SWIM-H2020 SM Expert Facility Activity
EFS-LB-1, Task 1

Report on the assessment of the water resources/ balance in Nahr El-Kelb River Basin, based on the outputs of the WEAP model (under current and future scenarios), including a brief on the scenarios (D1.2 & D.1.3)

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1.0	Report on the assessment of the water resources/ balance in Nahr El-Kelb River Basin, based on the outputs of the WEAP model (under current and future scenarios), including a brief on the scenarios	Maggie Kossida (SWIM-H2020 SM non-key expert on Programmes of Measures) Abbas Fayad (SWIM-H2020 local non-key expert on WEAP model)	Suzan TAHA (SWIM-H2020 SM key water expert)

THE SWIM AND H2020 SUPPORT MECHANISM PROJECT (2016-2019)

The SWIM-H2020 SM is a Regional Technical Support Program that includes the following Partner Countries (PCs): Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, [Syria] and Tunisia. However, in order to ensure the coherence and effectiveness of Union financing or to foster regional co-operation, eligibility of specific actions will be extended to the Western Balkan countries (Albania, Bosnia Herzegovina and Montenegro), Turkey and Mauritania. The Program is funded by the European Neighborhood Instrument (ENI) South/Environment. It ensures the continuation of EU's regional support to ENP South countries in the fields of water management, marine pollution prevention and adds value to other important EU-funded regional programs in related fields, in particular the SWITCH-Med program, and the Clima South program, as well as to projects under the EU bilateral programming, where environment and water are identified as priority sectors for the EU co-operation. It complements and provides operational partnerships and links with the projects labelled by the Union for the Mediterranean, project preparation facilities in particular MESHIP phase II and with the next phase of the ENPI-SEIS project on environmental information systems, whereas its work plan will be coherent with, and supportive of, the Barcelona Convention and its Mediterranean Action Plan.

The overall objective of the Program is to contribute to reduced marine pollution and a more sustainable use of scarce water resources. The Technical Assistance services are grouped in 6 work packages: WP1. Expert facility,WP2. Peer-to-peer experience sharing and dialogue, WP3. Training activities, WP4. Communication and visibility, WP5. Capitalizing the lessons learnt, good practices and success stories and WP6. Support activities.

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Disclaimer:

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ABBREVIATIONS

a.s.l.	Above Sea Level
NEK	Nahr El-Kelb
m.s.l.	Mean Sea Level
MCM	Million Cubic Meters
Mm^3	Million Cubic Meters
MoEWI	Ministry of Energy and Water
RB	River Basin
WEAP	Water Evaluation and Planning System
WRMM	Water Resources Management System

EXECUTIVE SUMMARY

The current work is related to the SWIM-H2020 SM expert facility activity EFS-LB-1: “IWRM at the river basin scale, with a focus on capacity building and implementation aspects” and builds on the respective Project Identity Form (PIF). The activity falls under the SWIM theme “Decentralized water management and Growth” and aspires overall to support aspects of policy development and reform, and to provide institutional training, technical assistance and capacity building, through a series of sub-activities. The current report presents an analysis and quantification of the water resources in the Nahr-El Kelb River Basin in Lebanon, based on a semi-distributed physical-based water resources management model developed in WEAP21 software.

The Kelb River Basin is located on the windward part of Mount Lebanon, has an area of 287 km2, and is mostly covered by woodland (34% of the basin total area) and grassland (27%). Agriculture land use is 10.6% and urban areas occupy around 10%. Most precipitation occurs between December and March. The basin is managed by the Beirut and Mount Lebanon Water Establishment and supplies regions of the Kesrouane, and El Metn governorate. Population estimates for 2017 was estimated at 290,000 inhabitants. Water from the Jeita springs at 60 m.s.l. supplies approximately 60% of Beirut’s fresh water demand, which makes this basin of major source of water for around 2 million people (around 35% of Lebanon's total population).

The WEAP water resources management model of the Nahr El-Kelb has been set-up for the reference period between 2010- 2017, at monthly timestep, and includes all the components of the hydrological system, groundwater karst, water demand, water use and water supply in the basin, with the purpose of assessing the water balance and quantifying unmet demand in the basin, in the urban and agricultural sectors. The time period between 2018 and 2040 was used to evaluate the future scenarios, which have been built assuming an annual population increase of 2.6% and a steady agricultural area (i.e. no changes in the number of irrigated hectares or in the crop mix), and a future climate that reproduces the past climate (based on a statistical reproduction, following a random distribution, of the past 2000-2017 climatic variables).The model comprises of 19 sub-catchments, 8 groundwater bodies and 2 aquitard formations, 10 karstic springs and one aggregated spring representation, 12 major rivers links representing the Kelb river and its major tributaries, 41 runoff/infiltration links (carrying runoff and infiltration from catchments to rivers and groundwater bodies), 15 diversions representing karstic springs, 14 demand sites, 2 dams, 1 wastewater treatment plant (inactive), and 64 transmission links for linking springs to groundwater and demand sites to sources (i.e., springs, surface water, and groundwater), 23 return flow links (directing the water that is not consumed in a demand side to surface or groundwater body). The model has been overall calibrated and validated for the period 2000-2017, using observed streamflow data at the Jeita spring which is located at the basin outflow. The correlation factor and goodness-of-fit metrics where deemed satisfactory. The model tends to underestimate the winter streamflow, which is attributed to the simplified approach of WEAP in partitioning snow and rain as well as our limited understanding of the karst system that defines most of the groundwater flow in the basin. With regard to the hydrological balance, the model showed that on an average annual basis, 16% (or 104 Mm3/year) of the precipitation evapotranspirates (ranging from 12-18%), 62% (or 416 Mm3/year) flows to groundwater (ranging from 60-64%), and the remaining 22% (or 150 Mm3/year) becomes surface runoff (ranging from 21-24%).

Water demand has been simulated in the model using proxies. The urban water demand for the reference period 2000-2017 has been modelled by multiplying the total population in the basin with an average water use rate of 80 m3/capita, and considering an efficiency of 55% for the urban water supply network (which means 45% losses). The urban water demand for the future 2020-2040 has been modelled with the same way, but also incorporating a population increase of 2.6% per year. Thus, the resulting future urban water demands are higher than in the past (increasing trend). According to the calculations, the urban water demand in 2018 was 24 Mm3/year, and is projected to be 42.5 Mm3/year in 2040. This is a significant increase of 77%. The agricultural water demand has been modelled according to the crop water requirements, and their respective irrigation needs after deducting the contribution of the effective precipitation. The main irrigated crops are fruit trees and vegetables. For the fruit trees we assumed an irrigation need of about 5,500 m3/hectrare/year and for the vegetables about 6,300 m3/hectare/year. The resulting agricultural water demand is about 22 Mm3/year. It was assumed that this demand will stay the same in the future (conservative scenario) assuming that the irrigated area will remain the same and will not decrease due to urbanisation or abandonment.

The annual water supply delivered by all sources in the 13 demand node located in the Nah El-Kelb basin (Beirut is excluded here) as calculated by the model was about 60 Mm3/year on average during the reference period 2000-2017, of which 33 Mm3/year (i.e. 55%) supplied the urban sites and 27 Mm3/year (i.e. 45%) the agricultural sites. The contribution of the Chabrouh Dam in the basin's water supply is significant (average of 5.5 Mm3/year during the reference period 2000-2017) and varies per year (ranging from 3.6 to 9.2 Mm3/year) depending on the climatic variability (wet versus dry years). A higher supply potential is observed in the months of July-September and is attributed to the contribution of snow melt. Taking a closer look at the year 2007, the total supply (from all sources) to the urban demand sites was about 41.5 Mm3/year (for the year 2017). The supply from Jeita spring to Beirut (about 48 Mm3) is excluded. The highest contribution came from Spring Assal (about 16 Mm3), while the Chabrouh Dam supplied about 4.8 Mm3, which equals the 12% of the total provided supply in the basin. The total supply (from all sources) to the agricultural demand sites was about 26.4 Mm3/year (for the year 2017). The highest contribution came the "Groundwater Aquifer Mid. Mountain" (about 7.85 Mm3 or 30% of the total provided supply), while the "El Kelb drainage" supplied about 10.3 Mm3.

The model results demonstrated that the water supply in the basin cannot meet all demands, resulting in an unmet demand every year. The annual unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin was about 3.7 Mm3/year on average, ranging from 1 to 6 Mm3/year depending on the climate variability. Out of these 3.7 Mm3, about 1.1 Mm3 (i.e. ~30%) is the urban unmet demand, and 2.6 Mm3/year (i.e. ~70%) is the agricultural unmet demand. In the year 2018 the total unmet demand (all sectors) reached 5.47 Mm3/year. The average annual unmet demand will increase in the future 2020-2040 period, and will reach about 6 Mm3/year on average, i.e. a 62% increase (ranging from 1.4 to 15.4 Mm3/year), with the highest unmet demands occur in July-September. Overall, unmet demand will increase after the year 2020 since demand projections have been incorporated. The highest increase, about 135%, is expected in the urban unmet demand which will reach 2.5 Mm3/year on average. The agricultural unmet demand will increase about 33%, reaching 3.5 Mm3/year on average. The highest urban unmet demand is observed in Hardroun. Coastal South and

Mountain South agricultural areas experienced the highest unmet demands in the reference period 2000-2017 (about 1 Mm3/year and 1.3 mio me/year respectively). Yet, the greatest % increase in the unmet demand in the future is expected in the Mountain North agricultural area, which had almost no unmet demand currently. In view of this projected increase in the unmet demand in both sectors it is paramount to implement demand management measures (either water saving or increase supply measures) to mitigate the problem. An analysis of different demand management measures and their effectiveness in reducing unmet demand is currently under implementation as part of the SWIM-H2020 SM expert facility activity EFS-LB-1.

1 INTRODUCTION

The current work is related to the SWIM-H2020 SM expert facility activity EFS-LB-1: "IWRM at the river basin scale, with a focus on capacity building and implementation aspects" and builds on the respective Project Identity Form (PIF). The activity falls under the SWIM theme "Decentralized water management and Growth" and aspires overall to support aspects of policy development and reform, and to provide institutional training, technical assistance and capacity building, through a series of sub-activities.

The current report presents an analysis and quantification of the water resources in the Nahr-El Kelb River Bain in Lebanon, based on a semi-distributed physical-based water resources management model developed in WEAP21 software. The model has been set-up for the reference period between 2010-2018, at monthly timestep, and includes all the components of the hydrological system, groundwater karst, water demand, water use and water supply in the basin, with the purpose of assessing the water balance and quantifying unmet demand in the basin, in the urban and agricultural sectors.

The assessment and trends in the unmet demand will subsequently guide the design and testing (via simulation) of a bundle of measures (technical and/or institutional), with the purpose of selecting the most cost-effective ones, and subsequently defining relevant policy targets (on the basis of specific criteria). These policy targets will be then communicated upstream to the central decision-making level (i.e. the Ministry) with the purpose of being integrated into development frameworks and action plans related to the Water Law (and other sectors). The overall process will be complemented with stakeholders' involvement, training and capacity building of the river basin organizations. This bottom-up process in will act as a pilot application, to be replicated in other River Basins, so that systematic assessment of the water balance is performed, and information on needs and remedies is communicated from the local level to the central level, to better inform the national water policy.

2 OVERVIEW OF THE NAHR EL-KELB RIVER BASIN

The Kelb River Basin is located on the windward part of Mount Lebanon. The Basin has an area of 287 km2. Elevation ranges from 0 m.s.l.(mean seal level) at the basin outflow in the Mediterranean sea to 2,626 m.s.l. (mean sea level) at Mnt. Sannine. Climate is typical Mediterranean with precipitation falling between October and May. Most precipitation are observed between December and March. Precipitation above 1200 m.s.l. falls as snow. Precipitation is enhanced topographically and has a high spatial and inter-annual variability. Average estimated annual precipitation for the time period between 2000 and 2017 ranged from 570 mm in the coastal part to 2750 in the mountain regions.

Woodland is the major land cover (34% of the basin total area) followed by Grassland (27%). Agriculture land use is 10.6% and urban areas occupy around 10%, the remainder of the basin area is bare rocks and soils.

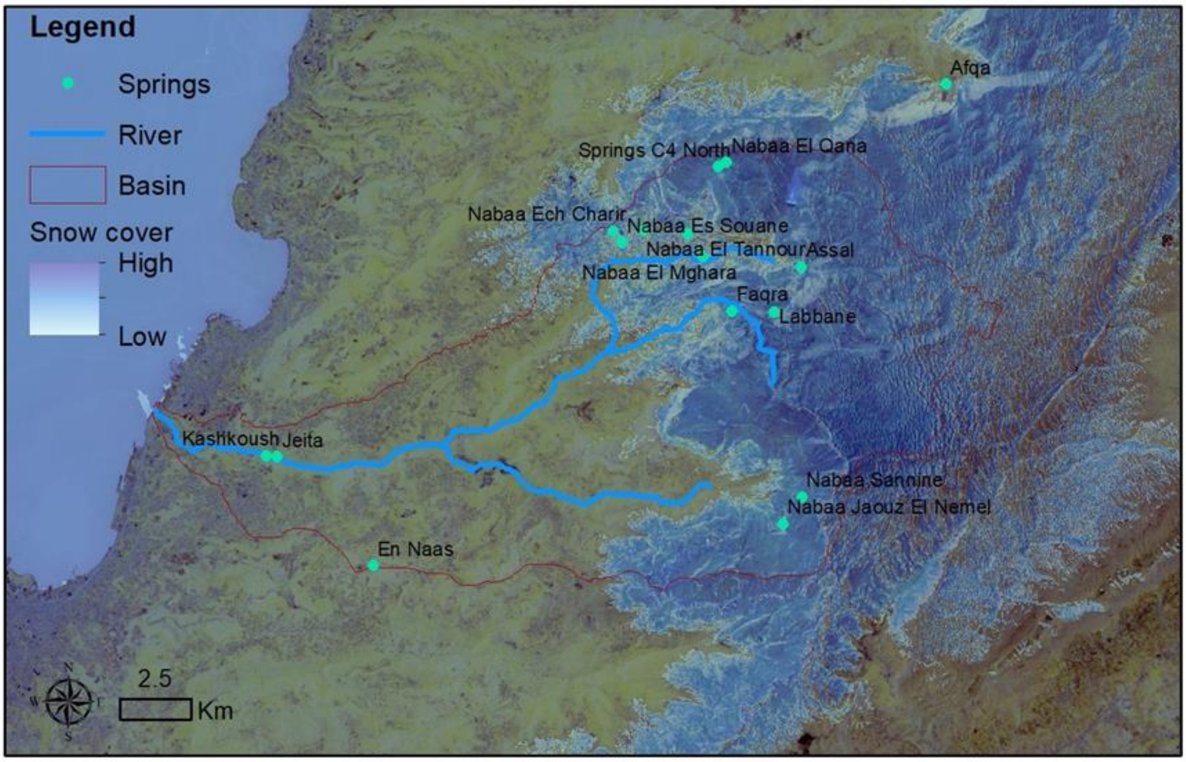
The basin is managed by the Beirut and Mount Lebanon Water Establishment and supplies regions of the Kesrouane, and El Metn governorate. Population estimates for 2017 was estimated at 290,000 inhabitants. Water from the Jeita springs at 60 m.s.l (mean sea level). supplies approximately 60% of Beirut's fresh water demand, which makes this basin of major source of water for around 2 million people (around 35% of Lebanon's total population).

Water availability is dependent on the seasonal precipitation and the high karstification which has an impact on the discharge of most springs. Spring discharge has a high seasonal variability ranging from 0-3.7 m³/sec during the dry season (June - November) to 1.9 - 9.6 m³/sec between February and May.

Main Issues

- Water demand increases during summer months with increasing demands from urban areas and agricultural lands. Water stress is more frequent during dry years.
- There is a limitation in the quantification of water demand, water supply, and water consumption which limits the proper assessment of the water imbalance (i.e., difference between water demand and water availability).
- Water contamination increases with the increase of urban and agricultural activities at mid-elevation to lowland areas which impacts the usability of water in downstream areas.
- There is a limited competition between water users due to the limited agricultural practices in the basin. The major impacts are related to the water available for transfer to the Beirut area from the Spring of Jeita.

Figure 2-1: The El Kelb River basin in Lebanon



3 THE WATER RESOURCES MANAGEMENT MODEL (WRMM) OF THE NAHR EL-KELB RIVER BASIN IN WEAP

A water balance model was developed for the Nahr El-Kelb basin for the time period between 2000 and 2017. The model included all the components of the hydrological system, groundwater karst, water demand, water use and supply in the basin. The model is run at monthly timestep, for each of the 19 sub-catchments and 15 demand sites. The model runs allowed the identification of the hydrological budget, streamflow, spring discharge, groundwater recharge, and dam storage. Streamflow data were used to compare simulated and observed flows at 5 gauges.

The total annual unmet, over the time period between 2000 and 2017 demand for agriculture ranged between 0.2 million m3 for wet years and 3.4 million m3 in dry years. Unmet demand for urban areas ranged between 0.3 and 1.5 million m3 over the same time period.

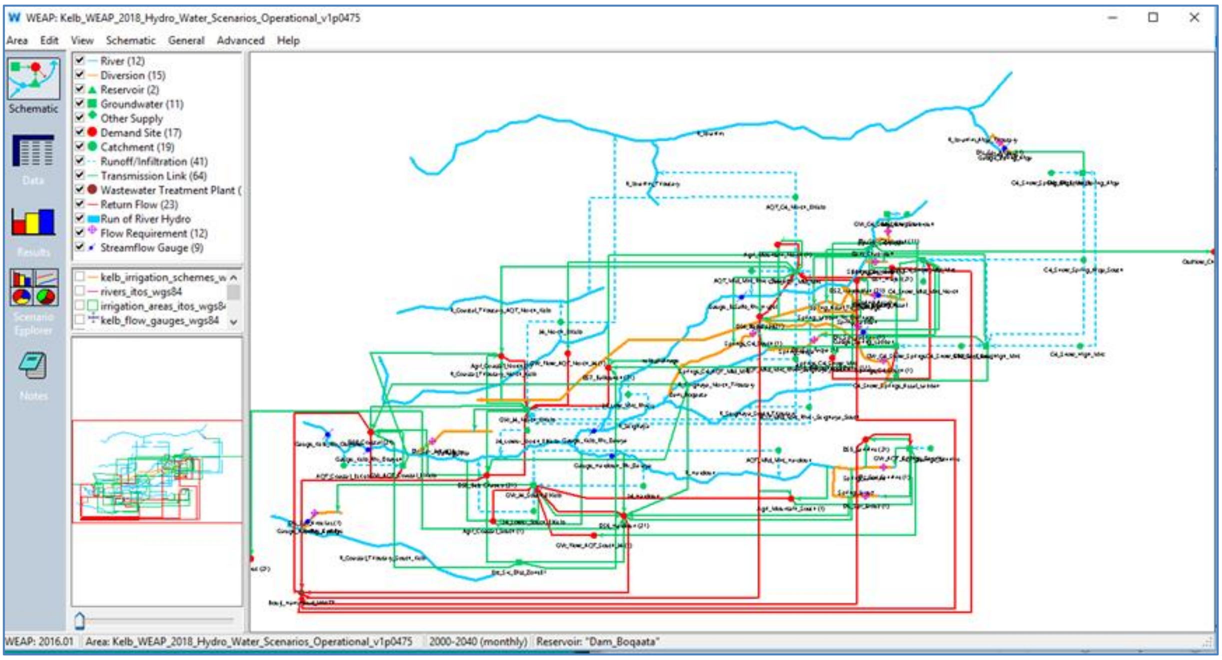
The water balance between demand and water availability was positive, resulting in most water demands being met for urban areas inside the basin with a 98%-100% of requirement is met at the northern part of the basin. Shortages were observed at the southern part of the basin between May and November with coverage reaching as low as 30% during summer months. Water supply for the Beirut area is the most affected given that water is transferred from the lower spring at Jeita. Water coverage (i.e., water met) for

Beirut ranged from 62% during winter season to less than 25% in the summer season. Water demand for agriculture was met at the northern sites. Unmet demand for agricultural activities at the southern sites ranged between 10% and 25% (March -June) 35% and 65% during summer (July - September).

3.1 The WEAP model setup

The Nahr El-Kelb River Basin model is set up using the WEAP software and was run at monthly timestep for the time period between 2000 and 2017. The time period between 2018 and 2040 was used to evaluate the scenarios. In order to set up the node-based disaggregated WEAP model, a detailed analysis of the study area has been implemented to post-process all the data collected and create the necessary input data for the model. A schematic representation of the model, with all the nodes and their interconnection (i.e., links) is illustrated in Figure 3-1 below.

Figure 3-1: Schematic representation of the WEAP model for the Nahr El-Kelb basin



The model comprises of 19 sub-catchments, 8 groundwater bodies and 2 aquitard formations, 10 karstic springs and one aggregated spring representation, 12 major rivers links representing the Kelb river and its major tributaries, 41 runoff/infiltration links (carrying runoff and infiltration from catchments to rivers and groundwater bodies), 15 diversions representing karstic springs, 14 demand sites, 2 demand sites used as a proxy for groundwater flow, 2 dams, 1 wastewater treatment plant (currently inactive), and 64 transmission links for linking springs to groundwater and demand sites to sources (i.e., springs, surface water, and groundwater), 23 return flow links (directing the water that is not consumed in a demand side to surface or groundwater body).

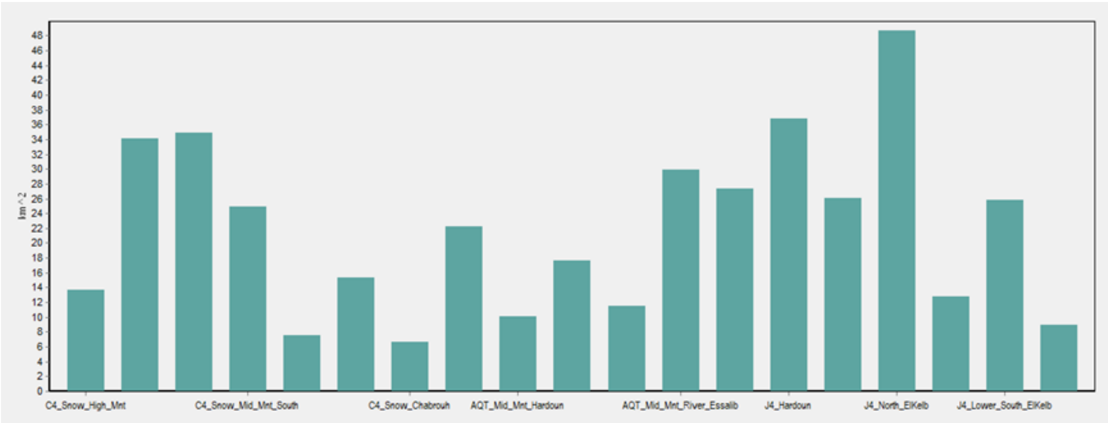
3.1 The WEAP model parameterization

The parameterization of the model included the meteorology, hydrology, groundwater, water demand and supply system.

3.1.1 Parameterization of catchments

The basin was subdivided into 19 sub catchment units with areas ranging from 6.6 to 48.7 km2. Figure 3 shows the areas of the different sub-catchment in the Kelb Basin. The subdivision was based on the surface hydrology and the interaction between surface and groundwater system. The 19 sub-catchment where distributed between 7 sub-catchments located in the headwater of the el Kelb basin, high to medium elevation mountains above 1000 m a.s.l (above sea level). All these headwater sub-catchment are snow dominated and underlaid with the upper cretaceous (C4) formation. Six (6) sub-catchments are located below the headwater catchment and contribute little to the aquitard formation beneath them. Five (5) downstream sub-catchment are located at lower elevations (range from 0 to less than 1000 m a.s.l.) and are mainly contributing to the Jurassic formation (J4), while a small sub-catchment is located at the outlet of the basin when it drains into the Mediterranean Sea.

Figure 3-2: Major sub-catchments and their areas in the Kelb Basin



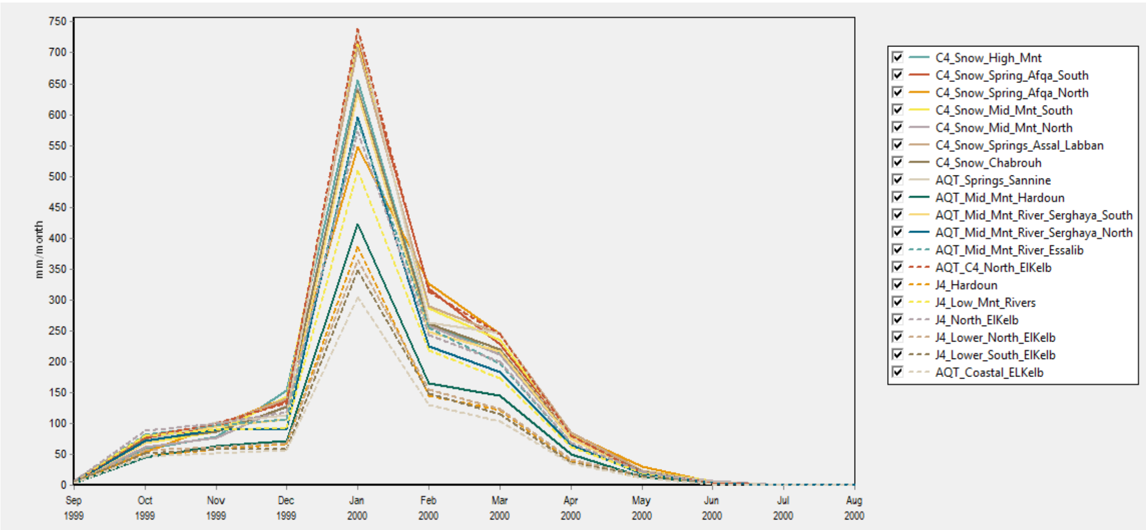
3.1.2 Parameterization of the groundwater system

The representation of the groundwater system was based on geology of the basin and the detailed groundwater study done by BGR in 2013 (Margane et al., 2013). The basin is subdivided into 5 groundwater C4 systems representing the contribution of the mountains and snow infiltration. Two (2) aquitard systesm are used for the transfer between the upper cretaceous (C4) and the lower Jurassic (J4) formation which is represented by 2 groundwater systems.

3.1.3 Climate of the basin

The climate of the basin is dominated by the Mediterranean climate and the increase of orographic precipitation. Most of the precipitation is limited to the winter season (Dec - March). We used local precipitation data from meteorological stations within the basin or in proximity to derive the meteorological forcing. Figure 3-3 shows the average precipitation during 2000 for all sub basins.

Figure 3-3: Monthly precipitation distribution for the baseline year (2000) over the different sub-catchment of the El Kelb basin



3.1.4 Parameterization of the demand sites

In the Kelb basin there are around 95 small villages and major administrative units. These different units were grouped into 9 demand sites and named according to the most populated region. One additional urban site is used to represent the transfer of water from the Jeita Spring to Beirut the Capital. The total permanent population of the area is 120,000 inhabitants based on the estimates of 1994. A 2.6% yearly increase was used to calculate the population in the basin through the entire simulation time period. Table 3-1 shows the baseline population for the different demand sites in the basin.

Table 3-1: Permanent estimated 2000 population per major aggregate demand sites

Demand site	Number of inhabitants in 2000
DS1 (Hrajel)	15,200
DS2 (Kfardebian)	11,150
DS3 (Aayoun_esSimane)	3,475
DS4 (Baskinta)	14,950
DS5 (Sannine)	1,250
DS6 (Hardoun)	27,225
DS7 (Ballouneh)	48,925
DS8 (Beit Chabeb)	49,125
DS9 (Coastal)	16,550

3.1.1 Parameterization of the land use and agriculture

In terms of land use the area is dominated by woodland (forest and shrubs) (33.7%) and grassland (26.9%). These are followed by bare soils and rocks (18.6%). Urban areas covers around 10.1%. The basin have limited industrial activities which are considered part of the urban areas. The total agricultural land is 10.6% and consists mainly of fruit trees (7.7% of the total basin area). The land use types are presented in Table 3-2.

The distribution of agricultural lands is presented in Table 3-3. Four Agricultural zones were chosen to represent the mountainous agriculture and coastal agricultural areas. Agriculture was subdivided between fruit trees and field crops. Due to the limited agriculture practices in the basin no subdivision of the agriculture was used.

Table 3-2: Land use in the Kelb basin (based on Corine Land Cover of 2000)

Land Use Type	% coverage of the total basin area
Woodland (Forest & shrubland)	33.7%
Grassland	26.9%
Bareland	18.6%
Urban areas	10.1%
Fruit trees	7.7%
Field crops	2.9%
Water	~0.1%
Total	**100%**

Table 3-3: Land use in the Kelb basin (based on Corine Land Cover of 2000)

Agriculture area	Area (ha)	% fruit trees	% crops
North Mountain	1330	85%	15%
South Mountain	540	75%	25%
North Coastal	1490	60%	40%
South Coastal	440	50%	50%
Total	**3800**	**70%**	**30%**

3.1.1 Parameterization of urban and agricultural water demands

The model includes 13 demand sites. The water demands sites in the study area are represented in WEAP by 9 domestic/urban demand nodes, and 4 agricultural demand nodes. Industrial demand is computed as percent of the domestic demand. These demand nodes are connected to the surface, groundwater and springs and irrigation canals using WEAP transmission links. All return flows are routed back to groundwater and streamflow for agriculture. A WWTP is considered part of the scenarios (start year 2025). In terms of water allocation priorities, meeting domestic water demand has been assigned a priority 1, irrigation and agriculture have been assigned a priority 2. Supply from surface water was given priority 1 and supply from groundwater was given a priority 2 in most cases.

To model the **domestic/urban water demand** the “Annual activity Level” method of WEAP has been chosen, and the demand per node (site) has been inserted as a function of the following parameters:

Annual Activity Level [cap]

ReadFromFile(..\Kelb_WEAP_2017_Data\socio\kelb_weap_pop_2000_2040.csv, 1)

Annual Water Use Rate [m3 cap-1]

Key\Urban_water_consumption\Median((100-Key\Scenarios\Domestic_water_saving[% cap])/100)*

Monthly Variation

MonthlyValues(Sep, 9.5, Oct, 9.5, Nov, 9.5, Dec, 7, Jan, 5, Feb, 5, Mar, 7, Apr, 9.5, May, 9.5, Jun, 9.5, Jul, 9.5, Aug, 9.5)

Monthly Domestic Consumption = 60% of Monthly Domestic Demand [it represents the % inflow consumed, lost from the system]

Loss Rate

100-Key\Scenarios\Domestic_network_efficiency[%]

Return flow = Inflow(1-consumption)*

Table 3-4: Key assumptions (user-defined variable) used in the domestic water demand calculations for the baseline 2000-2017 scenario.

Key Assumption	Value
Daily water use rate	0.21 m^3
Losses rate	45%
Population growth rate	2.6% yr-1

To model the **irrigation water demand** per node (site) the irrigation areas (km2) have been incorporated in the catchment according to average type of crop which where subdivided into 4 categories (mountain and coastal fruit trees and vegetables). Based on the Reference Evapotranspiration (ETref) and the crop coefficient Kc, the potential evapotranspiration PETcrop has been calculated for each crop type. Then, the irrigation need for each crop area has been identified based on the difference between the available precipitation and the PETcrop, and the required supply per crop and area has been determined.

Annual activity level = area [ha] as presented in Table 3-5

Table 3-5: Key assumptions (user-defined variable) used in the domestic water demand calculations for the baseline 2000-2017 scenario.

Key Assumption	*Annual water use rate (m^3/ha)*
Fruit_Mountain	*5,200*
Veg_Mountain	*6,100*
Fruit_coast	*5,900*
Veg_coast	*6,500*

The monthly variation in agricultural demands was defined as follow.

Fruit_Mountain_Monthly (%) MonthlyValues(Sep, 15, Oct, 5, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 2.5, May, 12.5, Jun, 20, Jul, 22.5, Aug, 22.5)

Veg_Mountain_Monthly (%) MonthlyValues(Sep, 15, Oct, 0, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 5, May, 10, Jun, 20, Jul, 25, Aug, 25)

Fruit_coast_monthly (%) MonthlyValues(Sep, 15, Oct, 5, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 5, May, 15, Jun, 20, Jul, 20, Aug, 20)

Veg_coast_month (%) MonthlyValues(Sep, 10, Oct, 0, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 5, Apr, 10, May, 15, Jun, 20, Jul, 20, Aug, 20)

The irrigation efficiency coefficient takes into account the conveyance method (closed pressurized pipe or open channel), and the method of irrigation (drip irrigation, sprinklers, or surface). The assessment of this coefficient, was based on expert judgement and feedback from stakeholders. The following rules were used for the baseline scenario (2000-2017).

*Irrigation_network_efficiency_mountain (%) 100-Round(percGroundwater*Key\Agriculture\Irrigation_network_loss\groundwater + percOpenchannels*Key\Agriculture\Irrigation_network_loss\open_channels + percClosedpipes*Key\Agriculture\Irrigation_network_loss\closed_pipes)*

percGroundwater	*0.4*
percOpenchannels	*0.3*
percClosedpipes	*0.3*

*Irrigation_network_efficiency_coastal (%) 100-Round(percGroundwater*Key\Agriculture\Irrigation_network_loss\groundwater + percOpenchannels*Key\Agriculture\Irrigation_network_loss\open_channels + percClosedpipes*Key\Agriculture\Irrigation_network_loss\closed_pipes)*

percGroundwater	*0.6*
percOpenchannels	*0.3*
percClosedpipes	*0.1*

*Irrigation_technique_efficiency_mountain (%) 100-Round(percDrip*Key\Agriculture\Irrigation_technique_loss\drip+percSprinkler*Key\Agriculture\Irrigation_technique_loss\sprinkler + percSurface*Key\Agriculture\Irrigation_technique_loss\surface)*

percDrip	*0.4*
percSprinkler	*0.3*
percSurface	*0.3*

*Irrigation_technique_efficiency_coastal (%) 100-Round(percDrip*Key\Agriculture\Irrigation_technique_loss\drip+percSprinkler*Key\Agriculture\Irrigation_technique_loss\sprinkler + percSurface*Key\Agriculture\Irrigation_technique_loss\surface)*

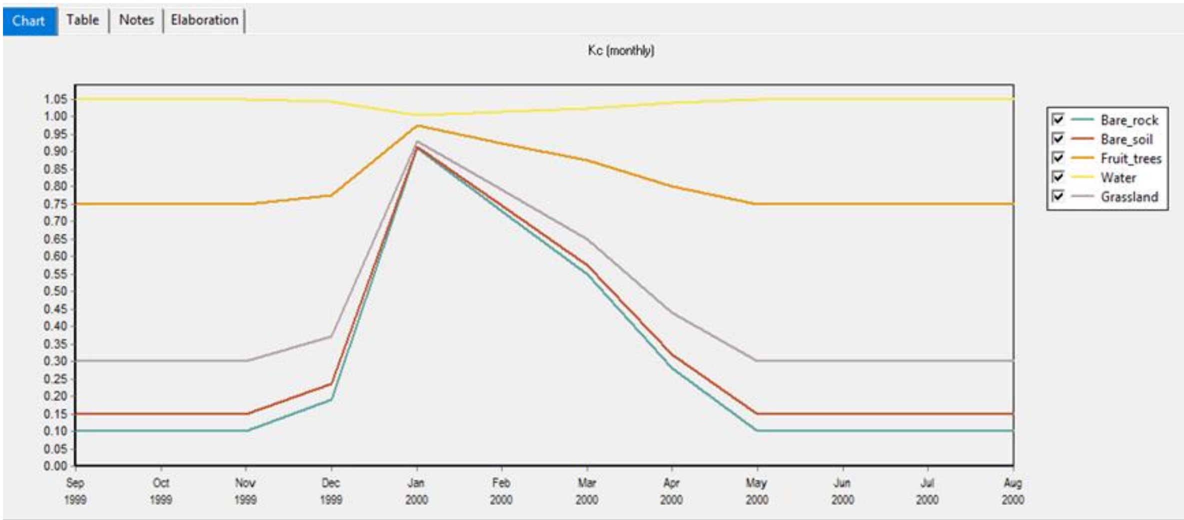
percDrip	*0.2*
percSprinkler	*0.4*
percSurface	*0.4*

Water abstraction for agriculture was distributed between surface and groundwater resources with surface abstraction given the first priority.

3.1.2 Parameterization of the hydrological system

The catchment processes in the model, such as evapotranspiration, runoff, infiltration, snow, etc., have been simulated using the Rainfall Runoff (simplified coefficient method) method which requires the land use and climate of the catchment site. Land use consists of three parameters: area, crop coefficient (as discussed in FAO Irrigation and Drainage Paper N°56, Allen et al., 1998) and effective precipitation, while climate is defined by the precipitation and the reference evapotranspiration (Penman-Monteith equation). These parameters were associated with each sub-catchment. Figure 3-4 shows an example of the monthly variation of Kc for the different land classes in the Chabrouh sub-catchment.

Figure 3-4: Monthly Kc variation for the different land classes in the Chabrouh sub-catchment



The calculations used by the RR method are described in details in the WEAP documentation and the key calculations are provided in Box 1.1.

Box 1.1: Calculation Algorithms used in the Rainfall-Runoff (RR) method

Calculation Algorithms used in the Rainfall-Runoff (RR) method

Crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Non-agricultural land classes can be included as well. The following equations were used to implement this approach where subscripts LC is land cover, HU is hydro-unit, TS is timestep (e.g., month), I is irrigated, and NI is non-irrigated:

- $PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$
- $ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$
- $PrecipShortfall_{LC,I} = Max (0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I})$
- $SupplyRequirement_{LC,I} = (1 / IrrFrac_{LC,I}) * PrecipShortfall_{LC,I}$
- $SupplyRequirement_{HU} = \Sigma_{LC,I} SupplyRequirement_{LC,I}$

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

- $Supply_{HU}$ = Calculated by WEAP allocation algorithm
- $Supply_{LC,I} = Supply_{HU} * (SupplyRequirement_{LC,I} / SupplyRequirement_{HU})$
- $ETActual_{LC,NI} = Min (ETpotential_{LC,NI} , PrecipAvailableForET_{LC,NI})$
- $ETActual_{LC,I} = Min (ETpotential_{LC,I} , PrecipAvailableForET_{LC,I}) + IrrFrac_{LC,I} * Supply_{LC,I}$
- $EF_{LC} = \Sigma_{TS} ETActual_{LC} / \Sigma_{TS} ETpotential_{LC}$

As a result, the actual yield can be calculated with the following equation:

- *ActualYield*LC = *PotentialYield*LC * Max (0, (1 - *YieldResponseFactor*LC * (1 - *EF*LC)))
- *Yield*LC = *ActualYield*LC * AreaLC
- *MarketValue*LC = *Yield*LC * MarketPriceLC

In the Rainfall Runoff method, runoff to both groundwater and surface water can be calculated with the following equations:

- *Runoff*LC = Max (0, *PrecipAvailableForET*LC - *ETpotential*LC) + (*Precip*LC * (1 - *PrecipEffective*LC)) + (1 - *IrrFrac*LC,I) * *Supply*LC,I
- *RunoffToGW*HU = ΣLC (*Runoff*LC * *RunoffToGWFraction*LC)
- *RunoffToSurfaceWater*HU = ΣLC (*Runoff*LC * (1 - *RunoffToGWFraction*LC))

Units and definitions for all variables above are:

Area [HA] - Area of land cover

Precip [MM] - Precipitation

PrecipEffective [%] - Percentage of precipitation that can be used for evapotranspiration **PrecipAvailableForET** [MCM] - Precipitation available for evapotranspiration

Kc [-] - crop coefficient

ETreference [MM] - Reference crop evapotranspiration

ETpotential [MCM] - Potential crop evapotranspiration

PrecipShortfall [MCM] - Evapotranspiration deficit if only precipitation is considered

IrrFrac [%] - Percentage of supplied water available for ET (i.e. irrigation efficiency)

SupplyRequirement [MCM] - Crop irrigation requirement

Supply [MCM] - Amount supplied to irrigation (calculated by WEAP allocation)

EF [-] - Fraction of potential evapotranspiration satisfied, averaged over the season (Planting Date to Harvest Date)

YieldResponseFactor [-] - Seasonal factor that defines how the yield changes when ETActual is less than ETPotential (water stress)

PotentialYield [KG/HA] - The maximum potential yield given optimal supplies of water

ActualYield [KG/HA] - The actual yield given the available evapotranspiration

Yield [KG] - Actual yield for the land class

MarketPrice [$/kg] - Unit value of the crop

MarketValue [$] - Total value of the crop for the land class

RunoffToGWFraction [-] - Fraction of runoff that goes to groundwater

RunoffToGW [MCM] - Runoff to groundwater supplies

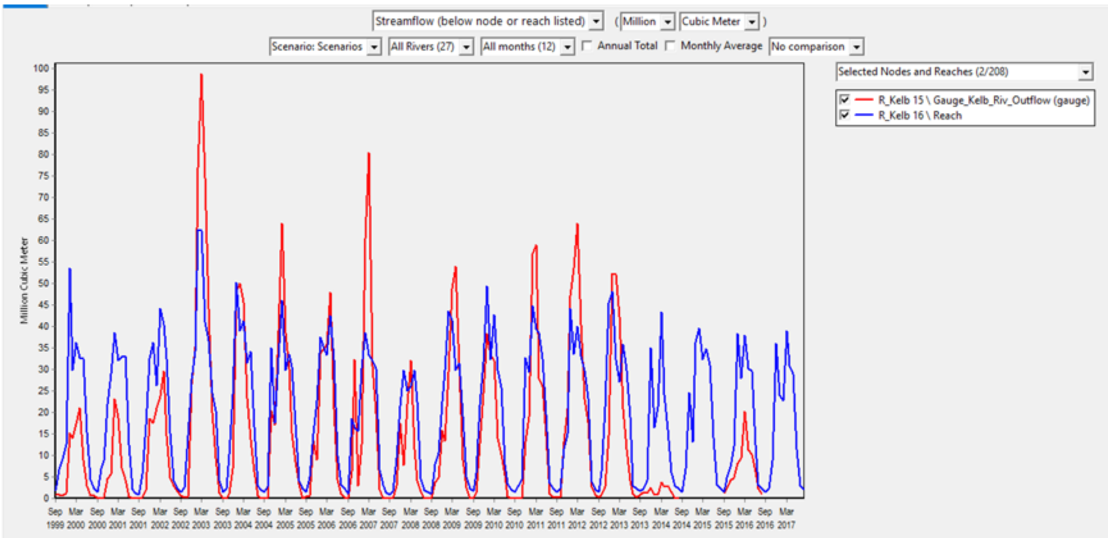
RunoffToSurfaceWater [MCM] - Runoff to surface water supplies

Source: Stockholm Environment Institute (SEI), 2015. WEAP Water Evaluation And Planning System. User Guide for WEAP 2015, August 2015.

4 CALIBRATION AND VALIDATION PROCESS

Limited information was available to calibrate and validated (CalVal) the model. With only few gaging stations available in the basin. The purpose of the CalVal was to achieve a better representation of the catchment physical processes. Major sources of uncertainty in the model are associated with the simplified RR model used within the WEAP which lacks explicit snow accumulation and snowmelt routines, and the presence of karstic aquifers in the basin and associated lag-time in their discharge through the springs. The model has been overall calibrated and validated for the period 2000-2017, using observed streamflow data at the Jeita spring which is located at the basin outflow. Figure 4-1 illustrates the CalVal at the Jeita spring (2000-2017). The correlation factor and goodness-of-fit metrics where deemed satisfactory. It was obvious that the model tends to underestimate the winter streamflow. This is basically attributed to the simplified approach of WEAP in partitioning snow and rain as well as our limited understanding of the Karst system that defines most of the groundwater flow in the basin.

Figure 4-1: Comparison of observed versus simulated streamflows at the Jeita spring gauge



5 THE FUTURE SCENARIOS

The Nahr El-Kelb water resources management model has been extended to include future projections up to the year 2040, in order to allow the assessment of the future water balance and unmet demand.

With regards to the climate, the future timeseries of precipitation for the period 2020-2040 have been produced based on a statistical reproduction, following a random distribution, of the past 2000-2018 climatic variables, accounting thus for Mediterranean variability and assuming no climate change. In this future period, a declining precipitation sun-period 2032-2037 has been simulated, reflecting dry conditions and capturing thus a future climate change case. In these consecutive years (2032-2037) the annual precipitation is low, at about 563 Mm3 on average. The variation of the annual precipitation across the 2000-2040 period is reflected in Figure 6-2, while the monthly distribution of the precipitation across the different sub-catchments of the basin is presented in Figure 5-2. A comparison of the descriptive statistics of the two sub-periods (i.e. reference 2000-2017 and future 2020-2040) is presented in

Table 5-1.

Figure 5-1: Annual precipitation (in Mm3) in the Nahr El-Kelb river basin for the period 2000-2010

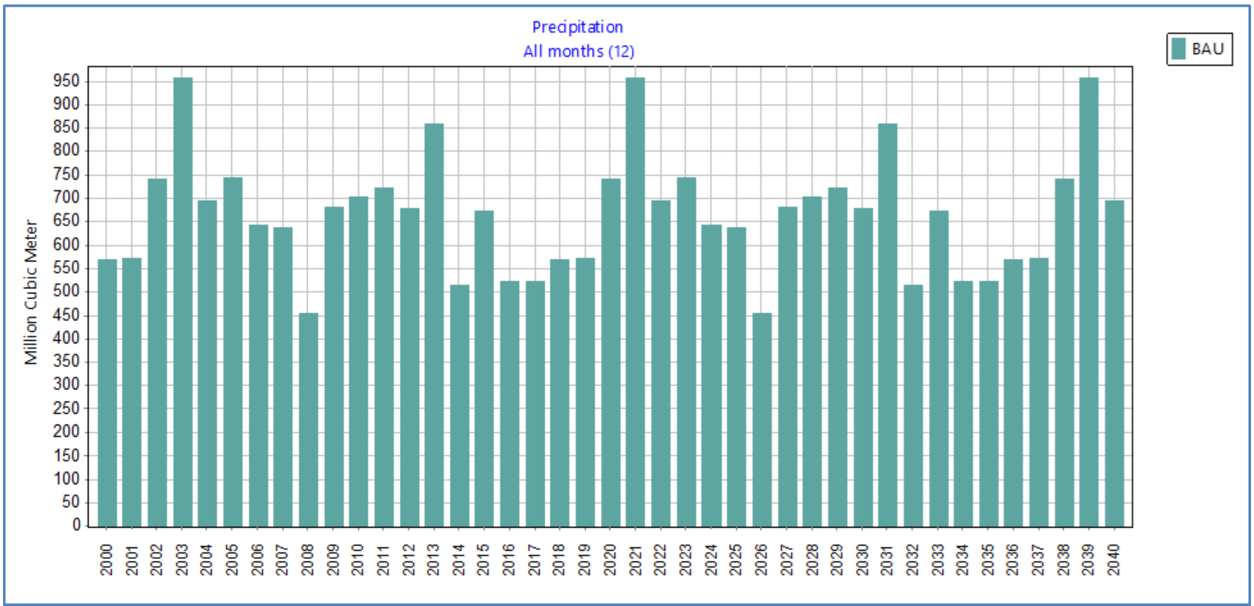


Figure 5-2: Distribution of the monthly average precipitation (in Mm3) in the Nahr El-Kelb river basin for the period 2000-2010

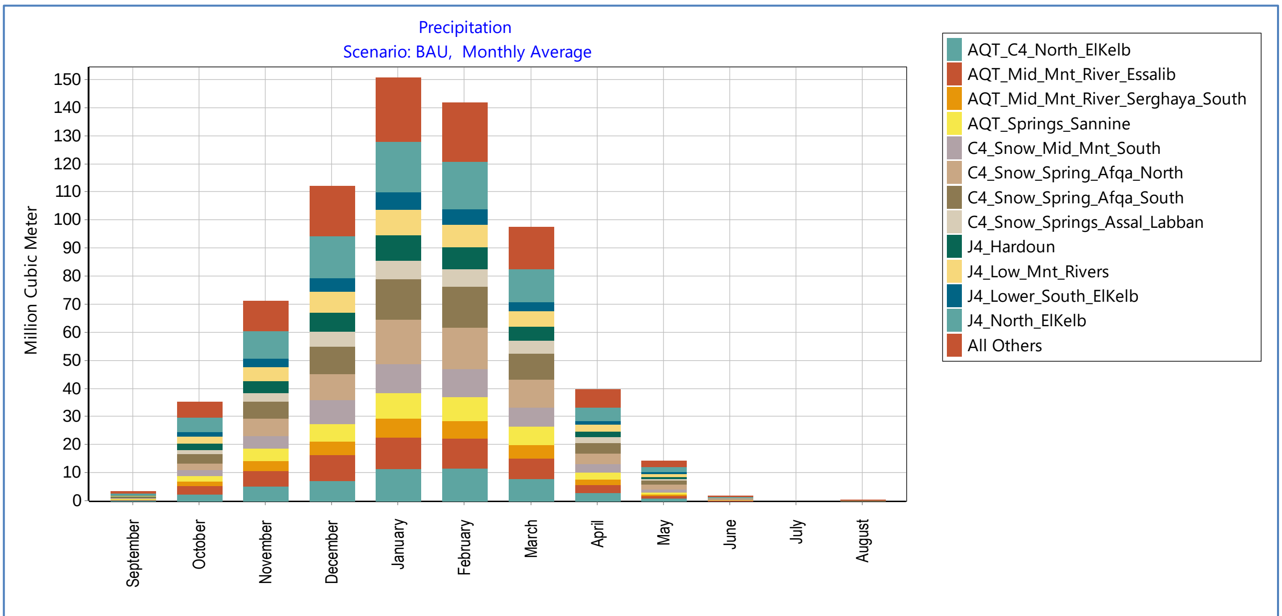


Table 5-1: Precipitation descriptive statistics (in Mm3) of the reference 2000-2017 and future 2020-2040 periods

Descriptive statistics	2000-2017	2020-2040
Mean	666.88	678.12
Standard Error	30.84	30.37

Descriptive statistics	2000-2017	2020-2040
Median	679.56	680.87
Standard Deviation	127.14	135.84
Sample Variance	16,163.77	18,451.49
Kurtosis	0.56	0.27
Skewness	0.45	0.59
Range	503.18	503.18
Minimum	454.59	454.59
Maximum	957.76	957.76
Sum	11337.00	13562.49
Count	17.00	20.00

The variation of the annual potential evapotranspiration across the 2000-2040 period is reflected in Figure 5-3. A comparison of the descriptive statistics of the two sub-periods (i.e. reference 2000-2017 and future 2020-2040) is presented in Table 5-2.

Figure 5-3: Annual potential evapotranspiration (in Mm3) in the Nahr El-Kelb river basin for the period 2000-2010

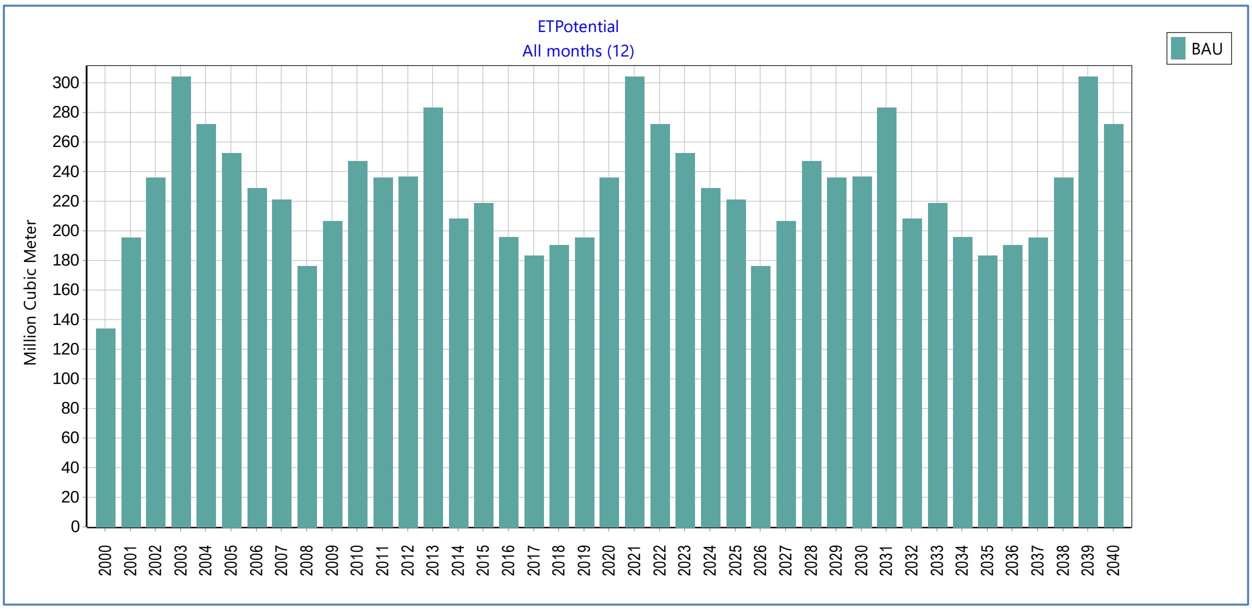


Table 5-2: Potential Evapotranspiration descriptive statistics (in Mm3) of the reference 2000-2017 and future 2020-2040 periods

Descriptive statistics	2000-2017	2020-2040
Mean	229.5	233.4
Standard Error	8.518	8.641
Median	228.9	232.3
Standard Deviation	35.12	38.64

Descriptive statistics	2000-2017	2020-2040
Sample Variance	1234	1493
Kurtosis	-0.14	-0.74
Skewness	0.512	0.417
Range	127.8	127.8
Minimum	176.2	176.2
Maximum	304	304
Sum	3901	4668
Count	17	20

The future socio-economic conditions have been modelled assuming an annual population increase of 2.6% and a steady agricultural area (i.e. no changes in the number of irrigated hectares or in the crop mix). The population increase in each urban demand site in the Nahr El-Kelb river basin from 2000 to 2040 is shown in Figure 5-4. The average population for the reference period 2000-2017 is 236,449 capita, while for the future 2020-2040 period is 414,890 capita, thus an increase of about 755 in the average values (Table 5-3). The Irrigated areas (ha) and crops in the Nahr El-Kelb river basin for the period 2000-2040 have remained constant (i.e. the irrigated areas will not decrease due to urbanisation or abandonment and the existing crops will not be replaced by any alternative ones) as shown in the Table 5-4.

Figure 5-4: Population increase in each urban demand site in the Nahr El-Kelb river basin for the period 2000-2040

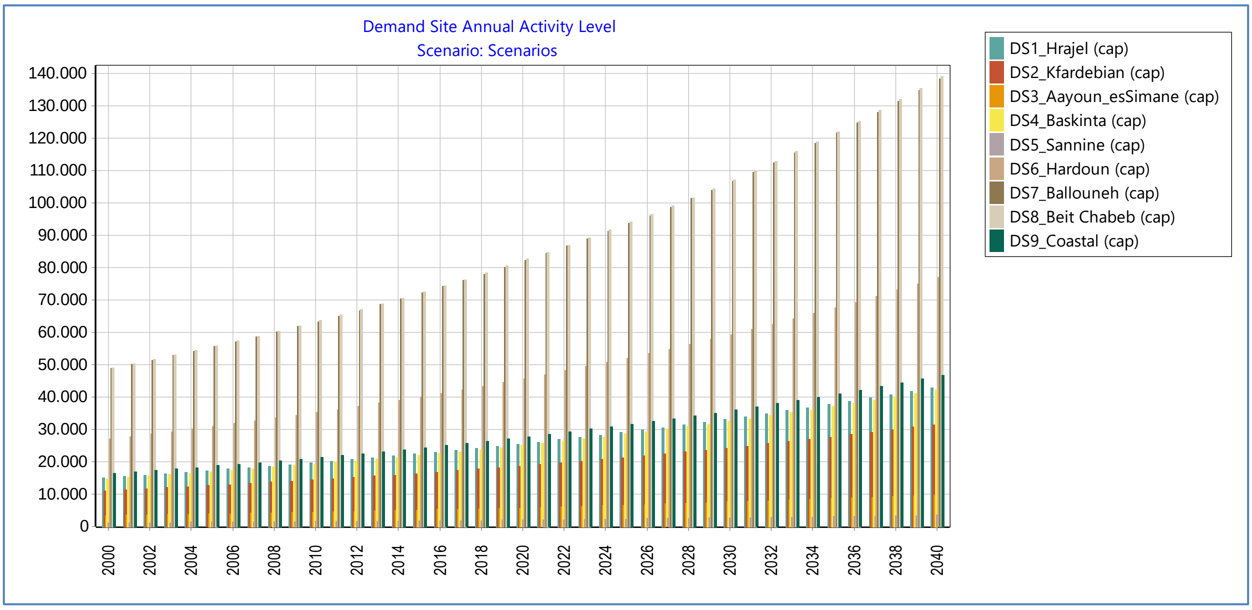


Table 5-3: Total population in the Nahr El-Kelb river basin for the period 2000-2040

Year	Population (capita)
2000	187,850
2017	292,264
2020	315,971
2030	409,793
2040	491,594
2000-2017 average	236,449
2020-2040 average	414,890

Table 5-4: Irrigated areas (ha) and crops in the Nahr El-Kelb river basin for the period 2000-2040

Site	Irrigated area (ha)	Crop mix	Annual water use rate
Agri_Mountain_North	1,330	85% fruit trees 15% vegetables	Fruit trees: 5,200 m3/ha/year Vegetables: 6,100 m3/ha/year
Agri_Mountain_South	539	75% fruit trees 25% vegetables	Fruit trees: 5,200 m3/ha/year Vegetables: 6,100 m3/ha/year
Agri_Coastal_North	1,490	60% fruit trees 40% vegetables	Fruit trees: 5,900 m3/ha/year Vegetables: 6,500 m3/ha/year
Agri_Coastal_South	440	50% fruit trees 50% vegetables	Fruit trees: 5,900 m3/ha/year Vegetables: 6,500 m3/ha/year
Total	3,799	2,648.75 ha fruit trees 1,150.25 ha vegetables	*Average annual water use rate:* Fruit trees: 5,550 m3/ha/year Vegetables: 6,300 m3/ha/year

6 RESULTS AND OUTPUTS

6.1.1 Hydrological balance in the Nahr El-Kelb (current and future state)

A detailed water balance model has been developed for the Nahr El- Kelb River Basin over the reference/ baseline period 2000-2017 and projected future (2020-2040) using the same distribution in the variability of the observed meteorology over the past 2 decades (2000-2017), allowing the representation of the components of the hydrological cycle and catchment process along with the water demand and use aspects in the catchment. All model features have been calculated at monthly timestep, for each of the 19 sub-catchments, 9 groundwater system, 2 dams, and 13 demand sites, allowing the identification of opening and closing stock, and exchange in flows. The total inflows and outflows (lump sum for the entire basin and all 19 sub-catchments) are shown in Figure 6-1. The inflows include precipitation, while the outflow components are the evapotranspiration, the surface runoff, and the flow to the groundwater. On an average annual basis, 16% (or 104 Mm3/year) of the precipitation evapotranspirates (ranging from 12-18%), 62% (or 416 Mm3/year) flows to groundwater (ranging from 60-64%), and the remaining 22%

(or 150 Mm3/year) becomes surface runoff (ranging from 21-24%). Figure 6-2 to Figure 6-5 show the monthly variation in precipitation, streamflow, evapotranspiration, and groundwater flow respectively.

Figure 6-1: Inflows and Outflows in the Nahr El-Kelb basin (2000-2040)

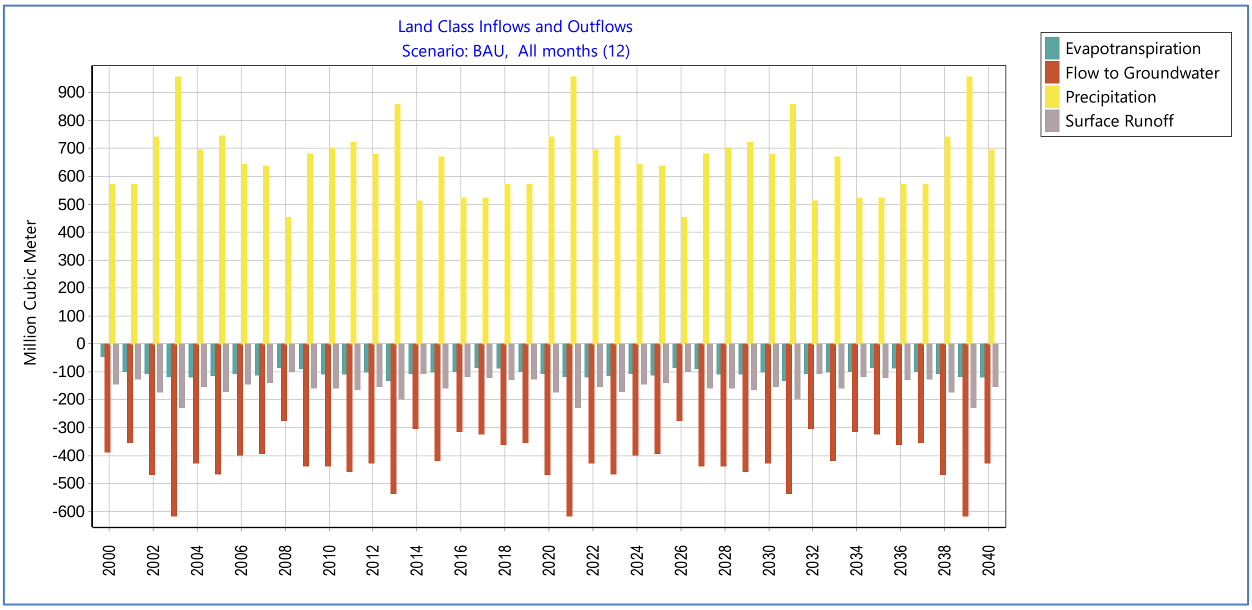


Figure 6-2: Monthly precipitation over the 19 sub-catchment in the Nahr El-Kelb basin (2000-2040)

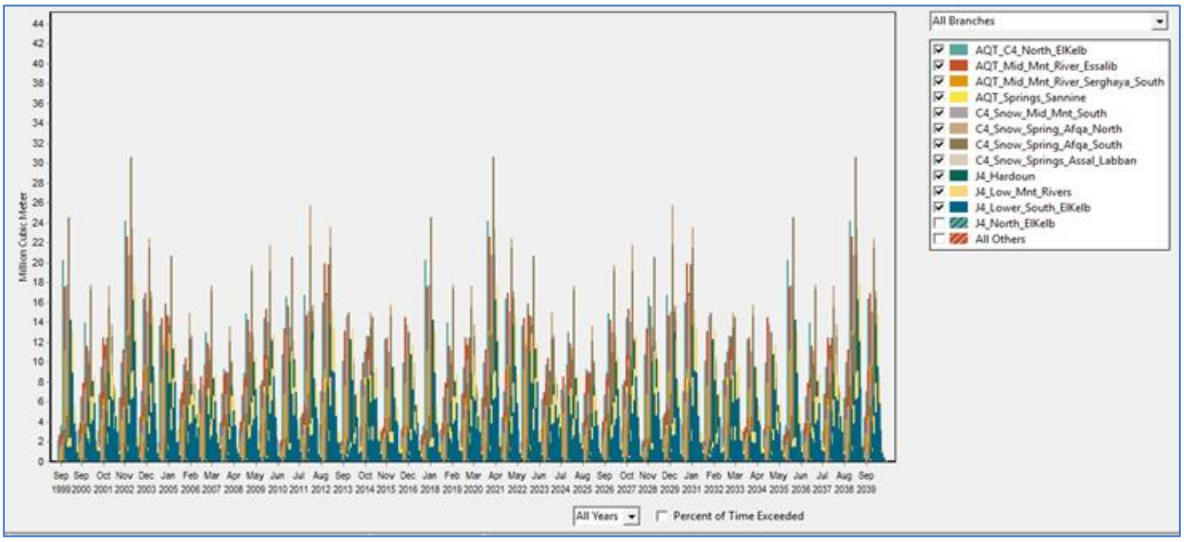


Figure 6-3: Monthly streamflow for the different springs and streams in the Nahr El-Kelb basin (2000-2040)

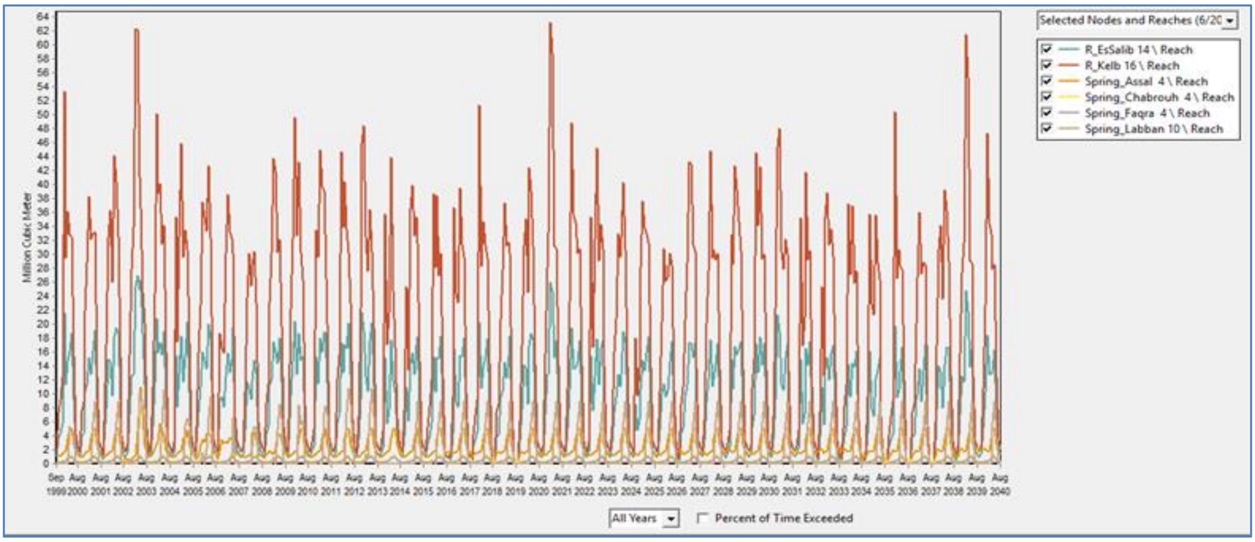


Figure 6-4: Monthly evapotranspiration over the 19 sub-catchment the Nahr El-Kelb basin (2000-2040)

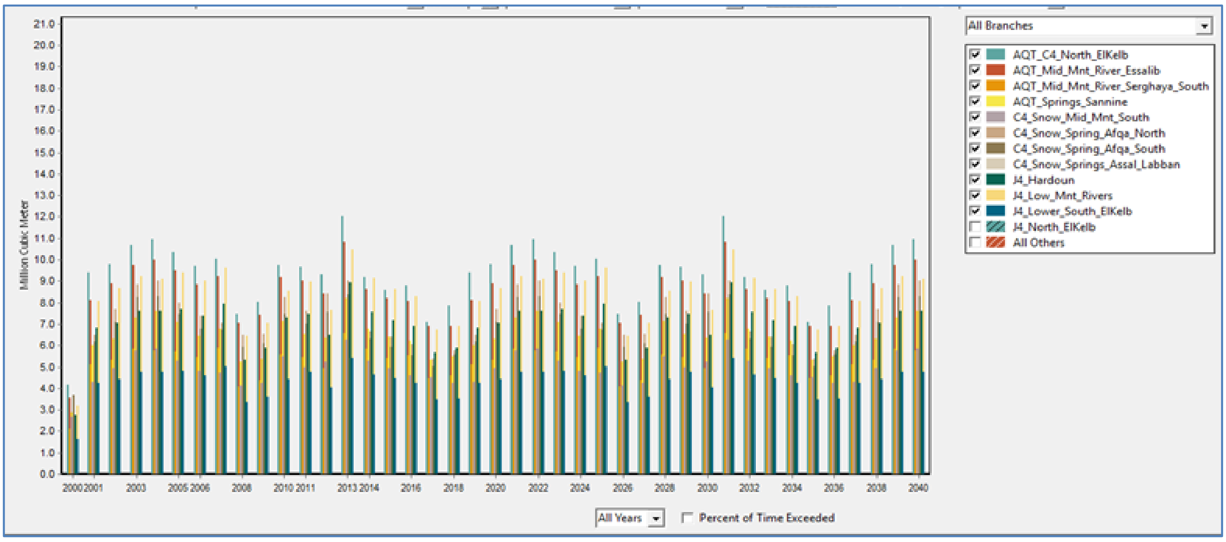
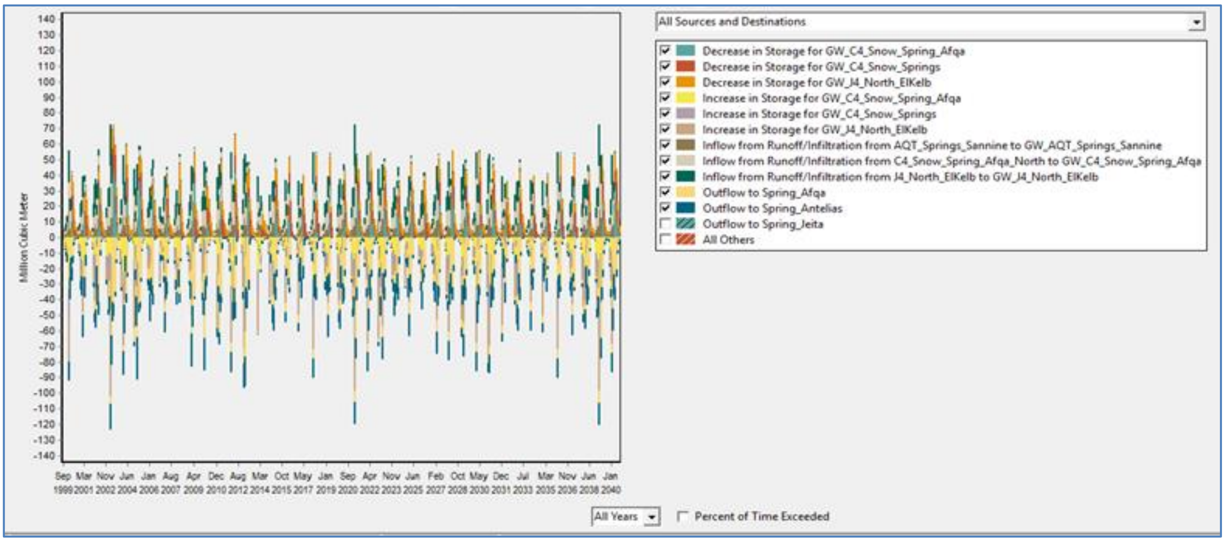


Figure 6-5: Monthly groundwater inflow/outflow the Nahr El-Kelb basin (2000-2040)



6.1.1 Water Balance in the Nahr El-Kelb (period 2000-2040)

The water balance in the Nahr El-Kelb river basin is analysed per component (water demand, water supply delivered, unmet demand) in the following sections

6.1.1.1 Water Demand in the Nahr El-Kelb (period 2000-2040)

Water demand has been simulated in the model using proxies. The urban water demand for the reference period 2000-2017 has been modelled by multiplying the total population in the basin with an average water use rate of 80 m3/capita, and considering an efficiency of 55% for the urban water supply network (which means 45% losses). The urban water demand for the future 2020-2040 has been modelled with the same way, but also incorporating a population increase of 2.6% per year. Thus, the resulting future urban water demands are higher than in the past (increasing trend). According to the calculations, the urban water demand in 2018 was 24 Mm3/year, and is projected to be 42.5 Mm3/year in 2040. This is a significant increase of 77%.

The agricultural water demand has been modelled according to the crop water requirements, and their respective irrigation needs after deducting the contribution of the effective precipitation. The main irrigated crops are fruit trees and vegetables. For the fruit trees we assumed an irrigation need of about 5,500 m3/hectrare/year and for the vegetables about 6,300 m3/hectare/year. The resulting agricultural water demand is about 22 Mm3/year. It was assumed that this demand will stay the same in the future (conservative scenario) assuming that the irrigated area will remain the same and will not decrease due to urbanisation or abandonment.

The variation of the total water demand (from all demand sites), as well as the urban and the agricultural water demands for the period 2000-2040 are shown in Figure 6-6 to Figure 6-8, while the monthly distribution of the total water demand is shown in Figure 6-9. Table 6-1 presents relevant data and statistics.

Figure 6-6: Total annual water demand (in Mm3/year) in the Nahr El-Kelb basin (2000-2040)

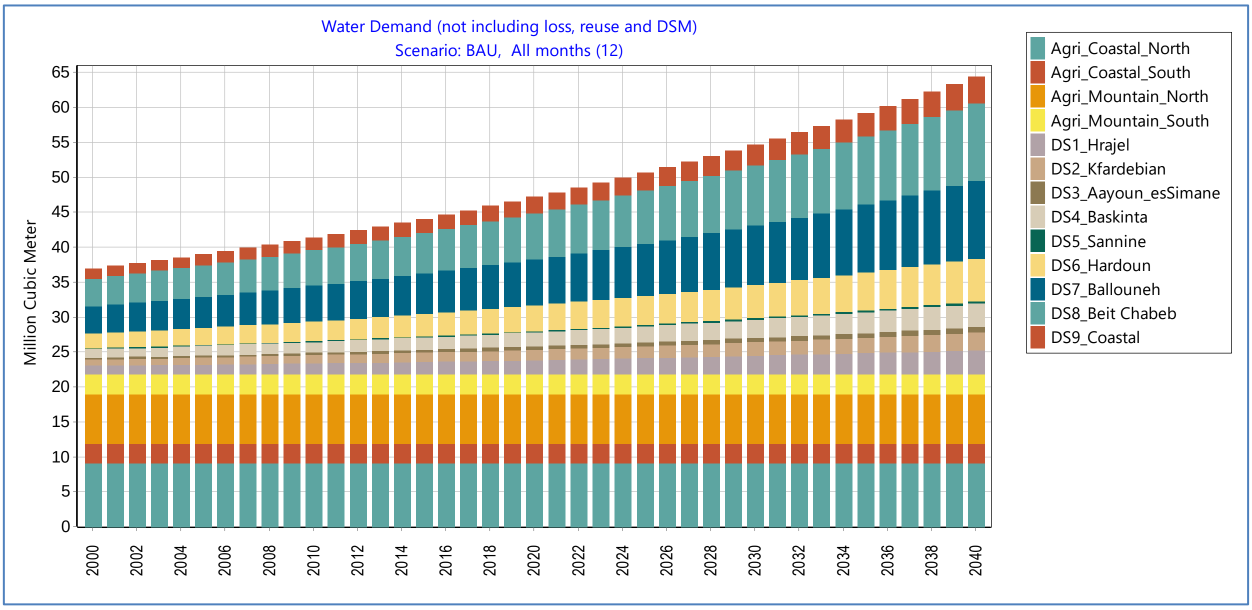


Figure 6-7: Urban annual water demand (in Mm3/year) in the Nahr El-Kelb basin (2000-2040)

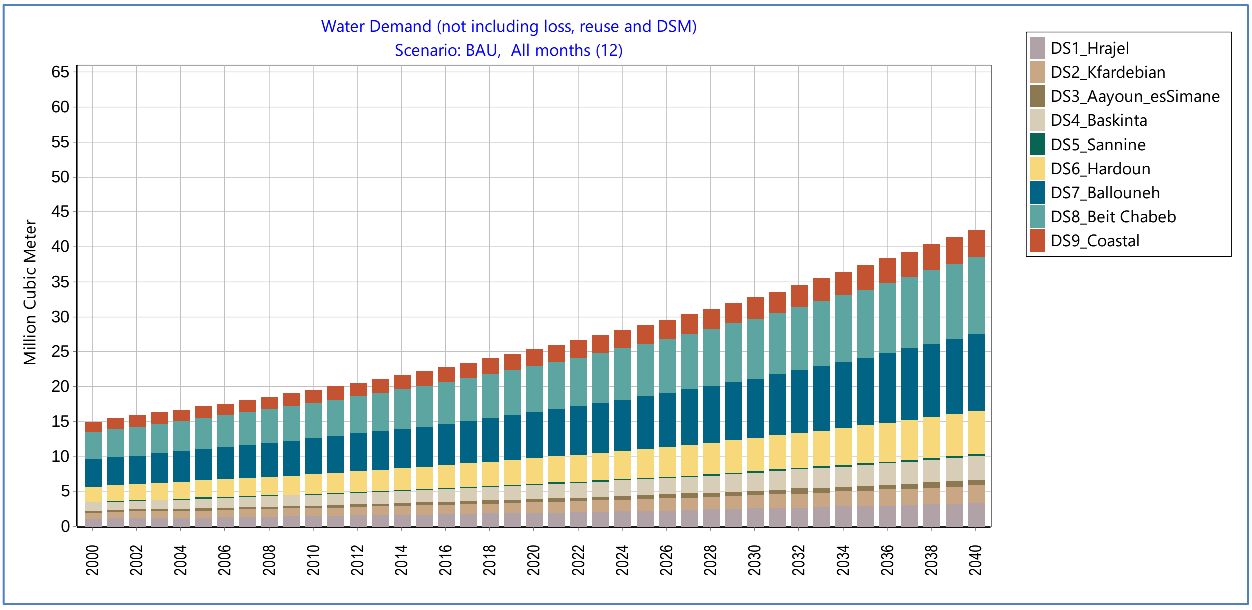


Figure 6-8: Agricultural annual water demand (in Mm3/year) in the Nahr El-Kelb basin (2000-2040)

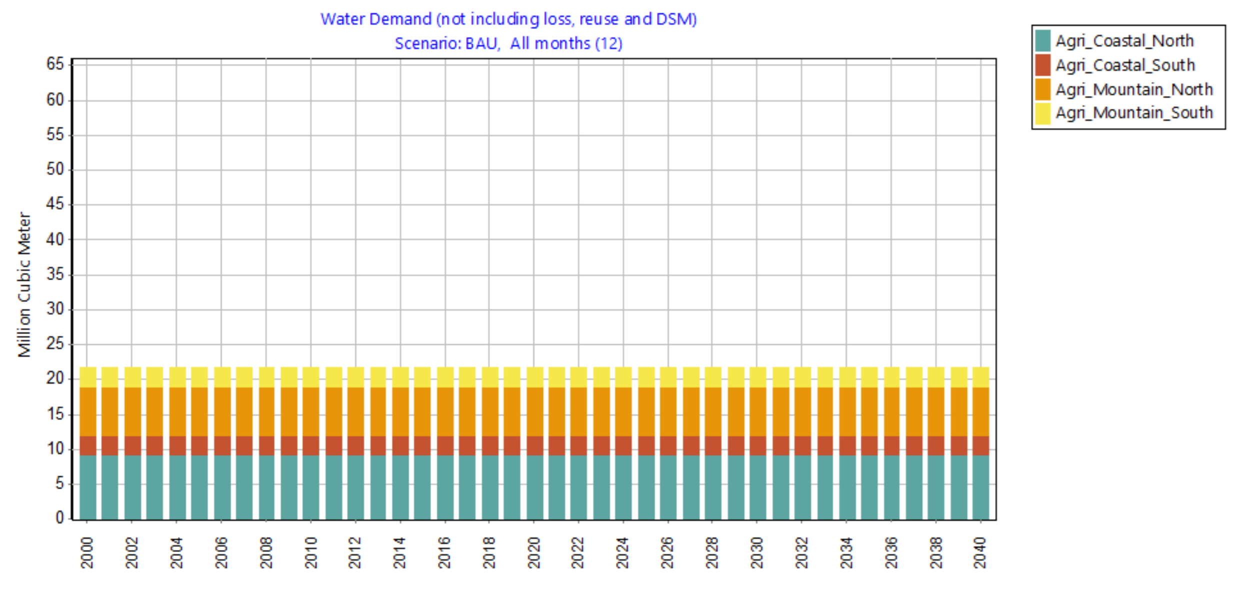


Figure 6-9: Monthly distribution of the total annual water demand (in Mm3/year) in the Nahr El-Kelb basin (2000-2040)

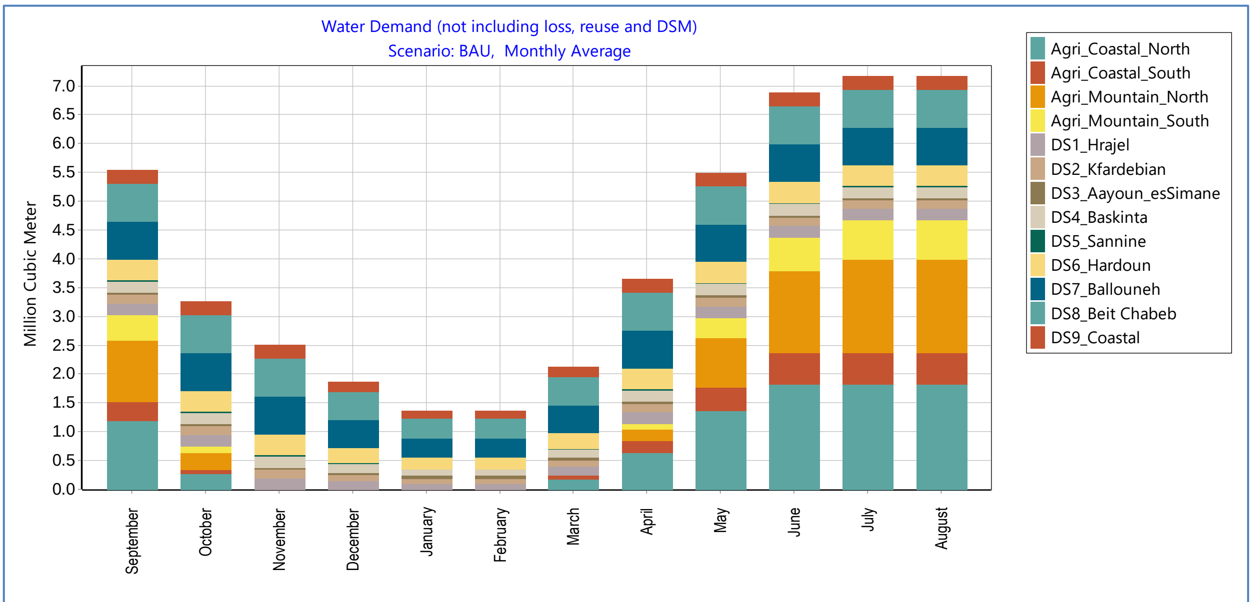


Table 6-1: Water demand values in the Nahr El-Kelb river basin for the period 2000-2040

Year	Total water demand (Mm3)	Urban water demand (Mm3)	Agricultural water demand (Mm3)
2000	36.93	15.03	21.90
2017	45.28	23.38	21.90
2018	45.90	24.00	21.90
2020	47.18	25.28	21.90

Year	Total water demand (Mm3)	Urban water demand (Mm3)	Agricultural water demand (Mm3)
2030	54.68	32.78	21.90
2040	64.42	42.52	21.90
2000-2017 average (reference)	*40.81*	*18.92*	*21.90*
2020-2040 average (future)	*55.09*	*33.19*	*21.90*
% increase between the reference and the future average values	*35%*	*75.5%*	*0%*

6.1.1.2 Water Supply in the Nahr El-Kelb (period 2000-2040)

The annual water supply delivered by all sources in each demand node is presented in Figure 6-10, and reference values are presented in Table 6-2.

Figure 6-10: Total water supply delivered (in Mm3/year) in each demand node in the Nahr El-Kelb basin (2000-2040)

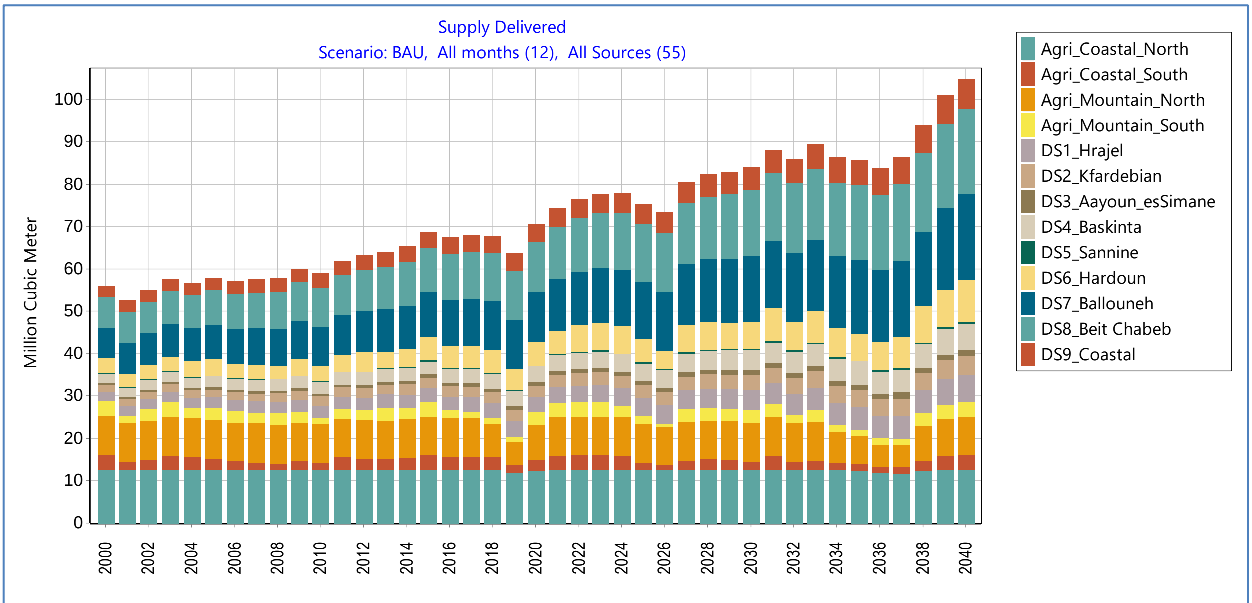


Table 6-2: Water supply delivered in the Nahr El-Kelb river basin for the period 2000-2017

Year	Total water supply (Mm3)	Urban water supply (Mm3)	Agricultural water supply (Mm3)
2000	55.87	27.00	28.87
2017	67.91	41.49	26.42
2018	67.67	42.67	25.00
2000-2017 average (reference)	60.33	33.32	27.01

The annual water supply delivered by the Chabrouh Dam to all the demand sites (lump sum) in the Nahr El-Kelb basin for the period 2000-2040, as well as the monthly distribution are presented in Figure 6-11and Figure 6-12 respectively. It can be observed that the Chabrouh Dam contribution is significant in the area, and amounts to an average of 5.5 Mm3/year during the reference period 2000-2017. The observed variability per year (ranging from 3.6 to 9.2 Mm3/year) depends on the climatic variability (wet vs. dry years). A higher supply potential is observed in the months of July-September and is attributed to the contribution of snow melt.

Figure 6-11: Annual water supply delivered by the Chabrouh Dam in all the demand sites (lump sum) in the Nahr El-Kelb basin for the period 2000-2040

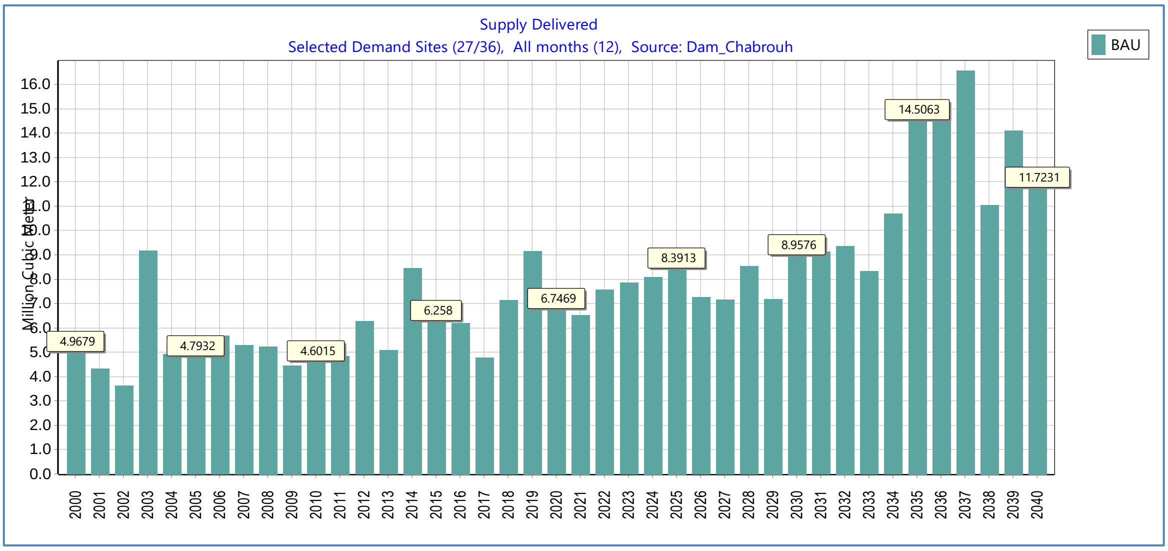
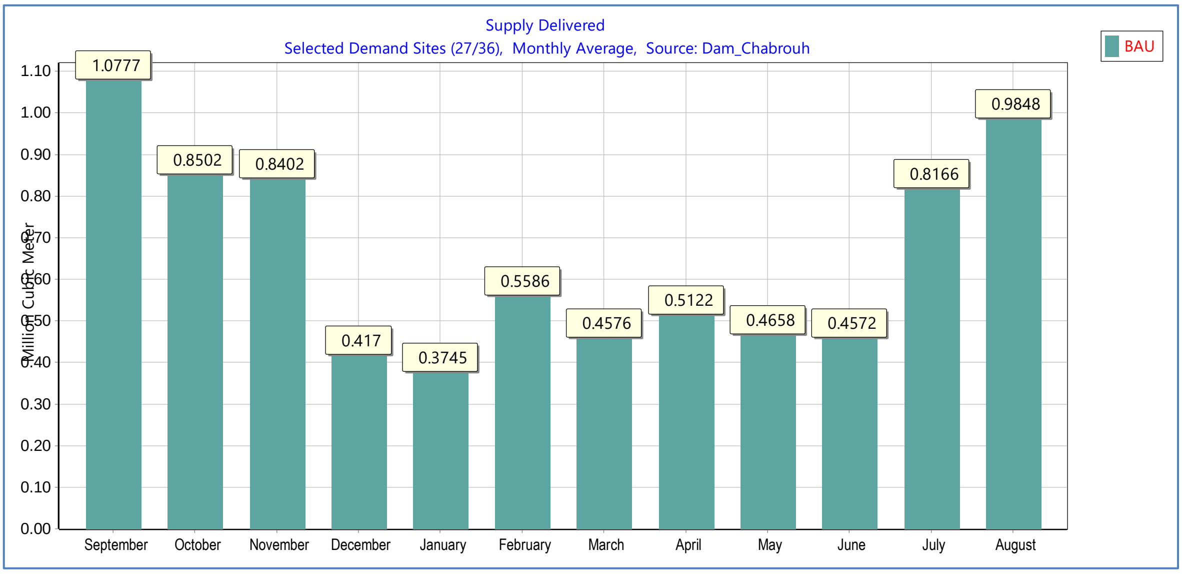


Figure 6-12: Monthly average water supply delivered by the Chabrouh Dam in all the demand sites (lump sum) in the Nahr El-Kelb basin for the period 2000-2040



Taking a closer look at the year 2007, the total supply (from all sources) to the urban demand sites was about 41.5 Mm3/year (for the year 2017). The supply from Jeita spring to Beirut (about 48 Mm3) is excluded. The highest contribution came from Spring Assal (about 16 Mm3), while the Chabrouh Dam supplied about 4.8 Mm3, which equals the 12% of the total provided supply in the basin. The volumes supplied to each urban demand site (as well as Beirut) from each individual water supply source are presented in Figure 6-13

Table 6-3 below.

Figure 6-13: Water Supply delivered in the year 2017 (Mm3/year) in all the urban demand sites in the Nahr El-Kelb basin from each water supply source (Chabrough Dam, Groundwater Aquifers, Rivers, Springs).

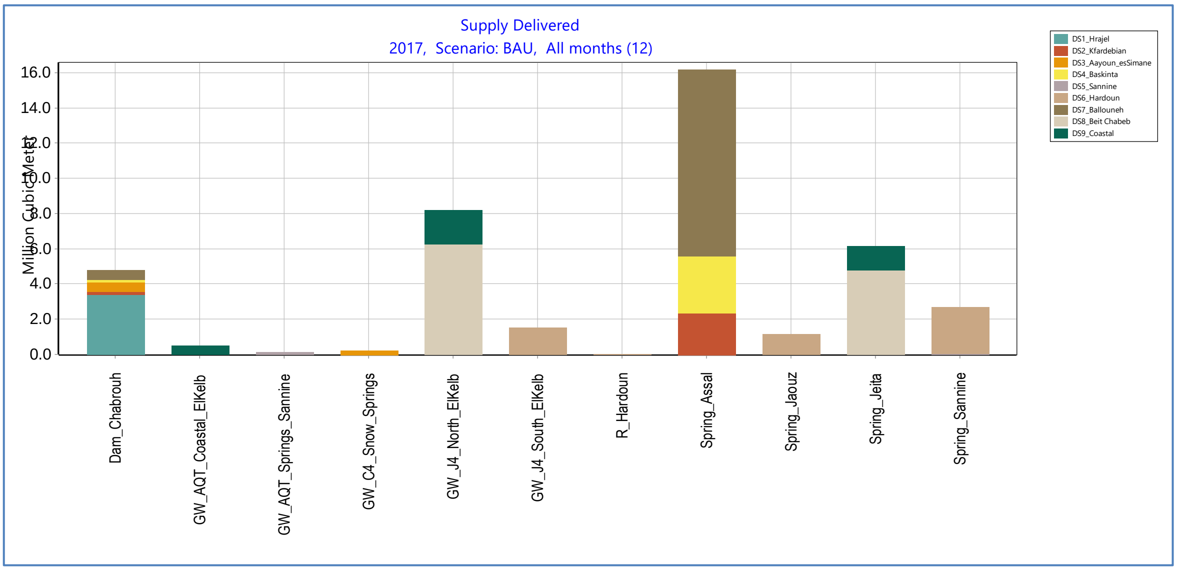


Table 6-3: Water supplied to each urban demand site (as well as Beirut) from each individual water supply source in 2017

SUPPLY SOURCES (year 2017, all units in Mm3/year)

Urban Demand sites	**Dam_Chabrouh**	**GW_AQT_Coastal_ElKelb**	**GW_AQT_Springs_Sannine**	**GW_C4_Snow_Springs**	**GW_J4_North_ElKelb**	**GW_J4_South_ElKelb**	**R_Hardoun**	**Spring_Assal**	**Spring_Jaouz**	**Spring_Jeita**	**Spring_Sannine**	***Sum***
DS1_Hrajel	3.44											*3.44*
DS2_Kfardebian	0.13							2.40				*2.52*
DS3_Aayoun_esSimane	0.55			0.24								*0.79*
DS4_Baskinta	0.17							3.21				*3.38*
DS5_Sannine			0.10								0.09	*0.19*
DS6_Hardoun						1.53	0.00004		1.17		2.59	*5.29*

DS7_Ballouneh	0.50							10.57				*11.07*
DS8_Beit Chabeb					6.30					4.79		*11.09*
DS9_Coastal		0.50			1.87					1.35		*3.72*
DS_Beirut										47.96		*47.96*
TOTAL	**4.79**	**0.50**	**0.10**	**0.24**	**8.17**	**1.53**	**0.00004**	**16.18**	**1.17**	**54.10**	**2.68**	***89.45***

The total supply (from all sources) to the agricultural demand sites was about 26.4 Mm3/year (for the year 2017). The highest contribution came the “Groundwater Aquifer Mid. Mountain” (about 7.85 Mm3 or 30% of the total provided supply), while the “El Kelb drainage” supplied about 10.3 Mm3. The volumes supplied to each urban demand site (as well as Beirut) from each individual water supply source are presented in the Figure 6-14 and Table 6-4 below.

Figure 6-14: Water Supply delivered in the year 2017 (MCM/year) in all the agricultural demand sites in the Nahr El-Kelb basin from each water supply source (Chabrough Dam, Groundwater Aquifers, Rivers, Springs)

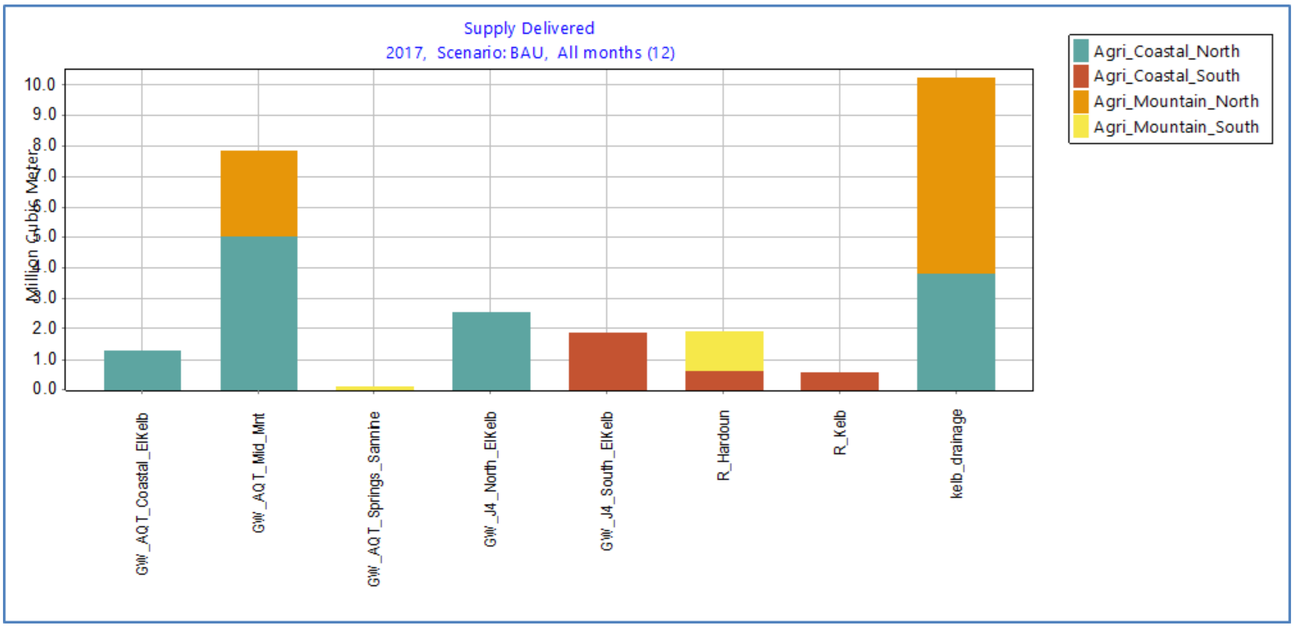


Table 6-4: Water supplied to each agricultural demand site (as well as Beirut) from each individual water supply source in 2017

	SUPPLY SOURCES (year 2017, all units in MCM/year)									
Agricultural Demand sites	**Dam_Chabrouh**	**GW_AQT_Coastal_ElKelb**	**GW_AQT_Mid_Mnt**	**GW_AQT_Springs_Sannine**	**GW_J4_North_ElKelb**	**GW_J4_South_ElKelb**	**R_Hardoun**	**R_Kelb**	**kelb_drainage**	***Sum***
Agri_Coastal_North		1.27	5.08		2.54				3.81	*12.71*
Agri_Coastal_South						1.89	0.63	0.57		*3.10*

Agri_Mountain_North			2.76						6.45	*9.21*
Agri_Mountain_South				0.13			1.27			*1.40*
TOTAL		**1.27**	**7.85**	**0.13**	**2.54**	**1.89**	**1.90**	**0.57**	**10.26**	***26.42***

6.1.1.3 Unmet in the Nahr El-Kelb (period 2000-2040)

The annual unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin for the period 2000-2040, as well as the monthly distribution are presented in Figure 6-15 and Figure 6-16 respectively. Relevant statistics are presented in Table 6-5.

In the year 2018 the total unmet demand (all sectors) reached 5.47 Mm3/year. The observed annual variability in the unmet demand, especially observed during the period 2020-2040 (high vs. lower numbers) also follow the climatic variability (wet and dry years) simulated in the model. The highest unmet demands occur in July-September. Overall, unmet demand is increasing after the year 2020 since demand projections have been incorporated. The irrigated land is assumed to stay the same, while population is assumed to increase at a rate of 2.6% per year. This population increase results in an increase in the projected demands for the years 2020-2040 and consequently in the unmet demand. The average unmet demand in the reference period 2000-2017 was 3.67 Mm3/year, and has increased to an average of 5.93 Mm3/year in the future 2020-2040 period. This represents a 62.4% increase, and it is thus important to implement demand management measures (either water saving or increase supply measures) to mitigate this problem.

Figure 6-15: Total annual unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin for the period 2000-2040

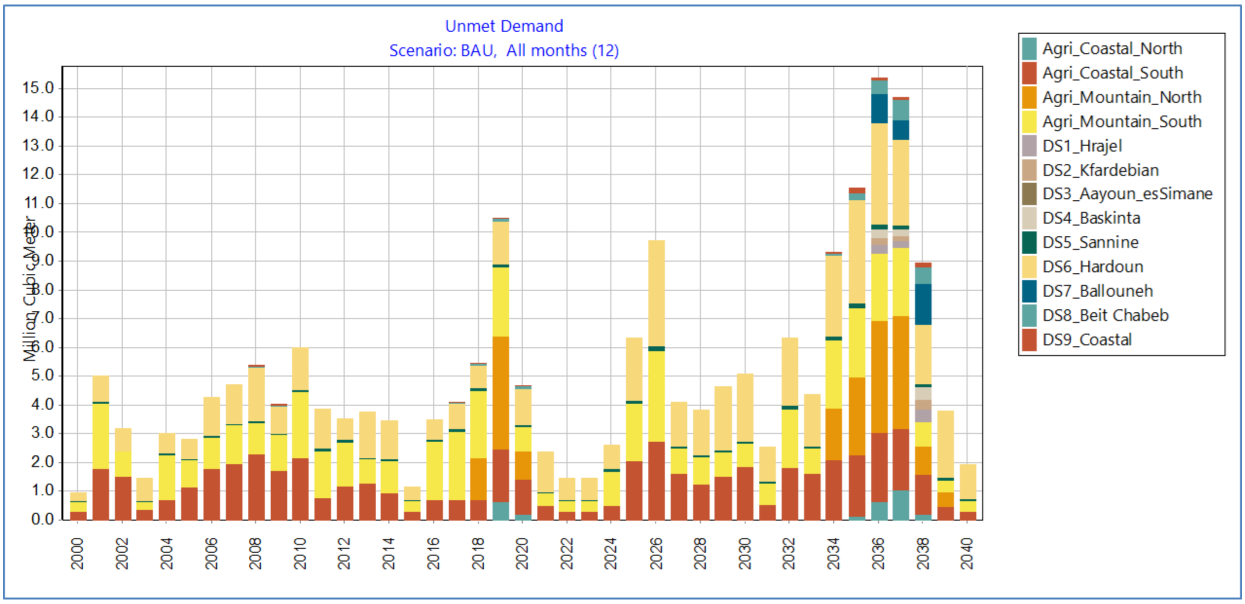


Figure 6-16: Monthly distribution of the unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin for the period 2000-2040

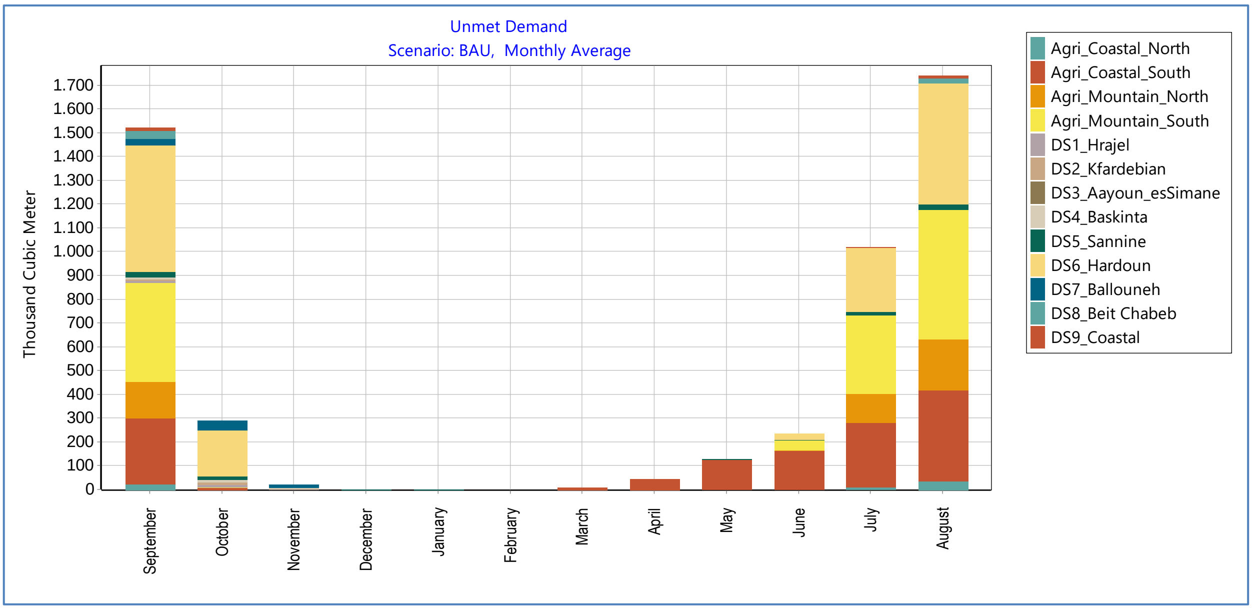
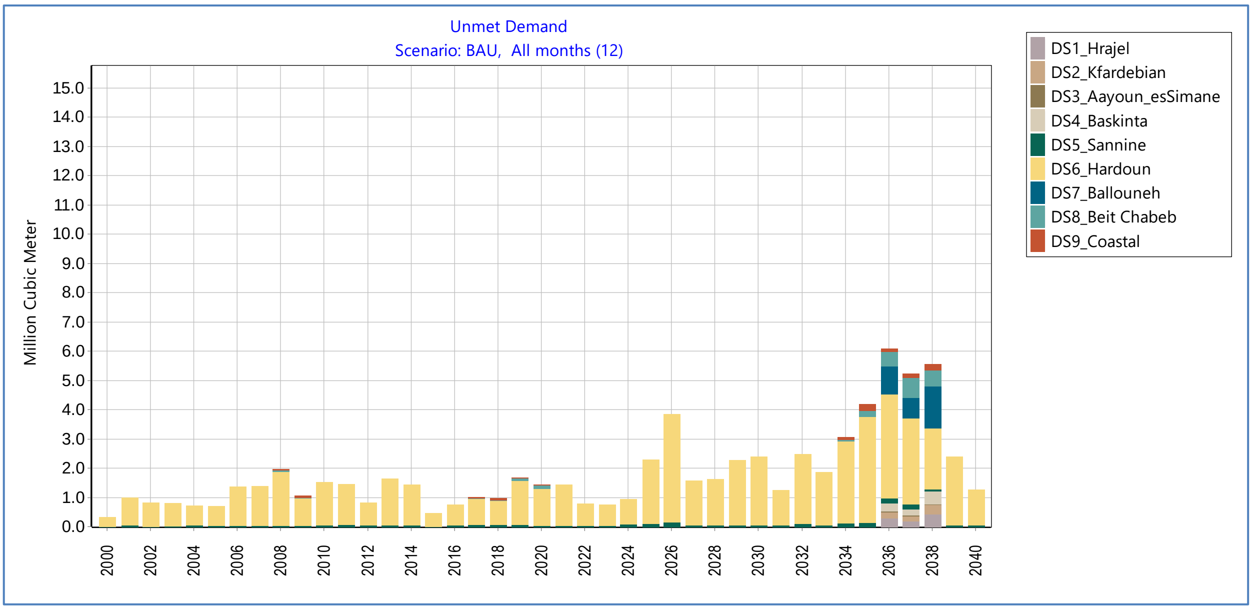


Table 6-5: Unmet demand values in the Nahr El-Kelb river basin for the period 2000-2040

Year	Total unmet demand (Mm3)	Urban unmet demand (Mm3)	Agricultural unmet demand (Mm3)
2000	0.97	0.32	0.64
2017	4.11	1.02	3.09
2018	5.47	0.96	4.50
2020	4.67	1.42	3.25
2030	1.96	1.28	0.68
2040	0.97	0.32	0.64
2000-2017 average (reference)	*3.67*	*1.07*	*2.60*
2020-2040 average (future)	*5.96*	*2.51*	*3.46*
% increase between the reference and the future average values	*62.4%*	*134.8%*	*33.0%*

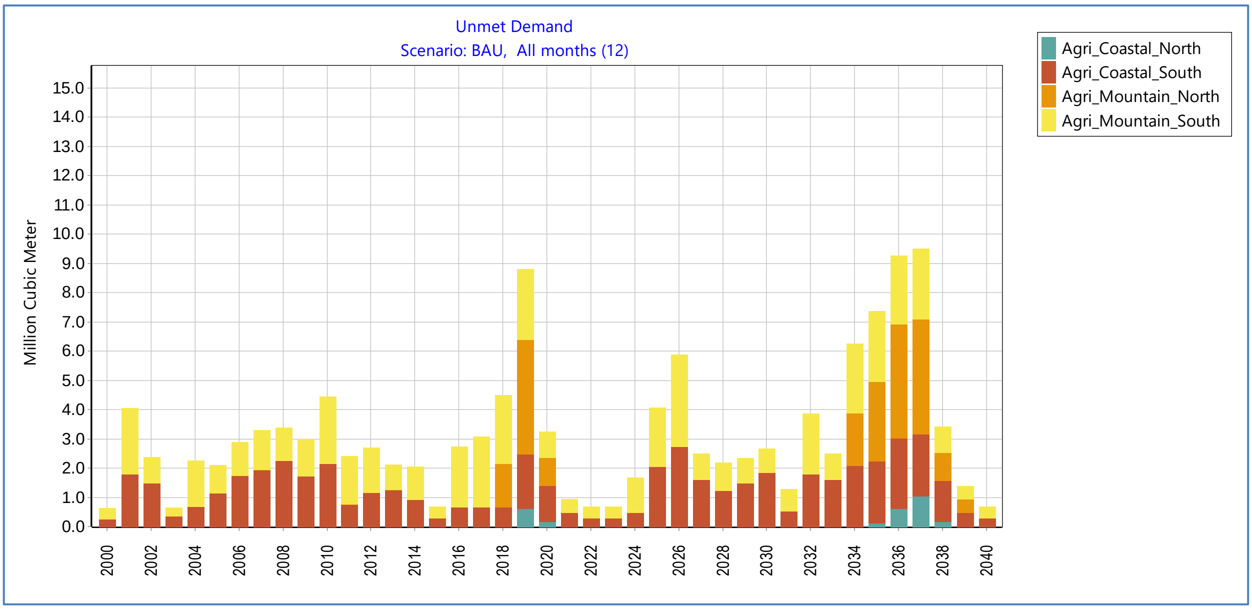
The unmet demand in the urban sector was about 1 Mm3 in 2018. It is projected to reach 2.4 Mm3 in the year 2030, and 6 Mm3 in 2036, which is more than 120% increase (Figure 6-17). The highest unmet demand is observed in Hardroun. Regarding the monthly distribution of the urban unmet demand, this is mostly occurring in July-October for the reference period 2000-2017, as well as for the future 2020-2040 period. Yet, there is an increase every month in the future. The month with the highest increase in unmet demand in the future (as compared to the reference period 2000-2017) is June, where 166% increase in unmet demand is expected in the future as compared to the current reference period.

Figure 6-17: Urban unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin for the period 2000-2040



The unmet demand in the agricultural sector was about 4.5 Mm3 in 2018. The maximum projected for the future is to reach 9.7 Mm3 in the year 2037 (Figure 6-18). Coastal South and Mountain South agricultural areas experienced the highest unmet demands in the reference period 2000-2017 (about 1 Mm3/year and 1.3 mio me/year respectively). Yet, the greatest % increase in the unmet demand is expected in the Mountain North agricultural area, which had almost no unmet demand currently. Regarding the monthly distribution of the agricultural unmet demand, this is mostly occurring in May-September for the reference period 2000-2017, as well as for the future 2020-2040 period. Yet, there is an increase every month in the future. The month with the highest increase in unmet demand in the future (as compared to the reference period) is April, where 70% increase in unmet demand is expected in the future as compared to the current reference period where the unmet demand was almost zero.

Figure 6-18: Agricultural unmet demand (as estimated by the WEAP model) in all the demand sites in the Nahr El-Kelb basin for the period 2000-2040



7 CONCLUSIONS

Current water supply cannot always meet the water demand in the Nahr El-Kelb river basin, resulting in unmet demands in both the urban and agricultural sector. This condition will be exacerbated in the future, as population growth projection and climate variability will increase the current water demands.

The demand site coverage (% of the water requirements met) for the urban sector are presented in Figure 7-1 and

Figure 7-2 for the reference period 2000-2017 and for the future 2020-2040 respectively. Similarly, for the agricultural sector the demand site coverage for the reference period 2000-2017 and for the future 2020-2040 are presented in Figure 7-3 and

Figure 7-4 respectively. The respective values of the % requirements met for each demand site and each month of the reference period 2000-2017 are shown in Table 7-1, while a comparison on how these percentages will change in the future 2020-2040 is given in Table 7-2.

The average demand coverage in the agricultural sector is always lower comparing to the urban sector (Table 7-3). The month of September exhibits the lowest coverage (i.e. 64% coverage for the agricultural sector, 81% for the urban, and 76% overall, across both sectors) (Table 7-3). Low coverage is also experienced in August in both sectors, while the highest coverage (98-100%) occurs from November to March. The same trends prevail also in the future 2020-2040 period, yet declines in the demand coverage are observed in both sectors, ranging from 0-4% declines in the agricultural sector, and from 0-2% in the urban sectors, with the highest % declines observed in September (Table 7-3).

Figure 7-1: Urban demand site coverage (% of requirement met in the urban demand every month) during the reference period 2000-2017

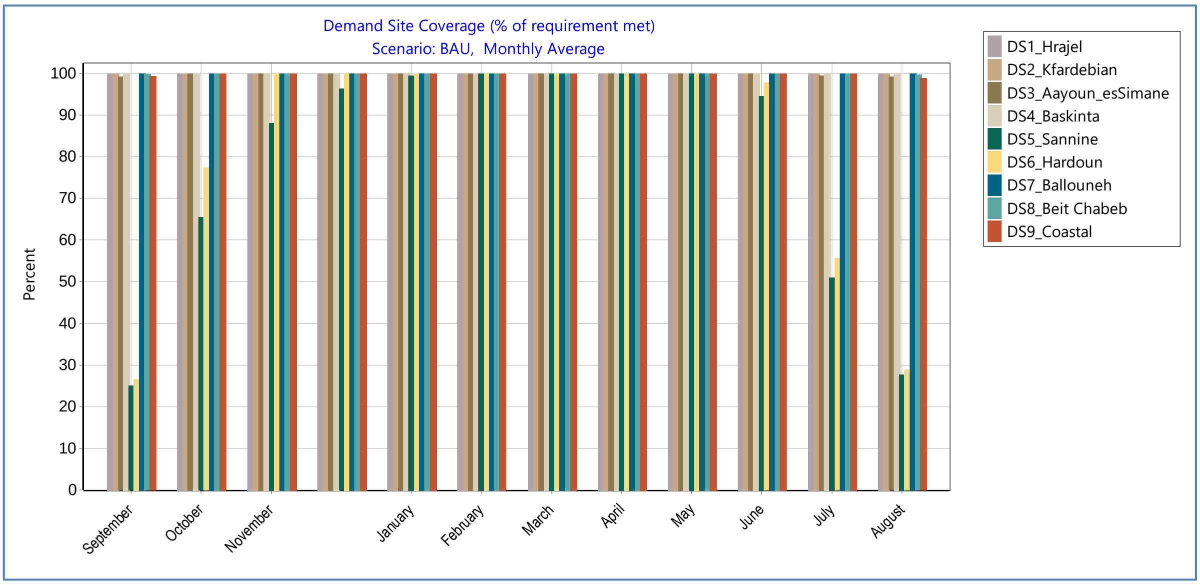


Figure 7-2: Urban demand site coverage (% of requirement met in the urban demand sites every month) during the future period 2020-2040

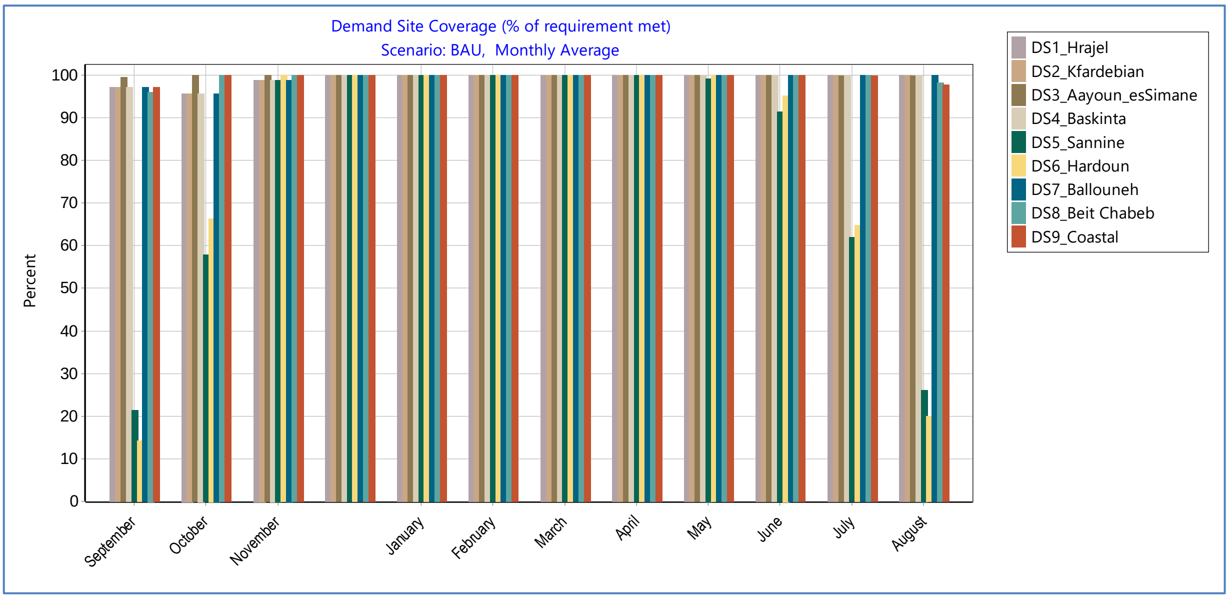


Figure 7-3: Agricultural demand site coverage (% of requirement met in the agricultural demand sites every month) during the reference period 2000-2017

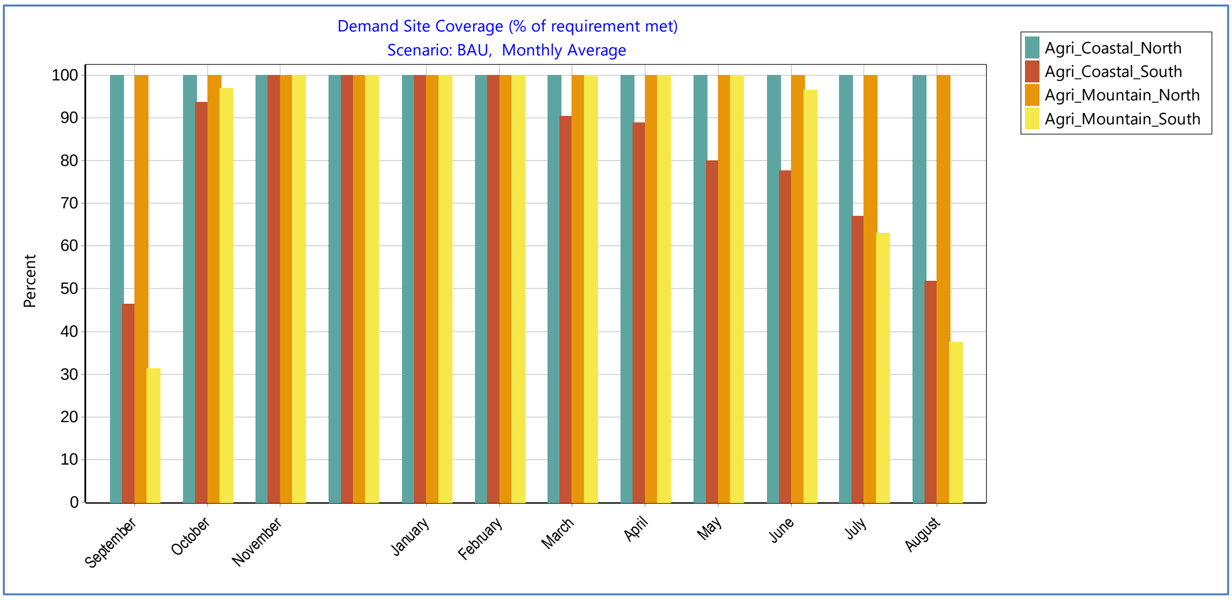


Figure 7-4: Agricultural demand site coverage (% of requirement met in the agricultural demand sites every month) during the future period 2020-2040

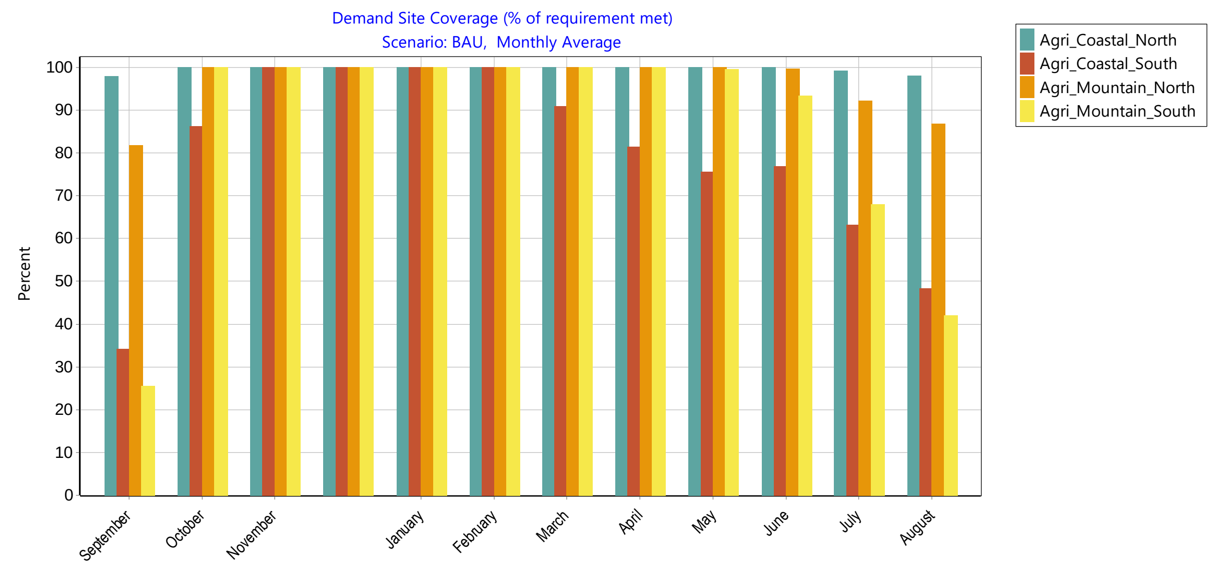


Table 7-1: Demand site coverage (% of requirement met in all demand sites every month) during the reference period 2000-2017

	% of the requirements met each month within the reference period 2000-2017											
Demand site	**SEPT**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**
Agri_Coastal_North	99	100	100	100	100	100	100	100	100	100	100	99
Agri_Coastal_South	40	90	100	100	100	100	91	85	78	77	65	50
Agri_Mountain_North	90	100	100	100	100	100	100	100	100	100	96	93
Agri_Mountain_South	28	99	100	100	100	100	100	100	100	95	66	40
DS1_Hrajel	98	98	99	100	100	100	100	100	100	100	100	100
DS2_Kfardebian	98	98	99	100	100	100	100	100	100	100	100	100
DS3_Aayoun_esSiman	99	100	100	100	100	100	100	100	100	100	100	99
DS4_Baskinta	98	98	99	100	100	100	100	100	100	100	100	100
DS5_Sannine	23	61	94	98	100	100	100	100	100	93	57	27
DS6_Hardoun	20	71	100	100	100	100	100	100	100	96	61	24
DS7_Ballouneh	98	98	99	100	100	100	100	100	100	100	100	100
DS8_Beit Chabeb	98	100	100	100	100	100	100	100	100	100	100	99
DS9_Coastal	98	100	100	100	100	100	100	100	100	100	100	98

Table 7-2: Changes in the demand site coverage (% of requirement met) in the future 2020-2040 period, as compared to the reference

Demand site	SEPT	OCT	NOV	MAY	JUN	JUL	AUG
Agri_Coastal_North	-1%	0	0	0	0	0	-1%
Agri_Coastal_South	-6%	-3%	0	-2%	0	-2%	-2%
Agri_Mountain_North	-8%	0	0	0	0	-4%	-6%

Demand site	SEPT	OCT	NOV	MAY	JUN	JUL	AUG
Agri_Mountain_South	-3%	1%	0	0	-1%	2%	2%
DS1_Hrajel	-1%	-2%	-1%	0	0	0	0
DS2_Kfardebian	-1%	-2%	-1%	0	0	0	0
DS3_Aayoun_esSiman	0	0	0	0	0	0	0
DS4_Baskinta	-1%	-2%	-1%	0	0	0	0
DS5_Sannine	-2%	-3%	5%	0	-1%	5%	-1%
DS6_Hardoun	-6%	-5%	0	0	-1%	4%	-4%
DS7_Ballouneh	-1%	-2%	-1%	0	0	0	0
DS8_Beit Chabeb	-2%	0	0	0	0	0	-1%
DS9_Coastal	-1%	0	0	0	0	0	0
AVERAGE CHANGE IN THE DEMAND COVERARE IN THE FUTURE	-3%	-1%	0	0	0	0	-1%
RANGE OF CHANGE across the sites	-8% to 0	-5% to 0	-8% to 0	-8% to 0	-8% to 0	-8% to 0	-8% to 0

Table 7-3: Demand site coverage (% of requirement met in all demand sites every month) during the reference period 2000-2017

	% of the requirements met each month within the reference period 2000-2017											
Demand sites/ Periods	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
PERIOD 2000-2017												
All agricultural demand sites	64	97	100	100	100	100	98	96	94	93	81	70
All urban demand sites	81	91	99	100	100	100	100	100	100	99	91	83
All demand sites	76	93	99	100	100	100	99	99	98	97	88	79
PERIOD 2020-2040												
All agricultural demand sites	60	97	100	100	100	100	98	95	94	92	81	69
All urban demand sites	80	90	99	100	100	100	100	100	100	99	92	82
All demand sites	74	92	100	100	100	100	99	99	98	97	88	78
% CHANGE IN 2020-2040 COMPARING TO 2000-2017												
All agricultural demand sites	-4	-1	0	0	0	0	0	-1	-1	0	-1	-2
All urban demand sites	-2	-2	0	0	0	0	0	0	0	0	1	-1
All demand sites	-3	-1	0	0	0	0	0	0	0	0	0	-1

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%. As domestic use is priority 1, the water allocation to this use has a higher reliability than agriculture. The reliability in water supply highly varies and in some cases as low as 60% (e.g. for the Agriculture_Coastal South area and the DS5_Sannine urban site) to as high as 99% (e.g. in the DS1_Hrajel and DS2_Kfardebian urban sites) as presented in Table 7-4 and Figure 7-5. Table 7-5summarizes the number of sites (nodes) per water use that fall under different reliability categories. The reliability categories have been defined as very high (>97%), high (90-97%), medium (75-90%) and low (<75%). In total, 75% of the agricultural users have low and medium reliability (25% and 50% respectively), while the remaining 25% have very high (>97%) water supply reliability. With regards to the urban user, 45% experience very high water supply reliability, 33% high, and the remaining 22% experience a low reliability of water supply.

Figure 7-5: Reliability (%) of each demand site of the different user categories in the Nahr El-Kelb basin

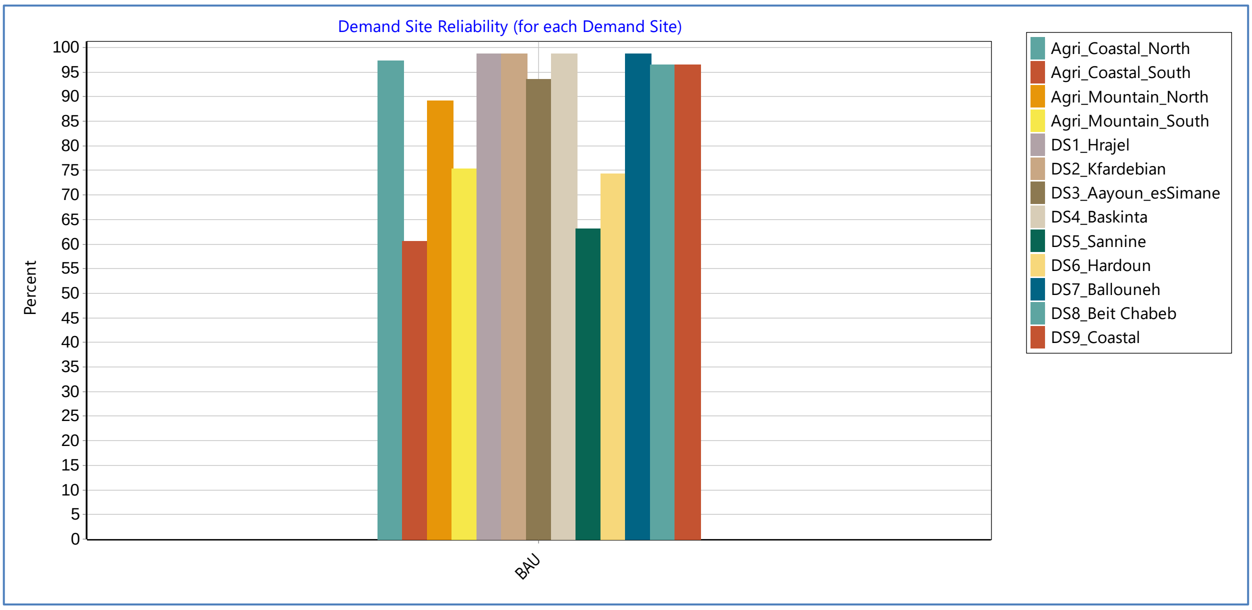


Table 7-4: Reliability (%) of each demand site of the different user categories in the Nahr El-Kelb basin (green: agricultural users; blue: urban users)

Demand site	% Reliability	Reliability Class*
Agri_Coastal_North	97.4 %	Very High
Agri_Coastal_South	60.6 %	Low
Agri_Mountain_North	89.2 %	Medium
Agri_Mountain_South	75.4 %	Medium
DS1_Hrajel	98.8 %	Very High
DS2_Kfardebian	98.8 %	Very High
DS3_Aayoun_esSiman	93.5 %	High
DS4_Baskinta	98.8 %	Very High

Demand site	% Reliability	Reliability Class*
DS5_Sannine	63.2 %	Low
DS6_Hardoun	74.4 %	Low
DS7_Ballouneh	98.8 %	Very High
DS8_Beit Chabeb	96.5 %	High
DS9_Coastal	96.5 %	High

* Very High (>97%), High (90-97%), Medium (75-90%), Low (<75%)

Table 7-5: Percent (%) of user for each use category (domestic, agriculture) that fall under the 4 reliability classes (low, medium, high, very high) for the period 2000-2040

Reliability	Domestic users	Irrigation users
Very High (>97%)	44.5 %	25 %
High (90-97%)	33.3 %	-
Medium (75-90%)	-	50 %
Low (<75%)	22.2 %	25 %

Finally, with regards to the model development some constraints and limitations have been encountered. Among the major limitations encountered during the model setup are those related to the nature of the karst groundwater system which is not supported by WEAP. Thus, proxies were used. The limited number of ground observations for precipitation data in the mountain regions remains a challenge in this snow dominated basin. The lack of water use data for urban and agriculture at different spatial and temporal scales required a number of aggregation and assumptions. Only a limited data was available for validating spring discharge and streamflow. Groundwater observations remain missing.

8 REFERENCES

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