AMERICAN UNIVERSITY OF BEIRUT

LEBANON'S FOOD QUESTION: CAN WE IMPROVE FOOD SECURITY IN LIGHT OF AVAILABLE WATER RESOURCES –THE CASE OF AREC

by
AYMAN MOENIS MAKARIM

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ABSTRACT
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Title: Lebanon's Food Question: Can we Improve Food Security in Light of Available Water Resources – the Case of AREC

Climate change and population growth are increasing the stress on the finite freshwater resources worldwide with direct implications on food security and nutrition. This water stress must be averted immediately through improved water and resource management plans and models. The Advancing Research Enabling Communities Center (AREC) at AUB is an example of a mid-size farm in a typical dry farmland area in the Bekaa Valley of Lebanon. In order to better manage the water resources and improve food security at AREC, the water balance for AREC was calculated as the difference between water supply and water demand. This is to create realistic scenarios which show us how we can improve food security through increased food production and water efficiency with climate change in mind. Based on Lebanon's Second National Communication report to the UNCC two climate change scenarios were taken: scenario 1 which assumes a 10% decrease in rainfall and a 13% increase in evapotranspiration (ETo) over a simulation period, and scenario 2 which assumes a 20% decrease in rainfall and a 26% increase in (ETo). By calculating the water requirements and potential yield for each scenario, the results showed us that proceeding with the current practices would certainly lead to a water deficit and reduction of food outputs. However, the recommended improved scenario provided an increase in food production from 432 to 742 tons/year without adding any water requirements. In light of new data collection technologies, many similar sized farms in Bekaa could increase food productivity if the same methodology is applied as it is the predominant food production region in Lebanon.

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ABBREVIATIONS

ASHA: American Schools and Hospitals Abroad
AREC: Advancing Research, Enabling Communities Center, AUB's research and education center
AUB: American University of Beirut
°C: Degrees Celsius
CC1: Climate change scenario 1
CC2: Climate change scenario 2
COVID-19: Coronavirus disease of 2019
du: dunum (1,000 square meters)
ESCWA*:* Economic and Social Commission for Western Asia
ETo: Crop evapotranspiration
FAFS: Faculty of Agricultural and Food Sciences
FAO: Food and Agriculture Organization of the United Nations
ha: hectare (10,000 square meters)
IPCC: Intergovernmental Panel on Climate Change
m: meter
mm: millimeters
m^2: square meter
m^3: cubic meter
MENA: Middle East and North Africa
NAS: National Agricultural Strategy
NGO: Non-governmental organization
RICCAR: Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
UN: United Nations
UNFCC: United Nations Climate Change
UNHCR: United Nations Commissioner for Refugees
WFP: World Food Program of the United Nation
%: percent

CHAPTER 1

INTRODUCTION

Climate change and population growth are increasing the stress on the finite freshwater resources worldwide with direct implications on food security and nutrition. In addition to the growing agricultural demand the rise of competition for fresh-water resources are also increasing for industrial, municipal, and domestic uses. However, agriculture is still by far the highest in fresh-water consumption with 70% of withdrawals accounting towards agriculture (Mohtar et al., 2017). Climate change is currently playing a major role by changing the hydrological cycle towards a more extreme and unpredictable pattern which exacerbates the effects on irrigated and rainfed agriculture, livestock production, and aquaculture.

Water resource management is a growing concern, as it is crucial to improving quality of life and sustainable development. The urgency to improve our water management has never been higher globally due to the forementioned elements, in addition to economic barriers as well as the recent COVID-19 global pandemic. Appropriate water management can benefit both water access in agricultural production and ensuring economic, social, and environmental sustainability. In addition, nutrition is an important variable in both the definition of food security as well as how we look at water use in agriculture. As food production relies on water availability, economic viability, and land availability, the constituents of our local diet can dictate the sustainability and availability for both water and agricultural resources. Therefore, water management must also successfully include the type of crops and nutritional value to achieve food security whilst ensuring water efficiency and sustainability.

Lebanon is a small and densely populated country located in the heart of a region notorious for political instability and conflict. The years of 2019 - 2020 have placed Lebanon in some of the worst political health and food security crises the country has seen in the 21st century. Lebanon was home to a mass protest which arose on October 17th across the country as a plea to the rising financial crisis. This civil uprising was directed at the failure to implement economic reforms on the financial and banking sectors which had direct detrimental effects on basic commodities (food, fuel, and water). Besides the economic crises, Lebanon like most countries was required to hastily take safety measures to readjust the health system to contain the COVID-19 outbreak. The regulations set to hinder the pandemic through lockdowns and safety measures have pushed already vulnerable families further into poverty. In addition to the regulations set, the MENA in general has been suffering the highest unemployment rates worldwide by region for the past 25 years (Worldbank,2020), Lebanon is not an exception. Since the mass protests in Lebanon, the national currency has been devalued by over 90 percent and by the start of 2021 there was an increase of over 300 percent in food prices (CAS,2020). Additionally, the economic crises is due to Lebanon relying on food imports which constitute 85 percent of Lebanese food consumption (FAO, 2020). This was already a critical issue as it directly affects all four pillars of food security (access, availability, utilization, and stability); furthermore, the catastrophic blast which hit the major trade transit ‘Beirut port’ destroyed the grain silos as well as thousands of surrounding houses leading to further economic and food security strain. Lebanon is also harboring the highest per capita refugee presence worldwide with one quarter of the total population, which has placed further stress on the current resources (UNHCR,2015).

Established in 1953 as an extension of the AUB campus, AREC (Advancing Research Enabling Communities Center) serves the Faculty of Agricultural and Food Sciences (FAFS) faculty members, students, and other AUB faculties interested in agriculture, health, environment, and sustainable rural livelihoods. AREC is AUB's research farm and a 100-hectare interdisciplinary research and outreach center on an elevation about 1000m. It is considered one of the regions' premier academic centers and caters to the needs of students, faculty, researchers, and local communities. It is located in a semi-arid area in the Bekaa valley and addresses some of the most pressing issues of our time, including the environment, drought, water management, and more.

Scientists and policy makers need to invest in strategies for increasing local production of high nutrition-low resource intensive crops in drylands including lentils, beans, and chickpeas, which currently have low levels of self-sufficiency in many drylands. It is important to coordinate such strategy with water, energy, and economic planning. As water resources are limited and often misused, it is crucial to identify and develop strategies to both increase efficiency and available water as well as food production. With the current available data on AREC this study will help develop scenarios for several climate conditions; several crop combinations, to optimize water use and food production at AREC. AREC represents a typical dryland mid-size farm that faces similar challenges especially in terms of water resources to many other places across Lebanon. With more data collection in Lebanon, it will become possible to scale up these scenarios and optimize local production on a larger scale such as central Bekaa Valley.

Particularly in Lebanon, given the uncertainty in currency exchange rates and the devaluation of the Lebanese Pound, diversification of agricultural investment is important to include specialized high value crops for export as well as high nutrition crops for local consumption. Following this information, this study has two objectives in mind to address some of these issues.

1.1. Objectives:

1. Identify and quantify water resources and water balance, as well as potential methods to increase usable water and water efficiency to achieve better food security - the case of AREC – AUB Farm (mid-size farm).

2. Optimize water use and food production at AREC under different scenarios of climate conditions and cropping patterns. This will allow AREC to choose the ideal crop planning and methods needed to grow and find an ideal food output in accordance with the water resources, maximize food output by optimizing water resources.

CHAPTER 2

LITERATURE REVIEW

This literature review aims to present the current food security situation in Lebanon, as well as the various elements affecting it. By looking at the food and water situation in Lebanon we can assess what elements need to be improved upon or changed if necessary. This literature review also highlights the missing data and research when it comes to improving food security in Lebanon through water and resource management.

Food security has been a growing subject of discussion in the MENA region over the past 40 years. The most common food security issue for countries in the MENA region has been derived from water security and scarcity. Lebanon has a unique geographical, economic, and political structure in the region, thus a case-specific study of its geographical water resources as well as unique economic and nutritional background must be examined prior to identification of improvements upon the food security program in Lebanon. This literature review attempts to identify the various elements directly influencing food security, most notably water resources, agriculture in Lebanon, the economic situation, and global pandemic. In addition to several other intervening factors which are identified and discussed as they are also directly affecting the pillars of food security; local diets, food systems, as well as the recent economic shock and health pandemic. Studies, analyses, and theories for each of the elements are available; however, Lebanon is still missing specific data on water resource management as well as detailed maps of our water resources.

2.1. Nutrition and Diet

Nutrition is an important variable in both the definition of food security as well as how we look at water use in agriculture. As food production relies on water availability, economic viability, and land availability, the constituents of our local diet can dictate the sustainability and availability for both water and agricultural resources.

Lebanon's food diet (Figure 1) is considered a Mediterranean diet, which has a relatively high component of fruits and vegetables, as well as some carbohydrates, dairy, and meat. However, a transition in the nutritional intake towards a western diet which predominantly has higher red meat, eggs, and fast-food sandwiches is becoming a trend. Rise in obesity and micronutrient deficiency are still at a rise due to higher caloric diets.

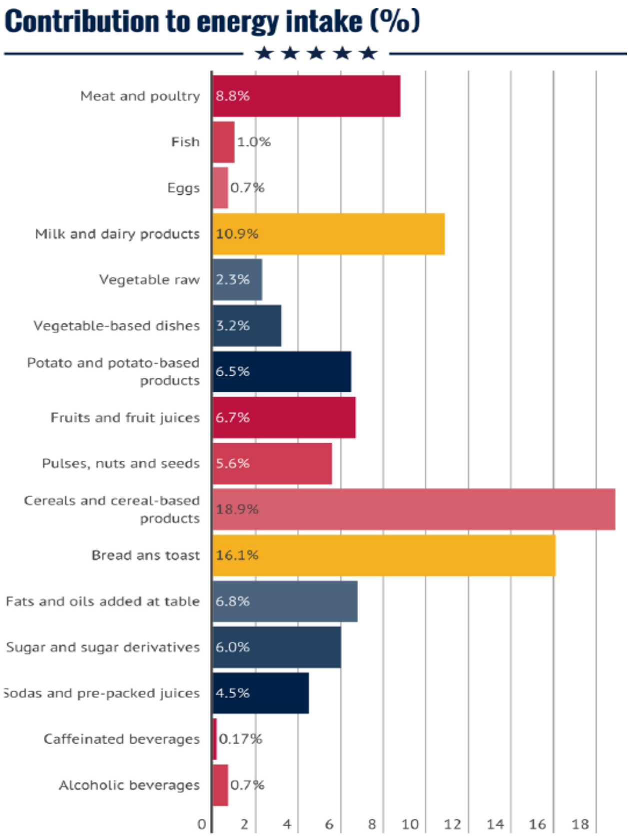


Figure 1 The Lebanese Diet by Food Group (Source: Nasreddine et al., Food consumption patterns in an adult urban population, adapted by ESCWA 2016).

2.2. Food Security in Lebanon from an Agricultural Perspective

Agriculture in Lebanon has been greatly affected by regional politics and economic changes. Lebanon has seen several changes in the Agricultural sector since 1943 and as recently as 2020. The first major change was between 1943 and 1953, which represented the move away from traditional agriculture to fruit production aimed at export. This was directed on improving regional trade and socioeconomic development, but not satisfying local food production sustainability. The second change was seen after the war in 1990 when Lebanon did not have state set policies or visions for the agricultural sector. This meant that the local production had to rely on international intervention and non-state actors and donors. Since then, Lebanon did not see significant growth in the agricultural sector until 2011 when the Syrian crises began. The war on Syria was a direct cause to the growth of the agricultural sector as unofficial Syrian workers joined the sector. Though unofficial, these refugee workers provided a significant growth in Lebanese agriculture "increasing the real value of agricultural output by 10% compared to the precise level" (Hamadé, Kanj 2020).

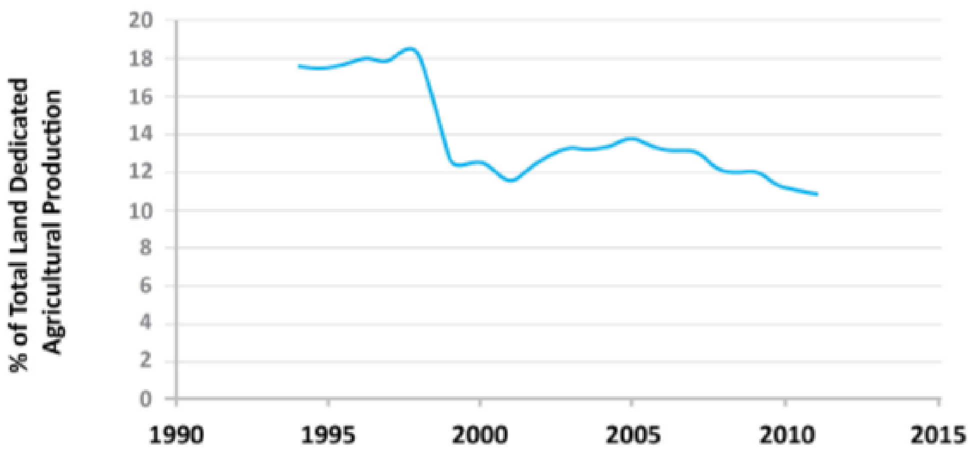


Figure 2 Percent of land dedicated to agriculture (Source: The World Bank)

Prior to this growth the percent in land dedicated to agriculture was following a declining trend. Though the sudden increase in refugees was considered a burden on the food stress levels, the increase in agricultural production showed resilience and cushioned many Lebanese and Syrians through income-generating opportunities.

2.3. Recent Changes and the Twin Crises

The most notable change in the Lebanese agriculture sector occurred between October 2019 and December of 2020 with the collapse of the Lebanese pound. The alarming increase in food prices and decrease in sales of high-end food products (by 56 percent) has direct impact on local agriculture. The food security issue is also directly affected as the accessibility and availability are under stress (Hamadé, Kanj 2020).

As stated by the World Bank, *"The country is witnessing a massive increase in poverty (28 to 55 percent) and extreme poverty (8 to 23 percent) 2019–2020, with the middle class shrinking from 57 percent to 40 percent (2019–2020)."* (RDNA 2020).

The change in pricing has affected the market directly as most of Lebanon's consumption is acquired through imports. The transition from imports to local production is now threatening the local capacity in food production. The predominant local production model (post the civil war) has relied on the import of irrigation systems, fertilizers, pesticides, and seeds. As this system of relying on the central bank to fix the Lebanese pound to the U.S. dollar has collapsed, this places the local agriculture production at financial risk. For example, the cost of producing vegetables has increased by an estimated 40 percent since 2019. The cost of new irrigation systems and investment have also increased by 80 percent forcing farmers to adopt extreme cost reduction strategies (Hamadé, Kanj 2020). This involves the use of local seeds and seeds smuggled from Syria, in addition to devolving into less efficient but cheaper irrigation methods (gravity irrigation instead of drip) as well as reduction in fertilizer use, which increases the water and water stress issues as they are already not regulated by any governing body. This increase in cost and recent restriction is amplified as 2021 has reached devaluation in the Lebanese pound as high as 25,000 pounds to $1.00 increasing operating costs to an estimate of 175 percent and 350 percent for new investments (CAS,2020). This is currenly far greater and needs to be calculated on a regular basis to keep up with the currency devaluation.

Two of the current problems in agriculture are directed towards food security as suggested by Lebanon National Agriculture Strategy for 2020 - 2025. Inadequate food consumption and unsustainable practices in agriculture are highlighted in both and this topic is discussed from an agricultural standpoint by the NAS pillars: 1) Restoring the livelihoods and productive capacities of farmers and producers; 2) Increasing agricultural production and productivity; 3) Enhancing efficiency and competitiveness of agri-food value chains; 4) Improving climate change adaptation/sustainable management of agri-food systems/natural resources; and 5) Strengthening the enabling institutional environment (Figure 3).

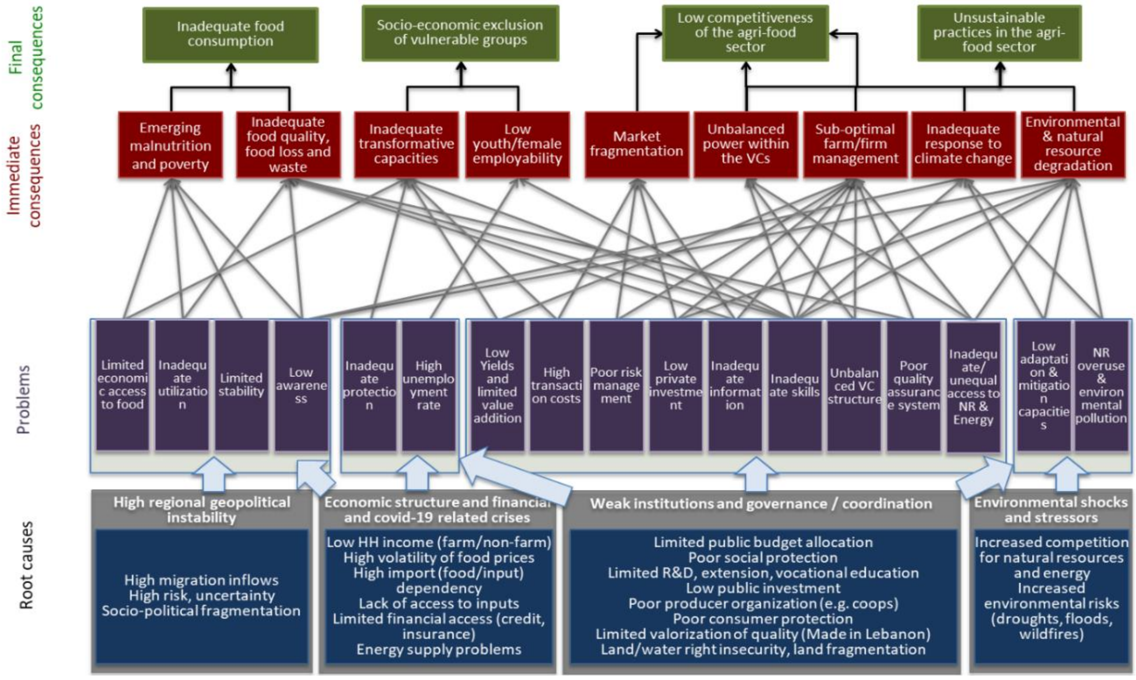


Figure 3 National Agriculture Strategy (NAS) ‘simplified problem tree of Lebanon agri-food sector

2.4. Water Resources in Lebanon

Lebanon’s water resources and geographical uniqueness in the MENA tend to mislead the public view into thinking Lebanon is not facing water scarcity and supply/demand issues. The unique Lebanese geography allows for diverse water availability from both surface and subsurface resources. Subsurface resources include various types of aquifers, water conduits, and rock formations. Surface resources include; lakes, rivers, springs, and snow. However, availability and accessibility to water are growing concerns as population growth, climate change, and economic barriers lead to increase in water stress levels.

2.4.1. Water Resource Quantification

Estimates show a range between 700mm - 1500mm in rainfall rate and 2000 - 2500 km^2 of snow cover (annually). In addition to 14 perennial watercourses, more than

1500 - 2000 springs with permanent flow, and ground water aquifers spread across Lebanon (Shaban,2020). Studies have been conducted on renewable water measurements in Lebanon over the years (UNDP and FAO in (1983), National Congress on Water Strategic Studies Center (1995), Climate change and water resources in Lebanon and the Middle East (2002), and Towards a water policy in Lebanon by Fawaz M. (2007)). Most recently Center for Economic Studies at Fransabank (2018) stated that the renewable water resources in Lebanon is averaging about 4.1 billion m^3/year.

2.4.2. Water Demand

Water demand is at an all-time high with increasing population and economic stress to increase food production. The World Bank estimates illustrated 30.5% (Domestic), 10.5% (Industrial) and 59% (Irrigation) in 2003. However, recent estimates showed fluctuation between 62-80% (Agriculture) depending on rainfall and local production demand (Figure 4). There has been a constant decrease in both surface and ground water (up to 60% by 2011) over the last 4 decades as the nexus between water, agriculture, energy, and most recently economical and food security constrains.

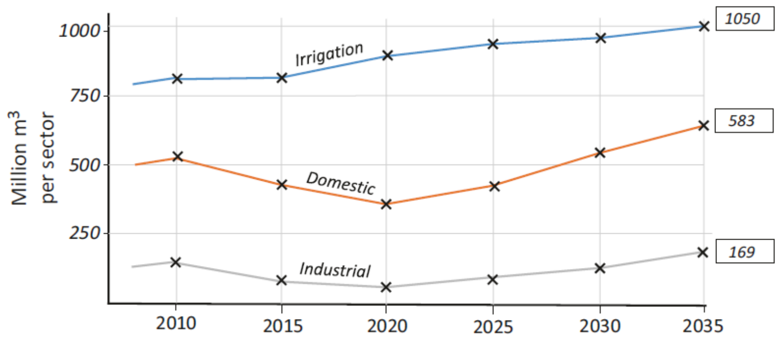


Figure 4 State of Environment Report (2010)

2.4.3. Water Supply

Water for the general public is usually provided by the public water sector, this is one of the most obvious signs that water supply falls short to demand in Lebanon as a large percentage of water is provided by the private sector through various means. First, the pipe-water provided by the government is usually not enough for most households, therefore private water supply providers fill in the gaps through unregulated groundwater wells and boreholes. Second, bottled water, water trading, and harvested water are also common in both rural and urban areas.

2.4.4. Water Balance

Following the standard water-poverty index which provides a threshold determined at 1000 m^3/capita/year, several estimates have been done for Lebanon with some being highly optimistic at ~3750m^3/capita/year in 1996 to estimates as low as 950 m3/capita/year in 1994. Studies estimated at 921 m^3/capita/year (NCSR 2016) follow the trend in the decrease of water availability.

> *"There is increasing trend in water demand in Lebanon, and it is also changing by different sectors. Thus, it is estimated that domestic demand is 467 mm3/year. The demand in (2030) will require 1258mm3/year for domestic, and it will increase from 163 to 440 mm3/year for industrial, and from 900 to 1220 mm3/year for agriculture, which is equivalent to 44%, 16% and 40%" (New Economic Policies: Instruments for Water Management in Lebanon 2016).*

2.5. Climate Change in Lebanon

Climate change studies and analysis of historical climatic records of Lebanon from the early 20th century projected a warming in climate. The Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources in the Arab

Region (RICCAR) led by the United Nation Economic and Social Commission for Western Asia (ESCWA) indicated the following:

- An increase in temperature of 1.2°C by mid-century and over 2°C by 2100. Water will face a reduction of 6 - 8% of the total volume of water resources with the increase in 1°C and 12 - 16% with a 2°C rise in temperature.
- A decrease in precipitation of 4 - 11% with drier conditions by the end of the century (up to 5 mm decrease in average monthly precipitation).
- Increased trend of warming, reaching up to 15 additional days with maximum daily temperature higher than 35°C and an increase in number of consecutive dry days when precipitation is less than 1.0mm by the end of the century.
- Increased incidences of drought conditions due to longer and geographical expansion of drought periods resulting in a hotter and drier climate.
- Continued sea level rise, rising by a total of 30-60 cm between 2020 and 2050.
- Decrease in forest productivity and shifts in species composition.

This projected change based on the moderate Representative Concentration Pathway (RP4.5) developed by the IPCC will have adverse effects mainly on agriculture and water resources in Lebanon. Drier conditions are likely to further accelerate the depletion of groundwater supplies especially in the Bekaa valley which is characterized by an arid/semi-arid climate (RICCAR, 2017; MoFA, 2018).

2.6. Infrastructure and Technical Solution

Several infrastructure and technical solutions have been proposed to address Lebanon’s water resource problems including artificial groundwater recharge, capturing groundwater discharge into the sea; dam reservoirs; mitigation of water pollution;

mountain reservoirs, rooftop rainwater harvesting, snowpack reservation and water-convey canals. Some of these solutions were already implemented or partially started however, it is still not achieving the goals to close the water balance gap.

2.7. Political and Policy Recommendations on Water

‘Lebanon’s National Water Sector Strategy (NWSS) drafted between 2008 and 2010, and approved by the government in 2012, represented a necessary and important step in the development of the Lebanese water sector. However, it remained a non-binding executive order that did not impose any legal requirement on public or private entities to take actions to implement it’ (Oxfam, 2017).

CHAPTER 3

METHODOLOGY

3.1. Study Area

Established in 1953 as an extension of the AUB campus, AREC serves FAFS faculty members, students, and other AUB faculties interested in agriculture, health, environment, and sustainable rural livelihoods. The Advancing Research Enabling Communities Center (AREC) is AUB's research farm and a 100-hectare interdisciplinary research and outreach center on an elevation about 1000m. It is considered one of the regions' premier academic centers and caters to the needs of students, faculty, researchers, and local communities. It is located in a semi-arid area in the Bekaa valley and addresses some of the most pressing issues of our time, including the environment, drought, water management, and more. AREC is considered as a mid-size farm in the semi-arid/dryland regions and was considered as a case study for this project.

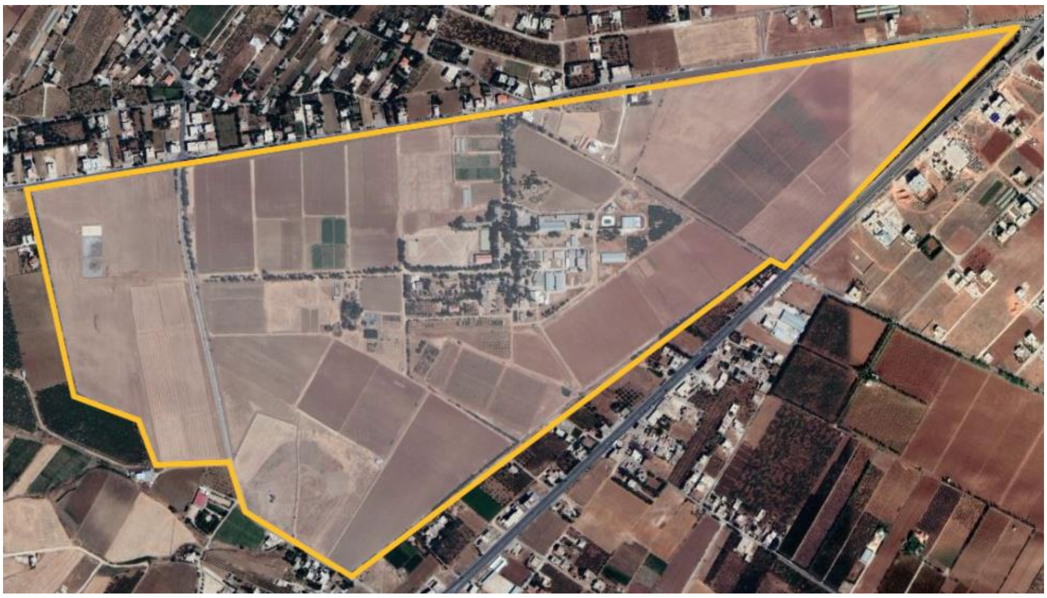


Figure 5 Map of AREC and its borders (retrieved from google earth)

3.1.1. Weather in AREC

AREC's weather station has collected data since 1957 for different climactic factors including temperature/soil temperature, rainfall, wind speed, and relative humidity.

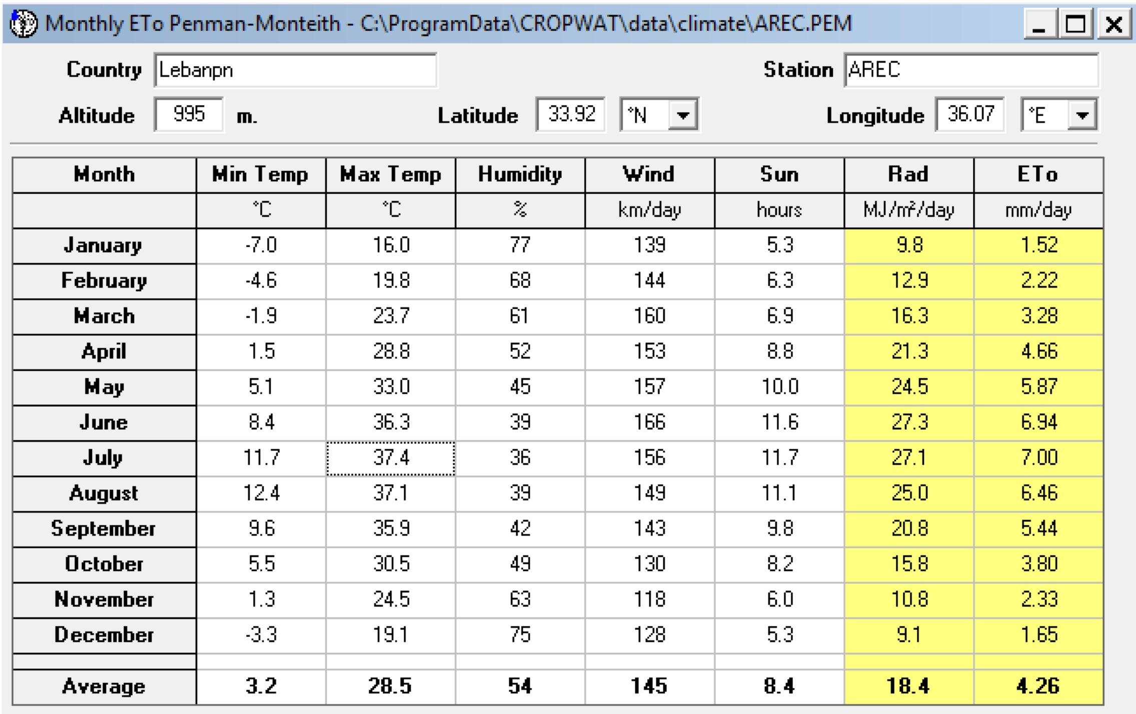
Table 1 Climatic data at AREC (average of 2011-2020):

Month	T_{max} (°C)	T_{min} (°C)	T_{mean} (°C)	RH (%)	U_2 (km/day)	Avg Sunshine Hrs (hr/day)	Rainfall mm/month	Eff Rainfall mm/month
January	16.0	-7.0	4.40	77.60	139.07	5.30	121.7	98
February	19.8	-4.6	6.60	68.80	144.10	6.32	70.6	62.6
March	23.7	-1.9	9.93	61.03	160.43	6.92	47.3	43.7
April	28.8	1.5	13.74	51.95	152.60	8.78	18.4	17.9
May	33.0	5.1	18.45	44.53	157.32	9.99	10.2	10
June	36.3	8.4	22.19	38.86	166.03	11.60	2.3	2.3
July	37.4	11.7	24.86	36.43	156.25	11.72	2.4	2.4
August	37.1	12.4	24.61	39.08	148.91	11.11	0.0	0
September	35.9	9.6	22.28	41.58	143.22	9.75	0.5	0.5
October	30.5	5.5	17.47	49.16	129.50	8.24	22.7	21.9
November	24.5	1.3	11.50	62.66	118.11	6.05	40.4	37.8
December	19.1	-3.3	6.68	75.32	127.78	5.27	90.8	77.6
							427.4	**374.7**

The table above describes detailed climactic data averages (2011 - 2020) at AREC. The hottest temperatures occasionally increase to 46°C in July and August, however the average for these months is 36 - 37°C for maximum temperature. As for the coldest temperature are often recorded at -10°C in January and the first half of February and one time it reached -16.2°C on January 10, 2014. The average rainfall is medium to low in the case of AREC as it is in the region in general, however, there is a seasonal window where rainfall is sufficient for certain crops.

Low evaporative demand with maximum relative humidity (>50%) and temperature (<10 °C) from November to March, and moderately high evaporative demand from April to September, with minimum relative humidity (<60%) and temperature (>15˚C) in average.

The ETo was calculated based on FAO Penman Monteith Equation (Allen et al., 1998, 2005) and using CROPWAT Software, the ETo is the highest in July with 7 mm/day as average (Figure 6).


Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\AREC.PEM

Country Lebanpn Station AREC

Altitude 995 m. Latitude 33.92 °N Longitude 36.07 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	-7.0	16.0	77	139	5.3	9.8	1.52
February	-4.6	19.8	68	144	6.3	12.9	2.22
March	-1.9	23.7	61	160	6.9	16.3	3.28
April	1.5	28.8	52	153	8.8	21.3	4.66
May	5.1	33.0	45	157	10.0	24.5	5.87
June	8.4	36.3	39	166	11.6	27.3	6.94
July	11.7	37.4	36	156	11.7	27.1	7.00
August	12.4	37.1	39	149	11.1	25.0	6.46
September	9.6	35.9	42	143	9.8	20.8	5.44
October	5.5	30.5	49	130	8.2	15.8	3.80
November	1.3	24.5	63	118	6.0	10.8	2.33
December	-3.3	19.1	75	128	5.3	9.1	1.65
Average	3.2	28.5	54	145	8.4	18.4	4.26

Figure 6 CropWat Climate Data

3.1.2. Cropping patterns

AREC has about 70 ha of agriculture land where, this area is generally used and followed by crop rotation. In recent years water availability has become a growing concern which led to the reduction of the irrigated/farmed areas which are described in the following table. In addition, there are several crops that have been added over the years but at a very small scale such as saffron and pomegranate. As these crops do not represent a large area, they have been grouped under crops of similar water demands in order to make sure they are still a part of the water balance.

After a general introduction on AREC and how it can represent larger areas, data on cropping patterns is the next step to understand what can be successfully implemented in AREC.

Table 2Crops and Current Areas

	Crop	**Current Areas (2020) in ha**	**Status**	**Irrigation system**
1	Wheat	2.7	Rainfed	
2	Barley/Vetch	3.8	Rainfed	
3	Corn	0.8	Irrigated	Sprinkler, drip
4	Potato	1.6	Irrigated	Sprinkler, drip
5	Tomato	1	Irrigated	Drip
6	Apple	1.2	Irrigated	Drip
7	Peach	0.3	Irrigated	Drip
8	Apricot	0.6	Irrigated	Drip
9	Grapes	2.1	Irrigated	Drip
10	Olives	0.4	Rainfed	
11	Lentil (Spring)	6	Supplemental	Sprinkler
12	Chickpea (Spring)	20	Supplemental	Sprinkler
13	Fallow	29.6	-	-
	Total (ha)	**70**	-	-

In order to better manage the water resources and improve food security for AREC, additional crops were included in the study such as beans, broad beans in addition to winter varieties of lentil and chickpeas (for rainfed agriculture).

3.2. Water Balance

The water balance for AREC was calculated as the difference between supply from surface, groundwater and rainfall and demand (agricultural demand). The treated wastewater was calculated and included for future scenarios as it is currently under construction at AREC. The water demand for domestic use and other use was excluded from this calculation as it is considered minor (less than 1,000 m^3/year), this water is provided through separate water well, and subscription, hence it was not included in the calculation.

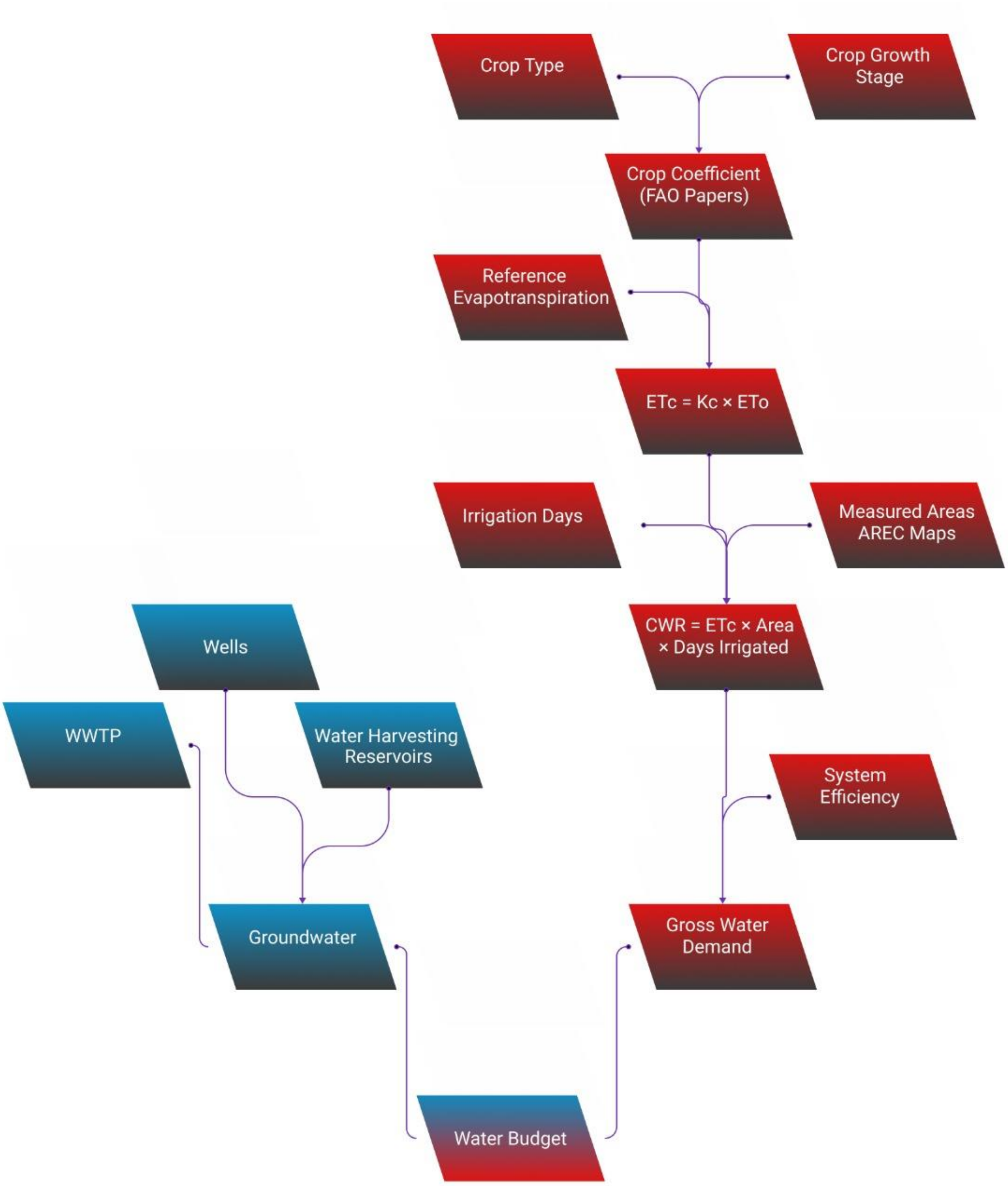


Figure 7 Illustration water budget calculation methodology.

3.2.1. Water Supply

The main source of water at AREC is groundwater as well as rainwater (directly stored in the soil as green water or collected in reservoirs). In order to quantify the groundwater, calculations were based on the operating hours of the existing wells. The flow varies throughout the year, and it gets lower mid-summer. For the purpose of this study, the average flow for each pump (Table 3) was considered. The total groundwater available is estimated to be about 101,936 m^3/year.

Table 3 Pump Operation and Flow

Location at AREC	**Pump Size (HP)**	**Operation Hours/day**	**Flow**	**Avg operating hours/year**	**Average flow**	**Total water (m^3)**
Orchard Pump	15	May-June (6 hrs) / July-Sep (12-14 hrs)	0-45	1530	30	45,900
Tell pump	10	May-June (6 hrs) / July-Sep (12-14 hrs)	36	1530	36	55,080
Submersible 1	3	May-Sep (0.5 hrs)	0-4	75	2.5	188
Submersible 2	3	May-Sep (0.25 hrs)	0-4	37.5	2.5	94
Submersible 4	4	May-Sep (0.5-1 hrs)	0-8	112.5	6	675
						101,936

The USAID/ASHA (American Schools and Hospitals Abroad) has recently funded AUB to develop and improve the current water infrastructure and management through wastewater treatment, rainwater harvesting and storage at AREC. The grant will provide the necessary finances to implement new infrastructure, training and upgrading pre-existing facilities such as the irrigation systems which should positively skew the current water balance and fill the water balance gap.

Table 4 Water Supply at AREC

	Capacity (m^3)	
	Current	**Under construction (ASHA)**
Parking Rainwater Harvesting	32	-
Pool rainwater harvesting	500	-
Groundwater	101,936	-
Pools		-
Rainfall (374mm)	22,253	-
From WWT (70m^3/day) ASHA	-	25,550
New reservoir (ASHA)	-	50,000
Rainwater harvesting from roof ASHA	-	160
Total	**124,721**	**75,710**

3.2.2. Water Demand

The domestic water use and the water needed for animal farming at AREC was calculated, and it amounted to less than 1,000 m^3/year which constituted less than 0.5% of total water demand, so it was excluded from the calculations.

The water demand for agriculture was calculated based on the crop water requirement of each crop depending on the growing season. The weather data for AREC were used to calculate reference evapotranspiration (ETo) using FAO Penman Monteith Equation (Allen et al., 1998, 2005). The crop coefficient Kc was also used from FAO table in Allen et al. (1998) and depending on the growing season at AREC and the length of the crop, the actual evapotranspiration for each crop was calculated as a result of ETc = ETo x Kc.

After removing the effective rainfall from the water demand of these crops the gross irrigation requirement was calculated by dividing the net water requirement by the efficiency (depending on irrigation system used). The total water demand was then calculated for the existing crop areas.

3.3. Yields and Water Productivity

For each crop, yield reductions are expected due to water stress. This crop yield reduction due to water stress was calculated by Doorenbos and Kassam (1979) was estimated based on the following formula

$$1 - \frac{Y}{Ym} = Ky\left(1 - \frac{ETa}{ETc}\right)$$

where Y and Ym are the actual and maximum crop yields, respectively; ETa and ETc correspond to actual and maximum evapotranspiration, respectively; and the coefficient Ky denotes the yield response factor, which relates the yield reduction (1 − Y/Ym) to the water stress (1 − ETa/ETc) for a given environment (Raes et al., 2006). In the literature, Ky values were estimated for almost all crops and are widely being used.

Table 5 Ky Values (FAO Drainage and Irrigation)

Crop	Ky
Apple	1.2
Wheat	1.05
Corn	1.25
Potato	1.1
Tomato	1.05
Beans	1.15
Broad Beans	1.15
Lentil	1.15
Chickpeas	1.15
Peas	1.15
Peach	1.2
Tomato	1.05
Olive	0.75
Apricot	1.2
Grapes	0.85

On the other hand, water productivity (WP) is defined as crop yield per cubic meter of water consumption, including ‘green’ water (effective rainfall) for rain-fed areas and both ‘green’ water and ‘blue’ water (diverted water from water systems) for irrigated areas. In this study, WP was calculated for each crop for the different scenarios.

3.4. Climate Change Scenarios

Based on the projections presented in RICCAR (2017), and the on “Lebanon’s Second National Communication to the UNFCC” Report (Ministry of Environment, 2015), and given that AREC is located in a semi-arid climate more susceptible to climate change, it was important to optimize water use and food production at AREC under several climate change scenarios. Two climate change scenarios were considered:

- Climate change 1: this scenario assumes a 10% decrease in rainfall and a 13% increase in ETo over the whole simulation period (moderate scenario);
- Climate change 2: this scenario assumes a 20% decrease in rainfall and a 26% increase in ETo over the whole simulation period (severe scenario).

From the projected decrease in rainfall and increase in temperature, the evapotranspiration and crop water requirements for all crops was recalculated. The effect of these climate variables on the average yield was also analyzed taking into consideration the yield reduction factor proposed by Doorenbos and Kassam (1979).

Calculations of water balance and comparisons included, in addition to the current scenario, an “improved scenario” which will be adopted in couple of years after implementation of the new ASHA project infrastructure for water management at AREC.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Current crop water requirements for the different crops

In order to calculate the crop water requirements for each crop, ETo data from AREC and the standard FAO crop coefficient (Kc) for the different crops were used. An example is shown below (Table 6) for the calculation of Kc of wheat based on FAO tables and length of the growing season stages. The crop coefficient and calculations for other crops are shown in Annex (A1-A7)

Table 6 Crop coefficient of wheat during the different growing stage

Wheat	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.4	0.8	1.15	0.4	**0.75**
Length (days)	30	140	30	25	**225**

On the other hand, the reference ET was used together with the crop coefficient for each growing stage to calculate the net crop water requirement (ETc) for each month (wheat example shown in Table 7).

Table 7 Crop water requirement for wheat

	Rainfall (mm/month)	**ETo (mm/day)**	**ETc Wheat (mm/month)**
January	98.00	1.52	37.7
February	62.60	2.22	49.7
March	43.70	3.28	81.3
April	17.90	4.66	129.8
May	10.00	5.87	160.8
June	2.30	6.94	38.9
July	2.40	7.00	-
August	0.00	6.46	-
September	0.50	5.44	-
October	21.90	3.80	-
November	37.80	2.33	28.0
December	77.60	1.65	40.9
Total (mm/year)	**374.70**	**-**	**-**
Total mm/season)	**349.13**	**-**	**567.1**

These calculations for net and gross water requirements are calculated based on mm/year. In order to convert to volume, the areas for each crop were used. The total crop water requirement at AREC is presented in Table 10. In this table, the total farmed area for the past season was 41.5 ha and 29.6 ha were left Fallow due to limited water resources. The total irrigation requirement for the whole AREC was about 192,014 m^3.

4.1. Water requirement under different scenarios

The water requirements for the current cropping pattern at AREC was calculated under different scenarios and is presented in Table 5 below. The first scenario – called "improved scenario" consisted of looking at the current practices and evaluating what can be improved and how. Especially in terms of changing the irrigtaion system used to a more efficient one or adding supplemental irrigation to rainfed crop to boost the yields. A description of the improved scenario for each crop is presented in Table 8 below along with the impact on water requirements.

Table 8 Improved scenario for the current cropping pattern at AREC

Crop	Gross Water Requirement (mm/ha/yr)		Description of Recommended Scenario
	Current scenario	Improved Scenario	
Wheat	-	256	256 mm of supplemental irrigation will boost the yield by 28%
Barley/Vetch	-	119	119 mm of supplemental irrigation will boost the yield by 24%
Corn	669	598	use drip irrigation will reduce the GWR by 71 mm
Potato	802	718	use drip irrigation will reduce the GWR by 84 mm
Tomato	1,029	921	use drip irrigation will reduce the GWR by 108 mm
Apple	1,086	1,086	same as current practice (drip irrigated)
Peach	1,036	1,036	same as current practice (drip irrigated)
Apricot	1,036	1,036	same as current practice (drip irrigated)
Grapes	872	872	same as current practice (drip irrigated)
Olives	-	-	same as current practice (rainfed)
Lentil	-	-	same as current practice (rainfed)
Chickpea (spring)	478	428	use drip irrigation will reduce the GWR by 50 mm

The two other scenarios presented in this study, consist of the moderate and extreme climate change scenario under the current cropping pattern of AREC. The same calculation that were used to calculate the net and gross water requirments for the crops under the current scenario was done after increasing the reference ETo and decreasing the rainfall as explained in the methodology for each climate change scenario.

The water requirements under the different scenarios are presented in Table 5 below. Under the improved scenario, the water requirements will slightly decrease due to adoption of more efficient irrigation systems or improved practices. However, the water demand will increase 19% by 2050 under moderate climate change scenario (Scenario 1) and 37.5% under extreme climate change scenario (Scenario 2). This increase in water requirement will require securing additional water resources for AREC or decreasing the farmed area and hence reduction in food production.

Table 9 Crop Water Requirements

		Water Requirement (m^3/yr)			
Crop	**Current Areas**	**Current scenario**	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**
Wheat	2.7	-	6,925	10,376	13,826
Barley/Vetch	3.8	-	4,526	8,654	12,782
Corn	0.8	5,351	4,788	5,420	6,053
Potato	1.6	12,833	11,483	13,023	14,563
Tomato	1	10,293	9,210	11,314	13,418
Apple	1.2	13,028	13,028	15,714	18,401
Peach	0.3	3,108	3,108	3,760	3,864
Apricot	0.61	6,319	6,319	7,646	7,858
Grapes	2.1	18,305	18,305	22,424	26,543
Olives	0.42	-	-	1,397	1,865
Beans	0	-	-	-	-
Broad beans	0	-	-	-	-
Lentil (Winter)	0	-	-	-	-
Lentil (Spring)	6	27,217	27,217	31,024	34,831
Chickpea (Winter)	0	-	-	-	-
Chickpea (Spring)	20	95,560	85,501	97,418	109,334
Peas	0	-	-	-	-
Fallow	29.6	-	-	-	-
		192,014	190,408	228,169	263,338

4.2. Water supply under different scenarios

The current water supply at AREC consists of groundwater and rainfall leading to a total of 124,721 m^3/year. This volume is expected to increase to 200,431 m^3/year after execution and operation of the new wastewater treatment plant and additional rainwater harvesting and reservoir systems at AREC. However, and due to climate change, this supply is expected to decrease by 8% moderate climate change scenario and by 14.5% under extreme climate change (by 2050) as shown in Table 10 below.

Table 10 Water Supply under different scenarios

	Capacity (m^3/year)			
	Current	Under construction (ASHA)	Climate Change Scenario 1	Climate Change Scenario 2
Parking Rainwater Harvesting	32	32	32	32
Pool rainwater harvesting	500	500	500	500
Groundwater	101,936	101,936	91,743	81,549
Rainfall (374mm)	22,253	22,253	20,0287	17,802
From WWT (70m3/day) ASHA	-	25,550	25,550	25,550
New reservoir (ASHA)	-	50,000	50,000	50,000
Rainwater harvesting from roof ASHA	-	160	160	160
Total	**124,721**	**200,431**	**188,012**	**175,593**

4.3. Water balance under different scenarios

Based on the calculated water requirement for the different climate scenarios, and the water supply, the water balance was calculated for the different scenarios assuming similar cropping patterns at AREC (Table 11 and Figure 7). This table shows that the deficit is currently about 67,293m^3, this gap can be covered after the implementation of the wastewater treatment plant and additional reservoirs that are currently under construction and additional areas can be planted. However, under extreme climate change scenario, the deficit will reach about 87,744m^3 per year, which mean even if efficiency is improved, the cropping area and food production will have to be decreased.

Table 11 Water Balance

	Current Scenario	Improved Scenario (2025)	Moderate Climate Change (2050)	Extreme Climate Change (2050)
Water Supply	124,721	200,431	188,012	175,593
Water Demand	192,014	190,408	228,169	263,338
Balance	(67,293)	10,023	(40,156)	(87,744)

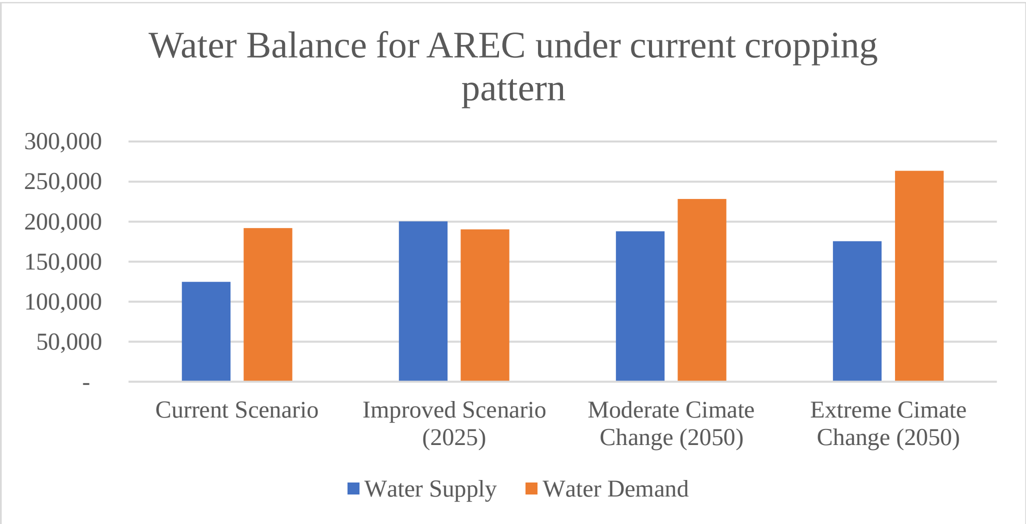


Figure 8 Water Balance for AREC under current cropping pattern for different scenarios

4.4. Yield and water productivity under different scenarios

In order to recommend changes and improvement in the cropping parttern, water use and food production at AREC, it was neccessary to look at water productivity for each of the crop (Table 13). Based on this, an additional scenario was recmmended that maximize these yields and water productivity especially by improving the irrigtaion practices (rainfed, deficit irrgation or supplemntal irrigation).

Table 12 Crop Yield

	Yield (ton/ha)				
Crop	**Current scenario**	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**
Wheat	4.27	6.00	6.00	6.00	4.23
Barley/Vetch	6.46	8.00	8.00	8.00	6.38
Corn	8.00	8.00	8.00	8.00	7.04
Potato	45.00	45.00	45.00	45.00	36.96
Tomato	150.00	150.00	150.00	150.00	126.77
Apple	38.19	38.19	36.10	34.59	26.23
Peach	51.05	51.05	48.24	46.23	40.96
Apricot	17.42	17.42	16.58	15.97	14.36
Grapes	22.51	22.51	21.26	20.36	19.70
Olives	9.73	9.73	9.06	8.59	10.55
Beans	1.07	2.00	2.00	2.00	1.01
Broad beans	2.50	2.50	2.50	2.50	1.54
Lentil (Winter)	2.00	2.00	1.99	1.62	1.62
Lentil (Spring)	1.59	1.59	1.59	1.59	1.45
Chickpea (Winter)	2.00	2.00	1.87	1.55	1.55
Chickpea (Spring)	1.75	1.75	1.75	1.75	1.58
Peas	1.50	1.50	1.50	1.50	0.97

Table 13 Water Productivity

Crop	Water Productivity (kg/m3)				
	Current scenario	Improved Scenario	Climate Change Scenario 1	Climate Change Scenario 2	Recommended CC2
Wheat	1.22	1.06	0.94	0.84	0.98
Barley/Vetch	1.88	1.80	1.59	1.43	1.50
Corn	1.39	1.39	1.23	1.11	1.09
Potato	6.48	6.48	5.74	5.15	5.27
Tomato	12.00	12.00	10.62	9.53	9.75
Apple	2.90	2.90	2.56	2.30	2.70
Peach	4.45	4.45	3.96	3.59	3.82
Apricot	1.52	1.52	1.36	1.24	1.34
Grapes	2.14	2.14	1.91	1.74	1.77
Olives	2.84	2.84	2.94	3.14	2.01
Beans	1.78	0.81	0.71	0.64	2.11
Broad beans	0.52	0.52	0.46	0.41	0.56
Lentil (Winter)	0.74	0.74	0.65	0.60	0.60
Lentil (Spring)	0.39	0.39	0.35	0.31	0.39
Chickpea (Winter)	0.70	0.70	0.62	0.57	0.57
Chickpea (Spring)	0.41	0.41	0.37	0.33	0.42
Peas	0.36	0.36	0.32	0.28	0.35

4.5. Recommended Scenario

Based on the projected deficit in the water balance and in order to increase water productivity, an additional scenario was recommended in order to maximize food production and better utilize water resources under extreme conditions of climate change scenario 2. This scenario suggests improving efficiency by changing the irrigation system used, using more water saving crops, adding supplemental irrigation for rainfed crops and using deficit irrigation strategies for crop that can tolerate a certain water stress without negatively impacting the yield. Based on Table 14 below shows the impact of these recommendations on water requirements.

Table 14 Gross Water Requirement

	Gross Water Requirement (mm/ha/yr)					
Crop	**Current scenario**	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended for CC2**	**Description of Recommended Scenario**
Wheat	-	256	384	512	176	150 mm supplemental irrigation
Barley/Vetch	-	119	228	336	176	150 mm supplemental irrigation
Corn	669	598	678	757	674	use drip irrigation +10% deficit irrigation
Potato	802	718	814	910	728	use drip irrigation +20% deficit irrigation
Tomato	1,029	921	1,131	1,342	1,053	use drip irrigation +20% deficit irrigation
Apple	1,086	1,086	1,310	1,533	973	use drip irrigation +50% deficit irrigation
Peach	1,036	1,036	1,253	1,288	842	use drip irrigation +40% deficit irrigation
Apricot	1,036	1,036	1,253	1,288	842	use drip irrigation +40% deficit irrigation
Grapes	872	872	1,068	1,264	885	use drip irrigation +30% deficit irrigation
Olives	-	-	333	444	263	250mm supplemental irrigation
Beans	-	198	238	278	-	Rainfed
Broad beans	470	470	539	608	263	Use drip irrigation +250 mm supplemental irrigation
Lentil (Winter)	-	-	-	83	-	Rainfed
Lentil (Spring)	454	454	517	581	412	Use drip irrigation +350 mm supplemental irrigation

Chickpea (Winter)	-	-	21	95	-	Rainfed
Chickpea (Spring)	478	428	487	547	368	Use drip irrigation +350 mm supplemental irrigation
Peas	408	408	469	529	263	Use drip irrigation +250 mm supplemental irrigation
Fallow	-	-	-	-	-	

In an effort to maximize land utilization especially by increasing the rainfed areas, a new cropping pattern was optimized, and Table 15 below shows the recommended cropping pattern for this scenario which increases the total farmed area from 40 ha to 70 ha. It will also use the water available under the extreme climate change scenario without any deficit in the water balance. On the other hand, this scenario will ensure an increase the food production by 72% (from 432 tons/year to 742 tons/year). This increase in food production is mainly coming from rainfed production (lentil, chickpeas, bean, etc.).

Table 15 Water Requirement and Food Production

	Crop	Current cropping pattern (ha)	Recommended cropping pattern (ha)	Water Requirement (m3/yr)		Food production (tons/year)	
				Current scenario	Recommended Scenario (2050)	Current scenario	Recommended Scenario (2050)
1	Wheat	2.7	12.5	-	22,059	11.5	52.8
2	Barley/Vetch	3.8	4	-	7,059	24.5	25.5
3	Corn	0.8	2	5,351	13,474	6.4	14.1
4	Potato	1.6	10	12,833	72,813	72.0	369.6
5	Tomato	1	1	10,293	10,526	150.0	126.8
6	Apple	1.2	1.2	13,028	11,679	45.8	31.5
7	Peach	0.3	0.3	3,108	2,526	15.3	12.3
8	Apricot	0.61	0.61	6,319	5,137	10.6	8.8
9	Grapes	2.1	2.1	18,305	18,580	47.3	41.4
10	Olives	0.42	0.42	-	1,105	4.1	4.4

11	Beans	0	2	-	-	-	2.0
12	Broad beans	0	3	-	7,895	-	4.6
13	Lentil (Winter)	0	15	-	-	-	24.2
14	Lentil (Spring)	6	0	27,217	-	9.5	-
15	Chickpea (Winter)	0	15	-	-	-	23.3
16	Chickpea (Spring)	20	0	95,560	-	34.9	-
17	Peas	0	1	-	2,632	-	1.0
18	Fallow	**29.6**	**0**				
	Total	**40.5**	**70**	**192,014**	**175,484**	**432**	**742**

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Water resource management and optimizing crop production in accordance with water supply are indeed effective methods in improving food security in Lebanon. By preparing the water balance for AREC and applying it to different levels of climate change provides us with a potential course of action to best fit each scenario.

Two of the scenarios are based on the projections presented in RICCAR (2017) and on “Lebanon’s Second National Communication to the UNFCC” Report (Ministry of Environment, 2015). Having climate change 1 as a scenario which assumes a 10% decrease in rainfall and a 13% increase in ETo over the whole simulation period (moderate scenario), and climate change 2 being the scenario assuming a 20% decrease in rainfall and a 26% increase in ETo over the whole simulation period (severe scenario).

The first step to increasing efficiency and food production was to understand our current situation and use of resources. AREC’s water resources were calculated using pumping and rainfall data which comes up to 124,721 m^3 . this value represents the current water supply in AREC. As for the water demand the key was to find out the current crop water requirement which was calculated to be about 192,014 m^3 for AREC. This number serves two major purposes; first, we are currently at a water deficit of 67,293 m^3 and this is the reason the total farmed area was not fully exploited leaving 29.6 ha fallow. Second, the crop water requirement allows the calculation of future water requirements with changing ETo and temperatures of the forementioned scenarios.

Before creating an optimized cropping pattern using this data, the ASHA project and its facets were a necessary inclusion, since this research is predominantly trying to optimize the future of food production at AREC. American Schools and Hospitals Abroad has recently funded AUB to develop and improve the current water infrastructure and management through wastewater treatment, rainwater harvesting and storage at AREC. This grant will positively skew the current water balance and fill the water balance gap which allowed the addition of an improved scenario. This addition is expected to increase water supply by 75,710 m^3 through a wastewater treatment and a water reservoir. By compiling this data and taking into consideration the increased water requirement and decrease in supply in accordance with each scenario a table was calculated to show the water balance for each scenario. The results showed that the current water deficit can be covered in the short run through the ASHA project, however, we will start falling short on water supply if any of the climate change scenarios come to pass. The moderate climate change provides a challenge however, through optimized cropping, deficit irrigation and other techniques it is still possible to see an increase in production compared to the current scenario with 10,023 m^3 of excess water supply. As for the extreme climate change it becomes very difficult to even maintain current production with an 87,744 m^3 water deficit.

In addition to finding the current crop water requirements, it was necessary to find the yield and water productivity for each crop in order to optimize a cropping pattern. This was done by first looking at ideal crop yield and water productivity as per AREC's region as well as direct comparison to current yield and water productivity data. The result was unexpected as the current yields and water productivity are too high to have an optimized pattern. The way this was solved was by looking at the highest decrease in water use whilst having a minimal loss in yield. The result of this optimizing is promising as it showed in potatoes for example a decrease in 6.48 kg/m^3 to 5.27 kg/m^3 in water productivity would greatly reduce water use whilst maintaining an acceptable yield. In a few cases such as beans the water productivity is worth increasing as little water is needed to greatly improve the yield, by moving from rainfed to deficit irrigation it became possible to see such results in production increase without seeing a large increase in water requirement. Through this recommendation it is possible to reduce the water requirement to 91.39% (175,484 m^3 instead of 192,014 m^3) of the current water requirement and increase in 71.76% (432 to 742 tons/year) in food production. In addition, this reintroduces the fallow 29.6 ha back into the crop rotation as the current reason for not using it is water shortage.

As for some of the issues and limitations of this research, many can be addressed in further application of this water balance methodology in order to improve on it. First, regarding the economic viability of introducing infrastructure was not addressed in this research due to the nature of the ASHA fund. However, regardless of investments in infrastructure and irrigation systems, with current available data collection technologies such as remote sensing it is possible retrieve much of the data needed for crop optimization at a fraction of the price of investing in physical infrastructure. Second, the inclusion of animal production was excluded for AREC as it represents a much smaller water footprint compared to the crop production, however, there certainly are areas of increased efficiency to be discussed in further studies. Another issue would be the social aspect and farmers willingness to introduce new cropping patterns and techniques in addition to the use of wastewater treatment in their farms. This very question is currently being addressed by a new study being conducted at FAFS Titled: "*Groundwater-Energy-Food Nexus:*

What is the current status of groundwater availability within the agricultural field and how are socio-economic practices shaping rural water availability?" by graduate student Ms. Rania Bou Said.

This will provide necessary social and economic data in order to improve on our current agriculture and food security system with focus on the economic and social aspects of such implications. Finally, regarding the application of such a methodology on a larger scale such as Bekaa or even further beyond is possible, however due to the data requirement for providing accurate results, simulations and time restrains, this falls beyond the capabilities of this specific research.

Based on this study, the results showed us that proceeding with the current practices would certainly lead to a water deficit and a reduction of food outputs. Therefore it is crucial to start working towards the recommeneded improved scenario as it helps fill the gap in food production and also fits within the local diet . This increase in food production from 432 to 742 tons/year highlights an oppurtunity to improve food security without adding water requirements. The case of AREC represents a scalable research as the Bekaa valley is the predominant food producer in Lebanon with an increase in production, this has direct implications on several aspects of food security. The first being domestic production which is a major contributor to availability; one of the pillars of food security. By studying the scenarios and working towards efficient use of our resources, this improves our local sustainability. The significance of this research as well as its implications on food and water security will be amplified the more it is adopted.

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APPENDICES

Appendix A1

	Rainfall (mm/month)	**ETo (mm/day)**	**ET Wheat (mm/month)**
January	98.00	1.52	37.7
February	62.60	2.22	49.7
March	43.70	3.28	81.3
April	17.90	4.66	129.8
May	10.00	5.87	160.8
June	2.30	6.94	38.9
July	2.40	7.00	
August	0.00	6.46	
September	0.50	5.44	
October	21.90	3.80	
November	37.80	2.33	28.0
December	77.60	1.65	40.9
Total (mm/year)	**374.70**		
Total (mm/season)	**349.13**		567.1

		ETc wheat	**567.13**	**640.86**	**714.59**
Wheat Season	Nov-2/3 may	Rain during season	349.13	314.22	279.31

Winter crops	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.4	0.8	1.15	0.4	**0.75**
Length (days)	30	140	30	25	**225**

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1	Non Irrigated	-	6.00	567.13	349.13	4.27	1.22
Scenario 2	Supplemental	256.47	6.00	567.13	567.13	6.00	1.06
Scenario 3	CC 13% more ET+10% less rain	384.28	6.00	640.86	640.86	6.00	0.94
Scenario 4	CC 26% more ET + 20% less rain	512.09	6.00	714.59	714.59	6.00	0.84
Optimized Scenario for CC2	CC 26% more ET + 20% less rain +supplemental	176.47	6	714.59	429.31	4.23	0.98

Appendix A2

	Rainfall (mm/day)	**ET (mm/day)**	**ET BV**
January	98.00	1.52	37.7
February	62.60	2.22	49.7
March	43.70	3.28	82.3
April	17.90	4.66	150.5
May	10.00	5.87	56.4
June	2.30	6.94	
July	2.40	7.00	
August	0.00	6.46	
September	0.50	5.44	
October	21.90	3.80	
November	37.80	2.33	28.0
December	77.60	1.65	40.9

				CC1 (ET+13%; Rain-10%)	CC2 (ET+26%; Rain-20%)
		ETc wheat	**445.50**	**503.42**	**561.33**
Wheat Season	Nov-2/3 may	Rain during season	344.27	309.84	275.41
		mm needed	101	194	286

Barley/Vetch crops	$K_{initial}$	$K_{development}$	$K_{mid-season}$	K_{late}	**Avg/total**
Kc	0.4	0.8	1.1	0.4	**0.74**
Length (days)	30	120	30	25	**205**

		GWR (mm)	Yield Ym (ton/ha)	ETm	ETa	Ya	WP (kg/m3)
Scenario 1	Non Irrigated	-	8.00	445.50	344.27	6.46	1.88
Scenario 2	Supplemental	119.10	8.00	445.50	445.50	8.00	1.80
Scenario 3	CC 13% more ET+10% less rain	227.74	8.00	503.42	503.42	8.00	1.59
Scenario 4	CC 26% more ET + 20% less rain	336.38	8.00	561.33	561.33	8.00	1.43
Optimized Scenario for CC2	CC 26% more ET + 20% less rain + suppl	176.47	8.00	561.33	425.41	6.38	1.50

Appendix A3

	Rainfall (mm/day)	**ET (mm/day)**	**Corn**
January	98	1.52	
February	63	2.22	
March	44	3.28	
April	18	4.66	
May	10	5.87	
June	2	6.94	93.7
July	2	7.00	197.4
August	0	6.46	229.3
September	1	5.44	53.3
October	22	3.80	
November	38	2.33	
December	78	1.65	

Rainfall	CC1 (ET+13%; Rain-10%)	CC2 (ET+26%; Rain-20%)
573.7	**648.32**	**722.90**
5.2	4.68	4.16
568.5	644	719

Potato	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.5	0.82	1.15	0.75	**0.88**
Length (days)	20	30	45	25	**120**

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1	Irrigated sprinkler)	802.09	45.00	693.98	693.98	45.00	6.48

Scenario 2	Irrigated (drip)	717.66	45.00	693.98	693.98	45.00	6.48
Scenario 3	CC 13% more ET+10% less rain+drip	813.91	45.00	784.19	784.19	45.00	5.74
Scenario 4	CC 26% more ET + 20% less rain+drip	910.16	45.00	874.41	874.41	45.00	5.15
Optimized Scenario for CC2	CC 26% more ET + 20% less rain+drip+20% deficit	728.13	45.00	874.41	701.48	36.96	5.27

Appendix A4

Rainfall (mm/day)	**ET (mm/day)**	**summer vegetables**
187.431667	1.91	-
112.066979	2.21	-
87.8504688	2.92	54.2
42.581875	3.67	85.1
26.0105952	4.76	129.6
9.7813244	5.84	201.5
3.75962798	6.14	218.7
6.08584821	5.82	207.3
13.1327381	4.77	164.4
73.7591964	3.76	129.2
111.625208	2.65	59.5
130.895774	2.13	

		CC1 (ET+13%; Rain-10%)	**CC2 (ET+26%; Rain-20%)**
ET (mm/day)	**1249.5**	**1,411.95**	**1,574.38**
Rain	**374.59**	**337.13**	**299.67**
	874.924	**1075**	**1275**

Summer vegetables	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.6	0.8	1.15	0.9	**0.99**
Length (days)	35	50	155	30	**270**

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1	Irrigated sprinkler)	1,029.32	150.00	1,249.51	1,249.51	150.00	12.00
Scenario 2	Irrigated (drip)	920.97	150.00	1,249.51	1,249.51	150.00	12.00
Scenario 3	CC 13% more ET+10% less rain+drip	1,131.39	150.00	1,411.95	1,411.95	150.00	10.62
Scenario 4	CC 26% more ET + 20% less rain+drip	1,341.80	150.00	1,574.38	1,574.38	150.00	9.53
Optimized Scenario for CC2	CC 26% more ET + 20% less rain+drip + 20% deficit	1,052.63	150.00	1,574.38	1,299.67	126.77	9.75

Appendix A5

	Rainfall (mm/day)	**ET (mm/day)**	**Beans mm**
January	98	1.52	-
February	62.6	2.22	-
March	43.7	3.28	-
April	17.9	4.66	
May	10	5.87	
June	2.3	6.94	
July	2.4	7.00	
August	0	6.46	
September	0.5	5.44	104.0
October	21.9	3.80	113.2
November	37.8	2.33	30.8
December	77.6	1.65	
	374.7		

Beans	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}
Kc	0.5	0.775	1.05	0.9
Length (days)	15	25	25	10

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1	Non-Irrigated	-	2.00	248.04	60.20	1.07	1.78
Scenario 2	Irrigated	197.72	2.00	248.04	248.04	2.00	0.81
Scenario 3	CC 13% more ET+10% less rain (suppl)	238.00	2.00	280.28	280.28	2.00	0.71
Scenario 4	CC 26% more ET + 20% less rain (suppl)	278.28	2.00	312.53	312.53	2.00	0.64
Optimized Scenario for CC2	CC 26% more ET + 20% less rain+ Rainfed	-	2.00	312.53	48.16	1.01	2.11

Appendix A6

	Rainfall (mm/day)	ET (mm/day)	winter Lentil mm
January	98	1.52	51.8
February	62.6	2.22	68.4
March	43.7	3.28	66.6
April	17.9	4.66	12.6
May	10	5.87	
June	2.3	6.94	
July	2.4	7.00	
August	0	6.46	
September	0.5	5.44	
October	21.9	3.80	
November	37.8	2.33	32.0
December	77.6	1.65	38.9
	374.7		

Lentil	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.4	0.75	1.1	0.3	**0.74**
Length (days)	25	35	70	40	**170**

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1& 2	Non-Irrigated	-	2.00	270.35	270.35	2.00	0.74
Scenario 3	CC 13% more ET+10% less rain (no suppl)	-	2.00	305.50	303.84	1.99	0.65
Scenario 4	CC 26% more ET + 20% less rain (no suppl)	83.02	2.00	340.64	270.08	1.62	0.60
Optimized Scenario for CC2	CC 26% more ET + 20% less rain+drip+ Rainfed	-	2.00	340.64	270.08	1.62	0.60

Appendix A7

	Rainfall (mm/day)	ET (mm/day)	Chickpeas (winter)
January	98	1.52	54.2
February	62.6	2.22	71.5
March	43.7	3.28	73.3
April	17.9	4.66	14.7
May	10	5.87	
June	2.3	6.94	
July	2.4	7.00	
August	0	6.46	
September	0.5	5.44	
October	21.9	3.80	
November	37.8	2.33	32.3
December	77.6	1.65	40.3
	374.7		

Chickpeas	$K_{initial}$	$K_{development}$	$K_{mid\text{-}season}$	K_{late}	**Avg/total**
Kc	0.4	0.775	1.15	0.35	**0.77**
Length (days)	25	35	70	40	**170**

		GWR (mm)	**Yield Ym (ton/ha)**	**ETm**	**ETa**	**Ya**	**WP (kg/m3)**
Scenario 1 & 2	Non-irrigated	-	2.00	286.25	286.25	2.00	0.70
Scenario 3	CC 13% more ET+10% less rain (no suppl)	20.65	2.00	323.46	303.84	1.87	0.62
Scenario 4	CC 26% more ET + 20% less rain (no suppl)	95.36	2.00	360.67	270.08	1.55	0.57
Optimized Scenario for CC2	CC 26% more ET + 20% less rain+drip+ Rainfed	-	2.00	360.67	270.08	1.55	0.57

Appendix B1

Crop	Net Water Requirement (ET actual) (mm/year)				
	Current scenario	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**
Wheat	349.13	567.13	640.86	714.59	429.31
Barley/Vetch	344.27	445.50	503.42	561.33	425.41
Corn	573.73	573.73	648.32	722.90	644.16
Potato	693.98	693.98	784.19	874.41	701.48
Tomato	1,249.51	1,249.51	1,411.95	1,574.38	1,299.67
Apple	1,318.78	1,318.78	1,411.65	1,504.52	973.28
Peach	1,147.25	1,147.25	1,217.70	1,288.16	1,073.68
Apricot	1,147.25	1,147.25	1,217.70	1,288.16	1,073.68
Grapes	1,052.52	1,052.52	1,110.67	1,168.81	1,114.20
Olives	342.10	342.10	307.89	273.68	523.68
Beans	60.20	248.04	280.28	312.53	48.16
Broad beans	479.09	479.09	541.37	603.66	276.08
Lentil (Winter)	270.35	270.35	303.84	270.08	270.08
Lentil (Spring)	402.12	402.12	454.40	506.68	376.48
Chickpea (Winter)	286.25	286.25	303.84	270.08	270.08
Chickpea (Spring)	422.68	422.68	477.63	532.58	376.48
Peas	418.20	418.20	472.56	526.93	274.16

Appendix B2

Crop	Gross Irrigation Requirement (mm/year)				
	Current scenario	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**
Wheat	-	256.47	384.28	512.09	176.47
Barley/Vetch	-	119.10	227.74	336.38	176.47
Corn	668.86	598.45	677.51	756.57	673.68
Potato	802.09	717.66	813.91	910.16	728.13
Tomato	1,029.32	920.97	1,131.39	1,341.80	1,052.63
Apple	1,085.70	1,085.70	1,309.54	1,533.38	973.28
Peach	1,035.90	1,035.90	1,253.39	1,288.16	842.11
Apricot	1,035.90	1,035.90	1,253.39	1,288.16	842.11
Grapes	871.66	871.66	1,067.80	1,263.94	884.76
Olives	-	-	332.57	444.12	263.16
Beans	-	197.72	238.00	278.28	-
Broad beans	469.99	469.99	538.98	607.97	263.16
Lentil (Winter)	-	-	-	83.02	-
Lentil (Spring)	453.62	453.62	517.06	580.51	411.76
Chickpea (Winter)	-	-	20.65	95.36	-
Chickpea (Spring)	477.80	427.51	487.09	546.67	368.42
Peas	408.42	408.42	468.82	529.23	263.16

Appendix B3

	Yield (ton/ha)				
Crop	**Current scenario**	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**
Wheat	4.27	6.00	6.00	6.00	4.23
Barley/Vetch	6.46	8.00	8.00	8.00	6.38
Corn	8.00	8.00	8.00	8.00	7.04
Potato	45.00	45.00	45.00	45.00	36.96
Tomato	150.00	150.00	150.00	150.00	126.77
Apple	38.19	38.19	36.10	34.59	26.23
Peach	51.05	51.05	48.24	46.23	40.96
Apricot	17.42	17.42	16.58	15.97	14.36
Grapes	22.51	22.51	21.26	20.36	19.70
Olives	9.73	9.73	9.06	8.59	10.55
Beans	1.07	2.00	2.00	2.00	1.01
Broad beans	2.50	2.50	2.50	2.50	1.54
Lentil (Winter)	2.00	2.00	1.99	1.62	1.62
Lentil (Spring)	1.59	1.59	1.59	1.59	1.45
Chickpea (Winter)	2.00	2.00	1.87	1.55	1.55
Chickpea (Spring)	1.75	1.75	1.75	1.75	1.58
Peas	1.50	1.50	1.50	1.50	0.97

Appendix B4

Crop	Water Productivity (kg/m3)							
	Current scenario	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**	**Highest field crop**	**Highest**	**Current Areas**
Wheat	1.22	1.06	0.94	0.84	0.98	1.22	1.22	2.7
Barley/Vetch	1.88	1.80	1.59	1.43	1.50	1.88	1.88	3.8
Corn	1.39	1.39	1.23	1.11	1.09	1.39	1.39	0.8
Potato	6.48	6.48	5.74	5.15	5.27	6.48	6.48	1.6
Tomato	12.00	12.00	10.62	9.53	9.75	-	12.00	1
Apple	2.90	2.90	2.56	2.30	2.70	-	2.90	1.2
Peach	4.45	4.45	3.96	3.59	3.82	-	4.45	0.3
Apricot	1.52	1.52	1.36	1.24	1.34	-	1.52	0.61
Grapes	2.14	2.14	1.91	1.74	1.77	-	2.14	2.1
Olives	2.84	2.84	2.94	3.14	2.01	-	2.84	0.42
Beans	1.78	0.81	0.71	0.64	2.11	2.11	1.78	0
Broad beans	0.52	0.52	0.46	0.41	0.56	0.56	0.52	0
Lentil (Winter)	0.74	0.74	0.65	0.60	0.60	0.74	0.74	0
Lentil (Spring)	0.39	0.39	0.35	0.31	0.39	0.39	0.39	6
Chickpea (Winter)	0.70	0.70	0.62	0.57	0.57	0.70	0.70	0
Chickpea (Spring)	0.41	0.41	0.37	0.33	0.42	0.42	0.41	20
Peas	0.36	0.36	0.32	0.28	0.35	0.36	0.36	0

Appendix B5

	Water Requirement (m3/yr)				
Crop	**Current scenario**	**Improved Scenario**	**Climate Change Scenario 1**	**Climate Change Scenario 2**	**Recommended CC2**
Wheat	-	6,925	10,376	13,826	4,765
Barley/Vetch	-	4,526	8,654	12,782	6,706
Corn	5,351	4,788	5,420	6,053	5,389
Potato	12,833	11,483	13,023	14,563	11,650
Tomato	10,293	9,210	11,314	13,418	10,526
Apple	13,028	13,028	15,714	18,401	11,679
Peach	3,108	3,108	3,760	3,864	2,526
Apricot	6,319	6,319	7,646	7,858	5,137
Grapes	18,305	18,305	22,424	26,543	18,580
Olives	-	-	1,397	1,865	1,105
Beans	-	-	-	-	-
Broad beans	-	-	-	-	-
Lentil (Winter)	-	-	-	-	-
Lentil (Spring)	27,217	27,217	31,024	34,831	24,706
Chickpea (Winter)	-	-	-	-	-
Chickpea (Spring)	95,560	85,501	97,418	109,334	73,684
Peas	-	-	-	-	-
Total	**192,014**	**190,408**	**228,169**	**263,338**	**176,454**