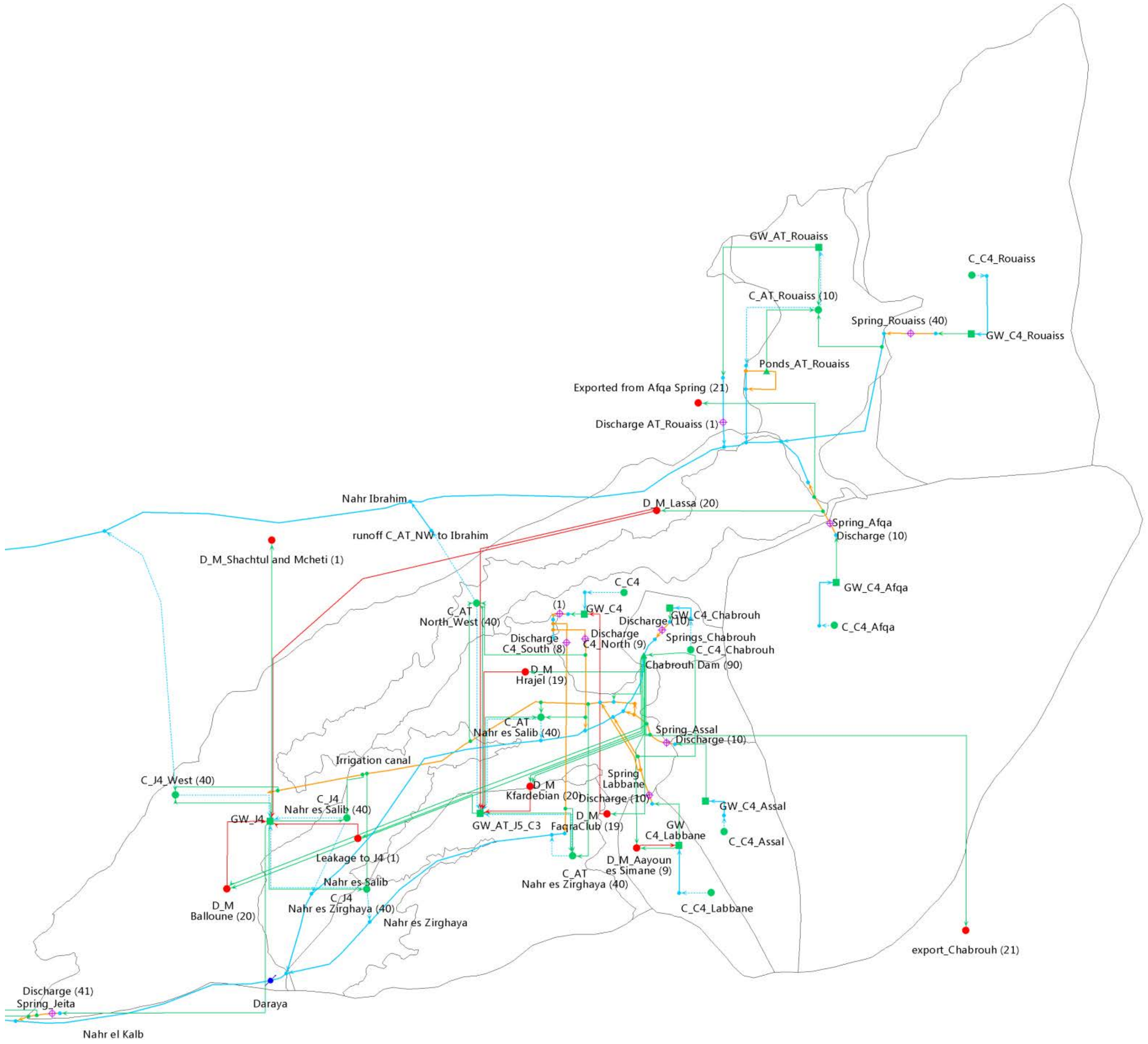

Figure 71: Schematic of the final WEAP Model 1 and 2

Annex II

Table 38: Natural and anthropogenic Water Balance (direct and indirect Flows) of the Jeita Catchment in MCM, according to Model 2

Element			Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	**Total**
P	Precipitation	Rainfall	3.3	31.7	55.7	54.9	57.6	46.9	96.7	40.8	15.9	0.6	0.2	0.2	**404.5**
		Snowfall	0.0	0.0	7.9	64.0	80.0	57.4	6.0	0.0	0.0	0.0	0.0	0.0	**215.3**
		Total	3.3	31.7	63.6	118.9	137.6	104.3	102.7	40.8	15.9	0.6	0.2	0.2	**619.8**
Groundwater recharge	Primary	Direct rainfall	4.3	11.7	27.0	23.4	23.3	19.1	23.8	4.5	6.1	3.7	3.8	3.8	**154.4**
		Snowmelt	0.0	0.0	0.0	0.0	0.0	0.0	29.0	154.1	31.8	0.3	0.0	0.0	**215.3**
		Total	4.3	11.7	27.0	23.4	23.3	19.1	52.8	158.6	37.9	4.0	3.8	3.8	**369.7**
	Secondary	Nahr Ibrahim	0.8	1.0	1.5	2.3	2.7	3.5	11.4	16.0	7.3	7.0	1.4	0.7	**55.6**
		Nahr es Salib	0.2	0.6	1.0	1.6	1.9	1.6	1.8	2.2	2.9	0.6	0.5	0.3	**15.2**
		Nahr es Zirghaya	0.1	0.3	0.7	1.4	1.6	1.4	1.3	0.9	1.1	0.2	0.1	0.1	**9.2**
		Riverbed infiltration	1.1	1.9	3.3	5.3	6.2	6.4	14.6	19.1	11.3	7.9	2.0	1.1	**80.1**
		Domestic return flow	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	**3.3**
		Irrigation return flow	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	**0.7**
		Domestic network losses	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	**3.4**
		Leakage Chabrouh dam	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.5	0.5	0.4	**3.3**
		Infiltration SR AT North West to Nahr Ibrahim	0.0	0.6	1.5	2.9	3.4	2.6	2.5	0.9	0.2	0.0	0.1	0.1	**14.8**
		Total	2.2	3.4	5.6	9.0	10.2	9.5	17.7	20.8	12.4	9.1	3.3	2.4	**105.6**
Surface run-off/streamflow	Primary	Direct runoff	0.0	4.1	14.3	29.6	34.7	25.8	24.4	7.0	1.4	0.0	0.0	0.0	**141.3**
	Secondary	Irrigation runoff	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	1.1	1.1	**3.6**
	Leaving the Jeita GW catchment	Nahr el Kalb	1.0	3.4	7.4	13.4	15.4	12.9	13.7	12.6	15.8	3.4	2.3	1.5	**102.8**
		Nahr Ibrahim	2.9	4.4	8.5	14.3	16.8	17.3	43.8	55.2	24.8	23.7	4.8	2.6	**219.2**
		Total streamflow leaving the Jeita catchment	3.9	7.9	15.9	27.7	32.2	30.2	57.4	67.8	40.6	27.2	7.1	4.1	**321.9**
ET	Primary	Direct (excl. irrigation)	3.1	9.1	5.7	15.0	13.1	14.7	22.1	13.3	6.5	2.3	2.4	2.3	**109.6**
	Secondary	Irrigation	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.4	3.9	3.8	**13.0**
		Domestic	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	**3.3**
		Total	2.6	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.8	2.7	4.2	4.1	**16.3**

Annex III

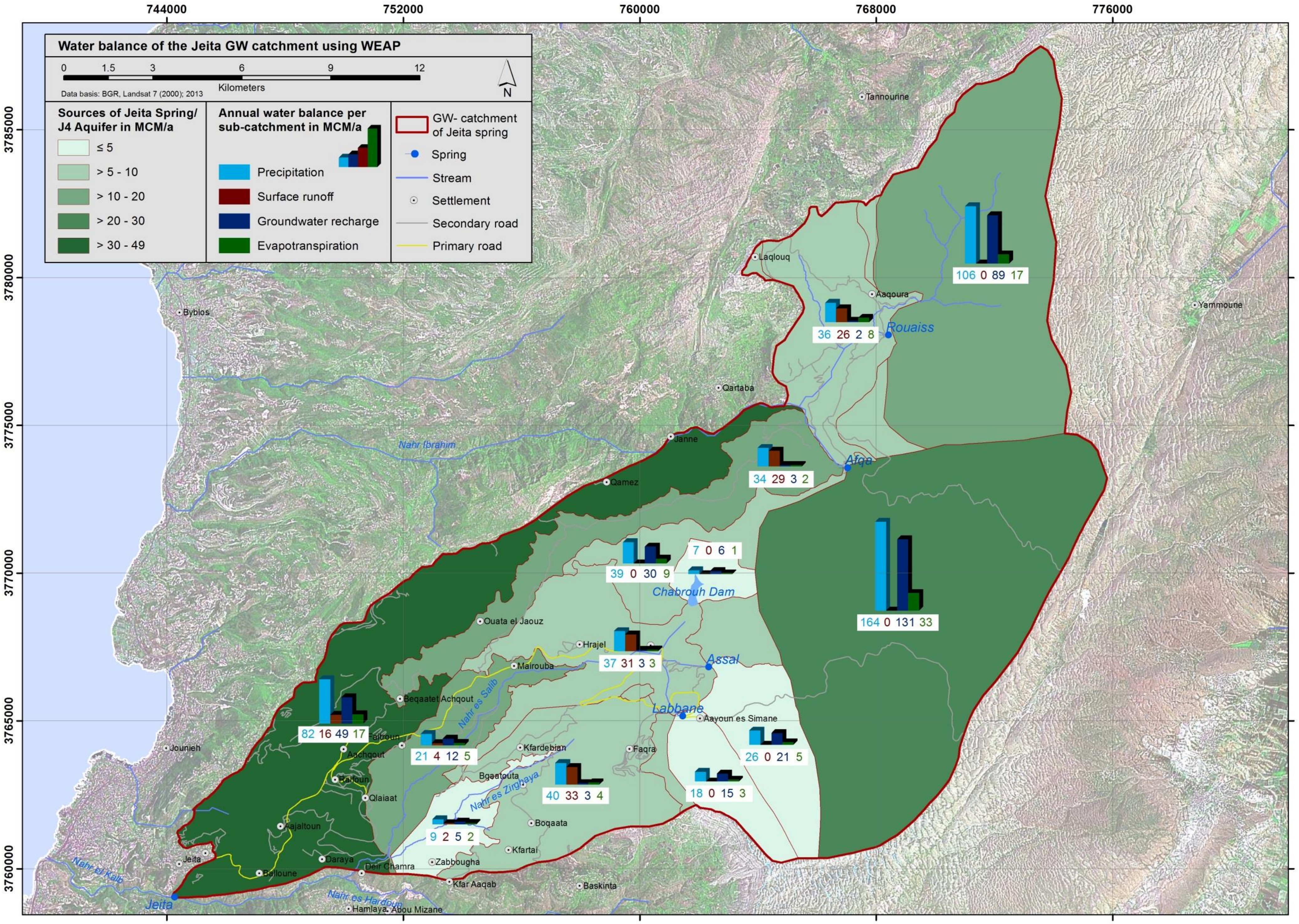

Figure 72: Annual Flow Paths within the Jeita Catchment in MCM, according to WEAP Model 2

Annex IV

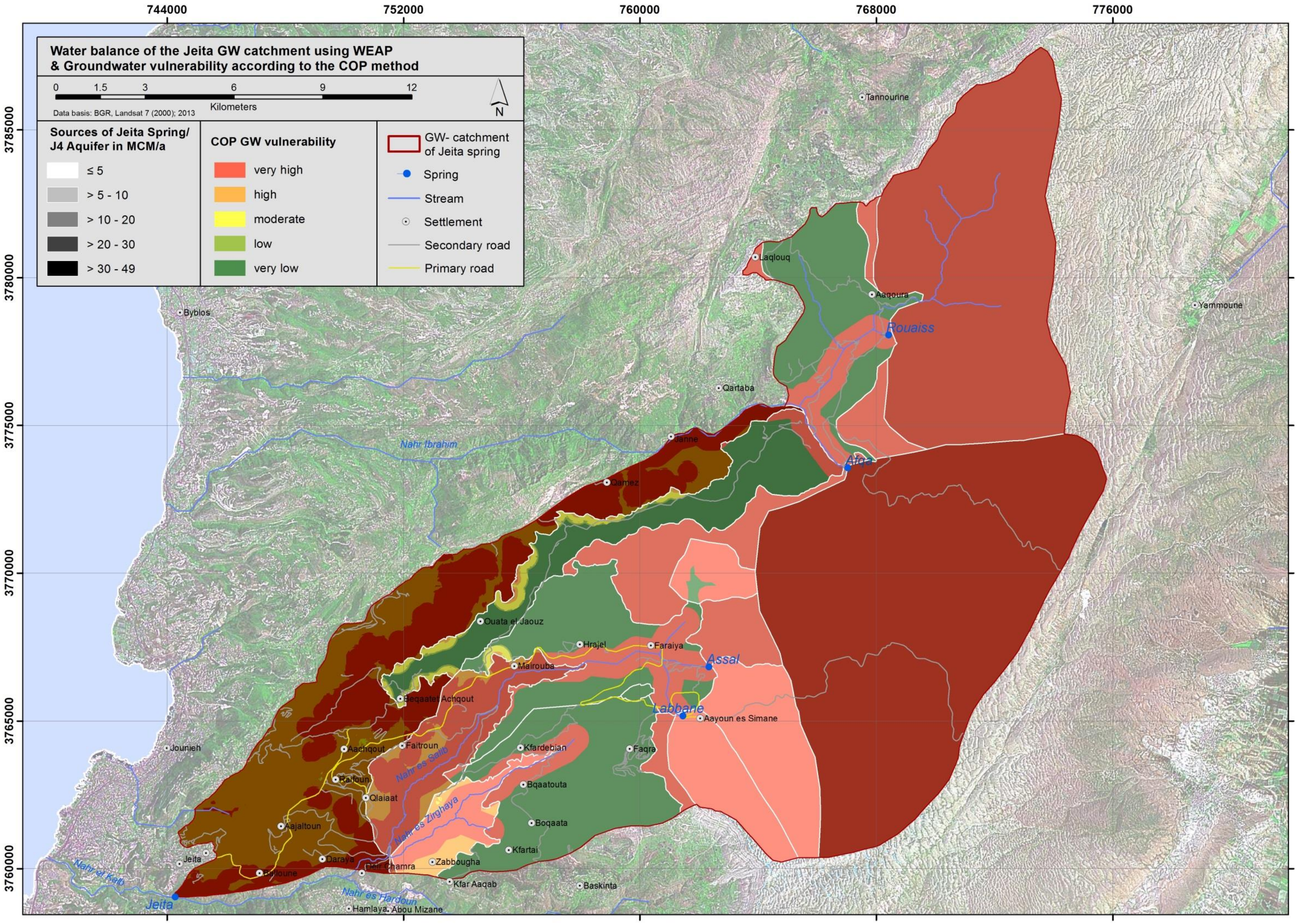

Figure 73: Origin of Flow Contributions to Jeita Spring and Groundwater Vulnerability in the Areas of Origin

Annex V

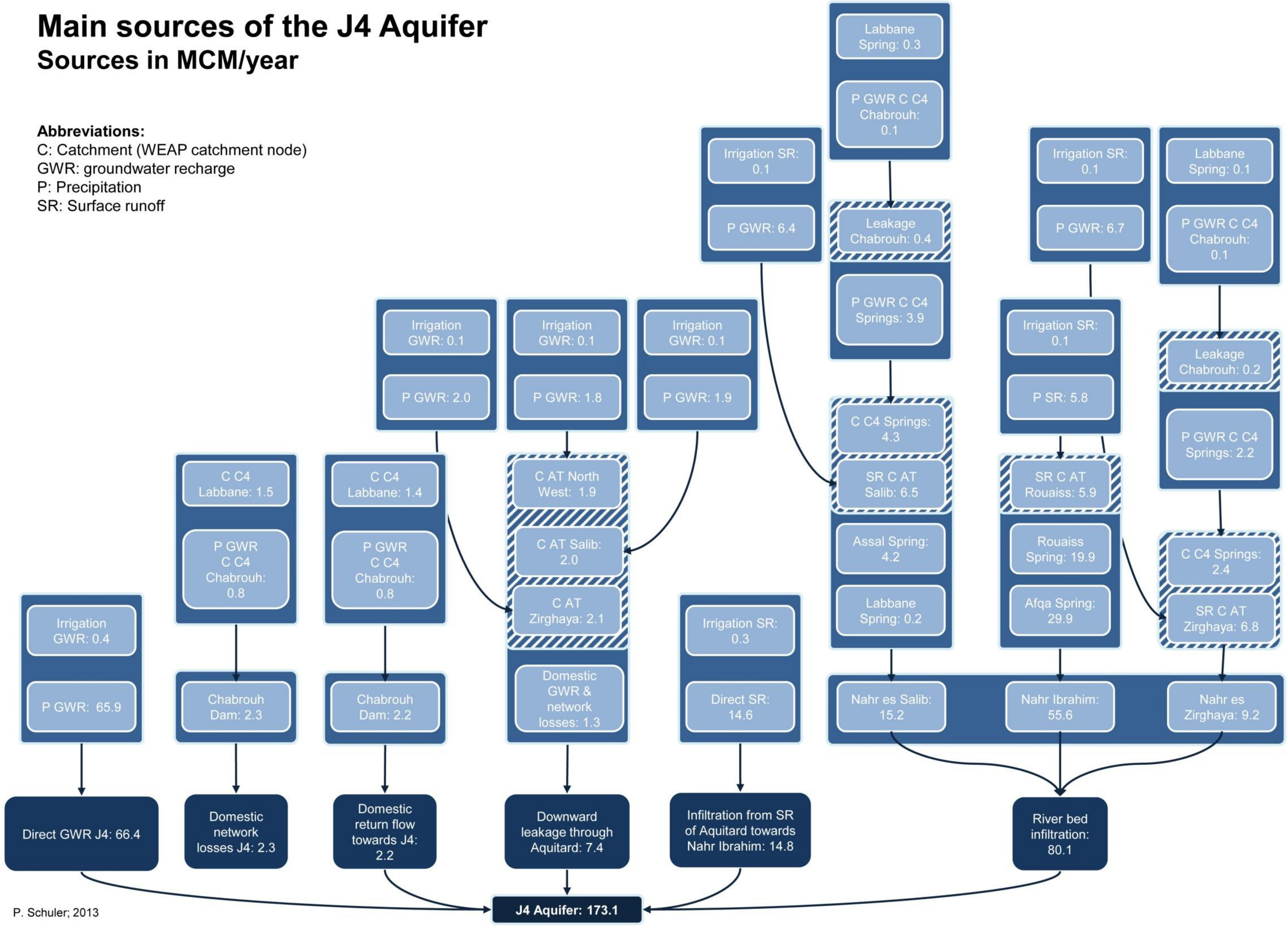

Figure 74: Annual Flows to Jeita in MCM, according to WEAP Model 2