SMART AND WISE GOVERNANCE OF WATER SUPPLY ALLOCATION USING WATER FOOTPRINT ASSESSMENT

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Contents

Abstract

This research evaluates to what extent the water footprint approach can be helpful for policy-makers for water allocation and water planning. In the study, the Milas-Bodrum sub-basin (Turkey), which experiences water shortages during summer months, was evaluated, and the water footprints of the sectors in which water demand is high were calculated. Subsequently, scenarios were investigated for the reduction of the blue water footprint of the sector with highest water consumption, considering the water use priorities in the sub-basin.

According to the calculations, the agriculture sector, which is responsible for around half of the total water consumption in the sub-basin, is the main water consumer. The other sectors are industry, household, tourism, and livestock, respectively. Therefore, the agriculture sector was particularly evaluated in the perspective of smart and wise use of water in the sub-basin. To reduce blue water footprints of the agriculture sector, six crops (tomato, maize, alfalfa, watermelon, olive, and citrus) which are intensively grown and have high economic value in the basin were selected, and FAO's AquaCrop model was used to simulate water consumption and yields under different practices, including full and deficit irrigation; no mulching and organic and plastic mulching; and furrow, sprinkler, and drip irrigation. Compared to full irrigation, deficit irrigation can provide a water saving up to 40%, depending upon the crop type, with a maximum of 10% loss in yield. Mulching, which prevents water evaporation from the soil, makes a positive contribution on water saving. The effectiveness of plastic mulching is approximately two times that of organic mulching, but has the negative effect of plastic pollution into the environment. According to the scenarios considered, the blue water footprint can be decreased around 27 m^3 for per tonne of tomato production, 44 m^3 per tonne for maize, 65 m^3 per tonne for alfalfa, 20 m^3 per tonne for watermelon, 264 m^3 per tonne for olive, and 36 m^3 per tonne for citrus. These figures refer to the case of drip irrigation accompanied with deficit irrigation and plastic mulching. The model provided the highest value of water productivity (ET_{wp}) with this scenario. Alfalfa, however, is not a suitable crop for drip irrigation and mulching according to FAO.

In terms or water saving, up to 26 million m^3/y of blue water could be saved with only a maximum of 10% loss in yield in the sub-basin if the scenario having the highest ET_{wp} would have been implemented. This water saving is almost equivalent to the amount of water consumed in the household sector. Despite the substantial amount of blue water saving in the sub-basin in the most effective scenario considered, alleviating water shortage in the sub-basin, the water shortage would not totally be solved. It is concluded that water footprint assessment can be a useful approach for analysing scenarios for water allocation and basin planning by policy-makers. It may help to identify to possible reduction of the water footprint of a crop production and assess the possible alleviation of water scarcity especially during summer months.

CHAPTER 1

Introduction

This thesis researches that how water footprint approach can be helpful for planning water allocation in Milas – Bodrum sub-basin in Turkey, and also evaluates stakeholders' engagement.

1.1 Background

Freshwater resources are now facing major pressures due to overuse of resources, anthropogenic water pollution and consequent water scarcity in a global dimension. These challenges, also, lead to many problems in terms of social and economic chain. To fully respond to these challenges, novel and holistic approaches are needed in planning, allocation, and management of freshwater resources from local to global scale. In this regard, the efficient use of freshwater, the continuous of environmental sustainability and social equity have been adopted and a new approach called Integrated Water Resources Management (IWRM) was introduced during the Dublin Conference (Hassing et al., 2009). This approach embraces various planning and management stages in itself.

One of the stages of IWRM is water allocation planning (WAP), a process aiming to allocate the volume of water available within a sub-/basin or region to the stakeholders demanding this water to sustain their life, business or economic activity (Speed et al., 2013). Similar to the objectives of IWRM, water allocation planning includes equity, environmental protection, determining priorities, balancing supply and demand, and promoting the smart use of freshwater resources (Speed et al., 2013; EPA, 2008). The successful implementation of water allocation is strongly dependent on the determination of quantity, time of availability and source of water (e.g. soil moisture, groundwater, surface water).

The fact that increasing demand, economic significance and decreasing freshwater sources due to different users has brought tangled challenges in the implementation of the process of water allocation plans. Major challenges faced in these planning stages are 'water rights', reallocation of overallocated water in a watershed, water pricing and determining the contribution of water to the economy (economic productivity) and environmental needs.

The water footprint is an indicator of freshwater use that looks at both direct and indirect water use for any kind of production activity, e.g., growing sugar beet, for the products produced by a business, consumed by an individual or group of individuals, or for the activities within a geographic area. The water footprint of a geographic area, e.g. the Bodrum-Milas River Basin, shows the total amount of water consumed and polluted in the area by industry, domestic water supply, and agriculture sector. The water footprint of a product such as a cotton t-shirt is the volume of freshwater used to produce the product, measured over the full supply chain.

1.2 Problem statement

The challenges mentioned in the previous part also exist in Milas – Bodrum Sub-basin in Turkey (see Appendix 1 for a description of the study area). The water economy of the basin consists of two major elements: agriculture and tourism. The waters of the sub-basin are also vital for wetlands and natural parks like Güllük, a discharge point of several tributaries of the sub-basin delta is. The study area experiences severe water scarcity during summer periods as a result of increased demand from domestic water supply (e.g. summer houses), tourism sector (hotels, cruise ships, and yachts) and agriculture when the availability of water is the lowest. Currently, water allocation plans and related investments focus only on increasing water supply as much as possible without considering environmental water needs, trade-offs among different water users and water rights.

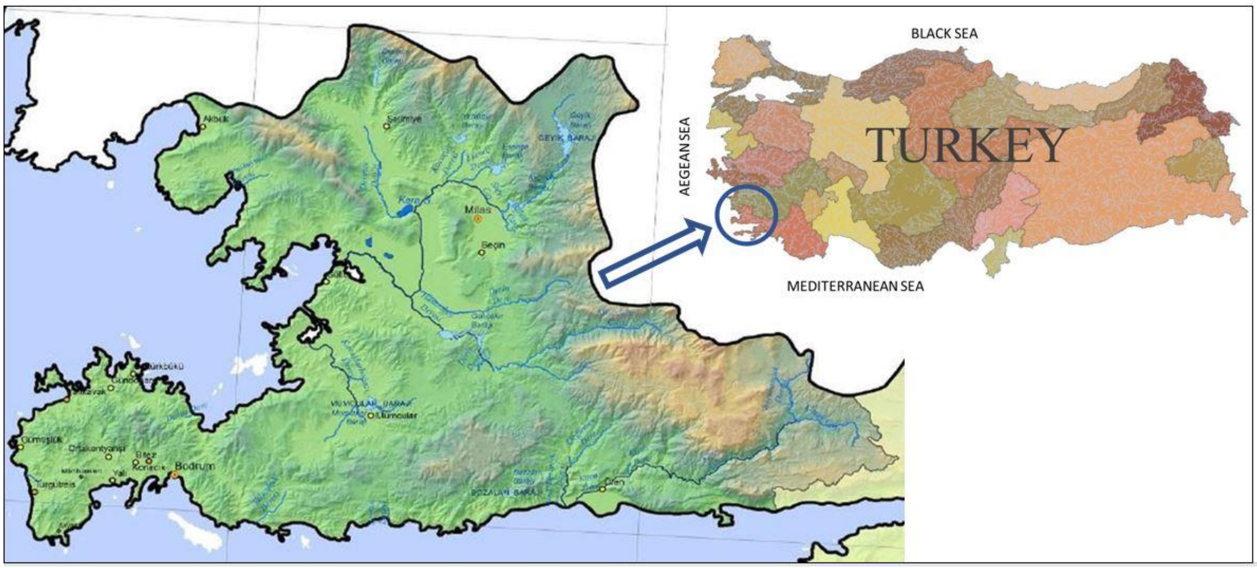

Figure 1.1 - Geographical position of the Milas-Bodrum sub-basin (TUBITAK, 2013).

It is anticipated that there will be a decrease in total discharge around the area as a result of climate change: a marked decrease of summer discharge, an increase of winter discharges and winter storms. In addition to climate change, population growth and increasing demand for water among users, industry, and ecosystems would affect the level of economic development within the basin. Change in flow regime would also put pressure on environmentally and economically important ecosystems like wetlands and environmentally protected areas (e.g. Güllük bay) which need a minimum flow of water in order to provide wildlife products including fish, plants, reed, and fruits. Therefore, an understanding of the current allocation of water and its sustainability, as well as exploration of smart water allocation schemes based on maximum allowable water use per stakeholder, are needed to open up discussions on how water should be managed in the basin to protect these areas in the future.

1.3 Objectives

This thesis aims to provide information to different stakeholders including farmers, local decision-makers, and water managers about how to address challenges using a coherent framework of analysis, Water Footprint Assessment, and to provide insight about how to overcome current and possible future water shortages in a region.

The Water Footprint Assessment (WFA) study of the Milas-Bodrum River Basin can be used as a part of the River Basin Management - Domestic Water Supply Allocation planning of the region aiming to provide a new strategy to connect water demand, supply and pollution under a single umbrella. The idea behind the WFA study is to identify actual pressures that different economic sectors put on the basin's water resources and ecosystems. The thesis also aims to identify how water stress can be alleviated under current conditions, to provide a strong basis for stakeholder dialogues on basin water management and domestic water supply allocation.

To achieve its objectives, the thesis will address the following research questions:

- What are possible scenarios which decrease blue water footprint in agriculture sector, and to what extent that scenarios can be helpful for water productivity?
- How can WFA be used as an analytical tool give insight on agriculture sector for different water supply allocation options under different irrigation managements?
- Can WFA help link all water users in a basin by establishing a common language across all stakeholders, including business, government and communities?

1.4 Thesis structure

In chapter 2, ways of data collection, approaches which used for the calculation of blue water footprint of the sectors, the scenarios used in agriculture sector, and information about the AquaCrop model were explained. Chapter 3 presents the results of blue water footprint of the sectors in the sub-basin and the outcomes of the model used for agriculture sector. Conclusions were interpreted in Chapter 4. Chapter 5 and Chapter 6 give references and appendices, respectively.

CHAPTER 2

Method and data

In this part, methodologies and approaches used while determining the current water budget and water footprints of dominant stakeholders regarding water demand in Milas – Bodrum sub-basin are explained, and afterwards scenarios which decrease water footprint of the agriculture sector have been investigated according to the priorities of water allocation in the region.

Agricultural and livestock data were collected from official reports and the competent authorities (Ministry of Agriculture and Forestry, 2018a; Ministry of Agriculture and Forestry, 2018b). Local population and tourist numbers were taken from the website of Turkish Statistical Institute (TurkSTAT, 2018) and Ministry of Culture and Tourism (2018), respectively. Meteorological data were taken from Turkish Meteorology Institute and its website (MGM, 2018). The data related to water like groundwater, surface water, and water demand were collected from State Hydraulic Works (DSI, 2018) and water supply data was taken from Muğla Water and Sewerage Administration (2018).

Interviews with the stakeholders were made face-to-face in the sub-basin. The aim of the interviews is to understand the implementation of water related works in the sub-basin; what kind of precautions are taken during drought seasons by actors, what the common methods in irrigation are, and what kind of problems are experienced, for example. The interviews were made with farmers, Directorate General of State Hydraulic Works (DSI), Muğla Water and Sewerage Administration (MUSKI), and irrigation unions. The results of the interviews will be used to put forward promising conclusions by integrating with numerical results.

2.1 Current water availability of Milas – Bodrum sub-basin

For determining of the existing water availability of the region, groundwater and surface water data were taken from the relevant institutions and organizations and evaluated. In order to evaluate water availability for the comparison of current water demands, average discharge and recharge of groundwater, mean monthly flows, and water released monthly from dams in the sub-basin due to provide water for different sectors were considered.

Groundwater resources in the region have been overexploited over the years by the sectors, and this situation is underlined in the Master Plan Report of Bati Akdeniz Basin, an official report prepared in the light of the investigations on groundwater resources (DSI, 2018). The report suggests that water supplies from wells in the region should be limited or terminated due to insufficient recharge and seawater intrusion. Average annual groundwater change in the region is presented in Table 2.1 below.

Table 2.1 - Average annual groundwater change in the Sub-basin (DSI, 2018)

Average annual groundwater water change of Milas-Bodrum sub-basin (Mm3/year)			
Groundwater Recharge via surface water and precipitation	26.14	Groundwater Discharge via human-use, evaporation, and discharges into sea/lake	59.47

Regarding surface water potential, Milas-Bodrum sub-basin has quite limited surface water potential especially in summer months compared to the average surface water availabilities of the other sub-basin in Batı Akdeniz Basin. Surface water potential of the sub-basin had been calculated using data between 1985 – 2014 in the official report and the results taken from the report are given in Table 2.2 (DSI, 2018). In the report, it is expressed that the water potentials of rivers (surface water resources) in the sub-basin were calculated by considering the flows of that rivers in lower parts of their catchment areas because the water released from the dams, which have been constructed the upper parts of the rivers, is directly pumped to drinking water treatment plants, irrigation systems, and industries, and there is no water release for aquatic life. Because of this, it is important to consider that if there were no the existing dams, the water collected in the rainy period would flow into the sea and it would be provided a smaller amount of water than in the dry period to the sectors. Therefore, while calculating the surface water availability of the sub-basin, I summed the amount of water released from the dams with the amount of water calculated in the official report as average monthly flow regimes, see Equation 1.

$$S = F + W \qquad \text{(Eq. 1)}$$

Where S = Surface water availability (Million m^3/month)

F = Flow regimes (Million m^3/month)

W = Water amount released from the dams (Million m^3/month)

Table 2.2 - Average annual surface water availabilities of sub-basins in Batı Akdeniz Basin (DSI, 2018).

Average annual surface water availabilities of sub-basins in Batı Akdeniz Basin including Milas-Bodrum sub-basin (Mm3/month)													
Sub-basins	Months												
	January	February	March	April	May	June	July	August	September	October	November	December	Total (Mm3/year)
Milas-Bodrum	94.7	107.3	71.6	36.1	13.4	6.4	6	4.6	4.9	8.7	24.3	57.3	436
Namnam Çayı	327.7	313.2	275.3	191.3	106.1	47.4	31.3	22.8	19.8	27.6	71.7	238.4	1673
Dalaman Çayı	179.3	190.8	182.7	151.8	94	72.4	64.9	55.6	44.1	54.6	84.8	153.2	1328
Eşen Çayı	236	221.8	220.6	195.6	148.7	106.5	83.8	75.8	77.1	106.6	134.7	202.4	1810
Demre-Akçay	245.3	259.7	229.9	158.4	104.2	62.5	48.7	42.3	38.3	45.3	82.5	172.1	1489

In the sub-basin, there are three dams constructed on two main rivers (Sarıçay and Kocadere) to provide water for the sectors in the region. The total amounts of the water released monthly from the dams in 2017 are taken from DSI, and given in Table 2.3 (DSI, 2018). The results are shown as a figure in Chapter 3.

Table 2.3 - Average total released water from the dams in the sub-basin in 2017 (DSI, 2018).

Dams	Average total released water from the dams in Milas-Bodrum sub-basin in 2017 (Mm3/month)												
Akgedik, Geyik and Mumcular	January	February	March	April	May	June	July	August	September	October	November	December	Total (Mm3/year)
	1.8	2.0	2.1	2.9	3.7	5.5	8.1	7.3	6.4	5.1	2.7	2.4	50.1

2.2 Determination of the current water footprint of the sub-basin

2.2.1 Estimation of water footprint of agriculture sector

Milas – Bodrum sub-basin is an area in which agricultural activities are respectively higher than the other sub-basins in the Batı Akdeniz River Basin. Due to availability of suitable environment and soil structures, and also farmers' habits dating back, olive farming is a dominant agricultural product in the sub-basin with 62,100 hectares and over 100,000 tonnes of olive production. Following agricultural crops are field crops (e.g. wheat, corn, and barley), vegetables (e.g. tomato, cucumber, and watermelon), and orchards like citrus and grape. In Table 2.4, the most common agricultural products and their productions are presented (Ministry of Agriculture and Forestry, 2018a).

Table 2.4 - Agricultural crops grown in the area and their annual productions in Milas-Bodrum sub-basin (Ministry of Agriculture and Forestry, 2018).

	Products	Area (ha)	Production (ton/yr)		Products	Area (ha)	Production (ton/yr)		Products	Area (ha)	Production (ton/yr)
Field Crops	Wheat	6000	20000	Vegetables	Tomato, greenhouse	90	7200	Orchards			
	Barley	2400	4900		Tomato	1000	50000		Pomegrante	40	1200
	Triticale	150	550		Cucumber, greenhouse	35	2100		Apple	50	1500
	Corn, silage	2000	105000		Cucumber	300	6000		Citrus	750	33750
	Maize	700	6600		Cauli	100	1000		Grape	105	735
	Cotton	500	1535		Pepper	250	2500		Peach	70	3500
	Clover	1300	32500		Strawberry, greenhouse	23	110		Others*	100	no data
	Vetch	600	7500		Artichoke	95	760				
	Potato	200	3000		Watermelon	900	62000				
	Sesame	500	400		Lettuce	160	1600		Olive Trees	62100	104500
	Tobacco	250	150		Cabbage	210	6300				
	Others*	1820	no data		Others*	1588	no data				

In the Milas – Bodrum sub-basin, for crops; wheat, barley, triticale, and also olive trees are rain-fed. However, olive trees grown for table olive, which represent 20% of total olive production, are irrigated (Ministry of Trade, 2018). Therefore, 20% percent of total olive production is considered during calculations. Tobacco and sesame are irrigated until the first week of June because of the nature of those which prefer arid climate (TAGEM, 2016). In terms of irrigation technique, furrow (flooding) irrigation is the method preferred the most in the region.

In the calculation of water footprint of each agricultural product, the existing database, WaterSTAT, published by Mekonnen and Hoekstra (2011) was used. WaterSTAT, water footprint statistics, presents statistics on green, blue and grey water footprints of crops, agricultural, and industrial products not only national level but also province level. In Figure 2.4, for the crop groups called 'others*', there is not official data which show what crops are grown even though agricultural production are made. However, these crops are also irrigated. Therefore, this uncertainty was solved by assuming that the farmland where these crops 'others*' are grown had been thought as if the other crops such as tomato, citrus, and wheat are produced. After made the assumptions mentioned above, the water footprint of each crop has been calculated by multiplying the amount of a crop grown on a hectare in tonne with the amount of water consumed in cubic meter per hectare.

For monthly distribution of total blue WF in agriculture sector, there were not any official data which show how much water is used for irrigation for each month. On the other hand, the presence of unlicensed water abstractions from wells or rivers in the region also makes the determination of exact water uses for this sector difficult. However, an official report, published by the directorate general of agricultural researches and policies (TAGEM), provides the amounts of average 10-day precipitation (in mm) and crop water need (in mm) for each crop grown with its growing period in the sub-basin (TAGEM, 2016). Using the data in the report, a crude assumption which may guide for the estimation of monthly water uses in agriculture sector was made. For calculation, the difference between crop water need and effective precipitation (80% of net precipitation used a crop suggested in the report) was determined. If effective precipitation is higher than crop water need in mm, it was accepted that there is not irrigation requirement for the relevant period. In other case, crop water need is higher than effective precipitation, the difference was accepted as net water requirement for that period. The next step for the solution of this uncertainty was to choose the value that represents crop water need for each period in the presence of more than one crop grown in the same period. Therefore, I assumed that when the highest value among the crop water requirements in the same period is selected, the water requirements of the other crops are met. Then, monthly water needs of the crops were calculated in percentage. In the end, total blue WF in agriculture sector was divided into months using the percentages obtained after these assumptions. The equations are given below. Table A.2.1 (in Appendix 2) demonstrates maximum monthly water needs together with crop water needs of the selected crops and average precipitation in mm for the sub-basin.

If;

$$\text{Crop water need (mm)} < \text{Effective precipitation (mm)}, \quad \text{No irrigation needed} \qquad \text{(Eq. 2)}$$

$$\text{Crop water need (mm)} > \text{Effective precipitation (mm)}, \quad \text{Irrigation needed} \qquad \text{(Eq. 3)}$$

Crude estimation for monthly irrigation;

$$\text{Net water need (mm)} = \text{Crop water need (mm)} - \text{Effective precipitation (mm)} \qquad \text{(Eq. 4)}$$

$$Monthly\ precentage\ for\ irrigation\ (\%) = \frac{Irrigation\ need\ per\ month\ (mm)}{Irrigation\ need\ \ per\ year\ (mm)} \qquad \text{(Eq. 5)}$$

The ratio obtained from Equation 5 was used to the estimation of monthly blue water footprints of the agriculture sector, calculated from WaterSTAT data. However, while investigating the effectiveness of the scenarios in the AquaCrop model, monthly irrigation amounts for the selected crops were taken from the model and considered.

2.2.2 Estimation of blue water footprint of livestock sector

Livestock, like agriculture, is also an important income for people living in the sub-basin. According to the official statistics, there are approximately 110,000 cattle, 55,000 sheep and goat, and 130,000 poultry (Ministry of Agriculture and Forestry, 2018b). Under normal situations, the water footprint of an animal consists of two elements; direct water footprint and indirect water footprint. Direct water footprint means the total amount of water consumed for drinking by an animal and used as service which is the water needed for cleaning of animal, farmyard etc, (Mekonnen and Hoekstra, 2012). Indirect water footprint refers to the water used to produce feed for animal, which consists of the sum of the green, blue, and grey water footprints of feeds like maize, barley, and clover.

In this thesis, only blue water footprints of the livestock in the sub-basin were taken into account. The required data for how much water is daily consumed as drinking and service water to an animal were taken the existing database published by Mekonnen and Hoekstra (2012) and mixed production system was adopted. Daily water consumptions of cattle (dairy), cattle (beef), sheep, goats, and poultry are 64, 34.1, 7.9, 5.4, and 0.27 L/animal, respectively.

2.2.3 Estimation of blue water footprint of industrial sector

In the sub-basin, Industrial water consumptions are based on mining, olive, dairy, and fishery (mainly fish farming in sea) industries. The largest water consumer for industry is Yeniköy thermal power plant in the sub-basin with 22.8 million m^3 of water consumption for its cooling unit (Ministry of Environment and Urbanization, 2017). This water is directly transferred from Geyik Dam to the plant. Also, many small and medium-sized businesses area available in the region.

In terms of industrial water use, there is no available data (Ministry of Environment and Urbanization, 2017) except for the water need of Yeniköy thermal power plant. However, a research published by Southern Aegean Development Agency in 2015 about the water footprint of Muğla province indicates that the blue water footprint of Milas – Bodrum sub-basin is 9.78 million m^3 per year (GEKA, 2015).

2.2.4 Estimation of blue water footprint of household sector

The population of the sub-basin is approximately 300,000 (164,000 for Bodrum and 136,000 for Milas) in winter, and the number of the houses is around 207,000 (146,000 for Bodrum and 61,000 for Milas) (TurkSTAT, n.d). On the other hand, water use for domestic purposes in the region in 2017 was determined as 217 L/person/day by Turkish Statistical Institute (TSI) (TurkSTAT, n.d). While calculating the blue WF of household sector, the amount of water determined by TSI was assumed as the blue WF of a person in household sector because the main proportion of the water used in household sector is discharged either to sea or to a receiving environment like a river after a treatment process (DSI, 2018) However, the quality of the water discharged to a receiving environment is lower than of freshwater abstracted from groundwater resources or surface water which is supplied to household sector after treated.

$$T = X * Y * Z \qquad \text{(Eq.6)}$$

Where T = Total monthly blue WF of household sector

X = Monthly population

Y = Number of days in a month

Z = Daily water use of a person

2.2.5 Estimation of blue water footprint of tourism sector and summer-house vacationers

Milas-Bodrum sub-basin is one of the most preferred holiday destinations for both domestic and foreign tourists. Especially in summer months, the population of the region increases four or five-fold. In 2017, the number of tourist visited the region was 1196887 people, with 3973120 stay overnight according the data (Ministry of Culture and Tourism, 2018).

To calculate blue water footprint of tourists on a monthly basis, total overnight numbers of tourists for each month were determined by divided the total overnight numbers of tourists in 2017 into the occupancy rate of the accommodation facilities on a monthly basis (Ministry of Culture and Tourism, 2018) (see in Equation 7).

$$A = B/C * D \quad \text{(Eq. 7)}$$

Where A = Total monthly blue WF of tourism sector,

B = Number of beds occupied by tourists in 2017

C = Monthly occupation rates of accommodation facilities in 2017

D = Blue WF of a tourist

For the determination of water consumption of accommodation facilities for per tourist per night, average water uses were investigated in literature. Hadjikakou, Chenoweth & Miller (2013), Antakyali, Krempe & Steinmetz (2008), and Gössling et al., (2015) were determined the average blue water footprint of a tourist as 300 L, 370 L, and 400 L, respectively, for the hotels both in the sub-basin and the Mediterranean region even though water consumptions differs according to services like pools, spas, golf courses etc. offered by accommodation facilities. In this research, 370 L/person/night was adopted for the determination of the blue water footprint of the tourists in the sub-basin.

While calculating the numbers of summer-house vacationers (SVHs), I assumed that average 3 people live in a house (permanent resident), the number of houses which provide permanent residence is found as 100,000 (Bodrum Municipality Report, 2018). Therefore, the rest of houses can be thought as summer houses (107,000) which provide accommodation during summer months (June, July and August) to summer house vacationers. Therefore, in the summer months (June, July and August), when average 4 people are considered to live both in summer houses and in the houses in which the local residents live, the population reaches 738,000 in the sub-basin. For the calculation, the equation below was used. The water consumptions of these people were assumed the same as local residents' water use (217 L/person/day) (see in Equation 8).

$$E = F * G * H \quad \text{(Eq. 8)}$$

Where E = Total monthly blue WF of SHVs

F = Monthly population

G = Number of days in a month

H = Daily water use of a person

2.3 Water regulation on basin water allocation in Turkey

In Turkey, in determination of sectoral water allocation in a basin, water budget of the basin and priorities of the sectors in the basin regarding water demand are considered. Moreover, order of priority in sectoral water allocation are determined among the sectors in the basin considering both environmental, economic and social values of water and the amount of water used by the sectors (Official Gazette, 2017). The order of priority for water allocation for a basin in general manner is drinking and other domestic uses (e.g., washing), environmental water requirement, irrigation, energy production (e.g., hydropower), and other water-use rights e.g., tourism, recreation, mining.

For the determination of environmental water need in the sub-basin, even though environmental water need is suggested as 15% of average monthly flow volume for maintaining 'moderate' quality of aquatic ecosystem and 20% of average monthly flow volume for maintaining 'moderate-good' quality of aquatic ecosystem by an expert in the Action Plan of Watershed Protection – Bati Akdeniz Basin (TUBITAK, 2013); however, according to the legislation, environmental water need cannot be less than 10% of average monthly flow volume, and this ratio has been legislated as the minimum water amount required to be released by a hydroelectric dam. Therefore, this ratio was accepted for calculations (Official Gazette, 2015).

2.4 Existing water issues in the eyes of the stakeholders

To fully understand the issues experienced in Milas – Bodrum sub-basin, interviews were made with the stakeholders who are responsible for allocation and governance of water, and farmers. Information obtained via the interviews are listed in Table 2.5.

Table 2.5 - Narratives about current issues in the sub-basin according to interviews

Stakeholders	Topics discussed	Results of the interviews
Farmers	Current water problems related to irrigation	▪ Mainly prefer inappropriate irrigation techniques ▪ See drip irrigation as a way that require an extra effort and time ▪ In lowland areas- they complain about sea-water intrusion ▪ Demand subsidizes for intensive and sustainable farming ▪ Need a guidance because they do farming according to their traditional agricultural practices ▪ Market requirements for drought-resistant crops suggested
DSI	Agricultural Irrigation, measured taken	▪ Open canals in use are not suitable for drip and sprinkler system, no pressure ▪ Crop pattern alternatives are needed ▪ For drought season, cropping system is preferred
MUSKI	Problems about water supply	▪ Lack of water supply during summer months ▪ Loss and leaks in water pipelines ▪ Unlicensed groundwater extractions ▪ Complains that small farmers irrigate their crops or plants using drinking water in the lack of irrigation water
Irrigation Unions	Water availability, irrigation techniques, incentives	▪ Do not use irrigation fees to reduce water consumption ▪ No rights sanctions against excessive water consumption ▪ No water supplied to farmers who are not members of the union

2.5 Evaluation of water footprint reduction in agriculture sector

Water use in agriculture sector constitutes the main proportion of the water demand calculated among the sectors in the sub-basin. Therefore, it has been evaluated that how the dependency on water of irrigated crops in the sub-basin could be decreased adopting different irrigation techniques and management practices by keeping the crop yield same and/or decreasing it to an acceptable level. The starting point of this idea is “more crop per drop” paradigm, and by following this, I aim that considerable amount of the ‘blue water’ used in irrigation could be saved, and the free-up water in this way would alleviate the conflicts on water among the sector in the sub-basin, and could be used for other productive uses, including environmental needs.

Different irrigation methods and management practices have been developed and their efficiencies have been the subject of research for many years for the effective use of water resources in the agricultural sector. Milas – Bodrum sub-basin is a region in which agricultural activities are intense and some crops produced are heavily dependent on irrigation water. Therefore, to minimize the effects of water shortage especially during summer months, agriculture sector was evaluated.

2.5.1 Determination of the model (AquaCrop) for the evaluation of irrigation techniques

The amount of water used to irrigate olive trees, maize, alfalfa, tomato, watermelon, and citrus constitutes approximately 85% of blue water footprint of agricultural sector in the sub-basin according to the pre-calculation made using WaterSTAT data. These crops are also listed as high-revenue crops for the sub-basin (SYGM, 2018) Therefore, these crops were primarily evaluated to see how much water can be saved using different irrigation methods and management strategies. FAO AquaCrop model was developed to simulate yield response to water and provides its users to develop irrigation and agricultural management strategies by offering them options to input actual soil, crop, climate data, for instance (FAO, 2017).

The especial features making different from other similar model are also focusing of water productivity, using canopy cover (CC) rather than leaf area index (LAI), future climate change scenarios, and crop – water yields. Even though having some limitations such as horizonal flow of water and single field scale under uniform spatial condition, the model has limited data needs, ability to simulate different crops, management practices, and user-friendly interface. For a broader explanation about the model, Irrigation and Drainage Paper 66 published by FAO could be investigated (FAO, 2012). The flowchart in Figure 2.1 illustrates how processes in the model are executed.

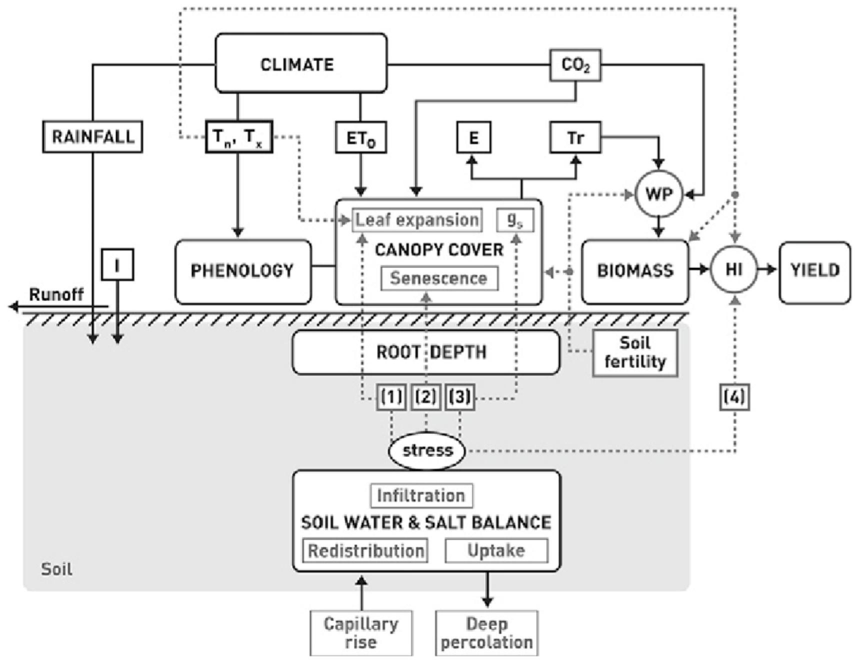

Figure 2.1 - Main processes implemented in AquaCrop (Steduto et al., 2009).

2.5.1.1 Preparation of input data for the AquaCrop model

In this research, AquaCrop model Version 6.1 updated May 2018 was used, and the main components of the model are shown in Figure 2.2. To set up the substructure of the model for the sub-basin, the climate, soil, groundwater data were entered. The climate data was obtained from two different sources. The temperature data were taken from the website of Meteorological Service of Turkish State (MGM, n.d.), the rainfall and evapotranspiration data were obtained from the report published by General Directorate of Agricultural Research and Policies (TAGEM, 2016). For CO_2 data, the file "GlobalAverage.CO2" which is embedded in the model itself was selected. Using daily precipitation and evapotranspiration data, the model produces more accurate outcomes; however, it also uses 10-daily and monthly data as input, and converts them into daily outputs. In this study, the 10-daily data of rainfall and evapotranspiration belonging to the sub-basin were used because of the fact that daily data could not be obtained. Soil and crop data were obtained from Muğla Directorate of Provincial Agriculture and Forestry (2018). The soil characteristic of the region in which agricultural activities being carried out is sandy-clay-loam, which was selected among the files in the model, called "SandyClayLosm.SOL". The groundwater level in the sub-basin changes between 0 m and 50 m (DSI, 2018), so the groundwater level was assumed as 4 meters and constant for the model because after 2-meter water deep, the results obtained from the model do not change.

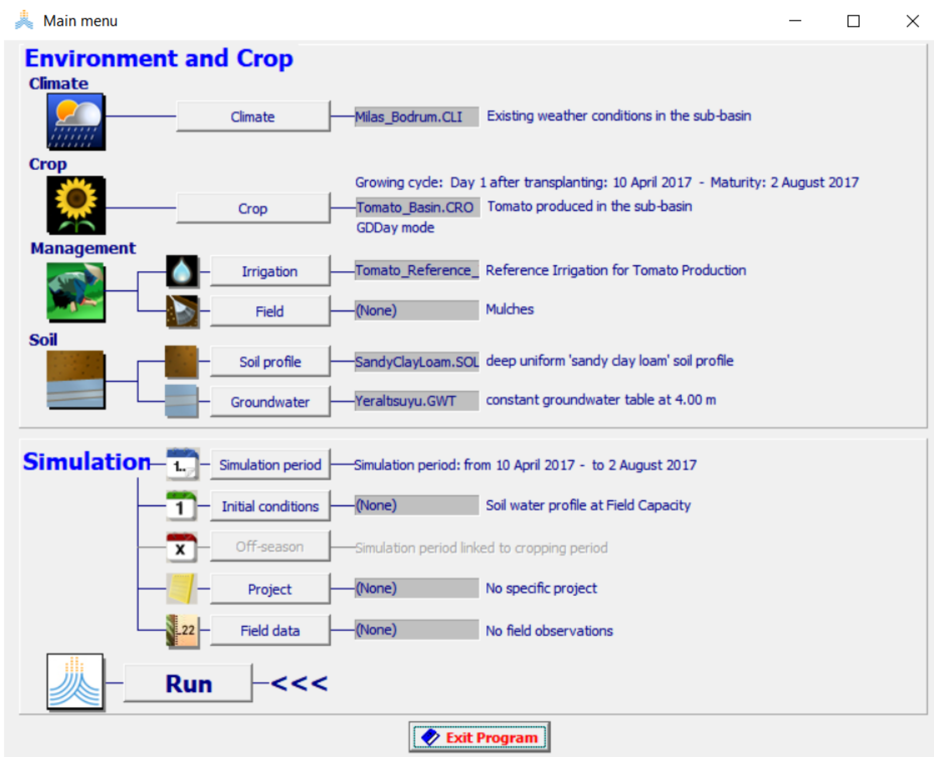

Figure 2.2 - Overview of the AquaCrop model with its main components.

The model includes some calibrated crop files in itself like cotton, sunflower, tomato, maize, and potato. The user has an advantage of describing a new crop using the guideline published by FAO (FAO, 2017) and/or adjusting the calibrated crops entering the data belonging to area on which he/she works.

For selected crops (tomato, maize, watermelon, alfalfa, olive and citrus) in the sub-basin, different irrigation methods and scenarios provided by the model were evaluated. The maize and tomato crop files were adjusted using local data like plant spacing and planting method (sowing or transplanting). For the other crops which are not included as pre-defined crop files in the model, new crop files were created using both local data belonging to that crop and reference conditions suggested in reference manual (annexes) provided by FAO (TAGEM, 2016; FAO, 2012).

2.5.1.2 Determination of irrigation techniques and field management

The AquaCrop model offers its user pre-defined irrigation simulation choices; rainfed-agriculture, surface (basin, furrow, border) irrigation, sprinkler irrigation, and drip irrigation. It also provides field management practices; soil fertility, mulches, and weed management. Moreover, the model provides an opportunity for deficit irrigation. Deficit irrigation is a method which aims reducing the amount of irrigation water without reducing crop yield or maximizing crop yield if possible (Capra et al., 2008).

In this research, I implemented deficit irrigation technique combining with irrigation methods (sprinkler, drip etc.) and mulching practices (organic or plastic) to see which combination can be more useful to reduce blue water footprint of a crop without reducing crop yield. For scenarios, production losses were determined after applied trial-and-error method which was based on ET water productivity in the model. ET water productivity means the ratio between yield and water; therefore, it aims the maximum yield per water used. Irrigation and management techniques were selected by considering crop types according to FAO Manual (FAO, 2018). Drip irrigation is favourable to watering individual crops or trees or row crops like vegetables. It is not suited for close-growing crops like wheat, oat, and rice. On the other hand, surface irrigation can be suited for all kinds of crops (FAO, 1989). Therefore, while modelling the crops grown in the region, alfalfa was considered as unsuitable for drip irrigation technique and mulching, so it was evaluated only for deficit irrigation.

2.5.2 Customization of selected crops of the model

Even though the AquaCrop model has some pre-defined crop files in itself, it also requires local conditions, local agricultural practices for each crop. For crops that not included as standard crop files in the model, new crop files were created using the guideline published by FAO, and local data obtained both literature and local sources (FAO, 2012; MEGEP, 2008). It is obvious that all parameters I entered in the model while creating the crop files for the crops not included as standard crop within the model may not support the model to present real-like result. However, calibrating and validating the crop new for the model require a pilot-scale field study for each crop. Therefore, I aimed the model to imitate the crop yield response to water by using the data I obtained the relevant sources (FAO, 2012; MEGEP, 2008; Ministry of Agriculture and Forestry, 2019).

2.5.2.1 *Customization of tomato crop*

In this sub-section, the stages of the calibration of tomato crop are explained. Turkey is the 4th largest tomato producer in the world with approximately 12 million tonnes per year due to its suitable climate (The Daily Records, 2018). Tomato production is account for around 40% of all vegetables in Turkey. In the sub-basin, the amount of tomato production was around 55,000 tonnes according to official reports (Ministry of Agriculture and Forestry, 2018). Around 5,000 tonnes of it, roughly 10% of the whole production, was produced in greenhouses, and the remaining amount was produced using traditional methods and mainly with furrow irrigation.

In the sub-basin, tomato planting period starts in the second week of April and harvested in the end of July, so growing period accounts for around 4 months. The day after of planting, tomatoes are irrigated for the first time and not irrigated until flowering period starts. The distance between tomato seedlings is around 50 cm (plant spacing) and the distance at rows is around 130 cm (row spacing) according to the regional management practices (Ministry of Agriculture and Forestry, 2019). On the other hand, the model gives “dry yield” and “biomass” as output. However, tomato production is calculated as “fresh yield”; therefore, dry matter content needs to be converted to “fresh yield”. For this study, dry matter content of tomato was assumed as 10%. The other inputs suggested in reference manual (annexes) are presented below in Table 2.6. The numbers in Table 2.6 have already been entered and calibrated within the model itself, therefore they have been accepted as presented in the model.

Table 2.6 - Parameters used for tomato production in the model (1) conservative generally applicable, (2) conservative for a given specie but may be cultivar specific, (3) dependent on environment and/or management, (4) Cultivar specific (FAO, 2018).

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	7.0
T_{upper}	Upper temperature (°C)	Conservative (1)	28.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	1.0 (direct seeding) 5.0 to 20.0 (transplant)
	Number of plants per hectare	Management (3)	15,000 – 80,000
	Time from sowing to emergence / transplant to recovery (growing degree day)	Management (3)	40 - 80
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.0075
CC_x	Maximum canopy cover (%)	Management (3)	Fairly to almost entirely covered
	Time from sowing / transplant to start senescence (growing degree day)	Cultivar (4)	Recovery + 1300 - 1600
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.004
	Time from sowing / transplant to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Recovery + 1500 - 2000
1.3 Flowering			
	Time from sowing / transplant to flowering (growing degree day)	Cultivar (4)	Recovery + 250 - 400
	Length of the flowering stage (growing degree day)	Cultivar (4)	600 - 900
	Crop determinacy linked with flowering	Conservative (1)	No
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.00
	Shape factor describing root zone expansion	Conservative (1)	1.5
2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m²)	Conservative (1)	18.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	55 - 65
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	None (Estimated)
	Excess of potential fruits (%)	Conservative (2)	Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	None (Estimated)
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Strong (Estimated)
	Allowable maximum increase (%) of specified HI	Conservative (1)	15 (Estimated)
4. Stresses			
Symbol		Type (1), (2), (3), (4)	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative (1)	0.15 (Estimated)
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative (1)	0.55 (Estimated)
	Shape factor for Water stress coefficient for canopy expansion	Conservative (1)	3.0 (Estimated)
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative (1)	0.50 (Estimated)
	Shape factor for Water stress coefficient for stomatal control	Conservative (1)	3.0 (Estimated)
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative (1)	0.70 (Estimated)
	Shape factor for Water stress coefficient for canopy senescence	Conservative (1)	3.0 (Estimated)
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative (1)	0.92
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar (4) Environment (3)	5.0
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative (1)	10.0 (Estimated)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative (1)	40.0 (Estimated)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative (1)	Not considered
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative (1)	1.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative (1)	12.8

2.5.2.2 Customization of maize crop

Silage maize production which is an important input together with alfalfa production for animal breeding in the sub-basin accounts for 18% of total blue water consumption of the agricultural sector according to the production data in 2017 and the existing database which shows how much water is required to grow a tonne of corn (reference, year). In the sub-basin, farmers produced 120,000 tonnes of silage maize in around a 2,250-hectare area in 2017.

According to the local practices in the sub-basin, the planting date starts in the second week of April and growing period lasts around 120 days. The sowing rate, 1000 seed mass, and the germination rate of maize were chosen as 30 kg seed/ha, 320 g, 95%, respectively (Ministry of Agriculture and Forestry, 2019). The soil surface covered by a seedling at 90% emergence was proposed 6.5 cm^2/plant in the reference manual (annexes) of the AquaCrop (FAO, 2012). Dry matter content of silage maize is suggested as between 30 – 35 % (FAO, 2012). For this study, dry matter content was assumed 30%. For the calculation of fresh yield of silage maize, the output "biomass" in the model was used because this refers to total dry yield of the crop above ground.

2.5.2.3 Customization of alfalfa (clover) crop

The model does not provide a data file for crop alfalfa; therefore, a new file is needed to be created in the model for this crop. In practice, alfalfa is a crop harvested four – seven times in the year according to the suitability of climate, the presence of sufficient water, and good management practices (TAGEM, 2016). However, the AquaCrop 6.1 model has not supported yet forage crops, which are generally harvested many times in year. Therefore, in literature, a few researchers who wanted to model alfalfa or another forage crops using the AquaCrop model executed different scenarios at least to mimic the yield response of forage crops to water. Huning and Droogers (2010) assumed that alfalfa is harvested one time, by ignoring multiple harvesting, in a year, and the total yield of alfalfa was accepted as the amount at the end of the season, with one harvesting. Nyathi et al. (2018) were investigated three forage crops, not including alfalfa, and tried the simulations by considering that each harvest in the season is simulated separately, then compared their simulated results with own measured results to see the validation of the model for the forage crops and found that the standard deviations range between 0.60 and 0.99, which were accepted as "sufficient" by them. Therefore, I followed the way of Nyathi et al. (2018) by adding small changes in order to mimic alfalfa's yield response to water.

In the region, alfalfa is grown between March and November, with four – seven times harvesting, here I assumed five times harvesting, and it is generally irrigated using sprinkler system. Alfalfa seeds are quite small (2g/1000 seeds) and directly sowed in soil. Farmers use approximately 30 kg Alfalfa seed per hectare in the region (Ministry of Agriculture and Forestry, 2015). Both the information belonging to the regional management practices and alfalfa's characteristic specifications found in the literature (FAO, 2012) were entered to the model to simulate the crop.

In order to imitate alfalfa crop in the model, in the beginning of the season, alfalfa is sowed in the soil for the first harvest. However, for the other harvest periods, alfalfa is assumed as a transplanted leafy crop because just after each harvest, alfalfa is available on the soil with around 5 – 10 cm, also keeping the plant density same. It was assumed that the simulation for canopy cover of alfalfa crop produces real-like results. Thinking canopy cover as one of the most important factors in the model is significant because it plays an important role for the determination of evapotranspiration (ET). If I assumed alfalfa is harvested one time at the end of the season as Huning and Droogers (2010) did, the canopies of alfalfa would totally cover the soil by excessively preventing water evaporation on the soil. However, it is known that the model does not present any choice to simulate root development of the crop for multiple harvested crops, so the uncertainty pertinaciously continues for the model, affecting to the results.

For the simulations, I also assumed according to the regional management practices that the first harvest time is 60 days later than sowing, and the other harvest times are 50 day later than previous harvesting, and 1,666,667 plant/ha for the crop, which was adopted from an earlier study (Rankin, 2007).

2.5.2.4 Customization of watermelon crop

Watermelon production is one of the most primer crop types in Turkey following China, the leader produces by far in the world, and its production has also started to become important in the sub-basin (Ministry of Agriculture and Forestry, 2018). In 2017, approximately 93,000 tonnes of watermelon were produced in around 1,350 hectares.

Watermelon, like alfalfa, is not a crop type pre-defined in the model. Therefore, a new crop file representing watermelon was created. Due to the absence of the pre-defined data file for the crop, I used the database of the crop provided by FAO and the data calibrated for watermelon as by Reddy (2015) in his research. Then, I adjusted the data obtained for the model according to the local conditions using local farmers' applications for the crop in the region. In the regions, the crop is planted with 2 m for row spacing and 0.75 m for plant spacing, which correspond to around 6,650 of plant seedling in one hectare. The planting date begins in middle of March and ends at the end of June, around 100 growing days. The crop prefers dry and hot conditions, so the growing rate increases at 22 – 30 ^{o}C. The maximum canopy cover, and dry matter content of the crop were assumed 95%, and 8%, respectively (Reddy, 2015; FAO, 2012). Moreover, Canopy growth coefficient (CGC) and canopy decline coefficient was selected 0.11 and 0.07, respectively. Abdelkhalik at al. (2019) found have found that the harvest index for watermelon ranges between 0.32 and 0.58 according to irrigation management. For full irrigation, they determined that the harvest index reaches maximum value with 0.43 in 2016, so this value was accepted.

2.5.2.5 Customization of olive trees

Olive farming is an important source of income for farmers in the region. A report published by the Ministry of Agriculture and Forestry indicates that olive yield for per tree is around 9 kg non-irrigated areas while the yield reaches around 33 kg per tree for irrigated areas, and there are approximately 200 olive trees per hectare in lowland areas (Ministry of Agriculture and Forestry, 2018). Dry matter content was accepted as 70%. Olive is not a pre-defined crop for the model, so a new crop-file was created. However, as mentioned before, the AquaCrop model cannot model perennial plants, so I tried to model the crop to mimic crop water productivity by following the approach in the report of Future Water written by Hunink and Droogers (2010). Reference Harvest Index for olive was accepted as 18%, and initial canopy cover was assumed %10. Growing cycle for olive starts in March and finishes in November.

2.5.2.6 Customization of citrus

Like olive and alfalfa, citrus is not a pre-determined crop in the AquaCrop model. Therefore, a new crop file was created considering the features of citrus crop and local management practices. Annual yield of citrus trees in the region is around 45 tonnes per hectare, and there are around 400 of citrus trees in a hectare. Initial canopy and maximum canopy were assumed as 0.6 and 0.7, respectively, in the line of FAO's database (FAO, 2012). Moreover, root depth and dry matter content were inputted as 0.5 and 0.2, respectively (FAO, 2012). Harvest Index for fresh fruit has been suggested as around 70% by Neto and Miranda (2009), so considering its dry mass content, it was assumed as 14%. Suitable temperature range for citrus is 10° C – 40° C, which was arranged in the model.

CHAPTER 3

Results

3.1 Results of the current blue water footprints in the sub-basin

3.1.1 Water footprint of agriculture sector

The results of the green, blue, and grey water footprint of each product group and olive farming in the sub-basin are presented in Table 3.1. According to the results, around three out of four of total agricultural WF in the sub-basin is green water footprint. Blue and grey WFs of agricultural crops are 14% and 10%, respectively, which is shown in Figure 3.1. Among the agricultural crop groups, field crops constitutes the main proportion of the WF with 67% in the basin.

Table 3.1 - Green, blue, and grey WFs of the crop production, in crop groups, in 2017.

Product Groups	Green WF (Million m3/year)	Blue WF (Million m3/year)	Grey WF (Million m3/year)
Field Crops	326.3	66.9	53.9
Vegetables	14.9	15.0	5.1
Orchards	15.1	12.1	2.7
Olive Trees	262.6	6.3	18.6
All Crops	618.9	100.4	80.3

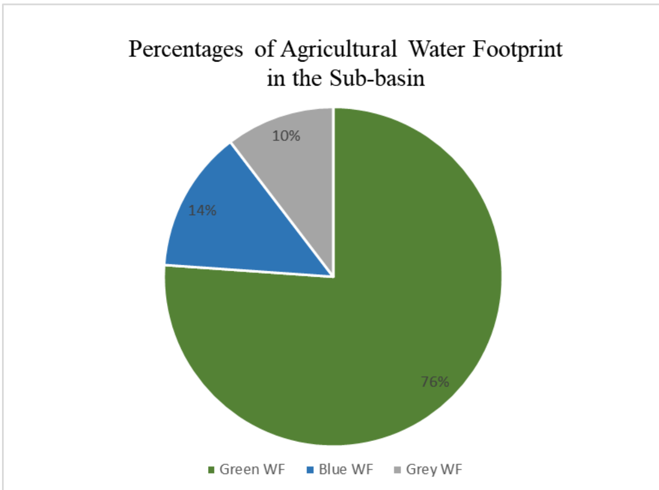

Figure 3.1 - Proportions of Agricultural WF in the sub-basin.

Regardless of production amounts of the crops grown in the sub-basin, wheat, corn, alfalfa, vetch, and olive are heavily dependent on rainfall (green water). Any decrease in rainfall may pose a threat for that crops such as decrease in production quantities or drop in product quality. On the other hand, some crops (olive, corn, tomato, watermelon, and citrus) also dependent on the presence of irrigation water (blue water). In a dry season, the productions of the crops are dependent on irrigation water, which probably increase water stress in the region. Moreover, in the absence of the availability of irrigation water, the productions of citrus, corn and tomato economically suffer from this situation. Table 3.2 gives monthly blue WFs calculated in the line of the assumptions that are made. In winter, there is no irrigation activities in the region while it reaches maximum during summer months.

Table 3.2 - Monthly Blue WFs in agriculture sector (million m3).

Total montly Blue Wfs of the Agricultural Sector in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
0.00	0.00	2.30	5.80	15.40	21.70	24.90	16.90	9.10	4.30	0.00	0.00	100.40

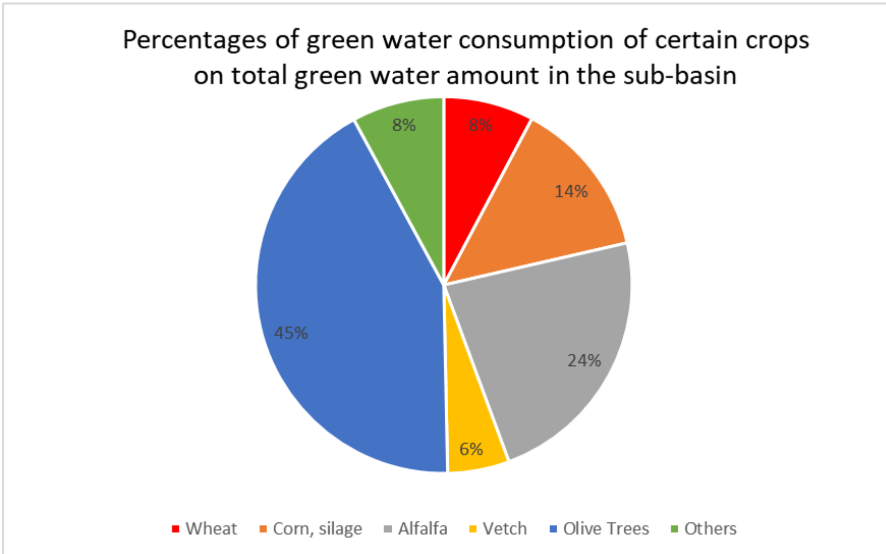

Figure 3.2 – The ratios of green WFs of certain crops on total green WF in the sub-basin.

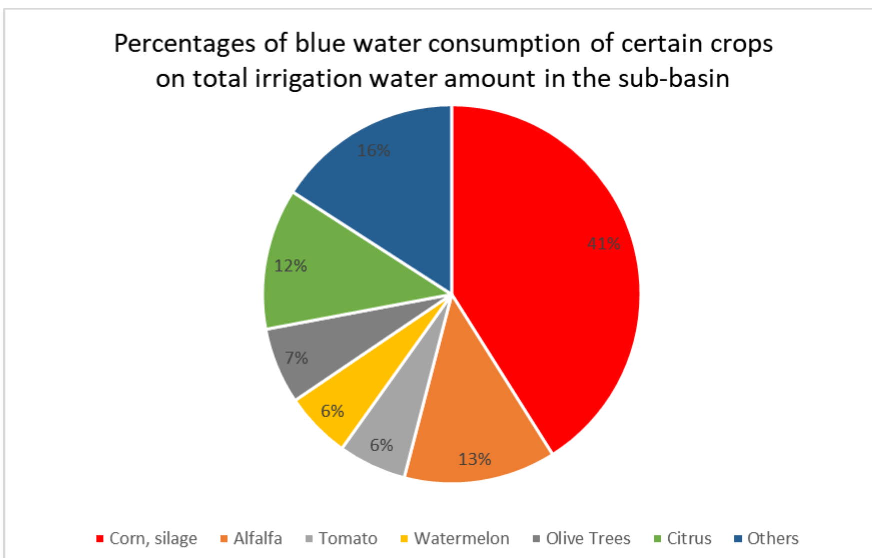

Figure 3.3 - The ratios of blue WFs of certain crops on total blue WF in the sub-basin.

3.1.2 Blue water footprint of livestock sector

In the basin, blue water footprint of livestock was calculated on a monthly basis and the results are shown below in Table 3.3. For the year of 2017, the total blue WF of livestock was calculated around 2.2 million m^3.

Table 3.3 – Monthly Blue WFs in livestock sector.

Total monthly Blue WFs of the Livestock in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
0.18	0.17	0.18	0.18	0.19	0.18	0.19	0.19	0.18	0.19	0.18	0.19	2.17

3.1.3 Blue water footprint of industrial sector

The monthly results of industry in the sub-basin were calculated using the references (see section 2.2.4). According to the references, annual blue WF of the industry is approximately 32.6 million m^3. On a monthly basis, blue WF was found as around 2.7 million m^3 by dividing annual amount into the number of months in a year.

Table 3.4 – Monthly Blue WFs in industrial sector.

Total montly Blue Wfs of the Industrial Sector in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	32.60

3.1.4 Blue water footprint of household sector

In the sub-basin, due to a stable population pattern, monthly Blue WFs of this sector do not remarkably change during the year. For the year of 2017, the monthly and annual blue WF of local people are shown in Table 3.5.

Table 3.5 – Monthly Blue WFs in household sector.

Total montly Blue Wfs of the Local Residents in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
2.02	1.82	2.02	1.95	2.02	1.95	2.02	2.02	1.95	2.02	1.95	2.02	23.76

3.1.5 Blue water footprint of tourism sector and summerhouses

Tourism sector has a crucial importance not only for the sub-basin but also for the country. The number of tourist and the blue WF of tourism on a monthly basis and are shown in Table 3.6 and Table 3.7, respectively. The annual blue WF of tourists who stayed in an accommodation facility like hotel was calculated 1.47 million m^3.

Table 3.6 – Monthly overnight numbers of the tourists in 2017 in the sub-basin.

Total Overnight Numbers of the Tourists Visited the Region on a Mothly Basis												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
163604	157394	197865	250865	357698	402306	561226	590649	496388	389865	209381	195879	3973120

Table 3.7 – Monthly Blue WFs of tourists .

Total montly Blue Wfs of the Tourism Sector in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
0.06	0.06	0.07	0.09	0.13	0.15	0.21	0.22	0.18	0.14	0.08	0.07	1.47

Another important parameter which increases the blue water consumption in the region is the presence of summer-house vacationists during summer months. The numbers and the results of the blue WF of summer-house vacationists (SHV) are shown in Table 3.8 and Table 3.9.

Table 3.8 – Seasonal population of SHVs in the sub-basin .

Total Population of the Summer-House Vacationists in the Sub-basin in 2017 (person)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
0	0	0	0	0	438000	438000	438000	0	0	0	0	1314000

Table 3.9 – Monthly Blue WFs of SHVs.

Total montly Blue Wfs of the Summer-House Vacationists in 2017 (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
0.00	0.00	0.00	0.00	0.00	2.86	2.95	2.95	0.00	0.00	0.00	0.00	8.74

The annual blue WF of people who visited the region for a length of time as tourist was calculated 10.21 million m^3 of water.

3.1.6 Environmental water requirements

For the sub-basin, minimum monthly environmental water needs were determined by considering 10% of average annual monthly flow regimes of the rivers between 1985 – 2014 in the region, which is a mandatory ratio for hydroelectric plants to protect aquatic life in Turkey.

Table 3.10 – Monthly environmental flow requirements.

Estimated Mothly Environmental Water Requirement in the sub-basin (Mm3)												
January	February	March	April	May	June	July	August	September	October	November	December	Annual
9.47	10.73	7.16	3.61	1.34	0.64	0.60	0.46	0.49	0.87	2.43	5.73	43.60

3.1.7 Comparison of water supply and water demand in the sub-basin

In this research, in the light of the official data and assumptions I already mentioned, the total blue water footprint of all the selected sectors (agriculture, livestock, tourism, industry, and local residents) was calculated approximately 212 million m^3, including minimum allowed environmental water requirement. Almost half of the total blue water footprint in the sub-basin was consumed by farmers for agricultural activities in 2017. While the environmental water requirement comes to the second rank with 43.6 million m^3, the second sector in the sub-basin in terms of blue water consumption is industry with 32.6 million m^3. The biggest blue water consumer of the industrial sector in the region is Yeniköy thermal power plant, with around 23 million m^3 of water. Even though tourism including the summer-house vacationers (SHVs) is seen the main source of revenue for the region both locals and the government, the blue water footprint of them was found around 10 million m^3. Figure 3.4 demonstrates approximately what percentage of 'blue water' was consumed by what sector in the sub-basin in 2017. In Turkey, while calculating the water consumption among sectors, environmental water requirement is not considered as a sector, so when the environmental water requirement in the sub-basin is kept separate, the ratio of agriculture sector increases up to 60%.

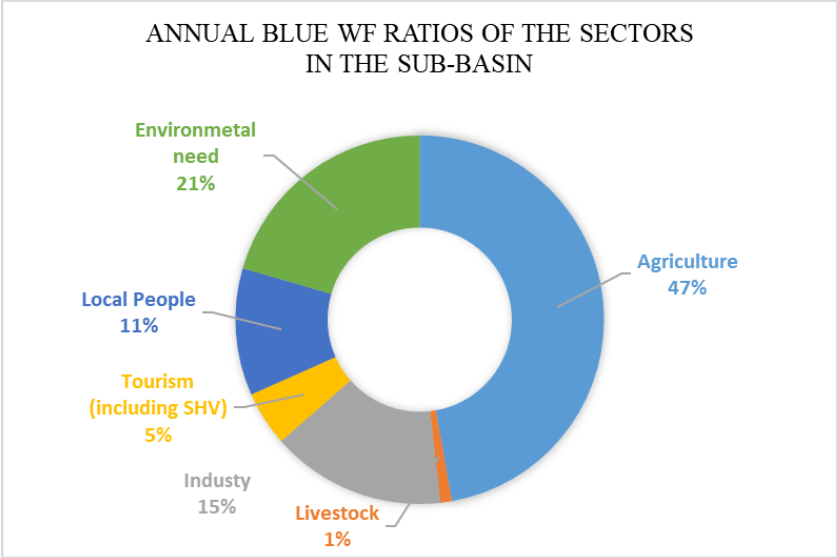

Figure 3.4 – Blue WF ratios of the sectors in the sub-basin in 2017.

On the other hand, Figure 3.5 below demonstrates the average monthly water availabilities for the year of 2017 in the sub-basin. The black line in Figure 3.5 was calculated as monthly water budget in 2017 and used to compare the monthly water demands and supplies in Figure 3.6.

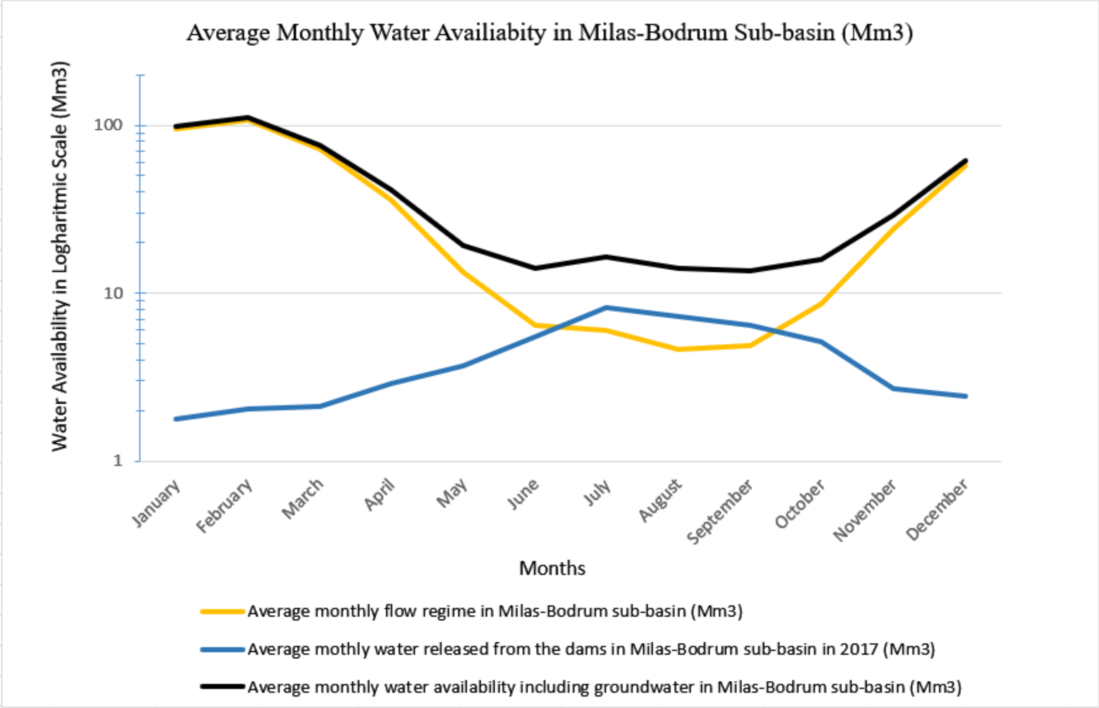

Figure 3.5 - Average Monthly Water Availability in Milas-Bodrum Sub-basin in 2017.

As a result of the calculations for water demand and supply, it can be mentioned that water shortage especially during summer months is experienced due to overuse of the resources by the sectors. This situation is also expressed in the report of the Ministry of Agriculture and Forestry as excess and uncontrolled water abstractions from the resources and periodic drought in some rivers (DSI, 2018). Except summer months, as can be seen in Figure 3.6 below, available water in the region satisfies the sectors' demands including the environmental water need. However, both increase in irrigation activities on current crop types, and touristic facilities and decrease in precipitation during summer months brake supply and demand equilibrium.

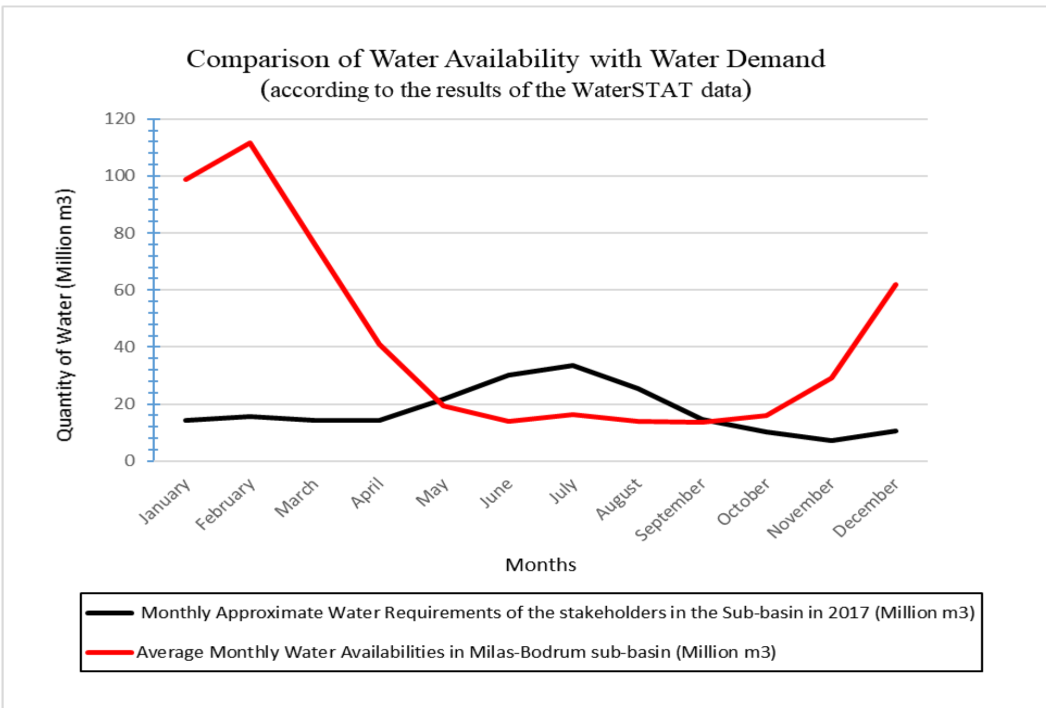

Figure 3.6 – Comparison of monthly water demands and supplies in the sub-basin in 2017.

3.2 Potential water footprint reduction in the agriculture sector

3.2.1 Tomato

To evaluate the water-use efficiency for tomato production using different irrigation methods and managements, I introduced full irrigation, deficit irrigation, deficit irrigation with organic mulching and deficit irrigation with plastic mulching as scenarios and implemented them combining with irrigation methods (furrow, sprinkler and drip). Figure 3.7 shows the results of the comparisons of scenarios in m^3 per tonne tomato production.

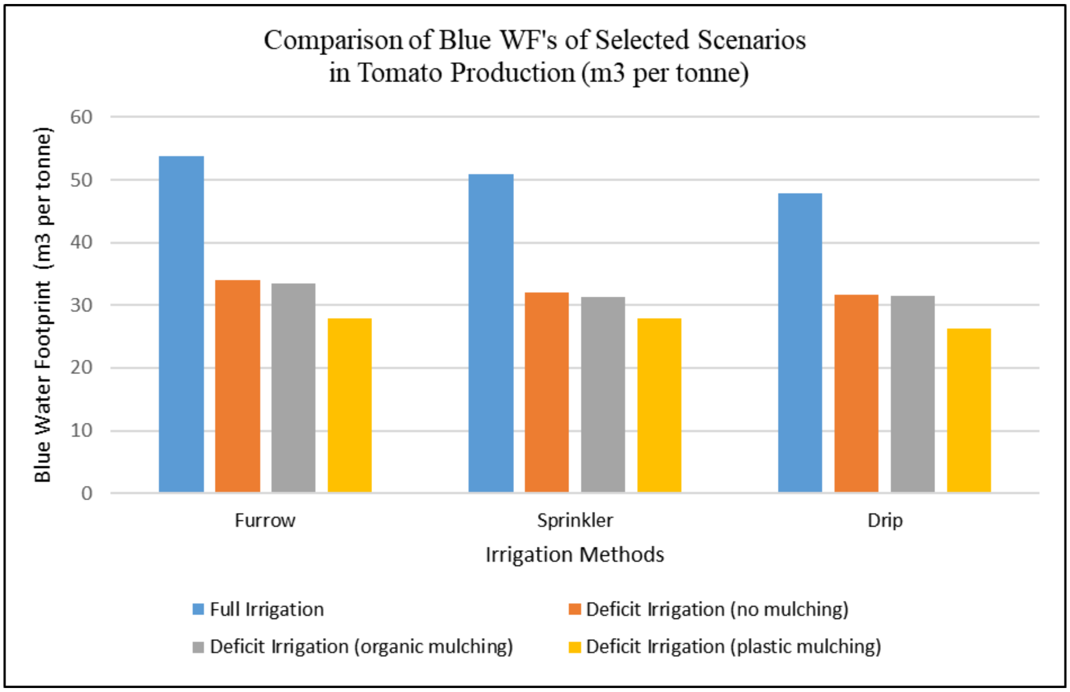

Figure 3.7 - The blue water footprints of tomato production according to selected scenarios.

According to the scenarios applied, deficit irrigation (no mulching) was provided a significant decrease in the requirement of irrigation water with a slight decrease in loss of production as percentage for all of irrigation methods compared to the full irrigation strategy. At this point, the losses in dry yield, compared to the full irrigation, experienced decreases of 3.3%, 6.5%, and 5.5% with furrow, sprinkler, and drip irrigation methods, respectively (see in Table A.3.1 in Appendix 3). Another scenario was to combine deficit irrigation with organic mulching. Here, this scenario performed insignificant outcomes compared to the deficit irrigation (no mulching) scenario. The underlying reason of this result can be explained that the ability of organic mulching to retain moisture of the soil is less than of plastic mulching (Narayan et al., 2017). However, organic mulching slightly made positive contribution to increase in dry yield of tomato production. This contribution indirectly have and positive effect on water productivity. The last but the most efficient scenarios in tomato production was the combination of deficit irrigation with plastic mulching for all irrigation methods. With this scenario, slight decreases in dry yield of the production around 1% can be seen; however, plastic mulching is useful for retaining of the soil moisture, which decreases blue water need of the crop (Narayan et al., 2017). For all irrigation methods, this scenario saved approximately 600 m^3 of blue water per hectare.

In 2017, regarding total blue water footprint of tomato production in the sub-basin in which around 50,000 tonnes of tomato was produced, 2.70 million m^3 of blue water for irrigation is calculated according to the result of the AquaCrop model with the reference scenario, the combination of full irrigation with furrow technique. However, this amount could be reduced to average 1.6 million m^3 of blue water footprint with deficit irrigation management (no mulching) for all the irrigation methods, and reduced to 1.31 million m^3 of blue water footprint with the combination of deficit drip irrigation with plastic mulching. Consequently, deficit irrigation may provide saving up to 1.1 million m^3 of irrigation water on tomato production in the sub-basin. This can be increased up to 1.4 million m^3 of irrigation water by combining deficit irrigation with plastic mulching.

3.2.2 Maize

The scenarios mentioned in tomato production section were also implemented in silage maize production in the model, and the results are given in Figure 3.8 below and Table A.3.2 in Appendix 3. In the model, full irrigation and deficit irrigation (with/out mulching) management techniques were evaluated using three irrigation methods. With full irrigation, a tonne of silage maize (fresh yield) can be produced consuming approximately 76 m^3 of irrigation water with furrow or sprinkler system. This amount decreases to 57 m^3 of irrigation water if drip irrigation is used.

Deficit irrigation scenarios are seen to be useful for all types of irrigation methods. In the model, by consenting a maximum 10% of loss of maize production, around 25 m^3 of water with furrow or sprinkler methods and around 13 m^3 of water with drip irrigation can be saved for a tonne of maize production. When plastic mulching is combined with deficit irrigation, the savings reach to 45 m^3 of water with furrow or sprinkler methods and around 25 m^3 of water with drip irrigation. Like in the result of tomato production, organic mulching made a quite less contribution to water saving due to the fact that it does not prevent evaporation from the soil substantially.

In 2017, in terms of the total blue water footprint of maize production in the sub-basin in which around 120,000 tonnes of maize was produced, 9.12 million m^3 of blue water was consumed according to the result of the model with the reference scenario, the combination of full irrigation with furrow technique. However, this amount could be reduced to average 6.2 million m^3 of blue water footprint with deficit irrigation management (no mulching) for the furrow and sprinkler irrigation methods, and reduced to 5.3 million m^3 of blue water footprint with deficit drip irrigation (no mulching). On the other hand, deficit irrigation with the combination of plastic mulching may decrease required irrigation water up to 3.78 million m^3 on maize production in the sub-basin.

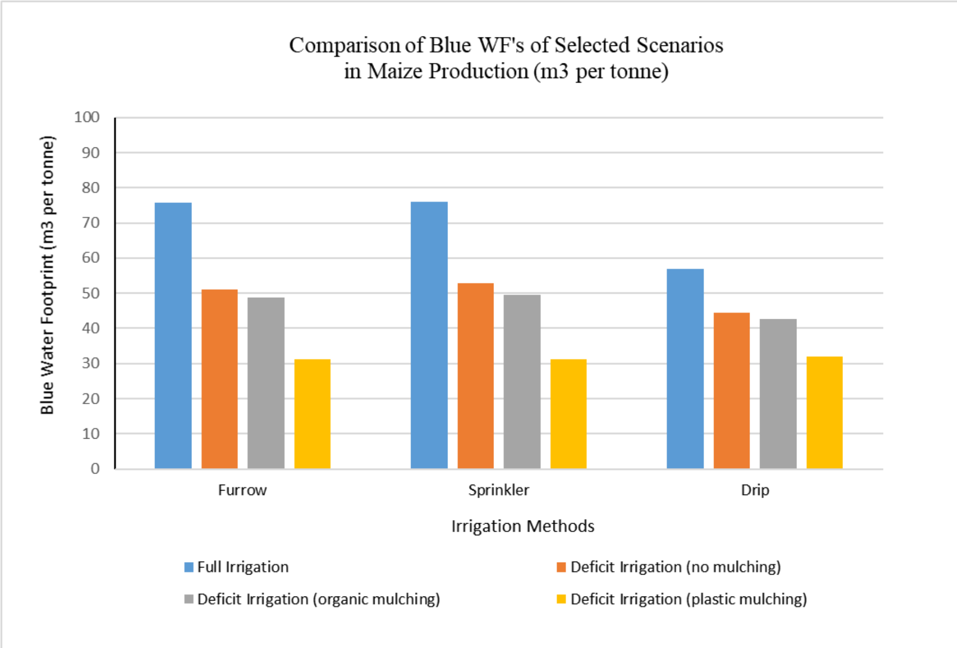

Figure 3.8 - The blue water footprints of maize production according to selected scenarios.

3.2.3 Alfalfa (clover)

For the determination of crop yield response of alfalfa crop, only sprinkler irrigation was evaluated because of the suitability of the technique for the crop. Drop irrigation is not suggested by FAO due to the high capital cost of installing of it and difficulty in application. On the other hand, mulching is not suitable for this crop. Therefore, deficit irrigation with sprinkler irrigation technique was tried with the model, and the results are given in Figure 3.9.

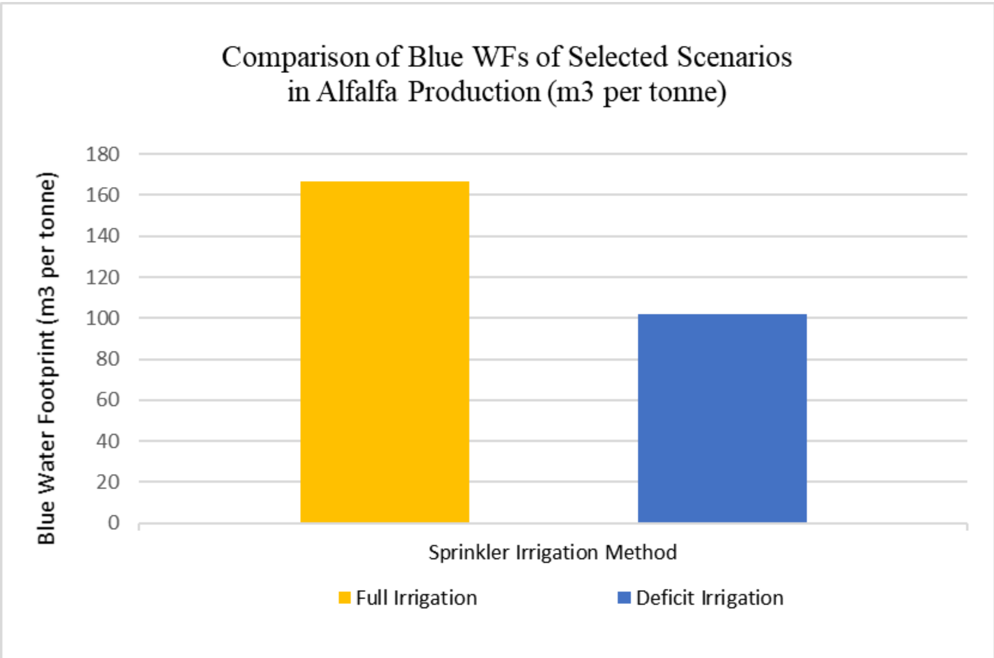

Figure 3.9 - The blue water footprints of alfalfa production according to selected scenarios.

With only 10% loss of production, 65 m^3 of water can be saved for per hectare according to the results of the model. In the beginning, I assumed 5 times harvesting for alfalfa in a year, but the fifth cutting, between 11th October and 29th December, corresponds to rainy period, so the alfalfa grown in this period does not need irrigation, and not considered during calculation procedures. Adopting deficit irrigation with sprinkler irrigation technique, around 2.1 million m^3 of water could have been saved in the sub-basin.

3.2.4 Watermelon

The water consumptions of watermelon production under different scenarios were evaluated and compared. The results are shown in Figure 3.10. A tonne of watermelon requires around 50 m^3 of blue water according to the model under the reference situation, the combination of full irrigation with furrow technique. Assuming that up to a maximum of 10% production loss, approximately 12 m^3 of blue water can be saved with deficit irrigation (no mulching) for per tonne of watermelon production compared to the results of full irrigation in the model. However, the most effective result is seen if drip irrigation with plastic mulching under deficit technique is preferred. The underlying reason is the contribution of plastic mulching which prevents evaporative water on the upper soil.

In 2017, watermelon production was 93,000 tonnes in the region. If drip irrigation were preferred with the combination of plastic mulching and deficit irrigation (29 m^3 per tonne), approximately 1.8 million m^3 of blue water could be saved.

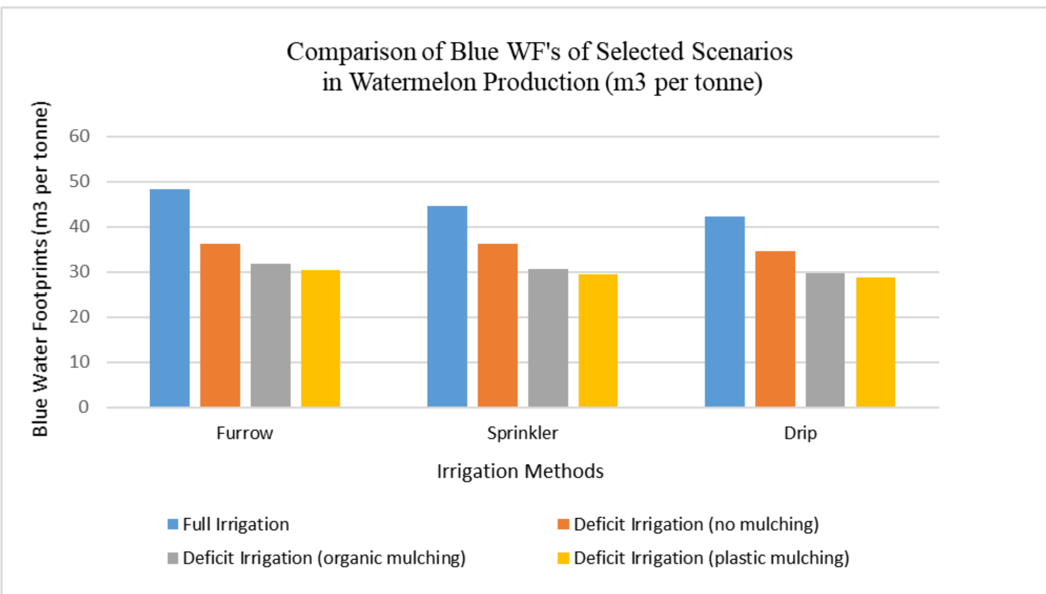

Figure 3.10 - The blue water footprints of watermelon production according to selected scenarios.

3.2.5 Olive trees

Olive trees for table olive production in the region are irrigated in low-land areas, which constitutes 20 percentages of the total yield with around 20,000 tonnes of olives. According to the olive production report published by the Ministry of Trade, average yield per hectare is estimated around

6.5 tonnes in 2017 (Ministry of Trade, 2018). Olive trees require around 800 – 1,200 mm of water for high yield (FAO, 2012). In the sub-basin, average precipitation is around 230 mm; therefore, the rest has to be supported with irrigation, which is around 750 mm. For deficit irrigation, the maximum allowed loss of production is 10%. The results of the model for the selected scenarios are provided in Figure 3.11.

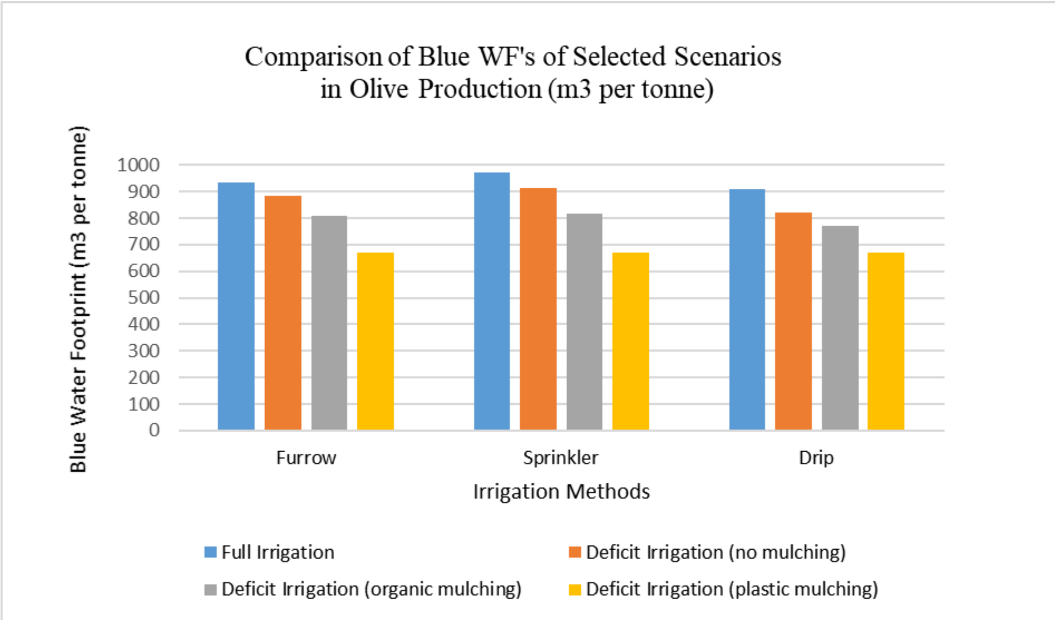

Figure 3.11 - The blue water footprints of olive production according to selected scenarios.

According to the results, all irrigation scenarios surprisingly show a similar trend. Compared to the results of other crops simulated (tomato, maize, watermelon, and alfalfa), deficit irrigation (no mulching) is lesser effective on olive trees and citrus trees (see Figure 3.12 below), which are in perennial crop groups. However, mulching scenarios provide remarkable water savings for all irrigation methods. Deficit irrigation with plastic mulching provides up to 250 m^3 blue water per tonne of olive production. Even though the model does not offer calibrated results for olive farming, some researchers found similar outcomes with what the model presents (Hijazi et al., 2014; Fader et al., 2016). Input irrigation parameters and the outputs are given in Table A.3.5 in Appendix 3.

3.2.6 Citrus Trees

In the AquaCrop model, water consumption amounts of citrus production were calculated for per tonne simulating the scenarios determined before. The model estimates blue WF of citrus is around 190 m3 per tonne for full irrigation with furrow method, which is the reference scenario, and approximately 150 m3 per tonne for deficit irrigation (plastic mulching). According to the scenarios, the most effective scenario which is deficit irrigation with the combination of plastic mulching are considered, around 1.35 million m^3 of blue water could have been saved in the sub-basin in 2017. Input irrigation parameters and the outputs are given in Table A.3.6 in Appendix 3.

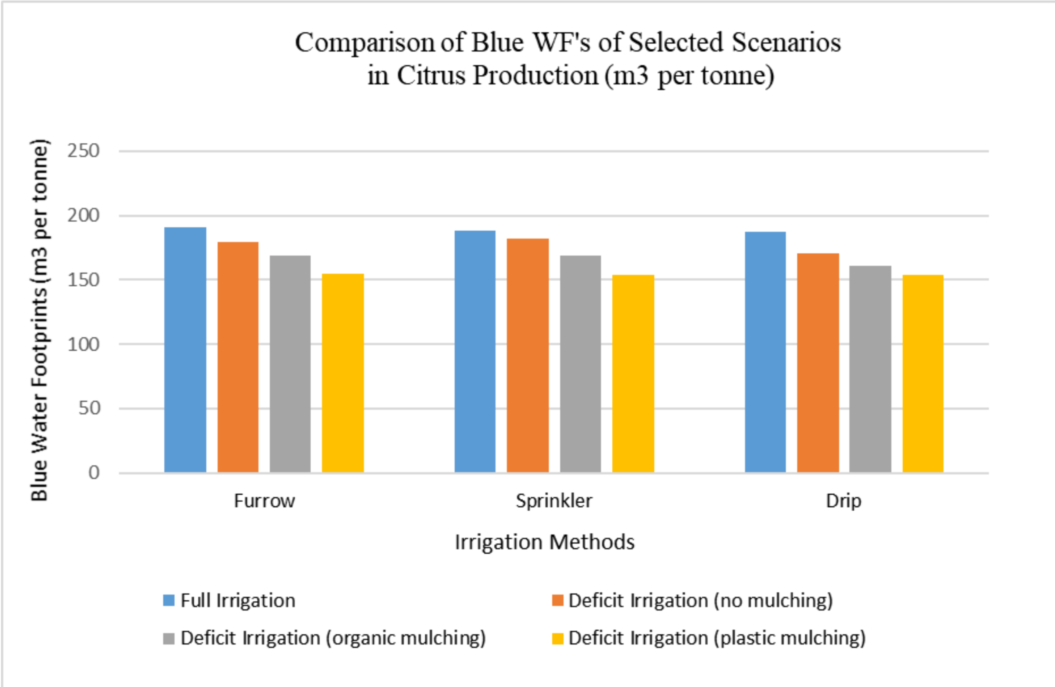

Figure 3.12 - The blue water footprints of citrus production according to selected scenarios.

3.2.7 Overall potential water saving and water scarcity alleviation

In the sub-basin, to reduce blue water footprints of water intensive and high-value crops, different irrigation techniques and management strategies were evaluated using the AquaCrop model. While tomato and maize are pre-defined crops in the model, watermelon which is an annual fruit was easily simulated using the guideline of FAO. However, alfalfa is a forage crop; olive and citrus are perennial crops. Therefore, the model is not capable of simulating them, so the crop files for these crops were created to mimic their yield responds to water, and local official data for management practices, FAO's guideline (FAO, 2012), and the report, Climate change impact assessment on crop production in Albania, published by Huning and Droogers (2010).

In the AquaCrop model, the reference scenario is full irrigation with the combination of furrow irrigation technique for the crops except alfalfa, which is irrigated with sprinkler in the sub-basin. Among the scenarios, the most effective scenario which has the highest ET_{WP} is deficit drip irrigation with plastic mulching. The total amount of agricultural WFs of the crops according to the reference scenarios is approximately 61 million m^3. The official report indicates that around 65 million m^3 of water is allocated for agricultural purposes in the sub-basin (DSI, 2018). Therefore, it can be expressed that the approach adopted in the model and its outcomes correspond to the value expressed in the official report. Figure 3.13 demonstrates the sum of estimated results of the water demand using blue WFs of crops in the AquaCrop model in line with the reference scenarios obtained from the literature, the official data and the assumptions made. In the figure, the total water demand of the all sectors including environmental water requirement is compared to the water availability of the sub-basin on a monthly basis in 2017. The figure clearly demonstrates the water scarcity during summer months in the sub-basin.

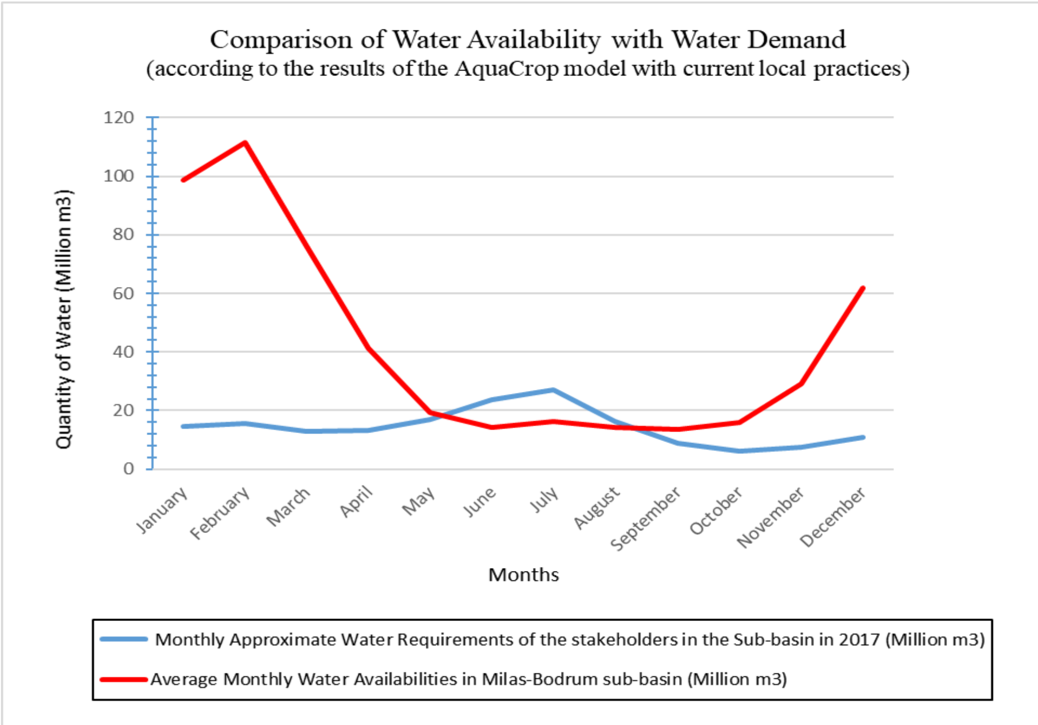

Figure 3.13 - Comparison of monthly water supplies and demands arranged the results of the AquaCrop model using local agricultural practices and assumptions in the sub-basin in 2017.

Figure 3.14 compares monthly water availabilities with the estimated monthly water demands which is re-arranged using the outcomes of the selected scenarios having the highest ET_{WP}, which provides the maximum water saving, in the model. These scenarios mainly consist of deficit irrigation with the combination of drip and plastic mulching. Only alfalfa among the selected cops is not a suitable crop for mulching and drip system in the line of the reference of FAO, so deficit irrigation with sprinkler system was evaluated for this crop. The monthly demands in Figure 3.14 also include the blue water footprints of the other sectors and minimum environmental water requirements.

Water deficit between demand and supply is seen to be remarkably reduced for summer months just selecting the scenarios providing high ET_{WP}. In the results of the model and assumptions made, around 26 million m^3 of blue water can be saved with a maximum of 10% loss of production. This water saving is only the result of the scenarios in agriculture sector in the sub-basin. Figure 3.15 below gives monthly irrigation amounts of both the reference scenario and the most effective scenario in the agriculture sector according to the result of the model on a monthly basis in 2017. The difference between the columns gives possible maximum water savings per month in the graph. In Appendix 4, the monthly irrigation amounts of the selected crops for both the reference scenario and the most effective scenario are given.

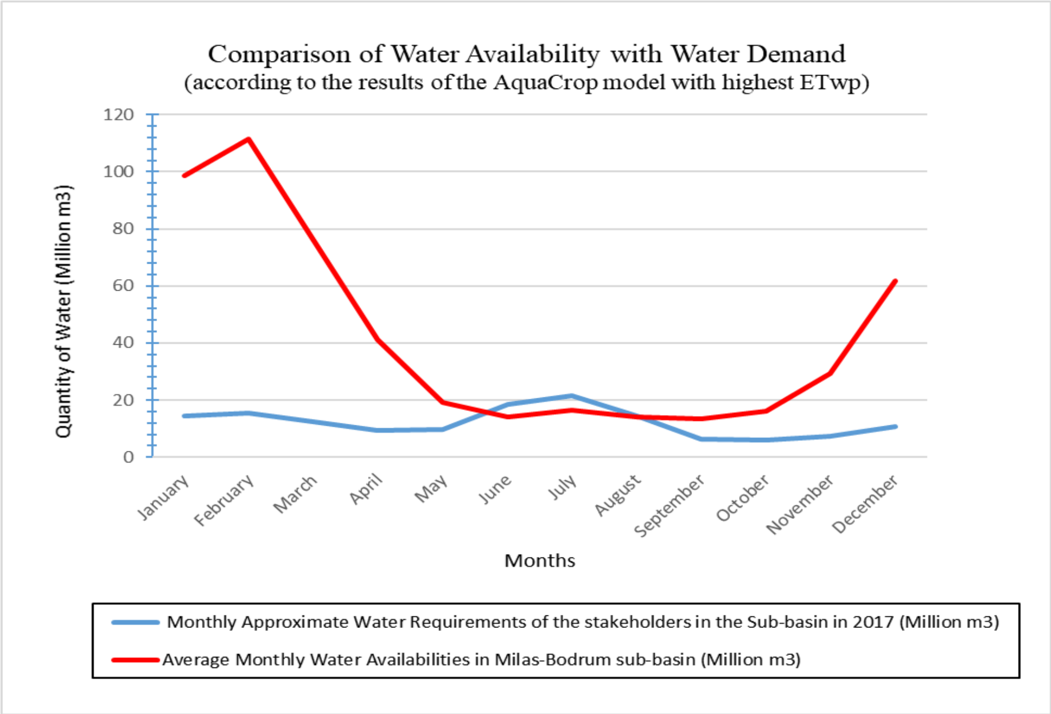

Figure 3.14 - Comparison of monthly water supplies and demands arranged the crops' blue WF results with highest ET_{WPs} obtained from the AquaCrop model in the sub-basin in 2017.

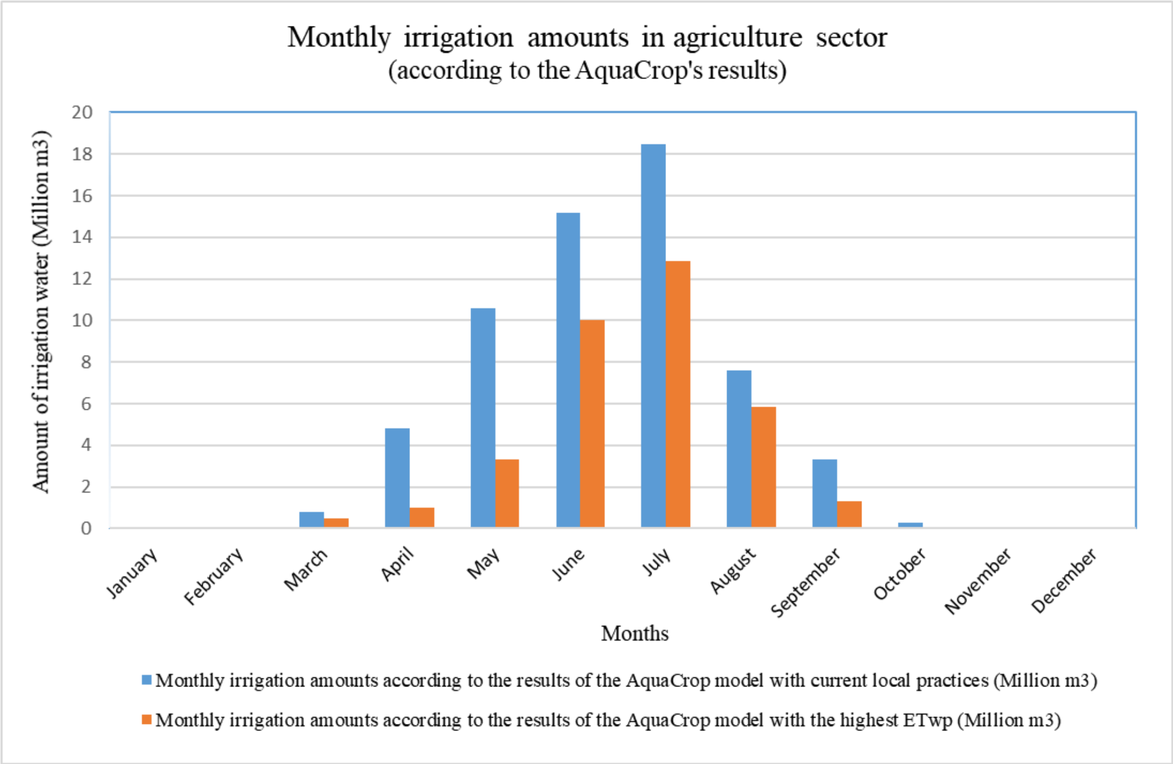

Figure 3.15 – Monthly irrigation amounts according to the results of both the reference scenario and the most effective scenario.

CHAPTER 4

Conclusions and recommendations

4.1 Conclusions

In this thesis, the water footprint approach has been employed to shed light on to what extent it can help policy makers during water allocation planning in river basins. The Milas – Bodrum sub-basin, experiencing water shortages especially in summer months, was selected for this purpose. The main water-using sectors were determined, and their blue water footprints were calculated. According to the calculations, the main water consumer in the sub-basin is agriculture sector, with 47% of blue WF if the environmental water requirement is considered; otherwise, the ratio reaches around 60%. The blue WFs of the other sectors (household, tourism, industry, and livestock) constitute approximately one-third of total blue WF. Therefore, the agriculture sector was specifically investigated in order to reduce its footprint due to the high priorities of the other sectors in the sub-basin.

The six main crops, mainly grown in the region, were examined in the AquaCrop model, and four different scenarios were run together with three different irrigation methods. Depending on crop type, deficit irrigation compared to full irrigation provides high water savings, up to 40%, with a maximum 10% of loss of production. In terms of the applicability of the irrigation techniques, furrow irrigation results in lower conveyance efficiency and field application efficiency than sprinkler and drip irrigation, so water is lost during irrigation, and controlling it is harder along with long canals than expected (FAO, 1989). In this respect, applying deficit irrigation with furrow irrigation will not give expected results as the model presents. Sprinkler irrigation, on the other hand, can be useful for irrigation but uniformity and preventing overlap are important issues required to be considered. Drip irrigation, compared to the other irrigation techniques, provides water for only the part of the root zone of crop. FAO clearly expresses that drip irrigation is thought to be the most efficient way of irrigating, crop water requirement does not change with irrigation techniques. Therefore, it is seen that the outcomes of the model for full irrigation can be thought as meaningful because the model gives similar results. Deficit irrigation provides more water saving without considering irrigation techniques. However, controlling water and watering the crop as needed are easy with drip irrigation. Therefore, reaching the results presented in the model with deficit irrigation necessitates using drip irrigation.

As for mulching, it decreases water evaporation making a positive contribution on water saving. Organic and plastic mulching were evaluated in the model. As expected, plastic mulching provides more water saving compared to organic mulching, because plastic materials keep water in the soil preventing water evaporation completely while organic materials like compost and straw are not totally capable of preventing surface evaporation. However, in practice, there are some disadvantages of using plastic mulching reported in the results of researches. Maughan and Drost (2016) express that using plastic mulching may result in environmental problems after its use due to its non-biodegradable characteristic, and strong winds may cause tear of plastic materials, ending with environmental pollutions. Even though biodegradable materials have already been produced to solve this issue, their high prices adversely affect their preferability by farmers. On the other hand, organic materials have economic, aesthetic, and need less labour force. Moreover, they enhance useful organisms and reduce fertilizer uses by increasing soil health (Ranjan et al., 2017).

At the end of these scenarios in the AquaCrop model, the blue water footprints can be decreased 27.6 m^3 for per tonne of tomato production, 44 m3 per tonne for maize, 65 m3 per tonne for alfalfa, 20 m3 per tonne for watermelon, 264 m3 per tonne for olive, and 36 m3 per tonne for citrus. Even though these values are remarkable for implementing drip irrigation accompanied with deficit irrigation – plastic mulching scenario, it should not be ignored that the AquaCrop model is not capable of simulating alfalfa, olive, and citrus. Regarding water savings, the maximum total water saving was found with drip irrigation accompanied with deficit irrigation - plastic mulching scenario except for alfalfa crop, which is not suitable for this scenario. The amount of water saved is approximately 26 million m^3 per year only with a maximum 10% of production loss. By only taking these precautions, it has been found that water shortage can be remarkably reduced during summer months. However, improvements made on irrigation water use are not sufficient alone because the sub-basin is expected to experience a decrease in precipitation according to the climate scenarios (SYGM, 2018).

4.2 Recommendations

One of the objectives of this research is evaluating how water footprint approach can be used by policy makers for basin planning processes. In this respect, making the results valuable is important. Before evaluating the results on behalf of policy makers, the validation of the AquaCrop model for crops which are not pre-determined in itself should be investigated by making case studies for that crops. Moreover, the model is not capable of considering horizontal water flows during irrigation, so this may weaken the reliabilities of the results, especially for furrow irrigation; it only considers vertical water flows. Therefore, a further research on this issue is required.

Regarding the interpretation of the outcomes of the scenarios, the results can be used by policy makers while setting allocation limits within the agriculture sector in basins. However, the allocation limits in agriculture sector needs to be updated depending on climatic conditions in basins. Educating farmers and encouraging them can be accepted a more reasonable way regarding the effective use of water resources in a basin. At first glance, drip irrigation system and mulching can be thought new investment costs and effortful by farmers. However, less water use will result in lower water rate and lower energy requirement for pumping. Therefore, this issue should be investigated which one is advantageous. Existing open canals which are suitable for furrow irrigation in the region should be transformed into pressurized piping systems for drip irrigation, which also reduces blue WF of the agriculture sector because evaporation happening in open canals will be prevented.

On the other hand, only irrigation techniques and management practices were evaluated in this research. However, changing crop pattern may be resulted in lower water footprint in agriculture sector for the sub-basin but while offering a new crop, which is drought-tolerant, the market where the crop will be sold should be investigated. Otherwise, for coming years, farmers will probably be reluctant to grow that crop. In order to create a self-sufficient basin in terms of fresh water resources, the amount of water allocated for irrigation purposes can be determined by legislation in the direction of these results. Focus on reducing water footprint of agriculture sector will not solve the water scarcity in the basin even though that sector consumes water the most. In this regard, to create and sustain an efficient allocation in the basin, water should be allocated for high-value purposes after fulfilling domestic and environmental requirements. Therefore, holistic solutions which adopt water footprint reduction in other sectors should be sought to reach a sustainable environment in the sub-basin before taking other actions like inter-basin water transfers or desalination.

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APPENDIXES

Appendix 1 – Information for Milas – Bodrum sub-basin

Turkey consists of 25 basins and one of its basins is Batı Akdeniz basin located in the south-west part of Turkey (see in Figure A.1.1). This basin has 5 sub-basins (see in Figure A.1.2). One of its basins is called as Milas-Bodrum, which has significant tourism regions, clearly shown in Figure A.1.3. The sub-basin consists of three districts called Bodrum, Milas, and Akbük with a population of approximately 300.000 (TurkSTAT, 2018). According to the population density, the sub-basin has the largest population among sub-basins.

Figure A.1.1 - Demonstration of water basins of Turkey.

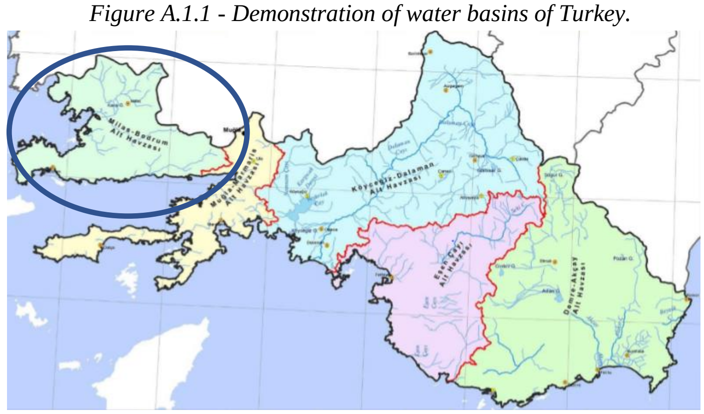

Figure A.1.2 - Sub-basins of Batı Akdeniz Basin.

Even though Muğla province is one of the provinces with the highest rainfall with an average rainfall of 1100 mm in Turkey, Milas -Bodrum sub-basin gets the lowest precipitation among the sub-basins with around 800 mm, and both its permeable soil structure and excessive demands for water especially during summer months due to agricultural and touristic needs, the sub-basin experiences water shortages (SYGM, 2018).

In the sub-basin, water needs for human consumptions are provided from reservoirs, Geyik, Akgedik and Mumcular, and groundwater resources. There are difficulties in meeting the water requirement of the sub-basin which is poor in terms of surface water availability and demand is being provided through groundwater resources. One of the challenges in the sub-basin is increasing water demands of stakeholders during summer months while precipitation decreases. Therefore, the sub-basin which has limited freshwater resources compared to the other sub-basins faces with water stress due to increasing number of tourists and water demands for agricultural activities during the summer months (GEKA, 2015). Tourism is one of the most dominant factors together with agriculture. In recent years, the number of foreign tourists reaches around 1,5 million. This creates direct and indirect water demand in the sub-basin.

Another challenge is that both farmers and other organizations (mainly hotels, industries) extremely use groundwater to provide water. Therefore, the low-rate of replenishment of groundwater and saltwater intrusion create a pose for basin (GEKA, 2015).

Both limited freshwater resources and uncontrolled nutrient and pesticide uses of farmers create hotspots in the region. The water qualities of dams are on the third level (out of four) which corresponds to “dirty”. Because of intense agricultural activities, industrial wastewater, and landfill leakage, these water bodies are under threat. Moreover, the sub-basin experiences uncontrolled wastewater discharges. In the sub-basin, activities such as agriculture, livestock farming, and aquaculture increase the ratios of nitrogen and phosphorus released to the environment, which impose a burden for both surface and groundwater resources. In terms of nutrient pollution, this sub-basin has the largest nutrient concentration among the sub-basins.

Agricultural activities are mainly intensive in upper regions of the sub-basin, so there is less need for agricultural irrigation in Bodrum Peninsula. Citizens in the peninsula mainly use groundwater for their vegetable gardens and trees. Even though the purpose of Mumcular and Geyik dams is to provide water for drinking and irrigation, these resources are mainly used for drinking water during the summer months (TUBITAK, 2013).

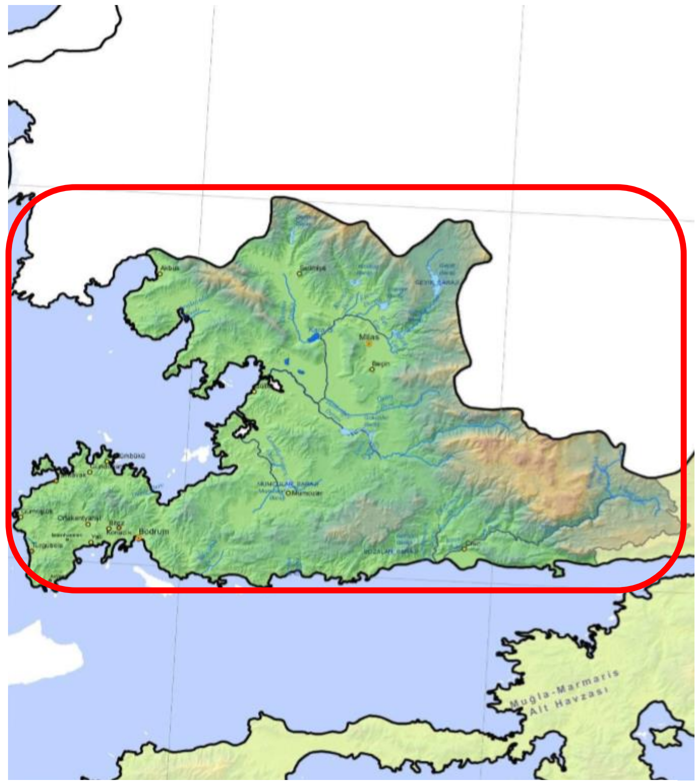

Figure A.1.3 - Geographical demonstration of Milas-Bodrum Sub-basin.

As for crop pattern of the region, mainly olive and citrus production, vegetables and cereals are preferred by farmers. Both economic return and suitable weather and soil conditions, farmers are used to grow these crops. While the amounts of Milas’ agricultural land, grass-pasture, and forestland are 80.173 ha, 7.541 and 119.000, respectively, these quantities are around 15.000 ha for agriculture, 2.000 ha for grass-pasture, and 34.000 ha for forestland in Bodrum (Ministry of Agriculture and Forestry, 2018). Milas is quite important for olive production because 10% of olive production in Turkey is produced in this region. There are approximately 8 million of olive trees in Milas (Ministry of Agriculture and Forestry, 2018). On the other hand, in this area, apiculture creates economic gain for local people (around 1400 families); therefore, the quality pasture and forest lands have enormous significance for them according to Milas Municipality Strategic Plan 2015-2019.

Appendix 2 – Calculation steps for the monthly percentages of crop water needs in the sub-basin.

The calculation procedure was explained in Chapter 2, here Table A.2.1 shows the numbers used for the calculations.

Table A.2.1 - Monthly percentages of crop water needs together with their calculation steps for the sub-basin.

	January			February			March			April			May			June			July			August			September			October			November			December			
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	
	Average Precipitation (mm)																																				Total (mm)
Effective Average 10-day rainfall	40.12	26.24	32.88	33.36	33.8	18.6	23.56	20.92	18.92	17.36	11.32	6.4	7.44	4.16	5	2.44	0.68	0.68	0.56	0.36	0.44	1.16	0	0.36	1.24	2.92	4.64	8.76	7.68	12.8	25.4	28.6	30.56	31.4	43.48	40.72	544.96
Crops	Crop Water Consumptions for each ten day (Etc, mm)																																				Total (mm)
Tomato										10.2	11.3	12.8	20.4	35	55.6	61.4	67.6	71.1	71.4	70.2	68.8	39.9															595.7
Watermelon								8.5	17.3	18.8	25	33.1	40.7	45.7	53.2	50.8	48.8	9.1																			351
Maize											4.3	8	9	12.8	29.9	45.8	66.7	74.8	75.2	74.1	80.9	55.1	6														542.6
Citrus	7.3	7.8	10	10.3	11.5	11.2	15	17.2	21.4	21.5	23.4	26	28.3	31	35.2	34.9	38.4	40.4	40.6	39.9	43.6	37.4	35	35.6	28.7	25.7	22	18.7	15.8	13.9	10.6	8.8	7.9	6.9	6.3	7.2	795.4
Alfalfa (Clover)				10.3	12.9	14.4	22	27	34.4	34.9	22.4	30.4	48.2	54.2	24.4	60.5	49.2	52.6	67.5	45.3	73.5	40.3	63.1	25.1	52	18	33.7	33.7	8.4	18	18.7	15					1010.1
Olive Trees								1.1	13.4	13.7	15.3	18	21.2	24.9	30.4	31.8	36.6	40.1	41.9	42.7	47	40.2	37.7	38.4	30.9	27.7	23.8	20.3	17	14.8	11.2	9.1	8.1	7	2.5		666.8
Maximum water use of selected crops for each 10-day period	7.3	7.8	10	10.3	11.5	11.2	22	27	34.4	34.9	23.4	30.4	48.2	54.2	55.6	61.4	67.6	74.8	75.2	74.1	80.9	55.1	63.1	38.4	30.9	27.7	33.7	33.7	17	18	18.7	15	8.1	7	6.3	7.2	
Monthly approximate water needs (mm)	0			0			21.56			53.62			141.4			200			228.84			155.08			83.5			39.46			0			0			923.46
Monthly percentages of crop water needs	0%			0%			2%			6%			15%			22%			25%			17%			9%			4%			0%			0%			100%

Appendix 3 – Input parameters of the crops under scenarios for the AquaCrop model and outcomes of the model.

Table A.3.1 - Scenarios that used in the AquaCrop model as input for tomato and the outcomes produced by the model.

Tomato												
Irrigation Types	Surface (Furrow) Irrigation				Sprinkler Irrigation				Drip Irrigation			
Scenarios	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)
Dnet (mm)	30	30	30	30	30	30	30	30	30	30	30	50
RAW depleted (%)	40	100 130 (at May 29)	100 130 (at May 29)	100 130 (at May 29)	40	100 130 (at May 29)	100 130 (at May 29)	100 130 (at May 29)	40	130	130	130
Irrigation off	31 July	20 July	20 July	20 July	28 July	20 July	18 July	19 July	29 July	16 July	18 July	12 July
Irrigation amount (mm)	540	330	330	270	510	300	300	270	480	300	300	250
Irrigation event (number)	18	11	11	9	17	10	10	9	16	10	10	5
Dry Yield (ton/ha)	10.035	9.702	9.856	9.702	10.036	9.386	9.594	9.702	10.036	9.485	9.548	9.527
Loss of Production (%)	0	3.3	1.8	3.3	0	6.5	4.4	3.3	0	5.5	4.9	5.1
ETwp (kg/m3)	1,76	1,86	1,93	2,18	1,73	1,85	1,93	2,18	1,87	1,88	1,93	2,20
Dry Matter Content	10%											
Total Tomato production (ton/ha)	100.35	97.02	98.56	97.02	100.36	93.86	95.94	97.02	100.36	94.85	95.48	95.27
Irrigation amount per hectare (m3)	5400	3300	3300	2700	5100	3000	3000	2700	4800	3000	3000	2500
Blue Water Footprint (m3/ton)	53.8	34.0	33.5	27.8	50.8	32.0	31.3	27.8	47.8	31.6	31.4	26.2

Table A.3.2 - Scenarios that used in the AquaCrop model as input for maize and the outcomes produced by the model.

Maize (Silage)												
Irrigation Methods	Surface (Furrow) Irrigation				Sprinkler Irrigation				Drip Irrigation			
Scenarios	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)
RAW depleted (%)	20	100	100	100	20	100	100	100	20	104	104	104
Irrigation Amount (mm)	400	250	235	150	400	250	235	150	300	210	200	150
Irrigation Event (number)	13	10	10	7	13	10	10	7	13	9	9	7
Biomass (ton/ha)	15.813	14.663	14.458	14.374	15.789	14.176	14.241	14.374	15.787	14.161	14.035	14.097
Dry Yield (ton/ha)	7.926	7.532	7.443	7.378	7.917	7.294	7.332	7.378	7.972	7.26	7.216	7.234
Loss of Production (%)	0	7	9	9	0	10	10	9	0	10	10	10
ETwp (kg/m3)	1.92	2.14	2.25	2.96	1.85	2.04	2.21	2.96	2.23	2.25	2.34	2.96
Evaporation (mm)	138.6	97.5	80.1	0	153.3	110.2	84	0	82.9	76	65.1	0
Dry matter content (%)	30											
Total Maize production (ton/ha)	52.7	48.9	48.2	47.9	52.6	47.3	47.5	47.9	52.6	47.2	46.8	47.0
Irrigation amount per hectare (m3)	4000	2500	2350	1500	4000	2500	2350	1500	3000	2100	2000	1500
Blue Water Footprint (m3/ton)	75.887	51.149	48.762	31.307	76.002	52.906	49.505	31.307	57.009	44.488	42.750	31.922

Table A.3.3 - Scenarios that used in the AquaCrop model as input for Alfalfa and the outcomes produced by the model.

Alfalfa									
Full Irrigation	Sprinkler Irrigation				Deficit Irrigation	Deficit Irrigation			
	1. Cutting	2. Cutting	3. Cutting	4. Cutting		1. Cutting	2. Cutting	3. Cutting	4. Cutting
Irrigation Event (number)	3	5	7	3	Irrigation Event (number)	1	5	6	2
Irrigation Amount (mm)	60	170	210	60	Irrigation Amount (mm)	20	100	130	30
Biomass (ton/ha)	7.81	7.35	7.39	7.43	Biomass (ton/ha)	7.532	6.546	6.593	6.74
Dry yield (ton/ha)	1.562	1.47	1.48	1.48	Dry yield (ton/ha)	1.506	1.309	1.319	1.35
Loss of Production (%)	100	100	100	100	Loss of Production (%)	4	10	10	9
ETwp (kg/m3)	0.76	0.53	0.5	0.8	ETwp (kg/m3)	0.75	0.52	0.51	0.77
Total Alfalfa production (ton/ha)	29.98				Total Alfalfa production (ton/ha)	27.411			
Irrigation amount per hectare (m3)	5000				Irrigation amount per hectare (m3)	2800			
Blue Water Footprint (m3/ton)	167				Blue Water Footprint (m3/ton)	102			

Note: The first harvesting corresponds to 15th of March and 13th of May, the second harvesting corresponds to 14th of May and 2nd of July, the third cutting corresponds to 3rd of July and 21th of August, and the fourth cutting corresponds to 22nd of August and 10th of October.

Table A.3.4 - Scenarios that used in the AquaCrop model as input for watermelon and the outcomes produced by the model.

Watermelon												
Irrigation Methods	Surface (Furrow) Irrigation				Sprinkler Irrigation				Drip Irrigation			
Scenarios	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)
RAW depleted (%)	74	162	162	162	74	162	162	162	74	162	162	162
Irrigation Amount (mm)	330	225	195	185	305	225	190	180	290	215	185	175
Irrigation Event (number)	11	10	10	10	11	10	11	11	13	11	11	11
Biomass (ton/ha)	12.959	11.85	11.721	11.667	12.963	11.836	11.837	11.726	12.965	11.86	11.724	11.678
Dry Yield (ton/ha)	5.474	4.958	4.899	4.877	5.476	4.952	4.946	4.894	5.477	4.958	4.984	4.872
Loss of Production (%)	0	9	10	10	0	9	10	10	0	9	10	10
ETwp (kg/m3)	1.32	1.31	1.44	1.64	1.31	1.3	1.44	1.63	1.32	1.31	1.44	1.63
Evaporation (mm)	76.6	76.4	40.5	0	77.6	77.2	40.6	0	74.7	74.6	39.6	0

Dry matter content (%)	8

Total Watermelon Production (ton/ha)	68.4	62.0	61.2	61.0	68.5	61.9	61.8	61.2	68.5	62.0	62.3	60.9
Irrigation amount per hectare (m3)	3300	2250	1950	1850	3050	2250	1900	1800	2900	2150	1850	1750
(m3/ton)	48.228	36.305	31.843	30.347	44.558	36.349	30.732	29.424	42.359	34.691	29.695	28.736

Table A.3.5 - Scenarios that used in the AquaCrop model as input for olive and the outcomes produced by the model.

Olive												
Irrigation Methods	Surface (Furrow) Irrigation				Sprinkler Irrigation				Drip Irrigation			
Scenarios	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)
RAW depleted (%)	100	120	120	120	100	120	120	120	100	120	120	120
Irrigation Amount (mm)	603	500	460	380	630	520	460	380	590	465	435	376
Irrigation Event (number)	6	5	5	4	5	4	4	4	5	5	5	4
Biomass (ton/ha)	25.115	22.729	22.815	22.752	25.215	22.845	22.646	22.752	25.215	22.672	22.678	22.601
Dry Yield (ton/ha)	4.517	3.967	3.987	3.964	4.539	3.988	3.934	3.964	4.539	3.955	3.954	3.925
Loss of Production (%)	0	10	10	10	0	9	10	10	0	10	10	10
ETwp (kg/m3)	0.47	0.45	0.48	0.54	0.46	0.44	0.47	0.54	0.49	0.47	0.49	0.54
Evaporation (mm)	158	159	99	0	170	168	100	0	123	128	82	0
Dry matter content (%)	70											
Total Olive production (ton/ha)	6.5	5.7	5.7	5.7	6.5	5.7	5.6	5.7	6.5	5.7	5.6	5.6
Irrigation amount per hectare (m3)	6030	5000	4600	3800	6300	5200	4600	3800	5900	4650	4350	3760
Blue Water Footprint (m3/ton)	934.470	882.279	807.625	671.039	971.580	912.738	818.505	671.039	909.892	823.009	770.106	670.573

Table A.3.6 - Scenarios that used in the AquaCrop model as input for citrus and the outcomes produced by the model.

Citrus												
Irrigation Methods	Surface (Furrow) Irrigation				Sprinkler Irrigation				Drip Irrigation			
Scenarios	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)	Full Irrigation	Deficit Irrigation (no mulching)	Deficit Irrigation (organic mulching)	Deficit Irrigation (plastic mulching)
RAW depleted (%)	100	150	150	150	100	151	151	150	100	150	150	150
Irrigation Amount (mm)	859	717	677	614	849	720	672	613	844	683	640	613
Irrigation Event (number)	11	8	6	6	11	7	8	8	11	9	6	7
Biomass (ton/ha)	64.362	57.464	57.64	57.25	64.362	57.462	57.292	57.471	64.362	57.617	57.243	57.267
Dry Yield (ton/ha)	9.011	7.998	8.009	7.95	9.011	7.93	7.974	7.98	9.011	7.996	7.958	7.954
Loss of Production (%)	0	10	10	10	0	9	10	10	0	10	10	10
ETwp (kg/m3)	0.77	0.77	0.8	0.86	0.77	0.77	0.79	0.86	0.8	0.8	0.81	0.86
Evaporation (mm)	106	119	70	0	119	133	72	0	75	88	53	0
Dry matter content (%)	20											
Total Citrus production (ton/ha)	45.1	40.0	40.0	39.8	45.1	39.7	39.9	39.9	45.1	40.0	39.8	39.8
Irrigation amount per hectare (m3)	8590	7170	6770	6140	8490	7200	6720	6130	8440	6830	6400	6130
Blue Water Footprint (m3/ton)	190.656	179.295	169.060	154.465	188.436	181.589	168.548	153.634	187.327	170.835	160.844	154.136

Appendix 4 – Monthly irrigation amounts according to the results of the AquaCrop model.

Table A.4.1 - Results under the current local conditions.

	Monthly irrigation amounts according to the results of the AquaCrop model with current local practices (Million m3)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
Olive					3.80	3.80	7.10	3.89	1.32				19.90
Citrus				0.65	0.60	1.70	1.11	1.16	1.24				6.44
Alfalfa			0.26	0.52	0.65	1.56	1.56	1.43	0.26	0.26			6.50
Watermelon			0.41	1.22	1.62	1.22							4.46
Maize				0.90	1.35	3.04	3.94						9.23
Tomato				0.80	1.00	1.60	2.00						5.40

Table A.4.2 - Results according to the most effective scenario.

	Monthly irrigation amounts according to the results of the AquaCrop model with the highest ETwp (Million m3)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
Olive						3.10	6.20	3.10					12.41
Citrus					0.79	1.42	0.70	0.72	0.98				4.60
Alfalfa			0.26	0.00	0.52	0.78	0.78	1.17	0.13				3.64
Watermelon			0.14	0.34	1.01	1.62							3.11
Maize				0.23	0.11	0.79	2.25						3.38
Tomato				0.30	0.40	0.80	1.00						2.50