EVALUATION OF THE WATER-FOOD NEXUS WITH THE FOCUS ON AGRICULTURAL WATER MANAGEMENT IN THE UPPER SAKARYA WATERSHED

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EVALUATION OF THE WATER-FOOD NEXUS WITH THE FOCUS ON AGRICULTURAL WATER MANAGEMENT IN THE UPPER SAKARYA WATERSHED

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ABSTRACT

EVALUATION OF THE WATER-FOOD NEXUS WITH THE FOCUS ON AGRICULTURAL WATER MANAGEMENT IN THE UPPER SAKARYA WATERSHED

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This study investigates the tradeoffs between water and food (agriculture) nexus and evaluates alternative scenarios focusing on sustainable water governance for agricultural production in Upper Sakarya Basin. For this purpose, pressures on surface water and groundwater resources are determined for the study period (2004-2016) by considering inputs and outputs such as demand, supply, and discharge by all sectors. With concentrating on the impacts on demand and supply dynamics, the effectiveness of management scenarios in the agricultural sector is evaluated using the WEAP model. Demand-oriented management scenarios propose various technical measures that include improvements in irrigation technology, shifts in the cropping pattern, and conservative irrigation strategies. Scenario analysis has shown that demand and supply decline in proportion to each other, resulting surface water reliability to rise at a relatively lower rate. It is suggested that water and food (agriculture) sustainability is facilitated when less water-intensive crops are favored and efficient irrigation techniques and deficit irrigation programs are adopted.

Keywords: Water Evaluation and Planning (WEAP), Hydrological Modeling, Demand Management, Agriculture, Scenario Analysis

ÖZ

SU-GIDA BAĞININ YUKARI SAKARYA HAVZASINDA TARIMSAL SU YÖNETİMİ ODAKLI DEĞERLENDİRİLMESİ

Özel, Beyza
Yüksek Lisans, Çevre Mühendisliği
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Mayıs 2021, #174 sayfa

Bu çalışma, su ve gıda (tarım) bağlantısı arasındaki etkileşimleri araştırmakta ve Yukarı Sakarya Nehir Havzası'ndaki tarımsal üretim için sürdürülebilir su yönetimine odaklanan alternatif senaryoları değerlendirmektedir. Bu amaçla, tüm sektörler tarafından talep, arz ve deşarj gibi girdi ve çıktılar dikkate alınarak çalışma dönemi (2004-2016) için yüzey suyu ve yeraltı suyu kaynakları üzerindeki baskılar belirlenmektedir. Arz ve talep dinamikleri üzerindeki etkilere odaklanılarak, tarım sektöründeki yönetim senaryolarının etkinliği WEAP modeli kullanılarak değerlendirilmektedir. Talep odaklı yönetim senaryoları kapsamında, sulama teknolojisindeki iyileştirmeleri, ürün desenine ilişkin değişiklikleri ve su tasarrufuna yönelik sulama stratejilerini içeren çeşitli teknik önlemler önerilmektedir. Senaryo analizi, arz ve talebin birbiriyle orantılı olarak azaldığını, ve bunun sonucunda yüzey suyu güvenilirliğinin nispeten daha düşük bir oranda arttığını göstermiştir. Yoğun su gerektirmeyen mahsuller tercih edildiği ve verimli sulama teknikleri ile eksik sulama programları benimsendiği taktirde, su ve gıda (tarım) sürdürülebilirliğine olanak sağlandığı öne sürülmektedir.

Anahtar Kelimeler: Su Kaynakları Değerlendirme ve Planlama (WEAP), Hidrolojik Modelleme, Talep Yönetimi, Tarım, Senaryo Analizi

To my family

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CHAPTER 1

INTRODUCTION

Water is a crucial resource in food production and food production systems that cause pressures on the quality and quantity of water resources. 2030 Agenda for Sustainable Development, adopted by United Nations in 2015, states 17 sustainable development goals in which food and water security are explicitly highlighted. Eradicating hunger, achieving food security and promoting sustainable agriculture are stated in Goal 2; ensuring availability and sustainable management of water and sanitation are stated in Goal 6 (United Nations, 2015a). However, such goals regarding food and water security have a strong dependence and should not be considered individually.

Economic development and population growth are the central pressures that risk the security of resources. As living standards are improved in developing economies, more resource-intensive consumption patterns have emerged. Furthermore, environmental pressures, including climate change, cause resource insecurity. Climate shifts to extreme weather events alter rainfall which in turn affect crop productivity. Governance failures related to managing shared resources (e.g., transboundary water and energy sources, food trade agreements) result in tension, leading to conflicts. Economic imbalance often intensifies the risk associated with the resource securities, as governments and consumers look for temporary, unsustainable solutions, such as producing expensive, water-intensive crops for export in water-deprived regions (World Economic Forum, 2011).

Moreover, current pressures on resource security are expected to increase soon. By 2030, the United Nations Food and Agriculture Organization (FAO) forecasts a %50 increase in food demand, whereas the International Food Policy Research Institute (IFRI) projects a %30-40 of increase in water demand (World Economic Forum, 2011). When considered the typical pressures and future risks that threaten water and food resources security, significant alterations that include sustainable water utilization practices and seek renewable resources to produce food are needed.

As Godfray et al. (2010) stated, the principle of sustainability is using resources at rates lower than the capacity of Earth to recover. The dependency on nonrenewable inputs is considered unsustainable. Therefore, the trajectory toward sustainability should occur even in the short term (Godfray et al., 2010). In Turkey, total water withdrawal corresponds to 20% of total renewable water resources, and agriculture holds a portion of 16% by itself. (FAO, 2008). Sustainable intensification requires agricultural land and water bodies used for food production to be managed to reduce negative impacts on biodiversity. In food production systems, the primary purpose should not be to maximize productivity and optimize production besides environmental and social justice outcomes (Godfray et al., 2010).

The goal to ensure food security only will not be sustainable without providing water security. Water security and water governance should facilitate each other to set the targets for water governance, and water governance leads towards water security through implementations. In this sense, water security should be regarded from a broad integrative perspective, aligned with well-established integrated water resources management approaches, and embedded within good governance processes necessary to secure water for all (Cook & Bakker, 2012). Availability of water is critical for future global food security. However, increasing demand, competition for water, and concerns for environmental quality have put agricultural water demand under investigation and threatened food security. As water scarcity increases and the competition by water uses, agriculture will be the first sector to lose water. In order to avoid the impending food crisis, a fundamental shift is required in the sense of water uses in food systems policy. Such investments should aim; conserving water and energy resources, develop, adopt and adapt climate-resilient alternatives; modernize irrigation; support domestic food supplies; readjusting agriculture for further development (Hanjra & Qureshi, 2010). Within this context, ensuring water and food security requires all interrelated components to be assessed within the integrated nexus approach, as shown in Figure 1.1. The water, food, and energy resources interactions are investigated under the Water-Energy-Food (WEF) Nexus scope.

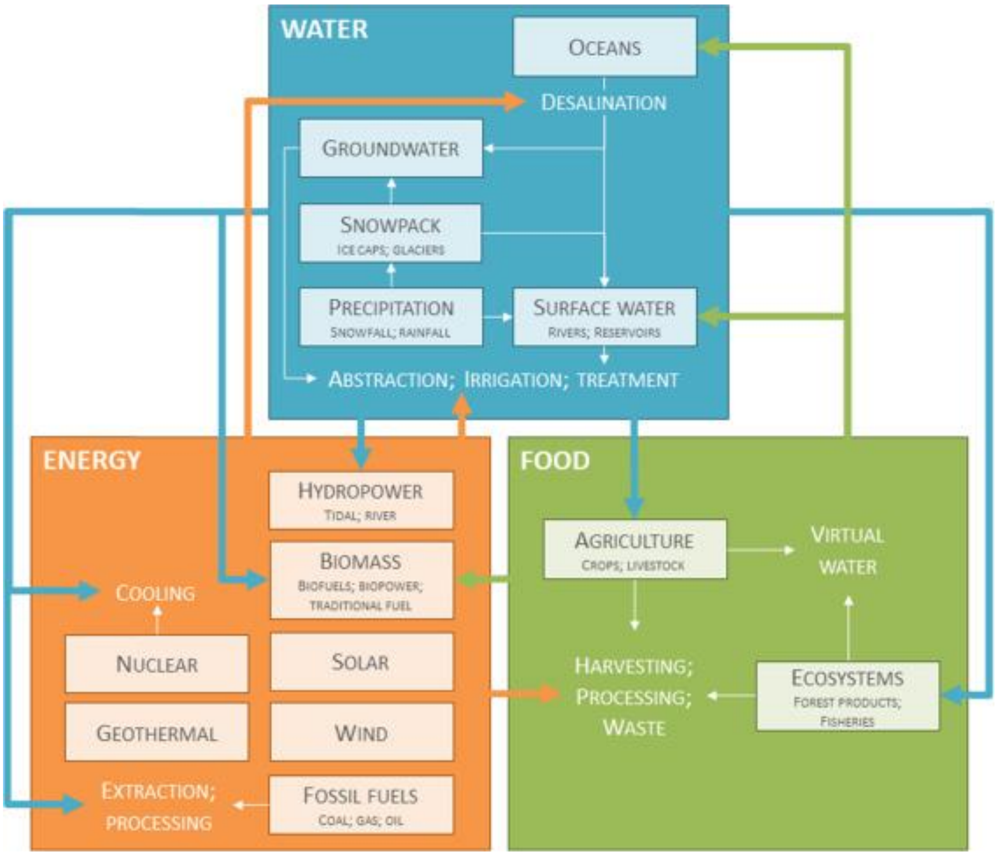


Figure 1.1. Water, energy and food nexus schematic (Biggs et al., 2015)

WEF nexus is considered a practical concept to describe the interrelated nature of our global resource systems. The nexus approach systematically analyzes the interaction between the environment and human activities and leads to integrated management of natural resources across various sectors and scales (FAO, 2014). From a general perspective, food and energy production requires water and impacts the quantity and quality of water; a food system and clean water supply require energy, and the misuse of water and energy impacts food supply and land use.

Since nexus interactions are complex and dynamic, sectoral issues should not be considered in isolation from one another. The broader context of drivers of change is required to be taken into account within the nexus. There are different perspectives of the nexus that vary in scope of research, objectives and understanding of drivers (FAO, 2014). In this study, water and food nexus will be the main subject. The concept of water and food nexus focuses on the efficient use of water required to produce food; in other terms investigates pathways to increase the product yield while reducing the water utilized. Food production has adverse impacts on water quality and quantity.

Agriculture, aquaculture and other food systems use a significant amount of water. Agriculture is responsible for %70 of freshwater withdrawals in the world (WWAP, 2015). Therefore, water efficiency or productivity should be evaluated, especially in regions where severe agricultural activities dominate. There are several measures to address challenges associated with the efficient use of water resources in agriculture. Policymakers under the agricultural domain can consider recommendations listed as follows;

- Enhancing irrigation infrastructure and management and increase irrigation efficiency and access (e.g., modernization of irrigation schemes),
- Improving water supply management (e.g., sustainable, decentralized water harvesting and storage systems, investments in the treatment of urban wastewater and its reuse for agriculture)
- Improving productivity, including that of water, taking account of the natural resource base (e.g., integration of natural resource management into agricultural policy, the use of ICTs and satellite imagery in agriculture)
- Reducing food losses and waste to help reduce pressure on land and water, and
- Using agricultural trade as an option to address water scarcity (e.g., strengthening of international disciplines on all forms of import and export restrictions) (FAO, 2017).

Furthermore, precision agriculture can be implemented as a management strategy. Recent technologies have emerged in precision farming, such as GPS systems, yield mapping, intelligent sensors and auto-steering systems. Through efficient sensing and decision support systems, such technologies support the farmer to increase yield, save food and time, increase profitability and reduce the negative impact on the environment (Pedersen & Lind, 2017).

Intending to modernize agriculture, Central Asia adopted measures concerning gradual crop diversification and water loss in the infrastructure. In order to follow the EU Roadmap to Resource Efficient Europe, which requires water withdrawal to stay below 20% of renewable water resources, 30% of the national agricultural subsidy is reserved for the provision of sustainable agriculture practices, including crop diversification and permanent grassland. In Cyprus, the government provides subsidies and low-interest loans to encourage farmers to shift towards high-efficiency irrigation systems. The policy resulted in a considerable change in irrigation behavior and efficiency. The United States adopted gravity and pressurized irrigation systems at half of the irrigated cropland, and gradual irrigation efficiency improvement was observed in the past few decades (WWAP, 2015).

Furthermore, conservation agriculture adaptations have spread worldwide. The total global area under conservation agriculture is in South America with 47.6%, the United States and Canada with 14.7%, Australia and New Zealand with 34.1% and the rest of the world with 3.5%. Zero tillage systems are widely practiced for soil and water conservation in most countries (Kassam et al., 2010).

1.1 Purpose and Outline of the Study

The outline of this study is demonstrated in Figure 1.2. This study evaluates Water-Food Nexus and investigates management alternatives to address water-related issues in the agricultural sector and achieve sustainable water and agricultural management in the Upper Sakarya basin.

The overall objective of this research to support decision-making for the authorities in terms of sustainable water management in agriculture to ensure water and food security at a basin scale. In order to produce outputs that will take part and serve in achieving the above overall objective, the specific objectives are to promote the efficient utilization and governance of available water resources in the Upper Sakarya basin by;

- Investigating linkages between the components of **Water-Food Nexus**
- Addressing nexus-oriented problems
- Evaluating best management practices that improve water efficiency in agriculture.

The study outline is explained in the following methodological steps.

Characterization of the basin & Identification of issues

Many institutions and organizations were visited in field survey, including Turkish State Hydraulic Works, Eskişehir DoPAF, Seyitgazi municipality and irrigation associations. Data used for the study were obtained by the stakeholders, technical reports, corporate data, and many other literature sources. Later, the study area was characterized, and nexus-oriented issues were identified based on obtained data with literature review and field visits. The pressures by all sectors on water resources such as withdrawals, discharges, inputs and outputs of surface water and groundwater are determined for the current state.

Model Setup

Within the scope of this study, Water Evaluation and Planning System (WEAP) model was utilized as the nexus evaluation tool. The study area was simulated for the period 2004-2016 in the WEAP environment incorporating hydro-system components such as demand site and catchment, supply and resources. The model was calibrated and validated for five streamflow gauges in 2004-2012 and 2013-2016.

Development of Scenarios

After the model setup, management alternatives to available practices were developed based on the following key considerations:

- Social (acceptability)
- Political (availability of supportive policy)
- Technical (infrastructural convenience)
- Facility (model capability)

Demand-oriented management scenarios were composed of various technical measures that include improvements in irrigation technology, shifts in the cropping pattern, and water-saving irrigation strategies.

Effectiveness of the Scenarios

The effectiveness of agricultural water management scenarios was evaluated using the scenario analysis module of the WEAP model, focusing on the relative change in model outputs such as irrigation demand, supply, shortfall, and reliability.

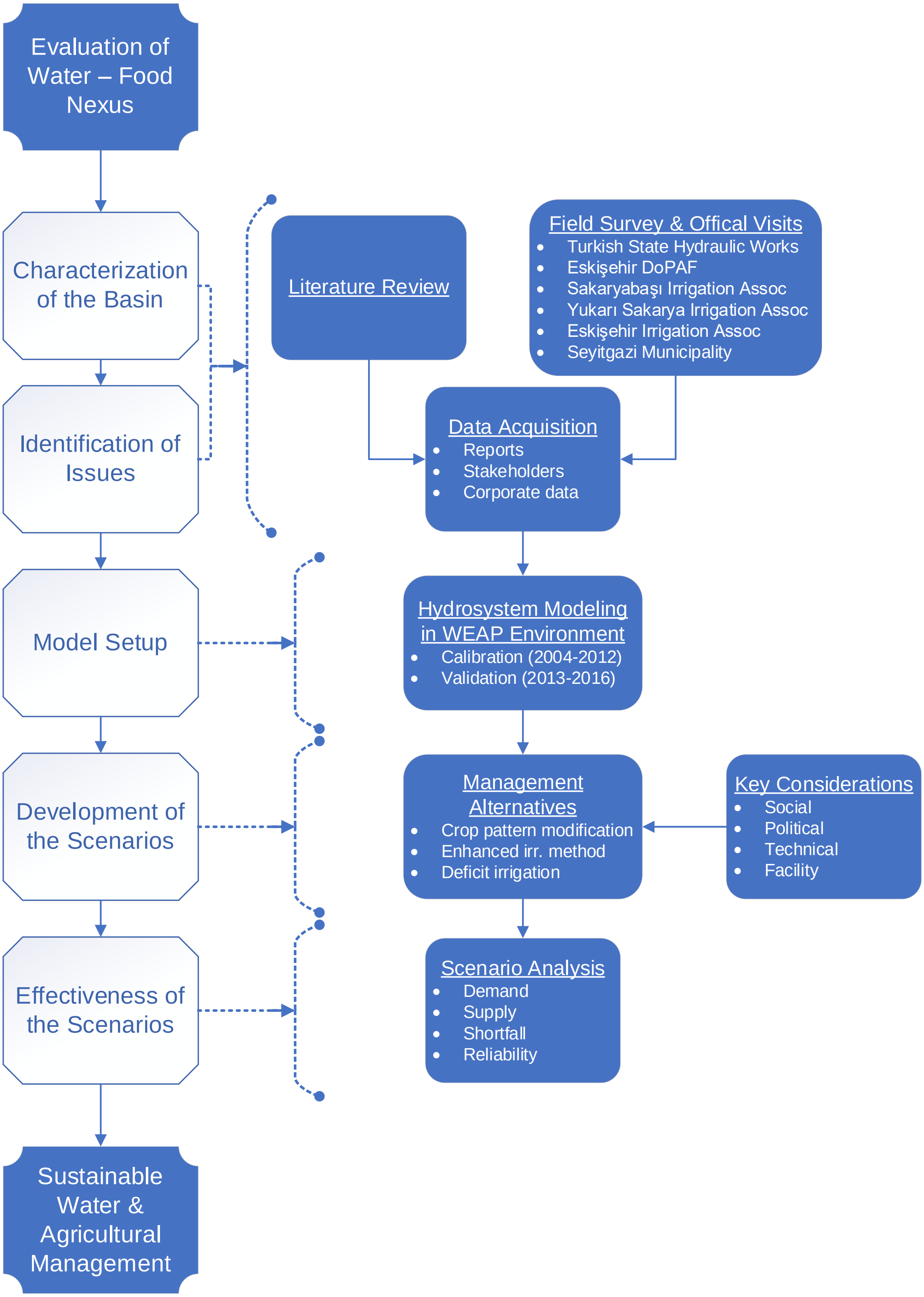


Figure 1.2. Outline of the study

Turkey’s third-largest river basin is Sakarya. The basin is delineated to 6 sub-basins namely, Upper Sakarya, Porsuk, Middle Sakarya, Ankara, Göksu and Lower Sakarya. The total drainage area of the basin is 63,300 $km^{2,}$ and the population density is 119 per capita/km^2 (DSİ, 2017). The study area is Upper Sakarya, with a drainage area of approximately 21,000 km^2. The WEAP model was applied for the upper sub-basin, where significant agricultural activities are held with approximately 1 million ha of total effective arable land. Agriculture is the most significant economic activity among the other sectors such as livestock, industry and mining.

In the study, the literature survey is given in Chapter 2. In this chapter, the security of resources followed by WEF Nexus is described. With the focus on the water and food nexus, solutions for sustainable agricultural water management are presented. In Chapter 3, WEAP is introduced as an integrated modeling system to evaluate solutions and support decision-making for the authorities and theoretical background on WEAP. Furthermore, the study area is described, and model application on sustainable agricultural water management is given. Results and discussion of the study are presented in Chapter 4. Results are composed of three parts as follows; calibration & verification, water budget and scenarios. Conclusion and recommendations are given in Chapter 5. This final chapter involves a summary of the WEAP model application, results and discussions, and recommendations for decision-makers to support measures represented in the scenario analysis and to achieve sustainable agricultural management goals in the basin.

CHAPTER 2

LITERATURE REVIEW

2.1 Water and Food Security

Water and food are vital resources required to sustain life. United Nations adopted the 2030 Agenda for Sustainable Development in which water and food resources are declared in need to be secured. In other terms, food security and water security are structured as goals to achieve sustainable development. Within this context, eradicating hunger, achieving food security and promoting sustainable agriculture are stated in Goal 2; ensuring availability and sustainable management of water and sanitation are stated in Goal 6 (United Nations, 2015a). However, such goals regarding food and water security have a strong dependence and should not be considered individually.

In order to provide water security, water of good quality and sufficient quantity should be available and accessible for humans and the ecosystem. Therefore, water security is a crucial element that links food, energy, ecosystem, population and economic growth. Water security should be ensured for humans and the environment by achieving the following goals:

- sustainable use of water systems;
- protection against water-related hazards;
- sustainable development of water resources and
- access to water functions and services (Schultz & Uhlenbrook, 2008).

However, several pressures and future risks threaten water security. As the population and the economy grow, more water is demanded by food, energy, and industrial and urban systems.

By 2030, without efficiency gains, water withdrawals in agriculture will increase 45%; industrial withdrawals will grow from 16% to 22% of global water demand; the world economy will demand energy at least 40% more. Because of accelerating water use rates, the world could encounter a 40% freshwater shortfall between water demand and available supply in 2030. Furthermore, climate change will put additional pressures on water security, intensify the gap between demand and supply by threatening the primary mountain glaciers, which account for the largest global freshwater reserves. Water has no subsidies nor alternatives. Therefore, water cannot be managed in the future as in the past (World Economic Forum, 2011). Considering the common pressures and future risks that threaten water security, water resources management becomes a critical concern.

Water security and water governance should facilitate each other to set the targets for water governance, and water governance leads towards water security through implementations. In this sense, water security should be regarded from a broad integrative perspective, aligned with well-established integrated water resources management approaches, and embedded within good governance processes necessary to secure water for all (Cook & Bakker, 2012).

Food security can be ensured by eradicating hunger. In order to provide food of sufficient quality and quantity, sustainable agriculture should be promoted and adopted worldwide. Statistics show that, since 1961, food supply per capita has risen over 30%, together with the utilization of nitrogen fertilizer (increased by 800%) and water resources for irrigation (increased over 100%). Further projections suggest that the world will demand 70-100% of more food by 2050. An important strategy to address the challenge of feeding 9 billion people in the future is emphasized as sustainability (Godfray et al., 2010). Considering that the increase in the food supply has resulted in a rise with a higher rate in water and other supplemental products, it can be stated that ensuring only food security is not sustainable unless other required resources are secured. Hence, the agricultural expansion would require integrated management, which concerns all related resources.

Availability of water is critical for future global food security. However, increasing demand, competition for water, and concerns for environmental quality have put agricultural water demand under investigation and threatened food security. As water scarcity increases and the competition by water uses, agriculture will be the first sector to lose water. In order to avoid the impending food crisis, a fundamental shift is required in the sense of water uses in food systems policy. Such investments should aim; conserving water and energy resources, develop, adopt and adapt climate-resilient alternatives; modernize irrigation; support domestic food supplies; readjusting agriculture for further development (Hanjra & Qureshi, 2010). Within this context, ensuring water and food security requires all interrelated components to be assessed within the integrated nexus approach. The water, food, and energy resources interactions are investigated under the Water-Energy-Food (WEF) Nexus scope.

2.2 History of WEF Nexus

Over the last decade, WEF Nexus has emerged as an integrated approach to address issues that threaten water, energy, and food security. Although similar holistic approaches such as integrated resource management have a long history, WEF nexus framing, which concerns resource-related problems in water, energy and food systems, accelerated in the late 2000s (Leck et al., 2015). Due to various global crises regarding food security that emerged in 2008, the interlinkages between the WEF nexus were brought into focus (Aboelnga et al., 2018).

In 2011, World Economic Forum published a book entitled “Water Security: The Water-Food-Energy-Climate Nexus.” In this book, connections were described between water security and nine sectors: agriculture, energy, trade, national security, cities, people, business, finance and climate. As further research in the book, future projections in business as usual conditions for 2030 and then associated solutions that can be implemented as alternatives to current practices were investigated (World Economic Forum, 2011).

The first major WEF nexus event, "*Bonn 2011 Nexus Conference: The Water-Energy and Food Security Nexus – Solutions for the Green Economy,"* is considered to have significant global importance in terms of increased nexus attention from an international organization, the private sector and other major groups (Leck et al., 2015). The background paper for the Bonn2011 Nexus Conference (Hoff, 2011) guides towards understanding the nexus interactions. It states the benefits, principles of the nexus framework, and opportunities for improving water, energy and food security.

In 2012, United Nations Conference on Sustainable Development, the so-called Rio+20, was held, expecting a significant outcome to launch Sustainable Development Goals (SDGs), which rely on the Millennium Development Goals and converge with the post-2015 development agenda (United Nations, 2020). In 2015, United Nations adopted the resolution "Transforming our world: the 2030 Agenda for Sustainable Development," including 17 Sustainable Development Goals (SDG) in which securities of food, water and energy were referred to as SDG 2, SDG6 and SDG7, respectively (United Nations, 2015a). Also, in the same year, the Parties of the United Nations adopted Paris Agreement which aims to limit the increase in the global average temperature to below two °C above the pre-industrial levels (United Nations, 2015b). The WEF nexus is recognized as an integral approach in aligning the 2030 Agenda and Paris Agreement (FAO, 2018).

WEF nexus is considered a practical concept to describe the interrelated nature of our global resource systems. The nexus approach systematically analyzes the interaction between the environment and human activities and leads to integrated natural resources management across various sectors and scales (FAO, 2014). Multidirectional and complex interactions exist between water, energy and food. Each of the bilateral relations between these components is influenced by climate change, economic and population growth, regulations/governance and technological development. From the perspective of water and energy nexus, water is used as cooling water for energy production and extraction, processing, and transportation of energy sources. However, evaporation harms the production efficiency of energy.

On the other hand, energy is used to treat, transport, and distribute water and wastewater and heating and desalination processes. Likewise, another nexus exists between food and energy. Energy is required during the processing and transportation of food; energy is also obtained from biofuels and food waste. As the nexus between water and food is considered, water is utilized to produce, process, prepare, and transport food. Food systems may have adverse impacts on the quality and quantity of water.

Since nexus interactions are complex and dynamic, sectoral issues should not be considered in isolation from one another. The broader context of drivers of change is required to be taken into account within the nexus. There are different perspectives of the nexus that vary in scope of research, objectives and understanding of drivers (FAO, 2014).

2.3 Water and Food Nexus

In this study, Water-Food Nexus will be the main focus. The nexus of water and food often focuses on the efficient use of water required to produce food; in other terms investigates pathways to increase the product yield while reducing the water used. Food systems may potentially have negative impacts on the quality and quantity of water.

Mcneill et al. (2017) examined models used to evaluate water and food safety (e.g., IMPACT-Water, GLASS, WATER-SIM). They argued that to ensure global food and water security, understanding the interrelation between water potential and food production is necessary. They thus stated that without water safety, food safety is not achievable. Linke (2014) carried out a study in an arid region where water and food safety are not sustained and stated that the water demand and supply should be balanced in areas where agricultural production is high and groundwater level is low. Options to adapt seawater for agriculture are also investigated to study efficient water resources management and crop production (Linke, 2014). In another study that focuses on water and food nexus, the indirect effect of water on food safety is investigated. A map is created for the global water potential and water demand in food production affected by dietary preferences in the study. According to the results, Turkey occurs among regions that move towards water scarcity (Varis et al., 2017).

Water scarcity creates water stress on crops and pressures food production. Approximately 1.6 billion people live in water-scarce watersheds as labor and financial resources fail to meet sufficient water potential (IWMI, 2007). Ronco et al. (2017) investigated the impact of water scarcity risk on agriculture in a semi-arid area and emphasized that wetlands are at significant risk due to drought. A study conducted in the Black Sea demonstrated water scarcity indices associated with water availability in the region. SWAT is used in the study to model water availability. Results have shown that water scarcity occurs in the summer due to the high irrigation demand and relatively lower water available in the reservoir (Fasel et al., 2016). Similarly, in a study where the SWAT model is used, water consumption in an area dominated by agriculture is investigated. The biophysical capacity of the available water is represented as in the spatial map of water scarcity (Karabulut et al., 2016).

Studies also review the water uses and determine the significant pressures which lead to water scarcity. Karabulut et al. (2016) provided a map representing the water use in various sectors and water potential in Europe’s second-largest river basin. Research using the SWAT model has shown that the water used for irrigation in particular and the water (green water) taken by plants from the soil is much higher than other sectors. Smidt et al. (2016) determined crops with higher water needs (e.g., cotton, maize) and suggested the primary cause of groundwater depletion is agriculture. Siciliano et al. (2017) state that investments in agriculture are mainly made for flexible crops (e.g., sugar cane, palm oil) to produce food, serve industrial purposes, and highlight. In addition, Vanham (2016) conducted detailed research on global freshwater use and compared his findings with the global water potential. According to the results, the amount of water consumed for food production did not exceed the freshwater potential of the world. Nevertheless, it should be noted that only the data of edible agricultural products provided by FAO was modeled in this research, and industrial crops are not taken into account (Vanham, 2016).

Due to the increasing consumption with the population growth, the global water capacity required to meet food production needs is investigated in several studies. Postel (1998) argued that 1 billion people who live in Africa and South Asia would suffer water scarcity in 2025. It is also revealed that irrigation water might be consumed more and provided less than expected in the future. Therefore, it is suggested that water-scarce countries will focus more on grain imports (Postel 1998). Water demand is estimated for the food production required for the expected population in 2050. According to Chartres and Sood (2013), under business-as-usual conditions, the growth rate of the food production sector will not allow the water capacity to be renewed. Ibarrola-Rivasa et al. (2017) calculated the need for water to produce food demanded concerning people's diet. Looking at the results, 40% of the global population in 2050 will live in countries where water demands are not met. Aside from the pressure of agriculture on water, Strzepek and Boehlert (2010) examined the pressure of competition in water consumption and listed the threats to agricultural water potential: increased environmental flow requirement and urban and industrial water demand water reserves affected by climate change. According to the model results, all these pressures will reduce the agricultural water potential by 18% in 2050 (Strzepek and Boehlert, 2010).

Considering the central pressures on water security (increase in resource consumption due to increasing population, malpractices, pollution, drought and extreme precipitation trends caused by climate change), water needs to be managed in a sustainable way to meet the increasing food need. While agriculture is the primary source of livelihood in 850 million rural areas globally, the water required for agricultural production cannot be found, and poverty will continue in rural areas unless advanced agricultural water management is adopted (WWAP, 2015). After reviewing agricultural water management research on efficient water use in agriculture, key findings are stated below.

2.3.1 Research on Water Efficiency in Food Production

Increasing water-use efficiency is referred to in the 6th of Sustainable Development Goals, which are at the core of the post-2015 development agenda. The two main options recommended to increase water use efficiency are reducing the water consumption and increasing the yield obtained in exchange for water spent. Water use efficiency should be investigated along the life cycle stages from food production to consumption within the context of the Water-Food Nexus. Water efficiency can be improved with concerted efforts across various sectors within a nexus approach. This section involves a research review on water efficiency investigated for three different sectors of food production; agricultural production, livestock production and food production industries.

2.3.1.1 Water Efficiency in Agricultural Production

Agriculture, aquaculture and other food systems use a significant amount of water. Agriculture is responsible for %70 of freshwater withdrawals in the world (WWAP, 2015). Since agriculture is the dominant water user, studies investigating the solutions to address water and food nexus problems have primarily focused on efficient water use in agriculture. Research conducted in areas dominated by agricultural activities generally aims to understand the water-food nexus and minimize water used per product within sustainable water management in food systems.

There are several measures to address challenges associated with the efficient use of water resources in agriculture. Policymakers under the agricultural domain can consider recommendations listed as follows;

- Enhancing irrigation infrastructure and management and increase irrigation efficiency and access (e.g., modernization of irrigation schemes),

- Improving water supply management (e.g., sustainable, decentralized water harvesting and storage systems, investments in the treatment of urban wastewater and its reuse for agriculture)
- Improving productivity, including that of water, taking account of the natural resource base (e.g., integration of natural resource management into agricultural policy, the use of ICTs and satellite imagery in agriculture)
- Reducing food losses and waste to help reduce pressure on land and water, and
- Using agricultural trade as an option to address water scarcity (e.g., strengthening of international disciplines on all forms of import and export restrictions) (FAO, 2017).

Furthermore, precision agriculture can be implemented as a management strategy. Recent technologies have emerged in precision farming, such as GPS systems, yield mapping, intelligent sensors and auto-steering systems. Such technologies support the farmer in increasing yield, saving food and time, increasing profitability, and reducing the negative impact on the environment through efficient sensing and decision support systems (Pedersen & Lind, 2017). Intending to modernize agriculture, Central Asia adopted measures concerning gradual crop diversification and water loss in the infrastructure. In order to follow the EU Roadmap to Resource Efficient Europe, which requires water withdrawal to stay below 20% of renewable water resources, 30% of the national agricultural subsidy is reserved for the provision of sustainable agriculture practices, including crop diversification and permanent grassland. In Cyprus, the government provides subsidies and low-interest loans to encourage farmers to shift towards high-efficiency irrigation systems. The policy resulted in a considerable change in irrigation behavior and efficiency. The United States adopted gravity and pressurized irrigation systems at half of the irrigated cropland, and gradual irrigation efficiency improvement was observed in the past few decades (WWAP, 2015). Also, conservation agriculture adaptations have spread worldwide. The total global area under conservation agriculture is in South America with 47.6%, the United States and Canada with 14.7%, Australia and New Zealand with 34.1% and the rest of the world with 3.5%. Zero tillage systems are widely practiced for soil and water conservation (Kassam et al., 2010).

Irrigating agricultural land is an economic decision. For a sustainable investment, the profit gained from the benefits of irrigation should be more than the costs to pay for the purchase, installation, operation, and maintenance to provide a remarkable return (Ministry of Agriculture and Forestry, 1997). Installing an irrigation system on arable land would be a sustainable investment and provided efficient water use. Therefore, with water use efficiency and crop productivity, the most appropriate irrigation system and plan should be determined by analyzing various climatic conditions, topography, and crop needs. Irrigation methods can meet different needs according to application techniques and irrigation programs.

Irrigation systems are used to manage the amount of water stored in the soil. Soil moisture decreases as water evaporates from the soil surface and is used by the plant in the soil. The process of water consumption in which soil moisture decreases because of evaporation and plant uptake is called evapotranspiration. If decreased soil moisture cannot be replaced by precipitation or irrigation, growth will be limited, and the plant will eventually dry out, as soil moisture cannot supply the water the plant needs. With the help of irrigation, when there is no precipitation, soil moisture does not limit the plant's growth. Soil moisture level, which limits the growth of the plant, is called the stress limit.

In contrast, the soil moisture level at which the soil becomes saturated with water is described as field capacity. The main principle of irrigation is to adjust the moisture in the soil to be between the stress limit and water holding capacity and thus not to limit the growth of crops. (Ministry of Agriculture and Forestry, 1997).

Irrigation methods are generally categorized according to application systems in the field. There are main application methods in irrigation; surface, pressurized, and subsurface (Aras, 2006). Surface irrigation, also called furrow irrigation, uses small channels (furrows) constructed along the field slope to enable water to be carried by gravity along the crop rows. This irrigation method is suitable for row crops that require sufficient moisture with adequate drainage or crops that vulnerable to water stress for a long time (between half and a day). (Rai et al., 2017). In pressurized irrigation methods, water is applied to soil through the land’s slope or the help of energy and pressure obtained by a power source. Pressure irrigation methods include techniques such as drip, sprinkler and mini spring. In the sub-surface irrigation method, water is reached to the plant root zone by applying irrigation under the ground and through capillary forces (Aras, 2006)

In addition to identifying the right choice of irrigation system, programming the irrigation is also an important consideration. An effective irrigation schedule should be prepared by predicting the amount of water needed by the crop and the irrigation period. Irrigation is planned concerning plant water consumption and adjustments might be required for desired quantity and quality of the crop. Thus, the product yield is prevented from decreasing due to either water stress which is generally caused by insufficient soil moisture for the plants or excessive irrigation (Armstrong et al., 2001). Full irrigation and deficit irrigation are commonly referred to apply water in a scheduled time and amount regarding irrigation programming approaches. Full irrigation is usually used to get the highest yield from the product in areas where water is readily available or where water costs are low. However, since excessive water is applied with this approach, soil aeration is reduced, and the gas transfer between the atmosphere and the soil becomes limited.

On the other hand, deficit irrigation meets the water needs of the crop from time to time. While full irrigation is applied in sensitive periods when rainwater cannot provide the soil moisture required for the growth of the crop, in other periods, deficit irrigation is applied, and the crop is allowed to encounter particular stress. This approach should be referred especially for efficient water use in arid regions (Sezen, 2012).

In researches on effective irrigation methods, the concept of water use efficiency in products is commonly referred to (Howell, 2001; Tahar Boutraa, 2010; Zhang et al., 2017). The general objective of such studies is to improve water use efficiency by increasing the product grown per unit of water used. Boutraa (2010) states that the crop, which is grown according to principles of water use efficiency, to prevent product loss in arid regions, yields more profit than the crop that is not grown according to principles of water use efficiency. In addition, Zhang et al. (2017) used an optimization model (GIS-Optice) to propose that the optimum product yield does not mean maximum product yield. According to their findings, even if the product yield is below the maximum potential, the most favorable results occur when water and energy are used efficiently. Howell (2001) made several suggestions to improve water use efficiency in irrigated lands; increasing the product obtained per unit of water used, reducing water losses, reducing pollution in water, allocating water in order of priority.

Further studies in which irrigation methods to be applied on agricultural lands are investigated, effective agricultural practice is searched by examining the physiological responses of crops to irrigation. Green et al. (2006) promoted understanding the biophysical characteristics of the crop for the development of sustainable irrigation techniques. They modeled how the plant takes the water from the soil with its roots. Investigating the effects of insufficient water resources on plant growth, Yu et al. (2016) developed a temporal-spatial model to understand how much water crops need. Thereby, the most efficient irrigation method can be selected based on crop behavior.

The studies conducted especially in arid regions to meet the water need of the crop under extreme climatic conditions compared the irrigation systems by using different methods. Kang et al. (2017) researched the effective use of crops in dry regions. They suggested using Alternative Partial Root Zone Irrigation (APRI) technology and Regular-Deficit Irrigation (RDI) to increase water and product yield. While RDI is applied to the entire root zone of the plant, APRI technology promotes applying the water in alternative ways to different parts of the roots based on the plant’s needs. The new system where almost half of the plant’s root zone is irrigated, and the other half remains dry increases the water use efficiency without significantly reducing crop yield. According to Pereira et al. (2002), when the deficit irrigation program and advanced irrigation technique are applied together, the need for irrigation water decreases. Improvement in irrigation technique directly affects the homogeneous irrigation of agricultural land; however, when the deficit irrigation program is preferred, the availability of precipitation significantly affects the economic outputs in agriculture.

Deficit irrigation can be applied in moderate climatic conditions, yet care must be taken as it can lead to crop loss when applied in arid regions (Pereira et al., 2002). On the other hand, Mailhol et al. (2004) approved the economic applicability of deficit irrigation if a sprinkler irrigation system is used. Soil structure also affects the homogeneous distribution of irrigation in agricultural land. When the sprinkler irrigation technique is applied in clay soil, the water can percolate through the deeper soil layers. Thus, this technique contributes to the renewal of groundwater resources during cultivation periods. In addition, Xue and Ren (2016) evaluated the sprinkler irrigation system using an agricultural and hydrological model (SWAP-WOFOST). When switching from surface irrigation to sprinkler irrigation, the average annual water yield increased by approximately 8-14%. Water is transferred to the crops in subsoil due to capillary rise, while total use of water decreases. Although applying this technique delays groundwater renewal, no continuous decrease in groundwater level is observed, and crop yield and water efficiency are preserved.

Similarly, Albaji et al. (2015) compared sprinkler systems and drip irrigation techniques with surface irrigation. In arid and semi-arid regions, the transition from surface irrigation technique (gravity irrigation) to pressurized irrigation techniques (sprinkler, drip irrigation) helps address water shortage problems in the local agricultural sector. Water is used more efficiently, and the sustainability of groundwater and surface water is provided. It is highly recommended to use sprinkler and drip irrigation techniques in regions with arid or semi-arid climates (Albaji et al., 2015).

Many other technologies investigate crops and soil with a focus on irrigation efficiency. Such technologies monitor soil moisture and crop behavior before irrigation and/or after the irrigation. The optimal irrigation distribution on crops can be explored regionally in many irrigation areas with the SWAP-EPIC reference model (Jiang et al., 2016). Images provided by satellite systems and aerial vehicles used in remote sensing are used to measure water consumption, water stress and water loss (evapotranspiration) rates in soil and plants to evaluate the effects of drought and climate change on the crop yield to manage soil moisture. (Al Zayed & Elagib, 2017; Sanders & Masri, 2015).

In order to benefit with full potential from the advanced irrigation systems implemented currently, it is deemed necessary to monitor the impacts of the applied technology on water efficiency and exchange information (e.g., criteria on water use, soil moisture) between farmers, investors, and decision-makers (Levidow et al., 2014).

While agriculture has the highest share in freshwater use, competition with other sectors in countries with water shortages is expected to decrease the amount of fresh water used in agriculture. Thus, water resources alternative to freshwater are researched for use in agriculture. Unconventional water sources such as seawater, natural mineral water, rainwater, agricultural drainage and wastewater must be subjected to special treatment before being used for irrigation purposes (Qadir et al., 2007). Many developing countries treat wastewater before use for irrigation in agriculture. Pereira et al. (2002) studied wastewater discharge and brine water in addition to irrigation water with human health and environmental concerns. They emphasized that the applied irrigation technique, treatment level and crop surveillance are of great importance at this point. According to the study of Oster and Wichelns (2003), it has been determined that brine and alkaline water might increase agricultural production efficiency much more than expected. However, soil, crop and irrigation strategies need to be strengthened when using such waters (cited in Qadir et al., 2007).

2.3.1.2 Water Efficiency in Livestock Production

Today, the global livestock sector is responsible for 30% of agricultural water consumption (Ran et al., 2017). In the global context, while growing forage crops corresponds to 38% of the total plant water need, irrigation of pastures corresponds to 29% of total agricultural water consumption (Weindl et al., 2017). Besides, the water used for drinking and bathing purposes to meet the needs of animals is also considered within the scope of livestock water consumption.

The increasing demand for animal products will double the freshwater requirements. Consumption of water resources in livestock should be investigated based on the following criteria. First, consumed water resources should be distinguished as blue and green water. These waters should then be categorized according to the land on which plants use them. Finally, competition among water resources should also be considered so that widespread use of green water in livestock production can be seen (Ran et al., 2017). According to Peden (cited in Descheemaeker et al., 2010), the concept of water efficiency is more stated explicitly in the livestock sector as the Livestock Water Productivity (LWP), which is the ratio of benefits related to livestock products and services to the amount of water used to produce them.

According to Ayalneh (2008), irrigation areas constitute alternative feed-lots for animals. When the animals are taken to the irrigation areas, they can find both drinking water from the canals and grazing from grass or crop residues. Thus, this integrated agriculture-livestock production system increases the total productivity (cited in. Descheemaeker et al., 2010). Kebebe et al. (2014) stated that the LWP is directly proportional to the assets determined by the animal type and count and family labor that farmers have. Relatively affluent farmers with large herds provide more benefits (meat, milk, field plowing service) using feeds obtained from waste products and grazing lands. The increase in the yield of livestock products contributes to the increase of LWP.

On the other hand, farmers with low livestock cannot effectively benefit from crop residues and pastureland feeding. However, on the contrary, the size of the landowner is inversely proportional to the LWP because the sparse distribution of limited amounts of resources in larger areas limits efficient water use (Kebebe et al., 2014). In developed countries, total agricultural water consumption decreases with the increase of LWP; however, irrigated lands continue to expand due to the resulting transition from pasture to agricultural lands (Weindl et al., 2017).

Livestock systems are categorized based on various factors. The farms that manage cropping and livestock together create a mixed crop-livestock farming system. While livestock is carried out in such farms, forage plants can be feed on agricultural lands. Mixed crop-livestock systems can be classified further as rainfed or irrigated based on the management of agricultural lands on the farm. In addition, livestock systems can also be categorized based on the management of the animals. Such categories range from total nomadism to stationary animal husbandry depending on the conditions in which animals are allowed for grazing (Robinson et al., 2011). Some studies on efficient water use in livestock production have investigated various animal husbandry systems and evaluated relative water consumption (Owusu-Sekyere et al., 2017; Ran et al., 2017). They study different systems such as dairy farming (Owusu-Sekyere et al., 2017) or red meat production (Ran et al., 2017) to determine the most water-intensive product in the related system. According to Owusu-Sekyere et al. (2017), butter and cheese products have the most water footprint among all dairy products. At the same time, all dairy products produced exclusively by animal husbandry consume more water than crop-livestock mixed systems. In addition, dairy farmers are advised to use rainwater so that the plants benefit most. Examining the water consumed according to the feeding types of the animals, Ran (2017) compared the feeding from natural pasture, planted pasture and mangers. Natural pastureland consumes the most water compared to the unit animal meat produced. However, the most water-efficient way of producing proteins that will benefit people is natural pastureland. Ran emphasizes that animal production efficiency and the ability to feed people well are crucial elements of sustainable animal husbandry.

When climate change impacts livestock production, temperature increases, rising sea level, and increasing salinity of waters might affect animal production. According to Nardone (2010), the global livestock sector corresponds to 8% of anthropogenic water use, and livestock water consumption can increase 2-3 times due to global warming. At the same time, the salinity increase in water emerges chemical, biological pollutants and high concentrated heavy metals. Especially in coastal areas, these salts, chemicals and heavy metals present in the water may adversely affect animal metabolism, fertility and digestive system and cause various diseases in livestock (cited in Rojas-Downing et al., 2017); therefore, animal production and food safety might be compromised. In order to ensure the accessibility of food, the water consumed to produce agricultural (including livestock) products for cross-country transfer (export and import) has been evaluated and referred to as virtual water trade. In order to determine the water pressures caused by virtual water transfer in exporting countries, a virtual water trade balance has been created. If the amount of virtual water exported is greater than the country’s edible water resources, the country has a water shortage. Countries should implement efficient water use practices in agriculture to prevent such situations, including livestock (Brindha, 2017; da Silva et al., 2016). It should be noted that the life cycle of food, such as production, processing, and transfer, significantly contributes to global warming in terms of water use and greenhouse gas emissions unless necessary actions have been taken.

2.3.1.3 Water Efficiency in Food Processing Industries

In addition to farming crops and livestock, food processing industries have an essential share in water consumption for food production. In general, the priority of the industries is to maximize production before efficient use of water. Even if some advanced processes increase product yield, however, they may not decrease total water consumption. An industry is prone to either supplying its water or using public water at the lowest price. Even the savings achieved by improving water efficiency to increase the profit can be reinvested to increase production (WWAP, 2015).

Van den Abeele et al. (2017) conducted a feasibility study to neutralize an individual industry regarding water balance. This method is attributed to water neutrality and is regarded as an effective means of reducing the pressure on global water resources. To that end, the recommended measures are listed as follows; redefining water quality requirements, preventing water consumption with appropriate practices, changing the techniques that consume water, techniques to improve the quality of surface and rainwater, measures to reduce the use of hot water, measures to reduce food residues. Meneses et al. (2017) emphasized that if water consumption decreases in production sectors, expenditures reduce by 25% with behavioral changes, 30% with water recycling (no treatment), and 60% surveillance. After reducing water consumption with the appropriate methods in the food processing industries, membrane filtration can be applied to recover and reuse the wastewater (Meneses et al., 2017).

While various applications are recommended for water efficiency in food production, it should be noted that dietary choices mainly shape water use. Specific amounts of water are needed in processes such as the cultivation and processing of every food produced in line with the consumer demand. When consumers prefer healthier alternatives in their diets (not to consume, e.g., sugar, oil, cereals), food production with high water demand and total water consumption will be affected (Damerau et al., 2016). Vanham et al. (2016) emphasized that meat consumption has a large share in water consumption. When processing foods for vegetarian or pesco-vegetarian diet preferences, much less water is needed, and if diets were switched with such preferences, water consumption would decrease by 36-42% (Vanham et al., 2016).

2.3.2 Water-Food Nexus Research in Study Area

Various studies are conducted within the Water-Food Nexus research in the Upper Sakarya basin. Most of the studies focus on the linkage between water and agriculture. Studies investigating irrigation network systems performance evaluate different factors such as water use or product yield per unit land in agriculture (Merdun, 2004; Çakmak and Beyribey, 2003; Uygan and Çetin, 2015). Water quality studies in the region analyze water bodies, irrigation water, or soil to measure pollutants from fertilizers and pesticides (Uygan et al., 2001; Uygan and Çetin, 2004). Furthermore, the WEAP model is utilized by applying a crop growth method to investigate the hydrological behavior of the Sakarya River Basin (Yaykıran et al., 2019). An overview of the selected studies on the Water-Food Nexus in the study region is provided.

The modeling study of Yaykıran et al. (2019) estimates the water budget components of the Sakarya River Basin and assesses plant growth modeling's applicability. The WEAP model configuration is suggested to calculate crop yields under climate change linked with WEF Nexus. Merdun (2004) evaluated the performances of 239 irrigation networks in Turkey (57 operated by the DSİ and 182 operated by irrigation associations) by comparative analysis based on external indicators in the watershed (e.g., unit production values). Also, different factors such as watershed characteristics, crop patterns, and project size are considered in the study. Similarly, Çakmak and Beyribey (2003) analyzed the irrigation systems' performance in the Sakarya basin based on comparative indicators of irrigation networks. When the excessive use of water in the basin is considered, it was concluded that the water is not used effectively, and the production yield per unit area and water are low. Uygan and Çetin (2015) studied drip irrigation systems of 13 irrigation projects in Eskişehir and Sakarya provinces. The study found that the irrigation systems have significant problems with water application, and farmers lack information about the drip irrigation system and its use. Karagöz and Fidan (2011) addressed irrigation-related problems in the Polatlı district of Ankara. They researched 677 irrigation projects operated by irrigation cooperatives regarding land size, family labor, education, crop pattern, agricultural and non-agricultural income, net and gross income and capital. Uygan et al. (2001) investigated boron pollution in water sources used for irrigation purposes in Eskişehir-Seyitgazi-Kırka districts. In the study, boron pollution is measured in irrigation water and soil. According to the results, it is observed that boron pollution damages the plants in the region.

Similarly, Uygan and Çetin (2004) researched the Seydisuyu watershed to determine boron pollution levels in water and soil and the accumulation and distribution of boron. According to the observations, boron levels in irrigation water and drinking water are higher than the limit value of 1 ppm. Furthermore, soil boron concentrations are smaller than five ppm except for certain areas nearby and plains in the region. Taban et al. (2000) determined the total exchangeable and extractable potassium contents and potassium adsorption capacity in paddy fields in the study area, including Mihalıcçık district of Eskişehir and Nallıhan, Güdül, Beypazarı and Kızılcahamam districts of Ankara.

On the other hand, this research intends to suggest and evaluate alternative demand management solutions to water-oriented problems concerning agriculture in the region. For this purpose, after analyzing the current situation, several scenarios were developed. The effectiveness of the alternatives was evaluated based on various aspects using the WEAP model to support decision-making for the authorities. Furthermore, this study includes the analysis regarding water budget components by aggregating all inflows and outflows associated with surface water and groundwater. This approach is expected to contribute as an integrated perspective instead of establishing a particular model component (e.g., catchment) for water balance calculations.

2.4 Nexus Tools

There are various decision support tools to comprehend the linkages in WEF Nexus. These tools are used to investigate the nexus tradeoffs and the evaluation of the nexus-oriented management strategies. In the studies that employ the nexus approach, the main objectives are most commonly stated to improve resource-use efficiency or management, enhance policy integration, and/or promote sustainable resource-use practices (Albrecht et al., 2018). Several considerations occur for categorizing nexus evaluation tools, such as purpose and scope of the study, model type, scale, data intensity, and model complexity. The list of available models to evaluate the nexus is given in Appendix A. After reviewing the representative case studies, Dai et al. (2018) assigned the following properties of each model;

- Nexus scope refers to a combination of nexus components (water, energy, food, land, use, climate and ecosystem) covered in the representative studies.
- Model type: Three types of models are stated. The quantitative analysis model is a method or tool to quantify the flows and not simulate a scenario in temporal scales. The simulation model is a single model capable of modeling scenarios in temporal scales. The integrated model is composed of single consolidated models and capable of scenario simulating.
- Geographical scale: Four scales of application are considered: city-, regional-, national-, and transboundary-level.
- Nexus challenge level: Three categories are defined; understanding the nexus, governing the nexus or implementing the nexus. Understanding the nexus implies that the studies only compute primary data to determine linkages and identify fundamental problems, risks or opportunities. Governing the nexus refers to the studies intend to guide a policy or institutional response towards the underlying problems in resource management. Implementing the nexus refers to the studies with the purpose to guide policy and/or technical interventions to improve productivity in resource use and establish effective resource management (Dai et al., 2018)

2.5 WEAP Model for the Evaluation of Water – Food (Agriculture) Nexus

In this study, the WEAP is used as an integrated modeling system to evaluate management strategies and support decision-making for the authorities. WEAP model is selected as a decision support tool to achieve the objectives of this study due to following reasons;

Ease of use: WEAP has a user-friendly and graphical interface that enables constructing, visualizing, and modifying the water systems and their data (Sieber & Purkey, 2015).

- Accessibility: WEAP is free to use for a non-profit, governmental or academic organization based in a developing country.

Data adaptability: WEAP allows the user to control the level of detail of the data structure to adapt the model based on the available information. Either the user can generate a model based on a limited data structure when adequate data might not be available or define a new set of variables and equations to simulate specific conditions that are not initially addressed by WEAP (Kaddoura & El Khatib, 2017)

Scenario analysis: WEAP is a scenario-based tool that provides the main guidance for decision-making by addressing a broad range of water use sectors.

- Demand management: WEAP has a unique capability to represent the effects of demand management on water systems. Water demands in final uses vary by different regions, techniques and processes in the model. With this approach, development objectives can be created for the basis of water analysis, and the effects of improved technologies on final uses can be evaluated (Sieber & Purkey, 2015).

WEAP model was developed by Stockholm Environment Institute (SEI). The model is used for the evaluation of water systems in over a hundred countries. Sieber and Purkey (2015) stated that policies developed for allocating a limited amount of water resources, environmental quality, and sustainability of water consumption are becoming increasingly important today. However, water resources management around the water supply is no longer sufficient. The WEAP model is a practical water resources management tool used in a framework in which water supply projects are shaped around the demand, and the water quality and ecosystem conservation issues are handled together with the holistic approach adopted as a result of this inadequacy in water resources management for the last ten years. The transparent structure of the WEAP model evaluates multiple, competitive use of water systems and makes it easier for stakeholders to participate in clearly conducted water development and management assessments (Sieber & Purkey, 2015).

In order to simulate water system operations, WEAP combines water supply and demands and addresses the problems of the system on the demand side and dynamics on the supply side. The model's water demand estimates are derived from water usage profile, equipment efficiencies, water reuse strategies, costs, and water allocation schemes. Water supply is estimated by reproducing managed supply components (stream regulations, groundwater withdrawal, reservoirs and water transfers) and natural supply components (evapotranspiration demand, surface flow, environmental flow). The main principle of the WEAP model is based on water balance accounting. The model can be applied to a simple river basin or complex transboundary river basins (World Bank, 2017).

WEAP model is used as a decision support tool in several studies evaluating the water and food nexus. Most of these studies focus on addressing issues related to agriculture which has adverse impacts on water resources.

WEAP model is used to evaluate demand and supply of irrigation water and consequently to determine unmet demand (Sampath et al., 2014); to evaluate the impacts of a new reservoir introduced to the system on improved water use in irrigation and suggest alternative solutions that may be of more importance compared to dam construction (Swiech et al., 2011); in collaboration with a risk-based economic optimization, model to provide an economic-hydrological framework which includes evaluation of policies regarding water delivered for irrigation and minimum environmental flow requirements to promote sustainable agricultural management (Blanco-Gutiérrez et al., 2013).

Irrigation scheduling strategies can be incorporated into the WEAP model application to investigate the water stress of cotton under regulated deficit irrigation in a semi-arid region (Bhatti & Patel, 2015). The model is combined with the Decision Support System for Agrotechnology Transfer (DSSAT) to link regional water supplies and management with field-level water demand and crop growth (Winter et al., 2017). The deficit in the irrigation demand is investigated under different scenarios in which irrigation efficiency is improved and non-revenue water is reduced (Al-Omari et al., 2015). Fowe et al. (2015) used WEAP to estimate irrigation water demand. They developed a deterministic genetic algorithm model to optimize irrigation water management, where the decision variable is water allocation for irrigation demand from reservoir and groundwater. In another study, WEAP is linked with MODFLOW to implement a coupled surface water-groundwater flow to investigate drought impacts on agricultural production and management alternatives that maintain agricultural production and the water system. The dynamic coupling of WEAP-MODFLOW is also suggested as a valuable tool for evaluating the effects of management scenarios that contribute to sustainable agricultural production (Dehghanipour et al., 2019). Investigation of water governance in agriculture is practiced in WEAP most commonly by developing various management scenarios which include alterations in water allocation strategies and irrigation water management, capacity building of human resources, dams and canal management (Salomón-Sirolesi & Farinós-Dasí, 2019); practices such as treated wastewater use for irrigated agriculture (Alfarra et al., 2012); policies in the marketing of agricultural products (Darani et al., 2017); or climate change adaptation strategies for agricultural sustainability (Jackson et al., 2012) and so on. Water quality modeling is also practiced by WEAP applications in which parameters such as BOD (Mishra et al., 2017; Assaf and Saadeh, 2008), COD (Al-Omari et al., 2018), DO (Mishra et al., 2017), temperature (Al-Omari et al., 2018) nutrients and salinity (Slaughter et al., 2016) are analyzed.

Furthermore, the WEAP model is used to investigate the water – food (agriculture) nexus concerning climate change adaptation strategies in several studies. (Golfam et al., 2019; Sridharan et al., 2019); (Ahmadaali, Barani, Qaderi, & Hessari, 2018); (Skoulikaris, Ganoulis, Tolika, Anagnostopoulou, & Velikou, 2017); (Santikayasa, 2016); (Amisigo, McCluskey, & Swanson, 2015); (Esteve, Varela-Ortega, Blanco-Gutiérrez, & Downing, 2015); (Yates, Miller, Wilby, & Kaatz, 2015); (Karamouz, Ahmadi, & Zahmatkesh, 2013); (Mehta, Haden, Joyce, Purkey, & Jackson, 2013); (Sutton, Srivastava, & Neumann, 2013); (Vicuña, McPhee, & Garreaud, 2012); (Joyce, Mehta, Purkey, Dale, & Hanemann, 2011); (Mulligan et al., 2011); (Purkey et al., 2008). For most of these studies, climate projections are provided as meteorological inputs to the WEAP model, and adaptation strategies are evaluated under different climate change scenarios.

CHAPTER 3

THE WEAP MODEL APPLICATION IN THE UPPER SAKARYA BASIN

The Water Resources Evaluation and Planning System (WEAP) model is applied to evaluate the water and food (agriculture) nexus to provide sustainable water and agriculture management in the Upper Sakarya Basin. The WEAP model development for the study area, including data collection and their introduction to the model, followed by the methodology related to the watershed delineation, catchment simulation, model calibration, and sector-based operational scenarios, are explained in this chapter. A schematic view of the WEAP model application of the Upper Sakarya Watershed is provided in Figure 3.3. Detailed outlooks are given in Appendix B.

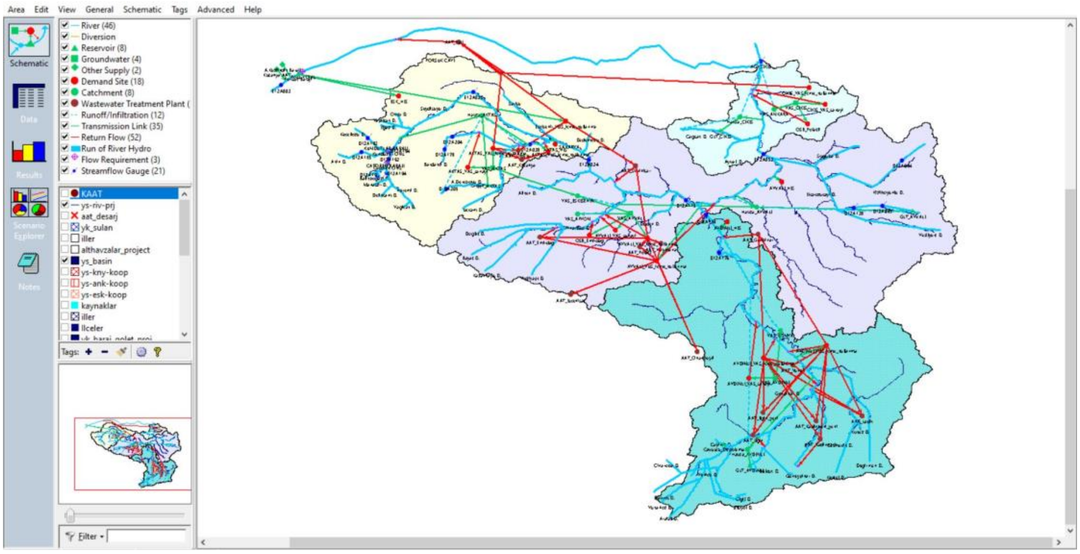


Figure 3.1. Schematic view of the WEAP model application of the Upper Sakarya

3.1 The WEAP Model Theoretical Background

The WEAP model incorporates a data view enabling create and organize the data by the user. The data structure is established as a hierarchical tree in the data view, as shown in Figure 3.2. The tree has branches categorizing the data under six main divisions: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions.

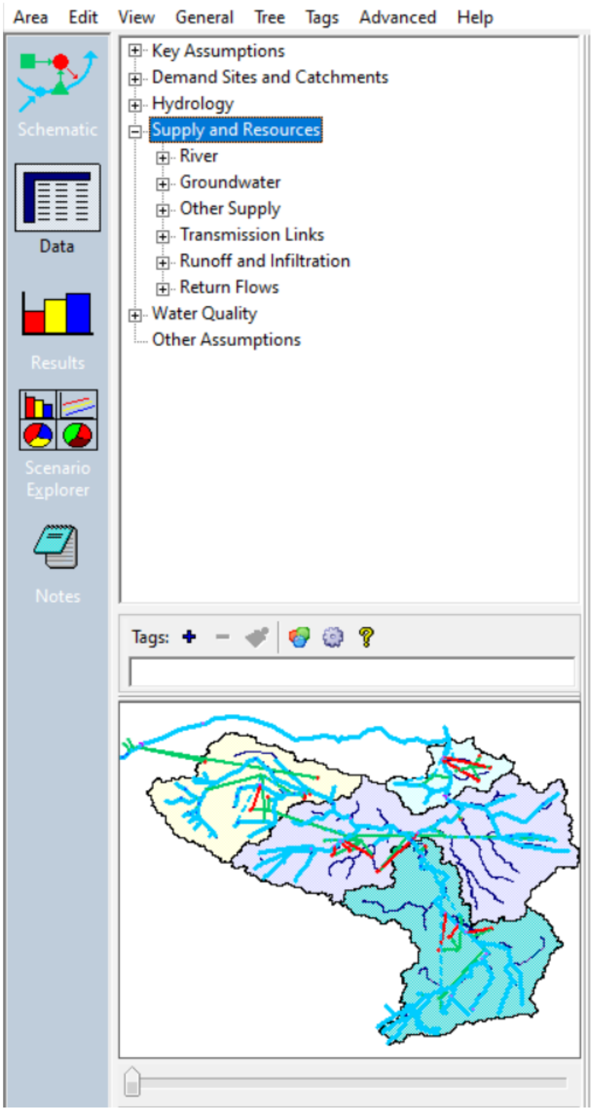


Figure 3.2. Data view of the WEAP model

The data tree branches that enable the organization of the model inputs are described in Table 3.1. These structures consist of physical and conceptual structures that represent the system established in the model. Data tree sections are divided into five main categories: assumptions, demand sites and catchments; hydrology; supply and resources; water quality.

Table 3.1 Overview of the data tree of WEAP model

	Branches	***Description***
Assumptions	Key Assumptions	Independent variables that are not directly calculated by the model and are defined by the user to be used as model assumptions
	Other Assumptions	Intermediate variables as of secondary importance after key assumptions
Demand Sites and Catchments	Demand Sites	Water need for different purposes (such as urban, industrial, agricultural)
	Catchments	The component that transmits the water collected by the basin into streamflow also constitutes agricultural water demand if deemed necessary.
Hydrology	Water-Year Method	User definition of the water year types (very dry, dry, normal, wet, very wet)
Supply and Resources	River	River network and its components
	Reaches	Section of a river between two nodes
	Reservoirs (Dam/Lake/Pond)	Reservoirs on the river network
	Hydroelectric Power Plants (Run of River Hydro)	Represents run of river HEPPs
	Flow Requirements	The component where minimum flow requirement such as environmental flow and tailwater is defined
	Streamflow Gauges	The component where the streamflow observed in gauges is defined

	Branches	***Description***
	Groundwater	Groundwater reservoir (aquifer)
	Local Reservoirs	Reservoirs located outside the river network
	Other Supplies	Surface water supply sources that are not modeled in WEAP application, such as inter-basin transfers
	Transmission Links	Water supply networks (e.g., drinking water, irrigation)
	Runoff and Infiltration	Links that transmits the flow out of catchment to the river
	Return Flows	Links that transmits wastewater from demand sites or treated effluent from the wastewater treatment plants
Water Quality	Wastewater Treatment	Wastewater treatment plant

3.1.1 Model Components and Data Requirements

The WEAP model requires specific data to represent the processes carried out in the study area and to perform simulations accurately. The data are categorized and defined in the model under different components of the basin. Such components configure the basin's structure and can be classified as water supply and resources, water and wastewater distribution systems, residential areas, agricultural areas, industrial sites, and power plants. The model has a schematic view that enables building the basin's structure and visualization of physical structure. The spatial map of the water system can also be created by utilizing GIS layers added to the schematic view. In Figure 3.2, model components are demonstrated for a sample area created in the schematic view of the WEAP model.

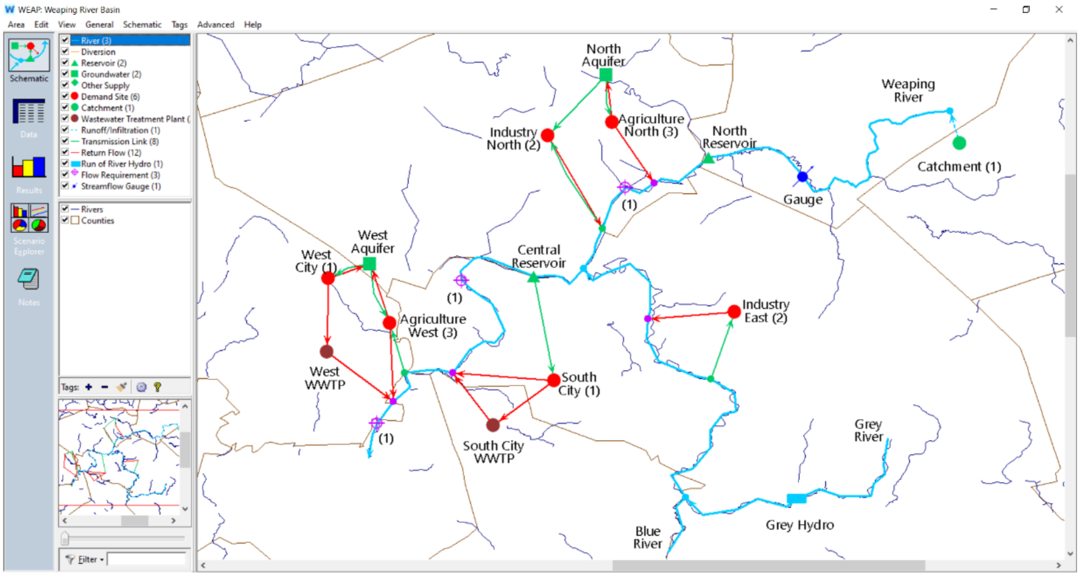


Figure 3.3. Schematic view of the WEAP model

The initial setup should be ensured before running the model. Time steps and units are defined in general settings. After the initial setup, the physical structure of the water system is established, and data is entered as inputs to the model. The data is entered into the model under five major categories of the data tree. Data requirements in each category are given in the following sections;

3.1.1.1 Assumptions

Assumptions are expressions that the user produces to use as a reference in the model elsewhere. Assumptions can be referred to as different inputs by linking the relevant input to the assumption defined. There are two types of assumptions (key and other) that users can define depending on the importance of the input. Assumptions less important variables compared to key assumptions should be entered under other assumptions. Key assumptions such as Gross National Product (GNP), water charge tariff, and population growth rate might be referred to in various scenarios.

3.1.1.2 Demand Sites

Demand sites represent the water users that withdraw water from a particular resource in the region. A demand site can consist of water users such as industrial sites that withdraw water for industrial production and residential/municipal/agricultural areas that use water for domestic/commercial/irrigation purposes.

Demand sites can be disaggregated into as many levels as required. For instance, Disaggregation based on sector, sub-sector, end-use, and operation may be needed where refined data is available. Under the agricultural sector, the irrigation area for each crop can be specified at the subsector level. Below the subsector level of crop area, the percentage of each irrigation technique may be assigned at the end-use level (Sieber & Purkey, 2015).

Inputs to be defined for demand sites are listed in the table below. These are grouped under different water use sections, loss and reuse, demand management, water quality, cost, priority and advanced.

Table 3.2 Demand site inputs to be defined in the WEAP model

Section	*Input*	*Description*
Water Use	Annual Activity Level	The annual level of activity driving demand
	Annual Water Use Rate	Annual water use rate per unit activity
	Monthly Variation	Monthly share of annual demand
	Consumption	% of inflow consumed
Loss and Reuse	Loss Rate	Losses within demand site increasing supply requirement
	Reuse Rate	Water reuse within demand site resulting in a decrease in supply requirement
Demand	Demand Site Management (DSM) Savings	% reduction in total monthly demand due to demand-side management programs

Section	*Input*	*Description*
	Demand Site Management (DSM) Cost	Annual demand site management costs per unit water saved
Priority	Demand Priority	Demand site's priority for supply
Advanced	Method	Method for determining the demand

3.1.1.3 Catchments

In the WEAP model, the catchment component represents a particular geographical area where precipitation is collected and transmitted as evapotranspiration, runoff and/or infiltration. Catchments are simulated based on five different methods. Calculation algorithms, hence the input data required for the simulation of catchments, differ relying on the simulation methods stated below;

1. Irrigation Demands Only Method (Simplified Coefficient Method)
2. Rainfall-Runoff Method (Simplified Coefficient Method)
3. Rainfall-Runoff Method (Soil Moisture Method)
4. MABIA Method
5. Plant Growth Model

Specified data required to simulate catchments for all methods are provided in Appendix C. Simplified coefficient method disintegrates into two different versions, which require the same type of input.

Irrigation Demands, the Only version of the Simplified Coefficient Method, is the simplest compared to other methods. With this method, the area can be defined as irrigated or non-irrigated. Within the boundaries of the irrigated area, water balance is created based on precipitation and evapotranspiration processes. If the rainfall cannot meet the evapotranspiration need, the water shortage creates an irrigation demand for the irrigated area. However, this method disregards runoff and infiltration processes or does not monitor soil moisture. Also, it assumes that all the water collected is used for plant evapotranspiration.

Rainfall-Runoff Method version of the Simplified Coefficient Method also uses the same data type as the other version. However, after the water is collected by rainfall and irrigation and used for evapotranspiration, the remaining water is transmitted into surface runoff or infiltration.

In the Rainfall-Runoff Method (Soil Moisture Method), the soil is assumed to consist of two layers. Water balance is structured in a more sophisticated way; correspondingly, more extensive data for soil type or land use characterization are required. Soil layers are defined as the upper soil layer and lower soil layer. Different processes take place in each layer. The water is collected by rainfall and irrigation in the upper soil layer and transmitted as evapotranspiration, surface runoff, interflow, and change in soil moisture. The soil moisture method enables the characterization of soil type or land use that affects these processes. In the lower layer, base flow and change in soil moisture are calculated.

MABIA method simulates daily using the Dual Kc Method, which separates the evaporation processes on the soil surface and the transpiration process of the plants. The method is embedded in the model in line with Irrigation and Drainage Paper No. 56, published by the Food and Agriculture Organization of the United Nations. The method establishes a water balance by simulating transpiration and evaporation, irrigation, crop growth, yield, and the catchment's reference evapotranspiration and soil water capacity.

The Plant Growth Method is practiced as a catchment simulation method in a study carried out by Yaykıran et al. (2019) in Sakarya River Basin. Plant Growth Method simulates soil hydraulic processes by a 13-layer model representing the first 3.5 meters of the soil layer. Furthermore, plant growth, crop demand, and yields are analyzed. The method has been developed to study the impacts of CO2 concentration in the air and temperature stress, and seasonal variations on the plants. This method is also very useful in managing the crop pattern in the studied basin by monitoring the plant growth rate and the amount of water used. The method further simulates surface runoff, deep percolation, evapotranspiration, water and temperature stress, biomass production, and crop yield.

3.1.1.4 Supply and Resources

The water system composed of supply and resources to be established in the model consists of seven components. These components are grouped as the river, groundwater, local reservoirs, other supplies, transmission links, runoff and infiltration, and return flows. Appendix 0 provides the general data requirements to define each component that constitutes supply and resources.

The river represents the main streams and all the components on the river network of the basin. Runoff generated by the catchment component is discharged into the river. Water is withdrawn from the river to supply water to meet, for example, agricultural, urban, and industrial demands. Withdrawn water is distributed according to the demand priorities and supply preferences of relevant components. The components that form the river are provided below:

- <u>Reaches:</u> River sections disintegrated with each node (a physical component along the river). A reach represents a river section between two nodes on the river. A reach is called the node above it.
- <u>Reservoirs:</u> Reservoir sources on the river. A river reservoir releases water directly to demand sites or downstream for use and can simulate hydropower generation (aside from the river hydro component).
- <u>Hydroelectric Power Plants (Run of River Hydro):</u> HPPs running on the river generate electricity based on the flow dynamics of the stream. The model calculates the water required to produce energy by the plant and sends the

water required from the river to the plant to meet the hydropower production needs.

- Flow Requirement: Represents the minimum instream flow required for different water needs (such as fish and wildlife, recreation, or navigation) at a point of a river.
- Streamflow Gauges: Stations that monitor streamflow at a point of a river. Measured data is entered to compare to computed streamflow.

Groundwater resources can be fed by natural recharge, leakage through the transmission links or water bodies, and inflows from the catchment, demand sites or wastewater-treatment plants. Furthermore, groundwater supply can be linked to many demand sites, catchments, reservoirs or rivers for different purposes.

Local Reservoirs are sources located outside the river network and are correspondingly managed independently of any river system, unlike the river reservoirs.

Other Supplies represent sources without storage capability yet have predetermined water amounts available monthly.

Transmission Links deliver water from resources to any demand sites, catchments, reservoirs or rivers for different purposes. Transmission links also deliver discharges of demand sites or wastewater treatment plants to other end-users for the re-use purpose. The transmission links to the end-users allocate the water to demand priorities and supply preferences.

Runoff and Infiltration links carry runoff or infiltration from the catchment to groundwaters, rivers, and reservoirs.

Return Flow links carry discharge of demand sites or wastewater treatment plants. Discharge or effluent from demand sites or wastewater treatment plants can be routed to any surface or groundwater resources, wastewater treatment plants, or demand sites.

3.1.1.5 Water Quality

If water quality modeling is enabled in WEAP, water quality constituents can be defined and tracked throughout the water system. The water quality modeling is performed either within WEAP or by linking the QUAL2K. Following inputs to be defined for the Wastewater Treatment Plant and other model components are included in water quality modeling. This study does not involve water quality analysis.

Table 3.3 Water quality inputs of the model components

Component	*Input*	*Description*
Wastewater Treatment Plant	Daily Capacity	Maximum daily process capacity of the treatment plant (in terms of effluent inflow)
Wastewater Treatment Plant	Consumption	% of inflow lost from the system during treatment or disposal processes
Wastewater Treatment Plant	Removal	% of the pollutant removed (i.e., removal efficiency)
Wastewater Treatment Plant	Concentration	The effluent concentration of the pollutant
Demand Sites & Catchments	Intensity	Annual production of the pollutant per unit of activity
Demand Sites & Catchments	Concentration	The concentration of the pollutant in outflows from the demand site
Demand Sites & Catchments	Inflow	Maximum allowed concentration of the pollutant present in inflow to demand site
River	Concentration	If the water quality is modeled in the river, the concentration of the pollutant in head flow; if not modeled, the concentration of the pollutant flowing out of the river
Reaches	Water Temperature	The temperature of water for each reach
Reaches	Concentration	The concentration of the pollutant in surface water inflow to reach
Reservoirs (River & Local)	Concentration	The concentration of the pollutant in water released from the reservoir
Reservoirs (River & Local)	Temperature	The temperature of water released from the reservoir

Component	*Input*	*Description*
Streamflow Gauges	Concentration Data	Measured data on the concentration of the pollutant
Groundwater	Temperature	The temperature of outflows from groundwater to river reaches
Groundwater	Concentration	The concentration of the pollutant in outflows from groundwater to river reaches
Other Supplies	Concentration	The concentration of the pollutant in outflows from the supply
Other Supplies	Temperature	The temperature of outflows from the supply
Runoff and Infiltration & Return Flows	Decrease	% decrease of the pollutant while flowing through the link

3.2 The WEAP Model Development for Upper Sakarya Basin

In the WEAP model, all flows are presumed to occur instantly so that a demand site will take water from the river, use it, and return the rest to a receiving water body at the same time step. The model can also allocate water to satisfy any particular demand in the system without regard to travel time since the river network's topology is limited. Thus, the simulation duration of the model should be at least as long as the residence time, including the filling and the emptying cycle of the streamflow in the study area. Furthermore, most of the studies on agricultural water management deem it acceptable to adopt monthly time steps for their purposes (Santikayasa, 2016; Esteve et al., 2015; Mehta et al., 2013; Yates et al., 2015; Jackson, 2012; Joyce et al., 2011; Purkey et al., 2008). Therefore, the WEAP model application of Upper Sakarya adopted monthly time series.

For the general overview of the WEAP model application of the Upper Sakarya Basin, flowcharts are depicted to demonstrate the conceptual model. Model components are given in Figure 3.4. Besides the rendering of model components, the flowchart is constructed based on data used for model inputs, the process applied by the user, output generated by the model. The flowchart is intended to demonstrate basic inputs defined by the user, the overall process contributing to modeling sector-based water use and procedures associated with the calibration process and scenario development.

In Figure 3.4, the hydrological components used during the installation of the model and the relationships between them are depicted, and the elements used in the flow chart are determined. The model components included in the flowchart are; river, dam (or pond), groundwater, catchment, demand site, wastewater treatment plant, and interlinkages. During the model setup, the connections between surface water and groundwater are not shown in the conceptual model since they are not established in practice in line with the applied methodology. The model simulation of the surface-water and groundwater dynamics is as follows. The streamflow reaching the stream is shown over the runoff link, representing the flows generated by the catchment component. In addition, the recharge reaching the aquifer from the surface water is introduced as an input to the groundwater reserve component.

In the flowchart, there are the outputs obtained as a result of the calculations in the model and the data categories and the operations performed by the user. The flowcharts are divided into two according to the model components accordingly; Figure 3.5 includes steps for modeling water resources, industrial, urban and livestock water demand and supply; and Figure 3.6 involves steps for simulation of the catchment, calibration process and scenario development. In general terms, flowcharts describe business rules related to the introduction of inputs from the data to the relevant model components, and operations carried out by the user in the model or outside the model, outputs obtained through model simulation, calibration and scenario setup procedures.

Detailed descriptions regarding the model development incorporating data, watershed delineation, catchment simulation method, calibration and validation, and scenario development are provided in the following sections.

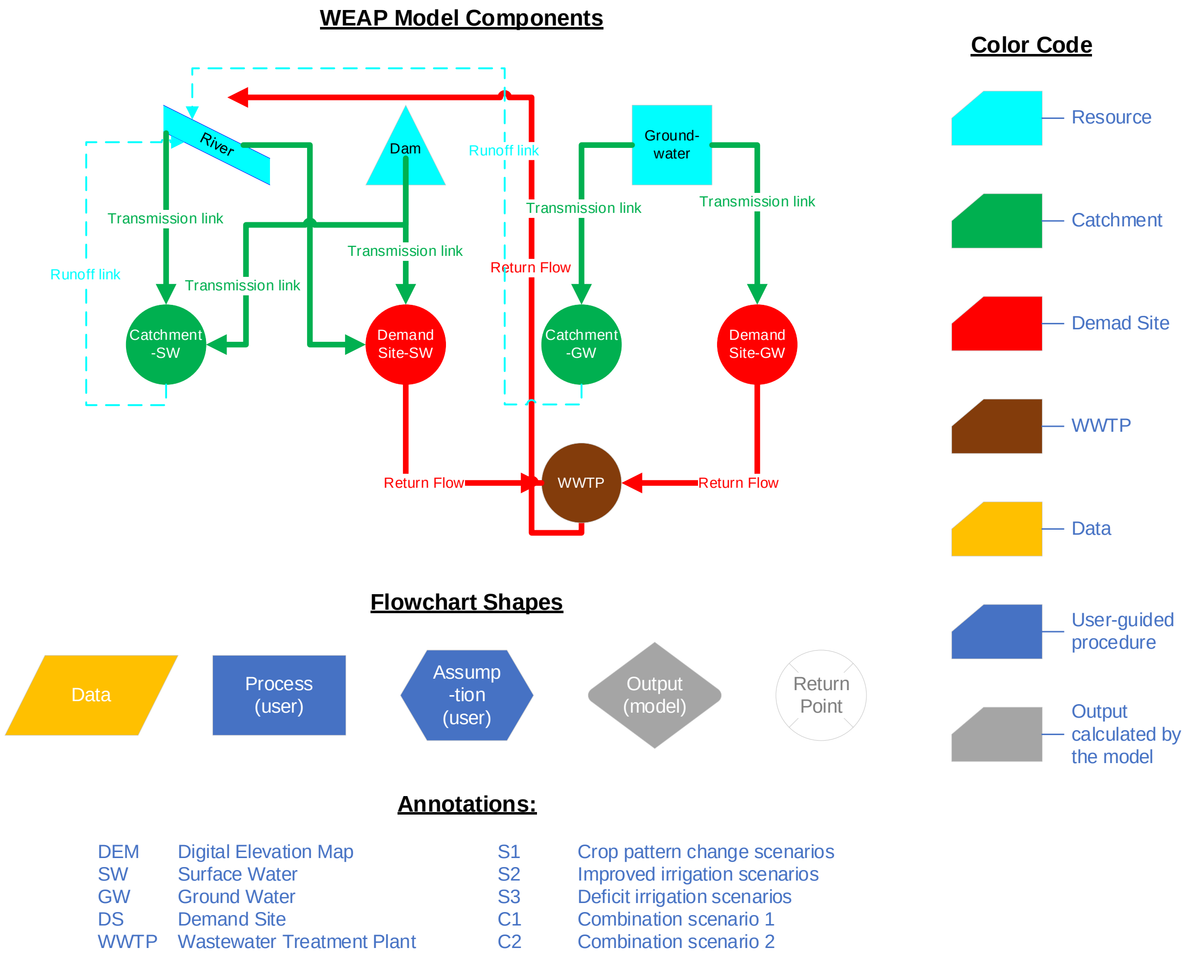


Figure 3.4. Legend of the conceptual model flowchart for the WEAP model application of study area

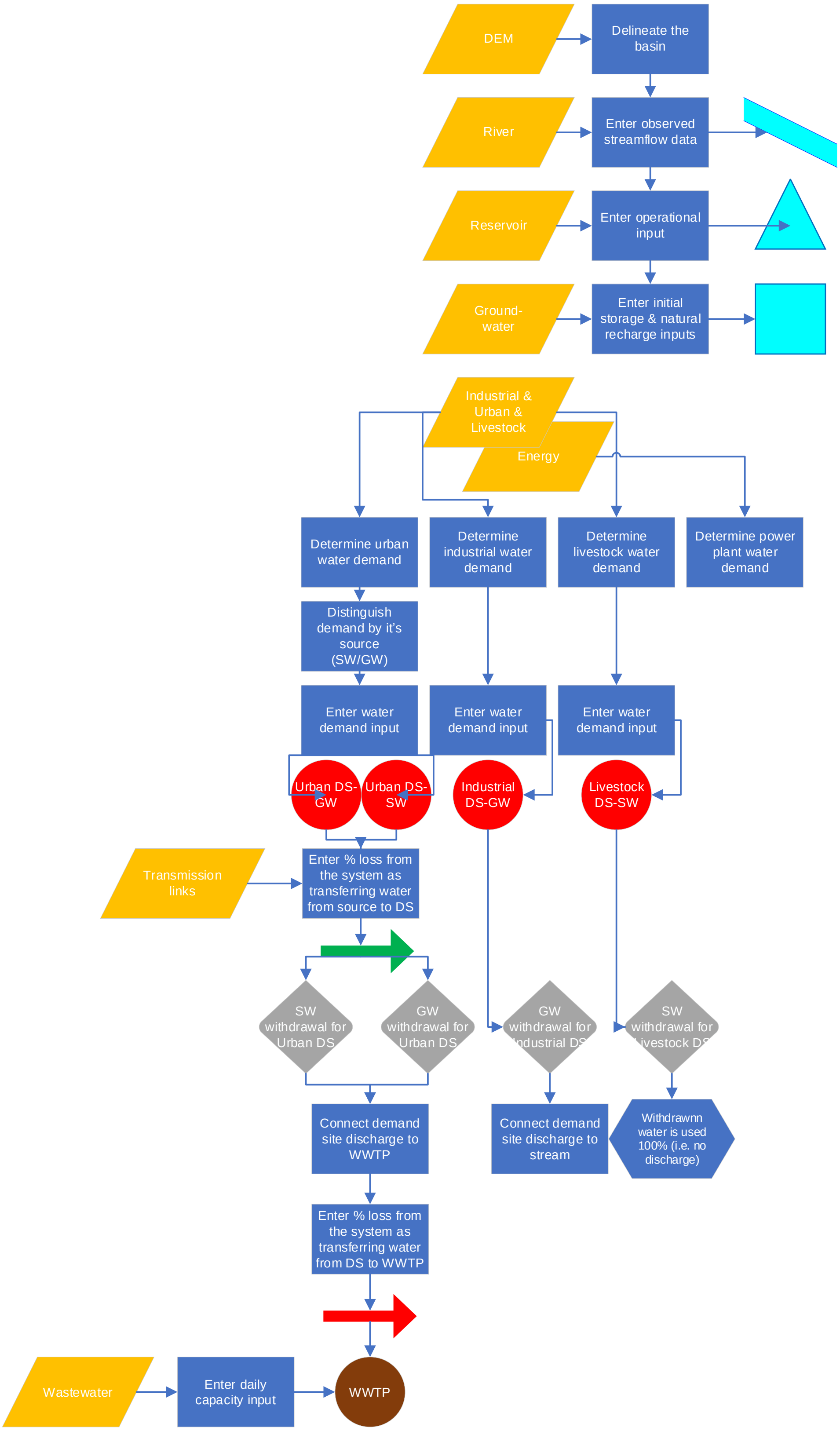


Figure 3.5. The conceptual model for simulation of resource, demand and supply

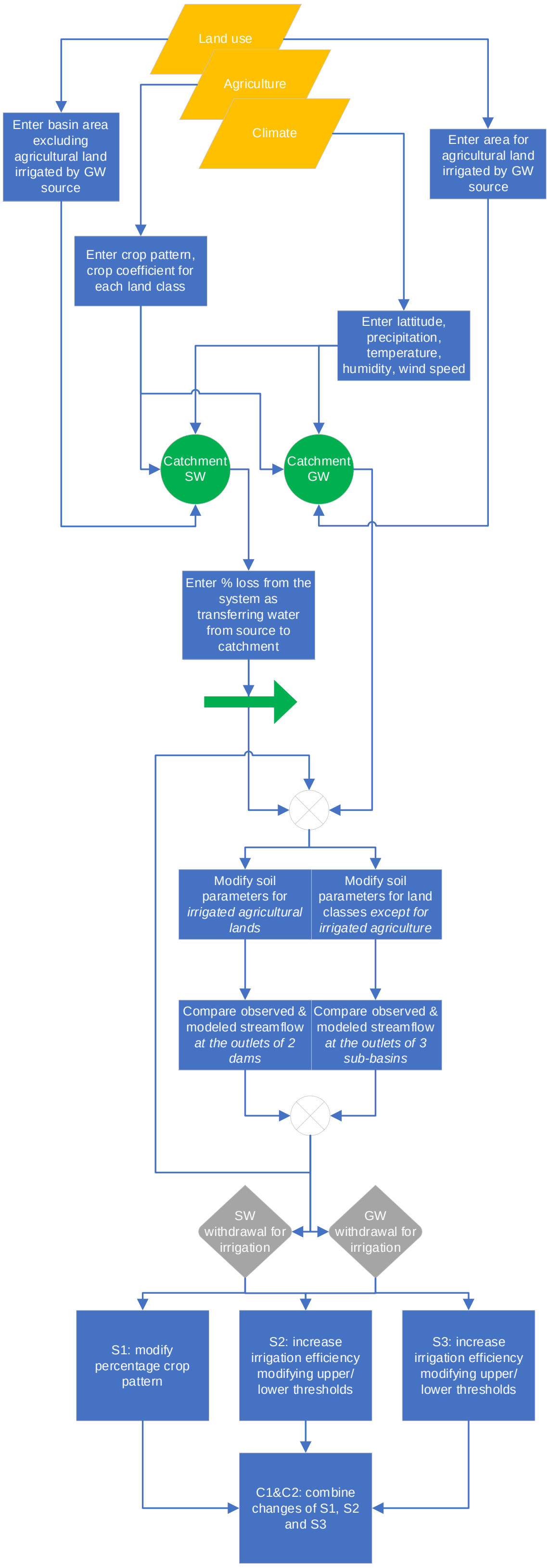


Figure 3.6. The conceptual model for simulation of catchment

3.2.1 Watershed Delineation

In order to determine the river network and the drainage area of the basin, the ArcGIS tool is used. Three different streamflow gauges are used in delineating the basin. Considerations in determining those gauges are based upon the gauging locations and the data available in the gauges. The information about gauges is given in**Error! Reference source not found.**, and the locations of the gauges are shown in Figure 3.7**Error! Reference source not found.** and Figure 3.8 in more detail. Each gauge is designated in the GIS environment as the pour point of a sub-basin. At the location where Sakarya River meets Porsuk Creek, another point is designated as the basin outlet. The study area is delineated into sub-basins according to these pre-determined points in the GIS environment. Each sub-basin is named after the gauging station located at the outlet. Thus, Upper-Sakarya basin is delineated into four sub-basins, namely Aktaş, Ayvalı, Aydınlı, and Outlet.

Table 3.4 List of streamflow gauges

Gauge	*Code*	*Status*	*Gauging Period*	*Catchment Area (km^2)*	*Approximate Height (m)*
Aktaş	E12A024	Open	1963-2011 2013-2016	4283	837
Aydınlı	D12A159	Open	1982-2008 2011 2015-2016	6865	790
Ayvalı Yaylası	E12A052	Open	1989-2008 2010-2011 2013-2016	19839	709

Figure 3.7. Schematic view of Upper Sakarya

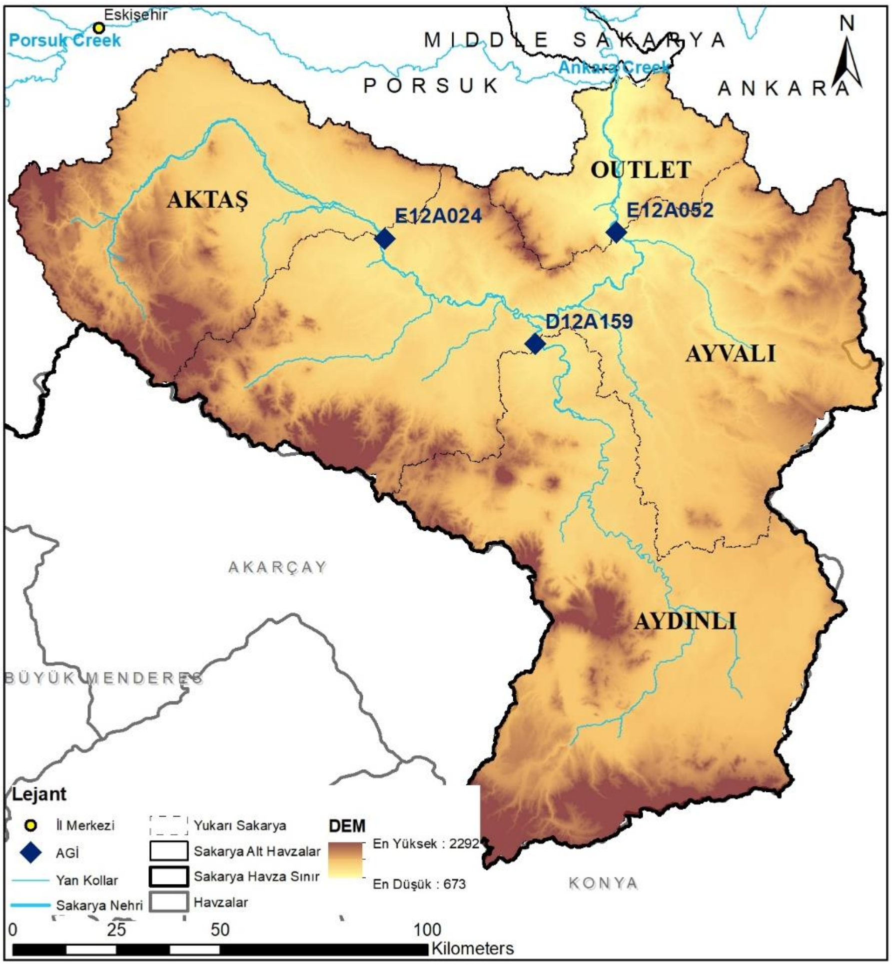


Figure 3.8. Sub-basins and gauging stations in the study area

3.2.2 Data Incorporation

The description and source of the data and their introduction to the WEAP model are explained in this section. Furthermore, model inputs, including land use/cover, meteorology, water use, streamflow, reservoir, aquifer, and wastewater treatment plants, are provided in this section.

The description and sources of the data used in the model setup are given in Table 3.5. In addition to the data provided in the table, the initial setup of timesteps and units is applied.

Table 3.5 Description and source of data entered to WEAP model

	Data	*Description*	*Source*
Catchments	Digital elevation Model (DEM)	Used to determine drainage area and river network	SRTM 1 Arc-Second Global (U.S. Geological Survey, 2000)
	Land Use	Required to define the classes including agricultural, pasture, forest, wetland, residential area	CORINE 2012 LULC, DSİ Agricultural Economy and Public Irrigation Final Reports, TurkStat
	Climate	Meteorology data including precipitation, temperature, humidity and wind speed, latitude are required to run the model	Turkish State Meteorological Service (MGM) data
	Agriculture	Crop pattern and crop coefficient (Kc) are required in order to calculate the agricultural water demand in the basin	Crop pattern from DSİ and TurkStat; crop coefficient from the report "Türkiye'de Sulanan Bitkilerin Bitki Su Tüketimleri" (TAGEM and DSİ, 2017)
Demand Sites	Industrial & Urban & Livestock	The amount of water supply for industrial, urban and livestock demand and leakage or evaporative losses of the water supply network is required	SYGM "Sakarya Havza Koruma Eylem Planı", DSİ "Nüfus Projeksiyonu ve Su İhtiyaçları Raporu", DSİ "Hidrojeoloji Raporu", Annual Reports of Water and Sewerage Administrations, TurkStat Municipality Water and Wastewater Statistics, and literature
	Energy	Data regarding hydropower and thermal power plants are required to determine water consumed due to cooling water withdrawal and evaporation loss from reservoir surface	EPİAŞ, plant visits and literature
Supply and Resources	River	Required for characterization of the river by defining head flows and flow dynamics	DSİ; Streamflow Gauges data
	Reservoir	Observed volume, inflows and outflows, water uses of dams are required for characterization of the reservoirs	DSİ; Operation and Maintenance data
	Groundwater	Storage capacity, available storage, maximum withdrawal and natural recharge are required for the simulation of groundwater	DSİ "Hidrojeoloji Raporu"
	Transmission Links	The amount of water drawn from the system at specific points along the water transmission links and the amount of water lost (e.g., evaporation, underground leakage) are required	World Bank (2016) report entitled "Türkiye Cumhuriyeti: Sürdürülebilir Kentsel Su Temini ve Sanitasyonu Raporu"
WQ	Wastewater	Daily capacity of urban wastewater treatment plants	Sakarya Havzası Master Plan Nihai Raporu (DSİ, 2017)

3.2.2.1.1 Demand Sites

Based on the water uses for domestic, industrial and livestock purposes, water demand sites have been defined for each sector based on sub-basins, one for each SW and one GW. Water allocations for irrigational purposes are calculated by the model based on calibrated soil parameters further details regarding irrigational water use are given in Section “3.2.2.1.2. Catchments”.

In order to distinguish the withdrawals from any source outside the basin boundaries to any component within the basin boundaries, or water allocations to any component located outside the basin boundaries, a separate component, independent of watershed boundaries, has been defined to represent the relevant demand site.

Water allocations in the Upper Sakarya are divided into three different sectors. These sectors are urban, industry and agriculture. Within the scope of the study, urban, industrial and irrigational water demands are divided into two as surface water and groundwater in terms of their sources. There are two components from GW and SW in each sub-basin for each sector. For the urban sector, allocations are entered, and a constant loss-leakage rate is defined. In the agricultural sector, crop coefficients are provided according to the crop pattern in the basin. The model is provided to calculate the agricultural water need. It is calibrated according to streamflow at the outlet of irrigation dams. Water allocations in urban, industrial and livestock sectors used as direct input are given in the table below.

Table 3.6 Sectoral water allocation data of Upper Sakarya (DSİ, 2015; DSİ, 2014; OSBÜK, 2019)

Allocation (hm^3/yr)	*SW*	*GW*	*Total*
Urban	6.9	34.4	41.4
Industrial		10.1	10.1
Livestock	14.7		14.7

SW allocations are obtained from the "Nüfus Projeksiyonu ve Su İhtiyaçları Raporu" (DSİ, 2014), and GW allocations are obtained from the "Hidrojeoloji Raporu" (DSİ, 2015). According to the obtained information, industrial water supply is provided from certified wells. However, considering GW industrial allocations, industrial water consumption of groundwater basins on which the OIZs are located is 0.05 million m^3 per year, which does not correspond to the consumption data (as of 0,8 million m^3 per year) obtained from the OIZ Information Portal (OSBÜK, 2019) of the Ministry of Industry and Technology. In this case, Polatlı and Emirdağ OIZs located in the basin are defined separately, apart from the industrial GW allocations, and the consumption values given in the OIZ Information Portal are entered. The list of the industries in the Upper Sakarya is given in the table below.

Table 3.7 Industries in Upper Sakarya (TÜBİTAK MAM, 2013)

Province	*Industry*	*Start Year*	*Production (1000 ton/year)*
Konya	Ilgın Sugar Factory	1982	130-160
Konya	Yılet Entegre	1995	
Eskişehir	Kaymaz Boron Mine	2011	
Eskişehir	Eti Kırka Boron Mine	1984	1 150
Ankara	Polatlı OIZ	1996	
Afyon	Emirdağ OIZ	2000	

There are nine power plants in the basin, and one of them is a thermal power plant (Ilgın Sugar Factory Thermal Power Plant). According to the calculations, the amount of water consumed by the energy plants is 0.01 million m^3 per year, this amount has been neglected, and no water requirement has been defined for the power plants.

The consumption rate parameter defined in the water demand sites is the ratio that represents the difference between the water coming into the component and the amount of water sent from the component in %. Urban water consumption rates have been determined by calculating the difference between the Daily Water Amount withdrawn per capita (Liter / Person-Day) and the amount of Daily Wastewater (Liter / Person-Day) Discharged in Municipalities on a regional basis. According to this calculation, 12% rates for Eskişehir and Afyonkarahisar provinces, 29% for Ankara provinces, and 9% for Konya provinces are defined as urban consumption rates (TurkStat, 2019b; TurkStat, 2019c). In order to represent the amount of water lost in industrial processes, the consumption rate of industrial sites is taken as 25%.

3.2.2.1.2 Catchments

In the WEAP model, catchment simulation methods implement water balance accounting based on catchment components where hydrological processes occur. The inflow received by the catchment component undergoes various hydrological processes and becomes runoff. Inputs including the land use and climate are required to simulate hydrological processes such as surface runoff, infiltration and evapotranspiration. Data sources, methods and assumptions are stated and explained for obtaining catchment inputs in the following sections.

3.2.2.1.2.1 Area

Multiple catchments are defined in the study. Each catchment is disintegrated into various land use/cover classes under five main categories: artificial, agricultural, forest and semi-natural, wetlands, and water bodies. Land classes entered into the WEAP model are categorized according to CLC 2012 (Copernicus, 2018) and given in Table 3.8. A predetermined area is entered for each land class. The sum of all the areas defined in the land classes of the catchments is equal to the study area. Area of land classes is obtained from CLC 2012, except the irrigated and non-irrigated agricultural areas. Information regarding irrigated and non-irrigated agricultural areas are obtained from DSİ and TurkStat, respectively, and these classes are disintegrated into crop patterns. A detailed description of consolidating the data to obtain areas of agricultural and other land classes is provided below.

Table 3.8 Land classes introduced to the WEAP model (Copernicus, 2018)

CLC Code	*Main Class*	*Sub Class*
1--	Artificial surfaces	-
211	Agricultural areas	Non-irrigated arable land*
212	Agricultural areas	Permanently irrigated land*
221	Agricultural areas	Vineyards
222	Agricultural areas	Fruit trees and berry plantations
231	Agricultural areas	Pastures
242	Agricultural areas	Complex cultivation patterns
243	Agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation
311	Forest and semi-natural areas	Broad-leaved forest
312	Forest and semi-natural areas	Coniferous forest
313	Forest and semi-natural areas	Mixed forest
321	Forest and semi-natural areas	Natural grasslands
323	Forest and semi-natural areas	Sclerophyllous vegetation
324	Forest and semi-natural areas	Transitional woodland-shrub
332	Forest and semi-natural areas	Bare rocks
333	Forest and semi-natural areas	Sparsely vegetated areas
4--	Wetlands	-
5--	Water bodies	-

* Classes not obtained from CLC data are disaggregated further into crop patterns

<u>Irrigated Agriculture</u>

Information regarding irrigated agricultural areas is obtained from The DSİ reports entitled "Tarımsal Ekonomi Raporu" (2016a) and "Halk Sulamaları Raporu" (2016b). In the WEAP model application of Upper Sakarya, irrigated agriculture is referred "permanently irrigated land" as classified in CLC. Figure 3.9 shows the irrigation fields of the Upper Sakarya. As the irrigated agriculture is introduced to the model, only the irrigation fields in operation are considered. Thus, the sum of irrigated areas increases by the year a new irrigation field has started operating.

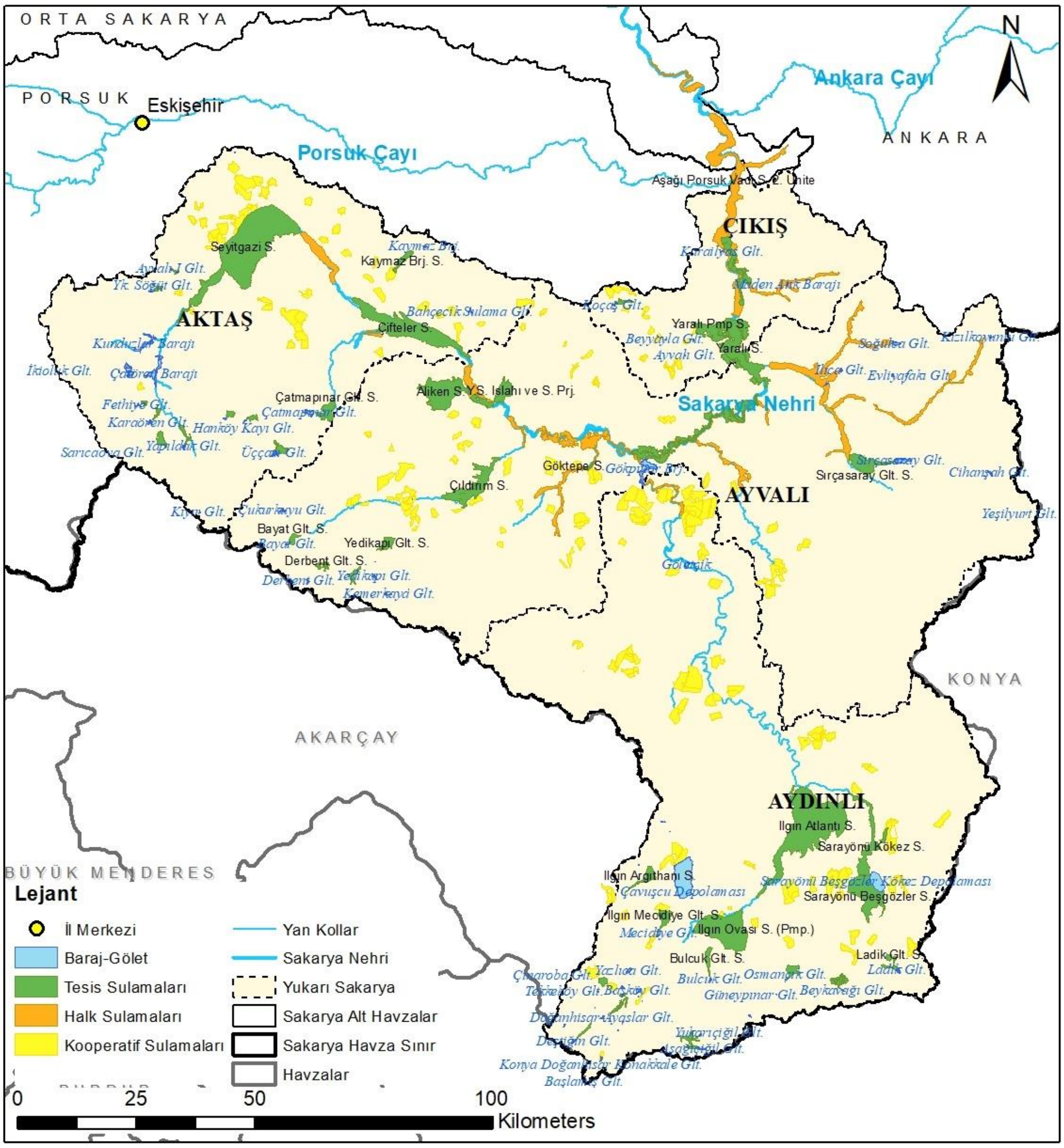


Figure 3.9. Irrigation fields and dams of Upper Sakarya

All the irrigation fields in the Upper Sakarya basin can be grouped under three categories; irrigation facilities, irrigation cooperatives and public irrigation. The list of irrigation fields is given in Appendix E. Surface-water sourced irrigations providing water from dams, ponds, and directly from the river via regulators named “irrigation facilities.” Groundwater sourced irrigations conducted by groundwater cooperatives in DSİ are named "irrigation cooperatives." The other irrigations are called public irrigations, including the agricultural areas of other institutions and organizations. Irrigation facilities use surface water resources such as dams, ponds or rivers. Public irrigational fields receive water from either surface water or groundwater resources. Irrigation cooperatives withdraw the groundwater resources only. However, the irrigation areas are introduced to the model, depending on the water resource used: the areas irrigated by surface water (SW) and the areas irrigated by groundwater (GW).

Irrigated agricultural areas are divided into two groups and defined in separate catchments for a refined representation of irrigation water resources (SW or GW). Irrigation facilities and surface water sourced public irrigations constitute the SW irrigation group. Irrigation cooperatives and groundwater-sourced public irrigations constitute the GW irrigation group. SW irrigation group is entered together with the other land classes to the catchment representing a sub-basin. Furthermore, transmission links supply surface water from reservoirs or rivers to those catchments to irrigate corresponding agricultural areas.

On the other hand, GW irrigation groups are discriminated against by the rest of the land classes. They are entered to separate catchment defined based on provinces, independent from sub-basins. Setting independent catchments to represent groundwater irrigations for each province is that crop patterns of irrigation cooperatives are provided based on districts. Later, public agricultural fields irrigated by groundwater are entered into these independent catchments so that all GW sourced irrigations are grouped. Furthermore, transmission links supply groundwater from aquifers to those catchments representing the GW irrigation group. The obtained areas and crop patterns of irrigated agricultural lands are given for SW and GW irrigation groups separately in Appendix F.

Non-irrigated Agriculture

Information regarding non-irrigated agricultural areas is obtained from TurkStat statistics on plant production (2019). Cultivated and fallow areas are entered into the model yearly by utilizing the non-irrigated agriculture statistics given in provinces. In the WEAP model application of Upper Sakarya, non-irrigated agriculture is referred “non-irrigated arable land” as classified in CLC.

Data on non-irrigated agricultural areas and crop patterns are obtained for the years between 2012-2016. By the year 2012, the non-irrigated agricultural areas and crop patterns change over the years. However, between 2004-2011, non-irrigated agricultural areas and crop patterns are assumed constant and equal to 2012. The obtained areas and crop patterns of non-irrigated agricultural lands are given for each sub-basin in Appendix F.

Land Use Data Integration

For the determination of the land use classes to be defined in the model, various data sources such as Corine, DSİ reports and TurkStat statistics have been analyzed. Corine data has been used to define land use classes other than the irrigated and non-irrigated agricultural areas. The agricultural data obtained from DSİ and TurkStat have been deemed valid to reflect crops in irrigated and non-irrigated agricultural lands yearly. However, compared to Corine's data, total agricultural areas obtained from other sources have emerged as a significant gap that needed to be handled.

The areas provided by DSI have been used as input to irrigated agricultural areas. Irrigated agricultural inputs are entered as the "Permanently Irrigated Land" under the mainland class of agricultural areas. The areas obtained from TurkStat have been used as input to non-irrigated agricultural areas. Non-irrigated agricultural inputs are entered as the "Non-Irrigated Arable Land" under the main class of agricultural areas. As shown in Table 3.9, the amount of area difference between Corine land classes (coded as 211 and 212) and those obtained from Turkstat and DSİ (coded as T and D) have been distributed to particular fields. These surplus areas have been reallocated to agricultural areas as following classes; pastures, complex cultivation patterns and land principally occupied by agriculture, with significant areas of natural vegetation (coded as 231, 242 and 243). According to areal proportion, surplus areas have been distributed to the land classes, as indicated in Table 3.9.

Table 3.9 Land use data integration

Data Name	*Data Source*	*Data Code*	*WEAP input*
Non-irrigated arable land	Corine	211	T
Permanently irrigated land	Corine	212	D
Pastures	Corine	231	231+(211-T+212-D) *(231/(231+242+243))
Complex cultivation patterns	Corine	242	242+(211-T+212-D) *(242/(231+242+243))
Land principally occupied by agriculture, with significant areas of natural vegetation	Corine	243	243+(211-T+212-D) *(243/(231+242+243))
Non-irrigated agricultural areas	Turkstat	T	-
Irrigated agricultural areas	DSİ	D	-

The land use/cover map prepared using CLC 2012 (Copernicus, 2018) for the study area is given in Figure 3.10. The distribution of land classes is given in Table 3.10 for each catchment. As seen in Table 3.10, a large portion of each sub-basin is constituted by agricultural areas.

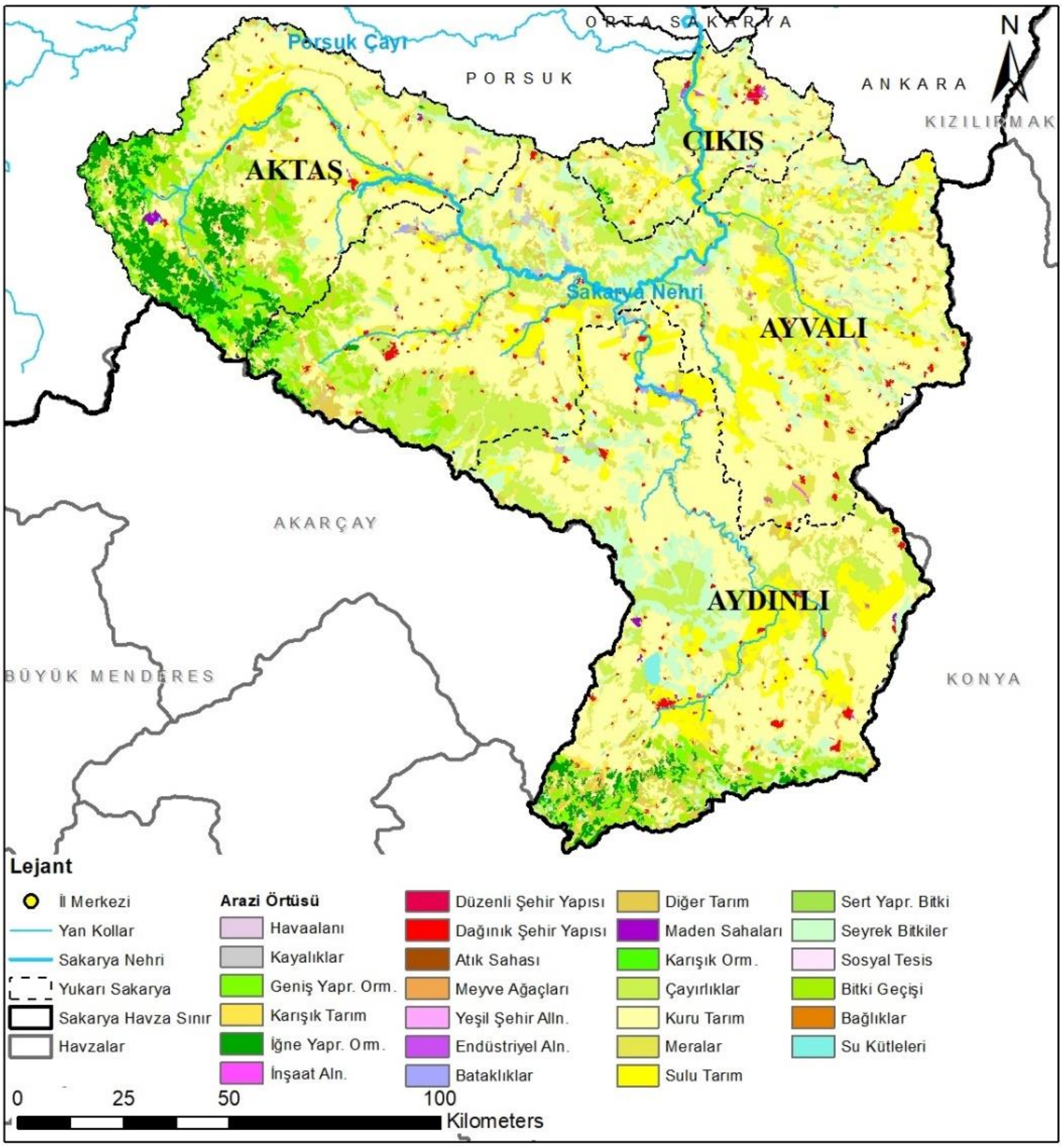


Figure 3.10. LULC map of the Upper Sakarya

Table 3.10 Distribution of land classes of each catchment defined in the WEAP model

Catchment	*Artificial surfaces*		*Agricultural areas*		*Forest and semi-natural areas*		*Wetlands*		*Water bodies*		*Total*
	ha	%	ha	%	ha	%	ha	%	ha	%	ha
Aktaş	3954.0	1.3	219578.0	71.8	81192.0	26.5	1151.0	0.4	1.0	0.0	305876.0

Catchment	*Artificial surfaces*		*Agricultural areas*		*Forest and semi-natural areas*		*Wetlands*		*Water bodies*		*Total*
	ha	%	ha	%	ha	%	ha	%	ha	%	ha
Aydınlı	8524.0	1.4	423083.0	68.6	182003.0	29.5	3030.0	0.5	334.0	0.1	616974.0
Ayvalı	10910.0	1.3	576601.7	67.7	258297.0	30.3	5487.0	0.6	193.0	0.0	851488.7
Outlet	3602.0	2.4	103780.7	68.6	43566.0	28.8	235.0	0.2	0.0	0.0	151183.7
Afyon*	-	-	3830	100	-	-	-	-	-	-	3830
Ankara*	-	-	3628.1	100	-	-	-	-	-	-	3628.1
Eskişehir*	-	-	16893.4	100	-	-	-	-	-	-	16893.4
Konya*	-	-	19367	100	-	-	-	-	-	-	19367
Total	26990.0		1366761.9		565058.0		9903.0		528.0		1969240.9

*Only represents the agricultural lands irrigated by groundwater resources in corresponding provinces

3.2.2.1.2.2 Kc

The plant coefficient (Kc) is the ratio of plant water consumption under standard conditions to reference plant water consumption. For the kc parameter defined in the model, the values obtained by TAGEM and DSİ (2017) for irrigated plants in Turkey with the approach called FAO-56 are used. In this approach, the Penman-Monteith combination method is applied using grass as a reference plant. While the Kc values are at the lowest level in the first planting period, they reach the highest level in the full development period of the plant and then decrease towards the end of the development period. This decrease depends on the characteristics of the plant and the irrigation management in the last period (TAGEM and DSİ, 2017).

The crop coefficient (Kc) is entered for each land class. The crop coefficient specifies the crop's water needs and varies monthly according to the Soil Moisture Method. Crop coefficients of cultivated crops are obtained from the report of TAGEM and DSİ (2017). For land classes other than cultivated irrigation, crop coefficients given in Table 3.11 are used. Crop coefficients vary monthly in cultivated areas due to the change in water needs depends on seed time, harvest, and different phases of plant growth. On the other hand, for land classes with generally permanent vegetation (Table 3.11), crop coefficients are assumed to be still for each month.

Table 3.11 Kc parameters for land classes (excluding cultivated lands)

Land Class	*Kc*
Artificial surfaces	0.77
Irrigated/Non-irrigated agricultural areas	0.88/0.96
Pastures	0.46
Forests	0.35
Semi-natural areas	0.30-0.46
Wetlands	0.90
Water bodies	1

3.2.2.1.2.3 Runoff Resistance Factor

Runoff Resistance Factor (RFF) is used to regulate surface runoff response. RRF is associated with the leaf area index (LAI) and land slope. It can vary among land class types (Sieber & Purkey, 2015). Given the correlation between those parameters, LAI values (Table 3.12) determined for similar land classes are used as initial values in the RRF parameter calibration for each land class type in the study area. Increasing the RRF causes a decrease in surface runoff.

Table 3.12 Initial values for calibration of RRF (Ingol-Blanco ve McKinney, 2013)

Land Class	*Leaf Area Index*
Artificial surfaces	8.00
Irrigated/Non-irrigated agricultural areas	4.22
Pastures	2.50
Forests	5.18
Semi-natural areas	1.31-2.50

Land Class	*Leaf Area Index*
Wetlands	6.34
Water bodies	0.10

3.2.2.1.2.4 Climate

Only four of the stations evaluated within the scope of Thiessen Polygons method throughout Upper Sakarya had complete precipitation data during the model period. The linear regression value between the stations lacking precipitation data and these four stations with complete precipitation data is calculated as 0.6 at most. Therefore, Thiessen Polygons method is not applied to determine average precipitation in the basin due to precipitation data. In this case, arithmetic means calculation is made by using eight different meteorological observation stations, as seen in Figure 3.11, to determine the average precipitation of each sub-basin. The stations are selected for each sub-basin so that the precipitation area (i.e., Thiessen polygon area seen in Figure 3.12) is within the sub-basin boundaries. The arithmetic average of the measured precipitation is calculated. 2 stations in the Aktaş sub-basin, four stations in the Aydınlı sub-basin, six stations in the Ayvalı sub-basin and two stations in the Outlet are selected.

The monthly data of total precipitation in mm (Figure 3.13), the average temperature in ^{0}C (Figure 3.14), relative humidity in % (Figure 3.15) and average wind speed in m/s (Figure 3.16) required to run soil moisture method are obtained from the Turkish State Meteorological Service for the study period (2004-2016).

Figure 3.11. Metrological stations located in the study area

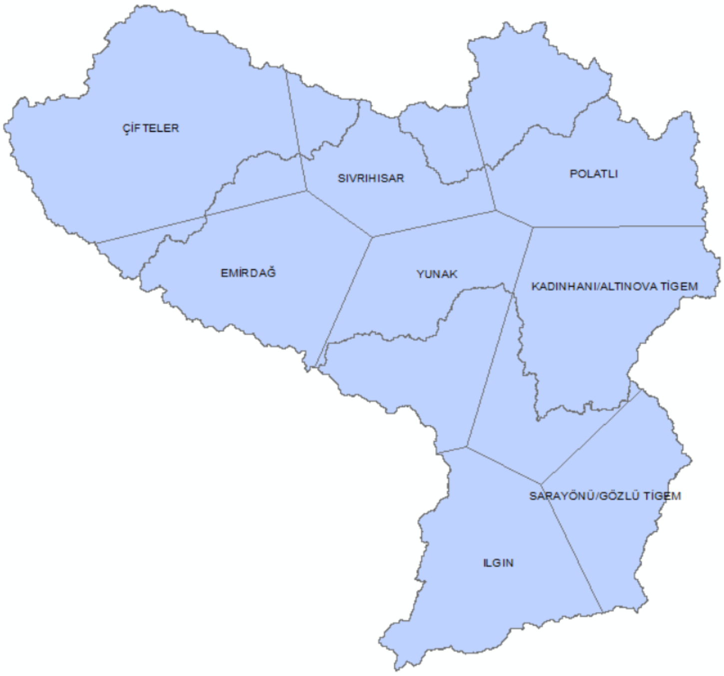
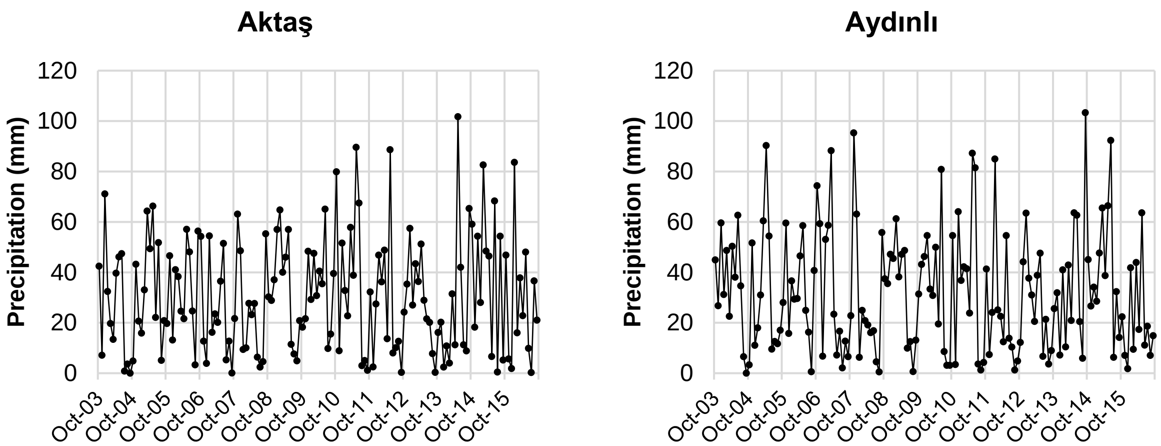


Figure 3.12. Thiessen Polygons of sub-basins based on meteorological stations



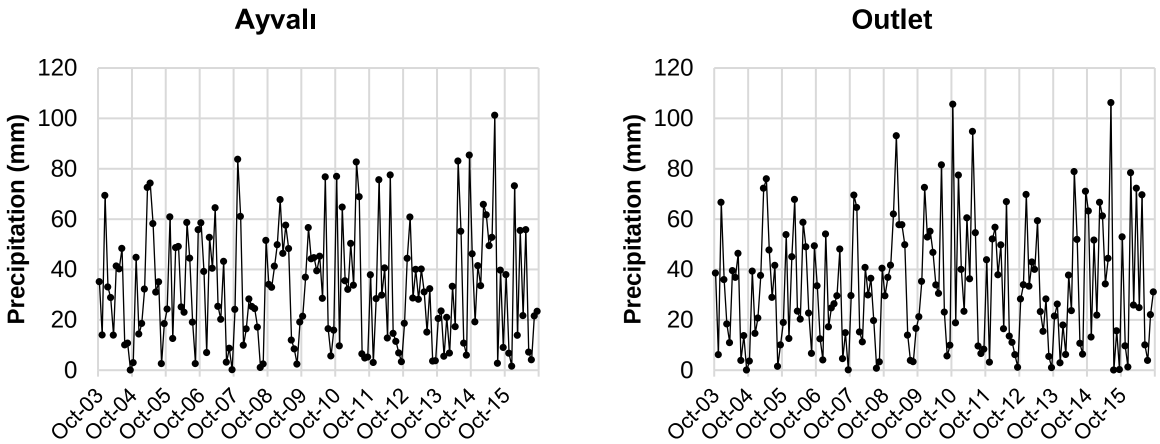


Figure 3.13. Monthly total precipitation in 2004-2016

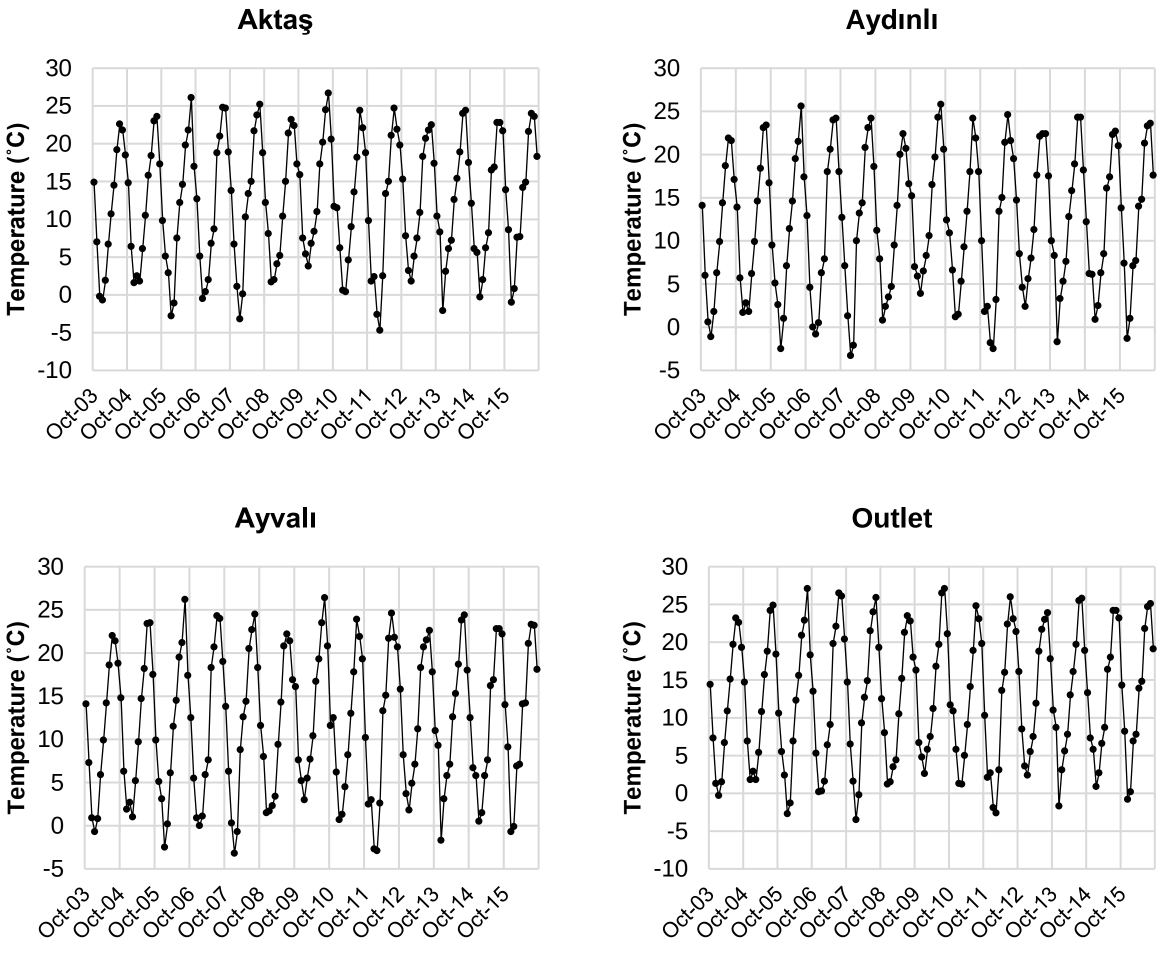


Figure 3.14. The monthly average temperature in 2004-2016

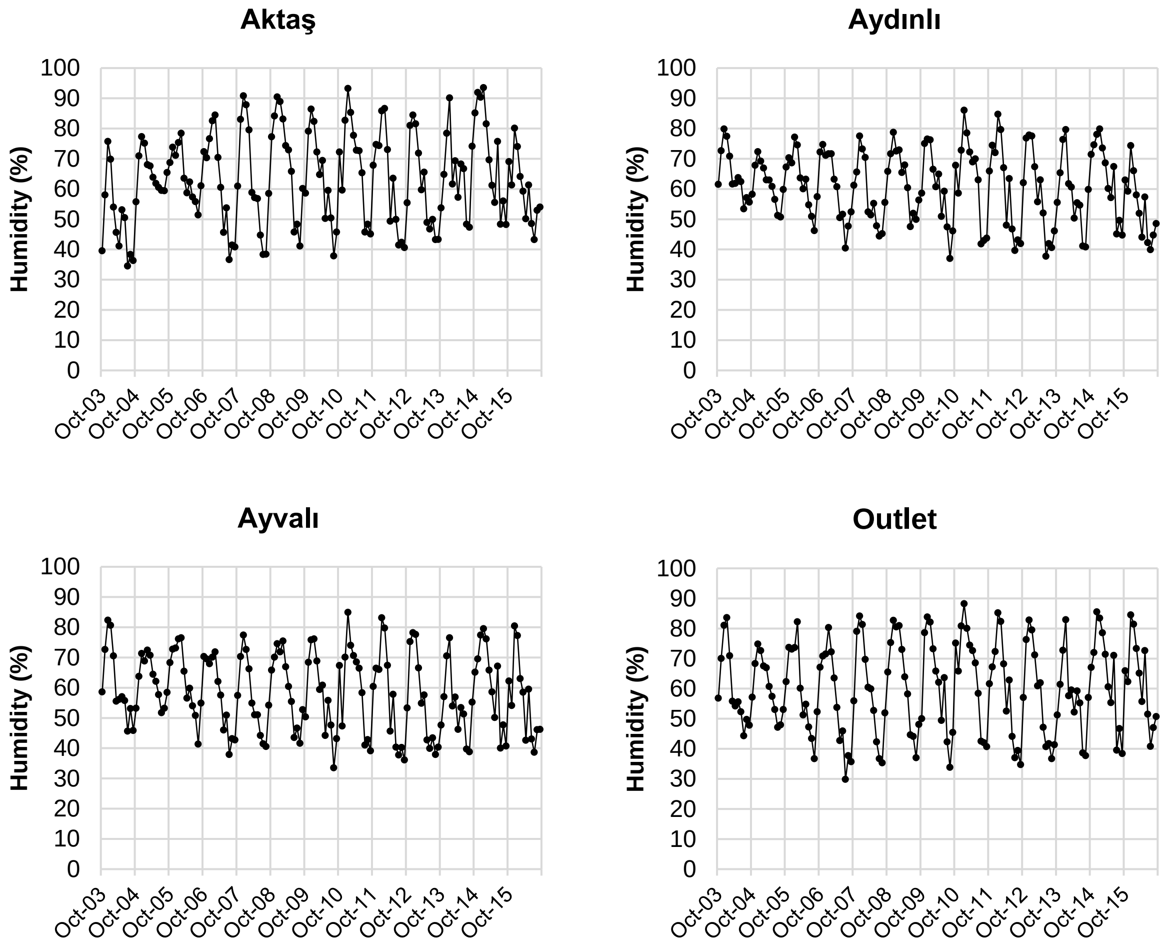
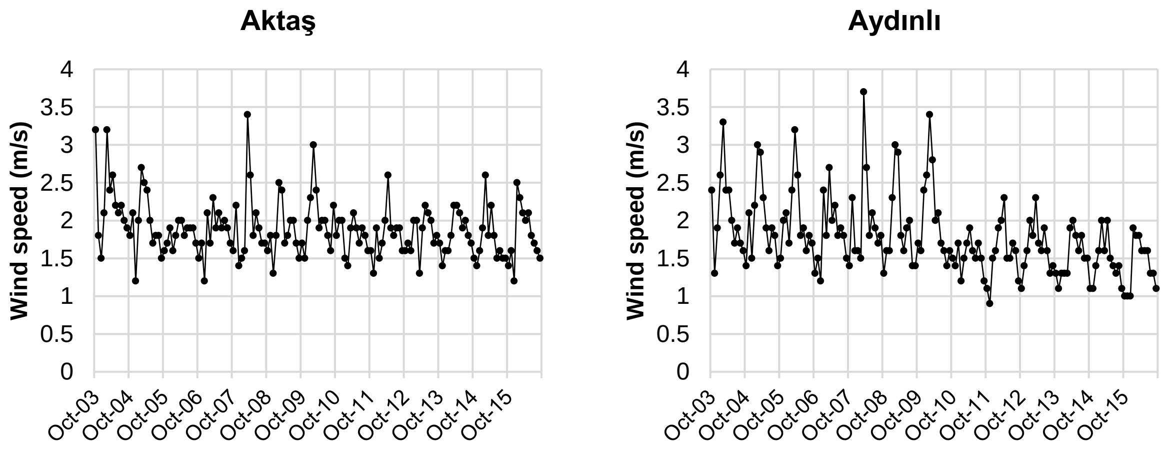


Figure 3.15. Monthly relative humidity in 2004-2016



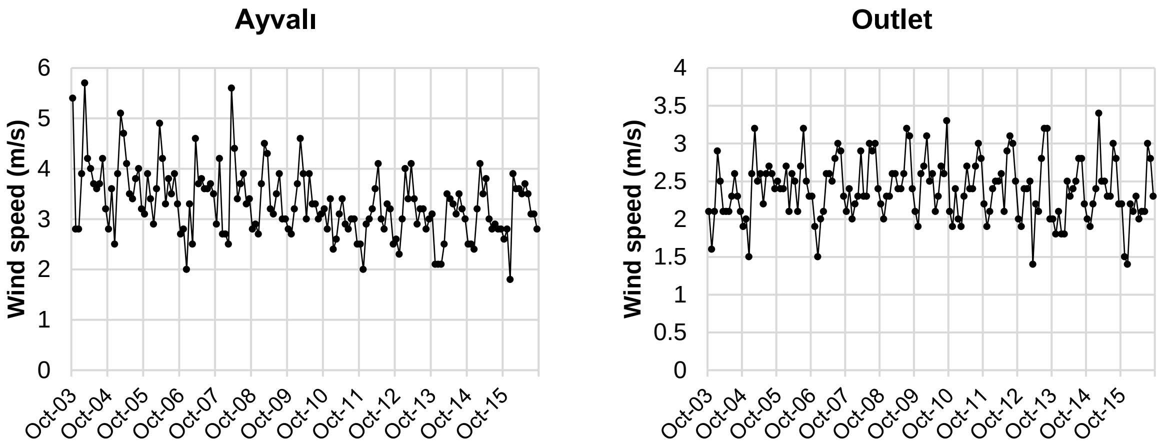


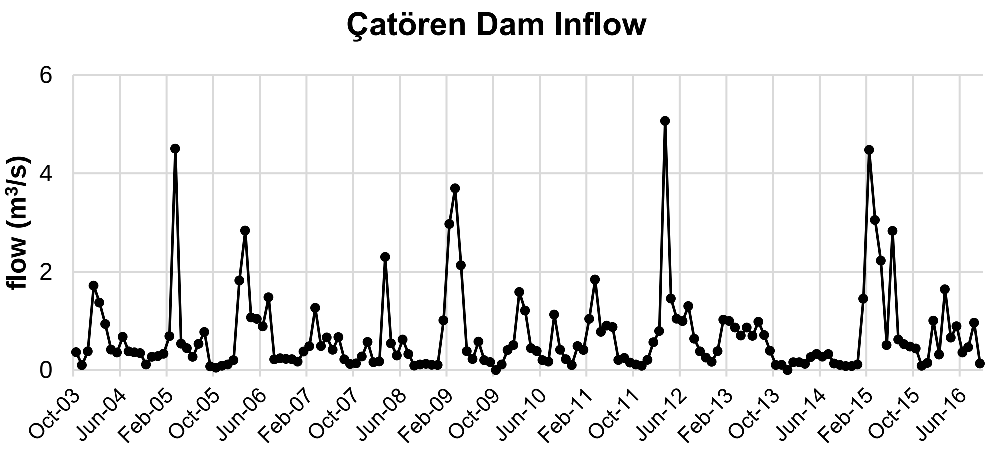
Figure 3.16. Monthly average wind speed in 2004-2016

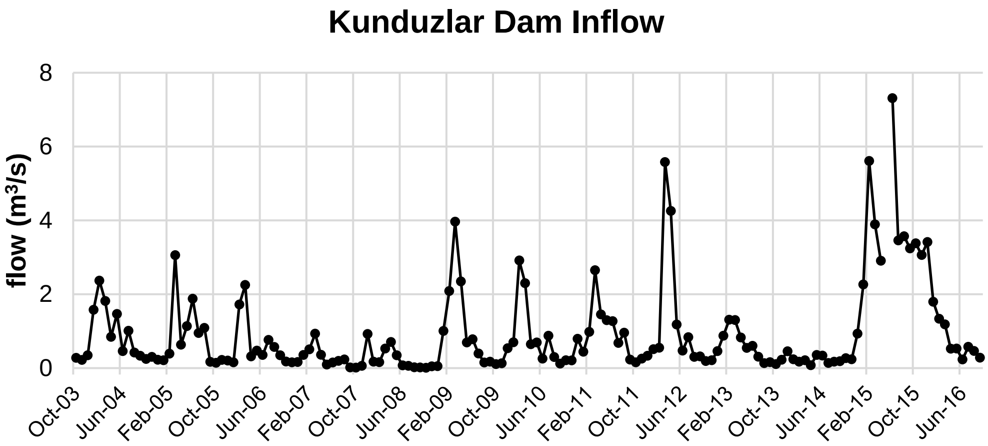
3.2.2.1.3 Supply and Resources

<u>*Streamflow*</u>

The streamflow data are provided for simulating the inflow at the head of the river (*i.e., head flow*) and for calibration/verification purposes. The inflow of Çatören, Kunduzlar, and Çavuşçu dams is introduced as the head flow of the river branch on which the dam is located. Locations of the gauging stations and dams are provided in Figure 3.17, and streamflow data for the modeling periods are given in Figure 3.18.

Figure 3.17. Gauges and dams in the study area





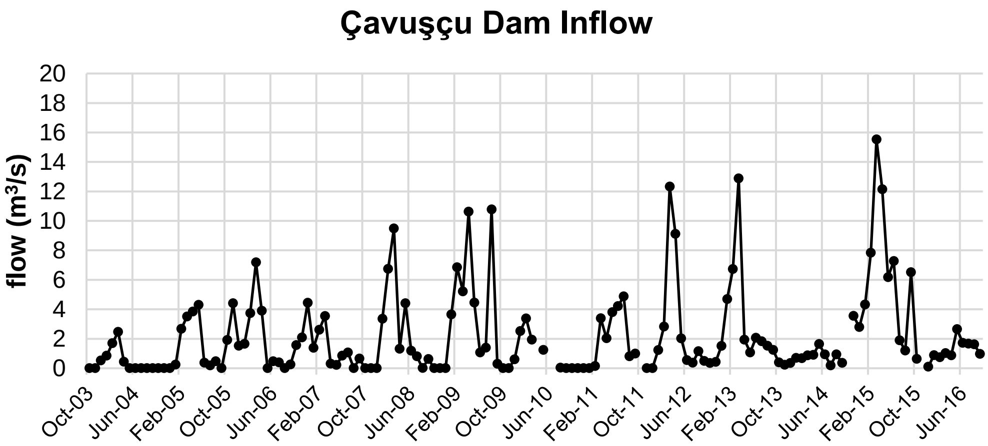
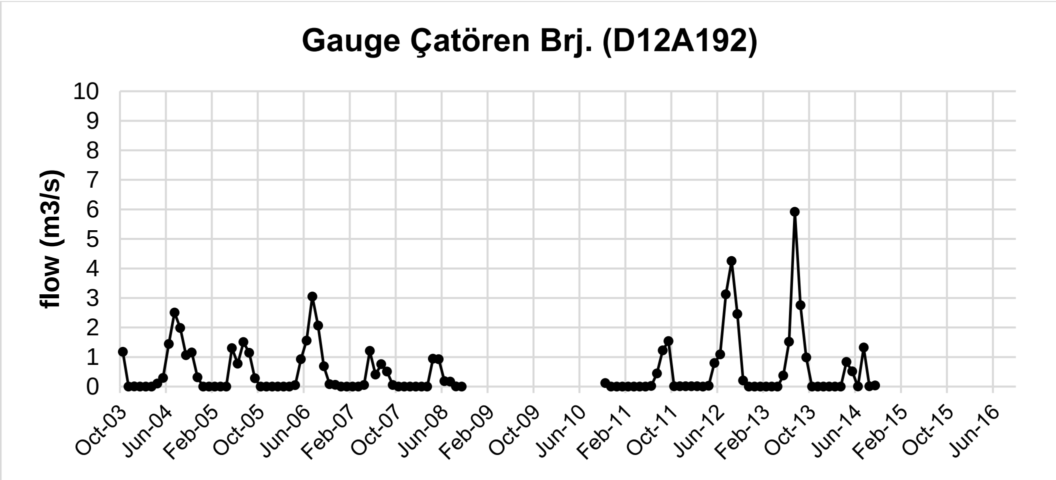
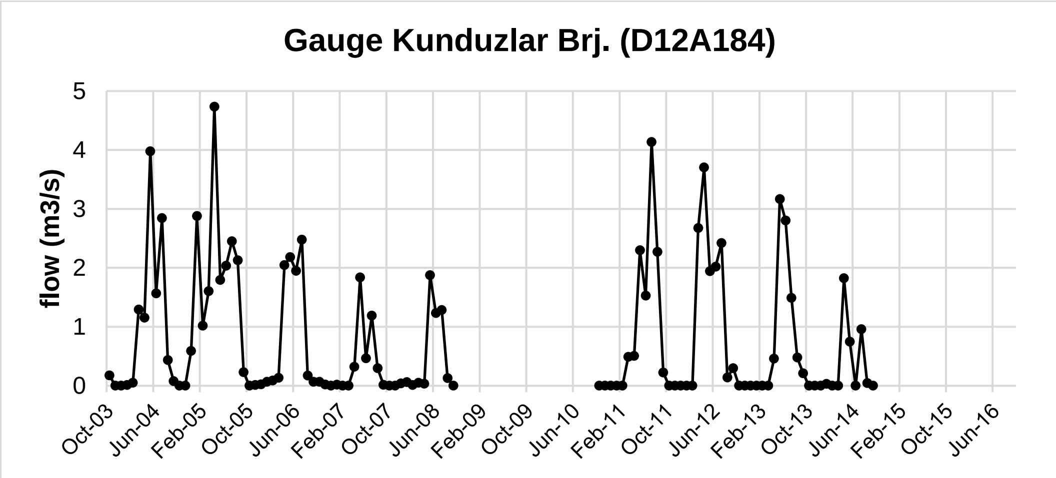
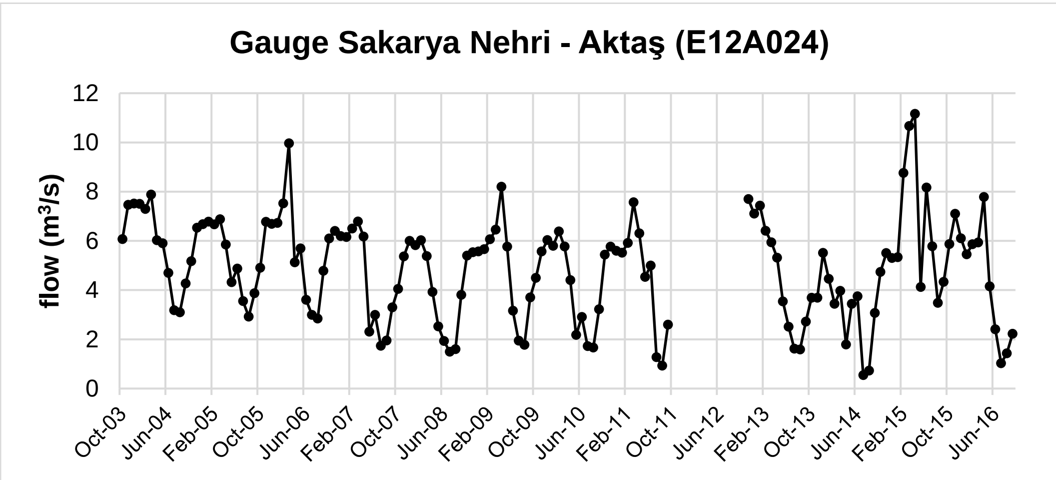


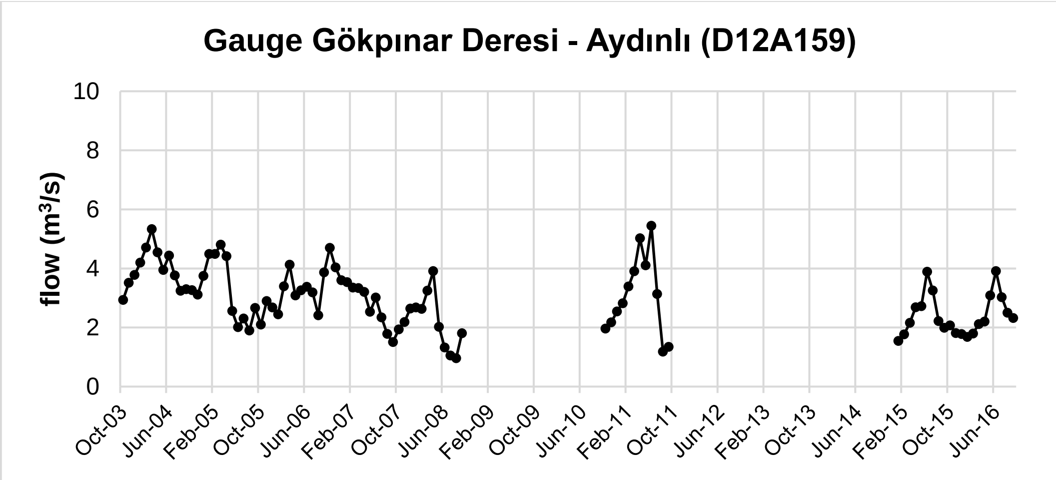
Figure 3.18. Inflow data of Çatören, Kunduzlar, and Çavuşçu dams in 2004-2016 (DSİ, 2017)

Long term streamflow data measured at gauges Çatören-D12A192, Kunduzlar-D12A184, Aktaş-E12A024, Aydınlı-D12A159 and Ayvalı-E12A052 are used for calibration and verification purposes (Figure 3.19).


Gauge Çatören Brj. (D12A192)
flow (m3/s)
10
9
8
7
6
5
4
3
2
1
0
Oct-03
Jun-04
Feb-05
Oct-05
Jun-06
Feb-07
Oct-07
Jun-08
Feb-09
Oct-09
Jun-10
Feb-11
Oct-11
Jun-12
Feb-13
Oct-13
Jun-14
Feb-15
Oct-15
Jun-16


Gauge Kunduzlar Brj. (D12A184)
flow (m3/s)
5
4
3
2
1
0
Oct-03
Jun-04
Feb-05
Oct-05
Jun-06
Feb-07
Oct-07
Jun-08
Feb-09
Oct-09
Jun-10
Feb-11
Oct-11
Jun-12
Feb-13
Oct-13
Jun-14
Feb-15
Oct-15
Jun-16


Gauge Sakarya Nehri - Aktaş (E12A024)
flow (m³/s)
12
10
8
6
4
2
0
Oct-03
Jun-04
Feb-05
Oct-05
Jun-06
Feb-07
Oct-07
Jun-08
Feb-09
Oct-09
Jun-10
Feb-11
Oct-11
Jun-12
Feb-13
Oct-13
Jun-14
Feb-15
Oct-15
Jun-16



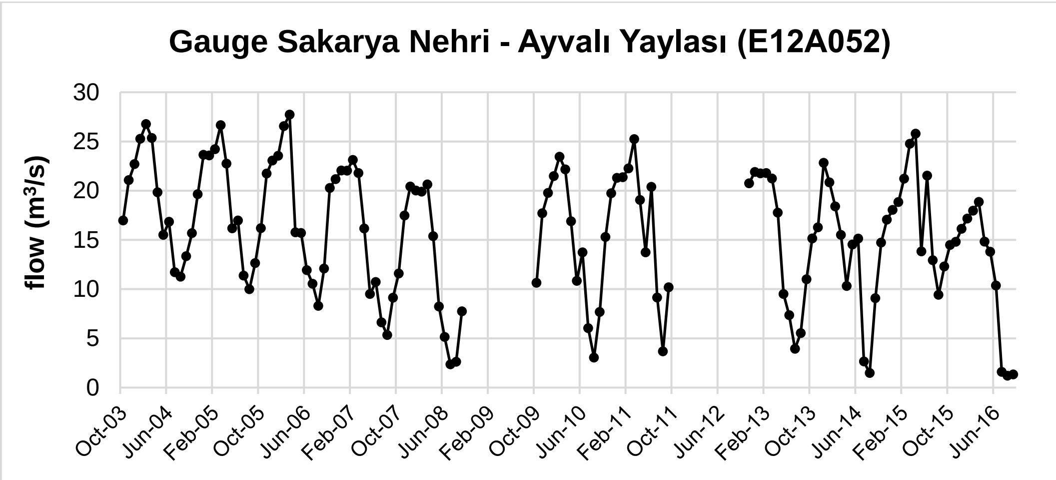


Figure 3.19. Streamflow data of Çatören, Kunduzlar, Aktaş, Aydınlı, and Ayvalı gauges in 2004-2016

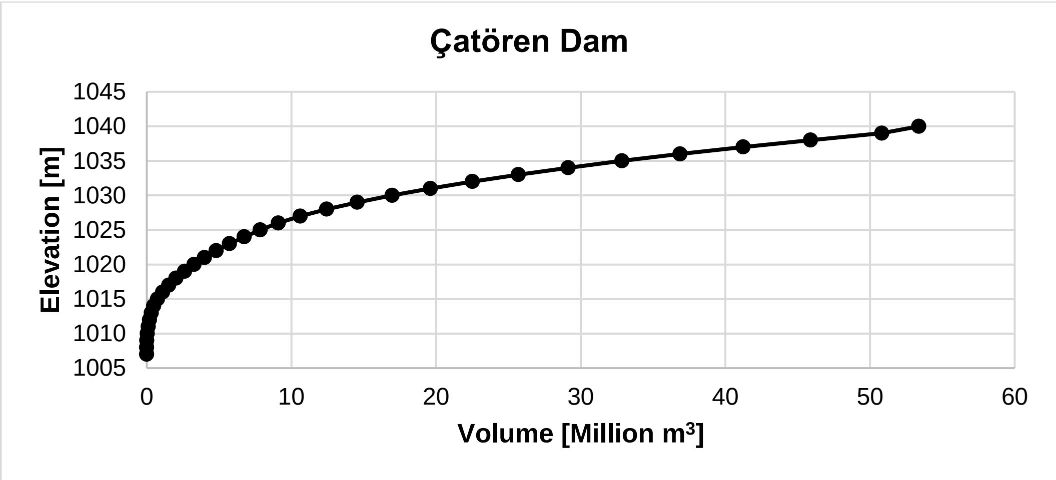
Reservoir

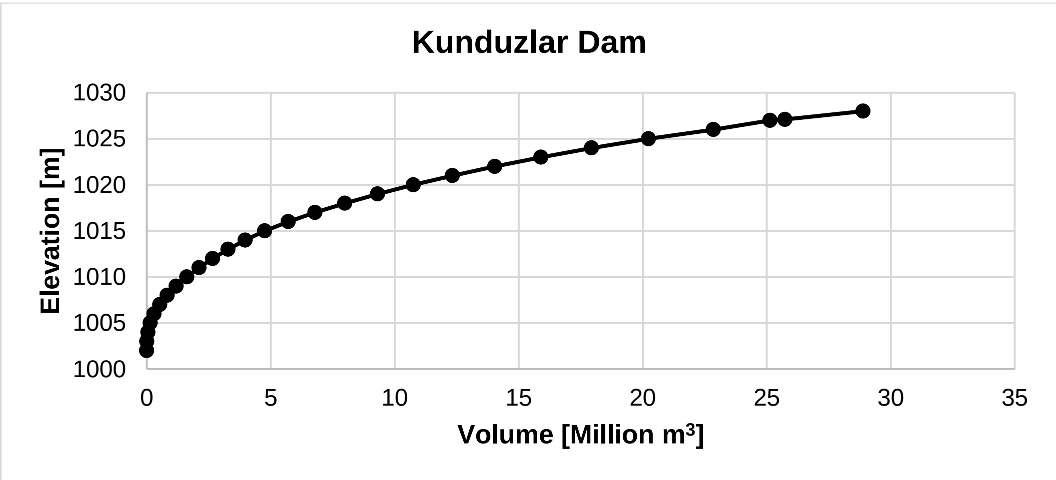
Operating data for the active dams in the study area is provided in Table 3.13, and volume elevation curves for those dams are depicted in Figure 3.20.

Table 3.13 Operating data of Çatören, Kunduzlar and Çavuşçu dams (DSİ, 2017)

Dam	*Sub-basin*	*Stream*	*Operation*	*Total pond volume (hm^3)*	*Active volume (hm^3)*	*Inactive volume (hm^3)*
Çatören	Aktaş	Harami Dere	1987	41.230	38.610	2.620

Dam	*Sub-basin*	*Stream*	*Operation*	*Total pond volume (hm^3)*	*Active volume (hm^3)*	*Inactive volume (hm^3)*
Kunduzlar	Aktaş	Akin Deresi	1985	23.420	20.760	2.660
Çavuşçu	Aydınlı	Boğazçay ve Akarsular	1970	184.140	161.670	22.470





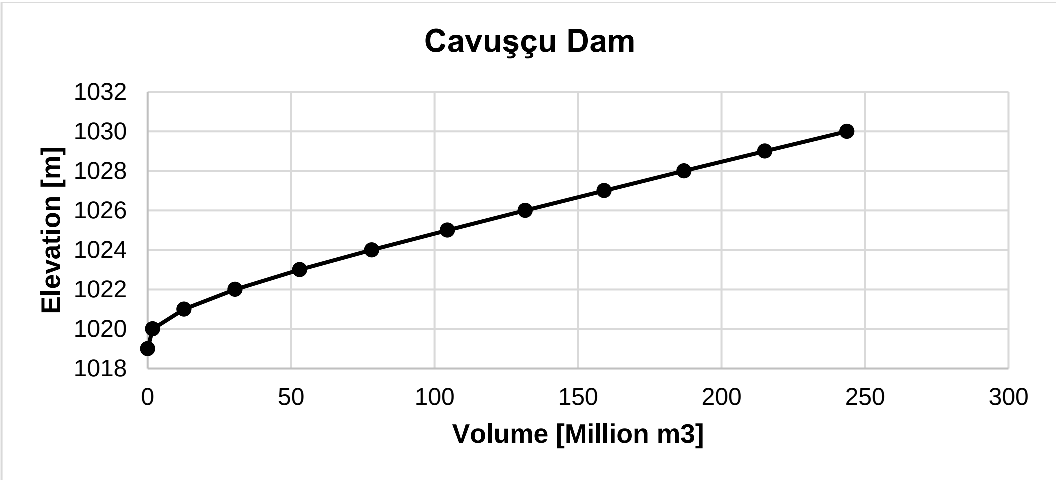


Figure 3.20. Volume-elevation curves of Çatören, Kunduzlar and Çavuşçu dams (DSİ, 2017)

Groundwater

There are 12 plains (groundwater basins) in the study area. The distribution of the groundwater potential of the basin according to the aquifers is given in Table 3.14.

Table 3.14 Groundwater's reserve and recharge information (DSİ, 2017)

Sub-basin	*Groundwater plain*	*Operating reserve*	*Aquifer total reserve*	*Recharge hm^3/y*
AKTAŞ	Kırka	6.5	173.5	185.6
	Seyitgazi	33.0		
	Han Bardakçı	50.0		
	Mahmudiye-Çifteler-Kaymaz	42.0		
	Sarısu	42.0		
AYDINLI	Kadınhanı-Sarayönü-Ilgın-Yüzükbaşı	360.0	360.0	287.1
AYVALI	Emirdağ	51.0	170.0	377.6
	Sivrihisar-Aliken	11.0		
	Sivrihisar Güneyi	95.0		
	Polatlı	13.0		
OUTLET	Günyüzü	21.0	27.0	62.7
	Ilıca Yüzükbaşı	6.0		

Transmission Links

3.2.2.1.4 Water Quality

Urban wastewater treatment plants in the study area and relevant operational information are provided in Table 3.15.

Table 3.15 Groundwater's reserve and recharge information (DSİ, 2017)

WWTP	*Province*	*Municipal*	*Capacity (m^3/d)*	*Treatment*	*Receiving body*
Çifteler	Eskişehir	Çifteler, Mahmudiye	1 496	BNR	Sakarya Nehri
Sivrihisar	Eskişehir	Sivrihisar	1 242	Biological	Kepen Suyu
Emirdağ	Afyonkarahisar	Emirdağ	5 400	Pyhsical-biological	Çay Deresi
Gökpınar	Konya	Gökpınar	1 000	Biological	Gökpınar Deresi
Yunak	Konya	Yunak	2 000	BNR	Irrigation canal
Kadınhanı	Konya	Kadınhanı	1 296	Pyhsical-biological	Irrigation canal
Sarayönü	Konya	Ladik	3 500	BNR	-
Ilgın	Konya	Ilgın	2 600	Stabilization pond	Canal

3.2.3 Catchment Simulation Method

Within the context of this study, Rainfall-Runoff Method (Soil Moisture Method) is implemented for the Upper Sakarya sub-basin of the Sakarya River Basin. Reasons to choose this method to simulate catchments in the study area are provided as follows;

- Enables demand management in the irrigated agriculture
- Easy to implement in the study area compared to other methods allowing demand management

- Requires fewer assumptions for implementing compared to other methods allowing demand management
- Requires data in monthly time-step

The method used to calculate hydrological processes in the catchment is the Rainfall-Runoff - Soil Moisture Method. When Rainfall-Runoff methods are compared, the Soil Moisture method is more complex than the Simplified Coefficient Method since it models the surface runoff using soil moisture data. The catchment is defined as two soil layers by this method, and various hydrological processes are modeled. When considering the precipitation collected in the upper layer of soil and irrigation water, evapotranspiration, runoff, interflow and change in soil moisture are modeled as described in Figure 3.21. In this way, the contribution of soil properties to hydrological processes can be demonstrated. In the lower layer of the soil, soil moisture and base flow reaching the stream are modeled. Therefore, the soil moisture method requires extensive soil and climate parameters to express these hydrological processes (Sieber & Purkey, 2015). In the soil moisture concept practiced in the rainfall-runoff calculation, the soil is divided into lower and upper layers. The upper layer of the soil corresponds to the depth of the root zone of the plants, while the lower layer represents the depth of soil below the root zone. Hydrological processes developing between these soil layers are modeled as shown in Figure 3.21.

Since hydrological processes take place in the catchment component, calculations are made within the scope of this component. Inputs related to land use, climate and irrigation are needed and provided to simulate hydrological processes of the catchment. Hydrological processes are carried out according to the soil moisture concept and are schematized in Figure 3.21. The inflow collected by the catchment component undergoes various hydrological processes and is conveyed to the streamflow. Catchment component inputs are water used for irrigation and the amount of precipitation collected by the catchment. When the loss-leakage amount is removed from the water allocated for irrigation, all the remaining water reaches the catchment component and is represented as input. Depending on the soil moisture concept parameters, the flow collected by the catchment is transmitted to the atmosphere and plants as evapotranspiration; the remaining flow is transmitted as surface flow, internal flow and baseflow. Plant roots uptake the water from the soil and release it through the leaves to the atmosphere through the evapotranspiration process. When the temperature in the catchment decreases, a portion of the precipitation is accumulated as snow, and when the temperature rises, the accumulated snow melts. According to the defined soil parameters, the flow reaching the stream from the soil surface, subsoil and groundwater are calculated. Flow reaching the stream is referred to as surface runoff (from the soil surface), interflow (from sub-soil) and base flow (from groundwater). Evapotranspiration, frozen snow and streamflow are subtracted from the total amount of water generated by precipitation, melting snow and irrigation; the remaining amount is preserved in the soil as moisture, and the net change in soil moisture is calculated. Overall mass balance equation for the catchment is given as follows:

Precipitation + Snow (Melt) + Irrigation – Evapotranspiration – Snow – Surface Runoff – Interflow – Baseflow = Net change in soil moisture

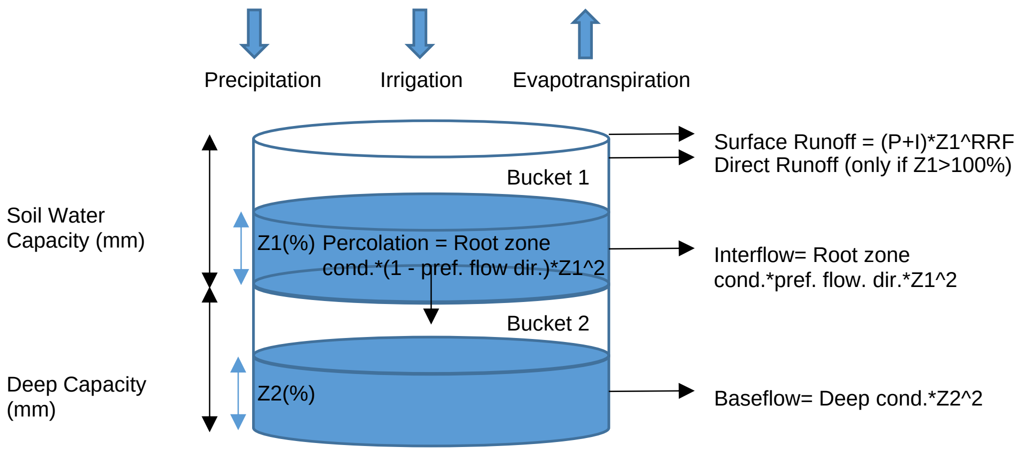


Figure 3.21. Schematic representation of soil moisture method (Sieber & Purkey, 2015)

3.2.4 Calibration & Verification

Model calibration is conducted for the 2004-2012 period and validation for the 2013-2016 period. The list of calibration parameters used for the catchment simulation using the Soil Moisture method is given in Table 3.16. Calibration parameters are modified spatially for each catchment component. Agricultural parameters of permanently irrigated lands are calibrated for the observed streamflow at the outlets of two dams, Çatören and Kunduzlar, which regulate seasonal flow to meet the downstream irrigation demand. Streamflow calibration at the outlets of three sub-basins, Aktaş, Ayvdınlı and Ayvalı, is performed by adjusting soil parameters of land uses other than irrigated agricultural lands.

Table 3.16 Calibration parameters of WEAP model application of Upper Sakarya

Parameter	*Default*	*Unit*	*Calibration Range*
Runoff Resistance Factor	2.00	-	0 - 100
Preferred Flow Direction	0.15	-	0 - 1
Soil Water Capacity	1000	mm	0 - 1000
Deep Water Capacity	1000	mm	0 - 300000
Root Zone Conductivity	20	mm/month	0 - 1000
Deep Conductivity	20	mm/month	0.1 - 100
Initial Z2	30	%	0 - 100
Lower Threshold	35	%	0 - 100
Upper Threshold	65	%	0 - 100
Freezing Point	-5	^oC	± 20
Melting Point	5	^oC	± 20

The WEAP model calibration and verification results are evaluated according to various performance criteria. The model's suitability is determined by evaluating four different criteria; R^2, Nash Sutcliffe Efficiency (NSE) Coefficient, PBIAS and

RMSE. The summary table of the model performance criteria that correspond to a suitability range is given in Table 3.17.

Table 3.17 Suitability ranges of the model performance criteria

Criteria	*Range*	*Suitability (Flow)*	*Suitability (General)*	*Reference*
R^2	$0<R^2<1$	>0,70	>0,50	Moriasi et al. (2015)
NSE	$-\infty<NSE<1$	>0,55	>0,50	Moriasi et al. (2015)
PBIAS	$-\infty<PBIAS<+\infty$	$\leq \pm 15$	$\leq \pm 25$	Moriasi et al. (2015)

3.2.5 Scenario Development

Stakeholder interviews are conducted during the fieldwork, technical institutes are consulted, and a wide literature survey is carried out to determine scenarios on agricultural water management. After extensive researches, many scenarios are determined and evaluated under various categories, including alternatives on alterations in cropping patterns, modernization of irrigation systems, deficit and supplementary irrigation practices, recovery and reuse. Then, potential scenarios considered to be included in this study are evaluated based on different aspects; social acceptability, availability of supportive policy, infrastructural convenience and model capability. An overview of the decision-making process to determine scenarios is given in Table 3.18. As seen from the table, several management alternatives are weighed regarding social, political, technical and practical criteria. However, only the scenarios deemed positive for more than two out of the four aspects are included in scenario development. Therefore, measures on modernizing irrigation methods, altering crop patterns and deficit irrigation are decided accordingly while the others are eliminated.

Table 3.18. Potential agricultural management scenarios under evaluation based on different aspects

Scenario	*Description*	*Social acceptability*	*Available subsidies*	*Technical capacity*	*Model capability*
Modernizing irrigation method	Increasing field application efficiency by advancing current irrigation methods (i.e., Practicing pressurized irrigation alternatives to surface irrigation)	+	+	+	+
Altering cropping pattern	Promoting crops demanding relatively less water rather than water-intensive alternatives	+	+	+	+
Deficit irrigation	Deficit irrigation is a strategy that scheduling irrigation based on crop growth stages. Full irrigation is applied during stages when a crop is susceptible to drought, and limited irrigation is applied outside these stages to stabilize the yield	+	-	+	+
Supplementary irrigation	Supplementary irrigation is described as adding a small amount of water when rainfall fails to provide sufficient moisture for normal plant growth of essentially rainfed crops. This approach intends to improve and stabilize crop yields (Oweis, 1997)	+	-	+	-
Recovery of wastewater	Recovering domestic/urban wastewater and its use in irrigation as an alternative water source	-	-	-	+
Recovery of rainwater	Harvesting and recovering the rainwater for its use in irrigation as an alternative water source	+	-	-	-
Reuse of irrigation drainage water	Reuse of water recovered by irrigation drainage for its reuse in irrigation	+	-	-	-

Increasing water holding capacity of soil	Maintaining sufficient soil moisture for plant growth by increasing the water holding capacity of soil to decrease irrigation amount and frequency. Practices such as applying bio-char or compost on the soil help to enhance water retention capacity	NA	-	+	+

The reference scenario has been started by the initial setup year of the model. The management scenarios include the technical measures that have been initially implemented a year after the model's initial setup.

a) *Historic baseline scenario (S0):* the business-as-usual scenario is referenced to compare with the management alternatives. The initial year of the baseline scenario is 2004. Water intensive crops (e.g., alfalfa, forage maize, sunflower). Irrigation method with lower application efficiency on the field (e.g., surface irrigation). No conservative irrigation program available (e.g., deficit irrigation)
b) *Crop pattern change scenarios (S1):* Promoting crops rather than water-intensive alternatives (e.g., vicia instead of alfalfa; safflower instead of sunflower)
c) *Improved irrigation scenarios (S2):* Establishing an irrigation method with higher application efficiency (e.g., switch to sprinkler/drip irrigation)
d) *Deficit irrigation scenarios (S3):* Irrigation is scheduled based on crop growth stages. Deficit irrigation is practiced at the stages when the crop yield is less affected by the water stress.
e) *Combination scenarios (C):* two scenario sets are compiled by the alternatives given in b, c, and d.

3.2.5.1 Crop pattern change scenarios (S1)

The acreage occupied by the baseline crop (e.g., alfalfa, forage maize, sunflower) has been replaced by the target crop(s) (e.g., vicia, trefoil, safflower) incrementally over each scenario, as seen in Figure 3.22. The general scenario group that practices crop pattern change is categorized as S1; scenarios applied for forage crops (alfalfa, forage maize, vicia, trefoil) and oilseeds (sunflower, safflower) have been grouped under S11, and S12 respectively. S11 group incorporates nine different scenarios that substitute alfalfa or forage maize with alternative crops that demand relatively less water. The S12 group incorporates three scenarios in which sunflower areas are interchanged with safflower. Percent of change in the acreage of crops subject to the S1 scenario group are given in Figure 3.22. Since a certain quota is set for the farmers each year to cultivate sugar beet, which needs excessive water, it is not considered in pattern change scenarios.

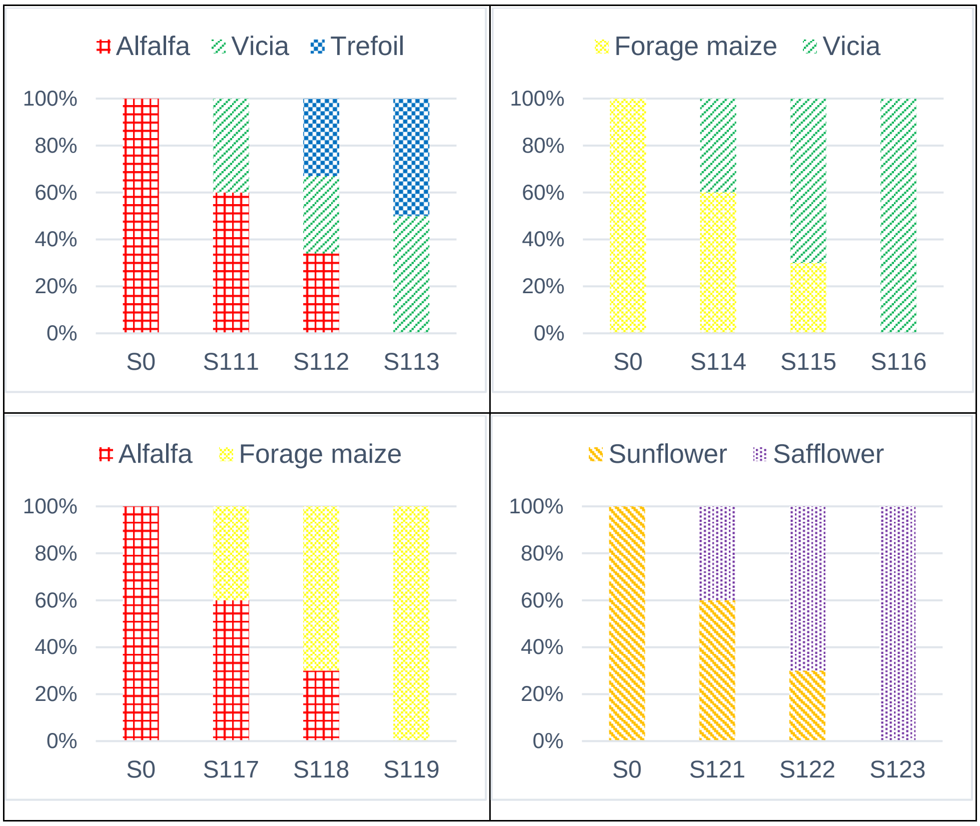


Figure 3.22. Percent change in crop pattern of forage crops and oilseeds

3.2.5.2 Improved irrigation scenarios (S2)

Management scenarios that target the efficient use of irrigation water with alterations in the current irrigation techniques have followed a similar approach studied by Mehta et al. (2013), Joyce et al. (2011), and Purkey et al. (2008). Improved irrigation scenarios have been developed by modifying the irrigation triggering mechanism to improve field application efficiency. Lower and upper threshold parameters specified for the related crop have been decreased to adapt more advanced methods on the field. Eventually, less irrigation water has been applied more frequently compared to the baseline scenario.

Scenarios applied for improved irrigation methods are grouped under three categories;

a) Surface to Sprinkler (S21)
b) Surface to Drop (S22) and,
c) Sprinkler to Drop (S23).

The irrigation methods of the crops cultivated in the basin have been evaluated. Subsequently, scenarios have been applied for the crops irrigated by the surface and sprinkler methods. In each scenario, threshold parameters (*i.e., soil moisture lower and upper bounds at which irrigation starts and stops*) are modified for the relevant crops to increase efficiency. The field application efficiency corresponding to the irrigation method is given in Table 3.19. Crops of interest are given in Table 3.20, based on the scenario applied. The grain is disregarded for the S22, and S23 scenarios since applying the drip irrigation method for grain would not be practicable due to the extensive cost of installing infrastructure on the crop's large cultivated land.

Table 3.19 Approximate field application efficiency of irrigation methods (Savva and Frenken, 2002; Howell, Irrigation Efficiency, 2003; Phocaides, 2007)

Method	*Surface/furrow*	*Sprinkler*	*Drip/trickle*
Efficiency (%)	60	75	90

Table 3.20 Crops of interest in improved irrigation scenarios

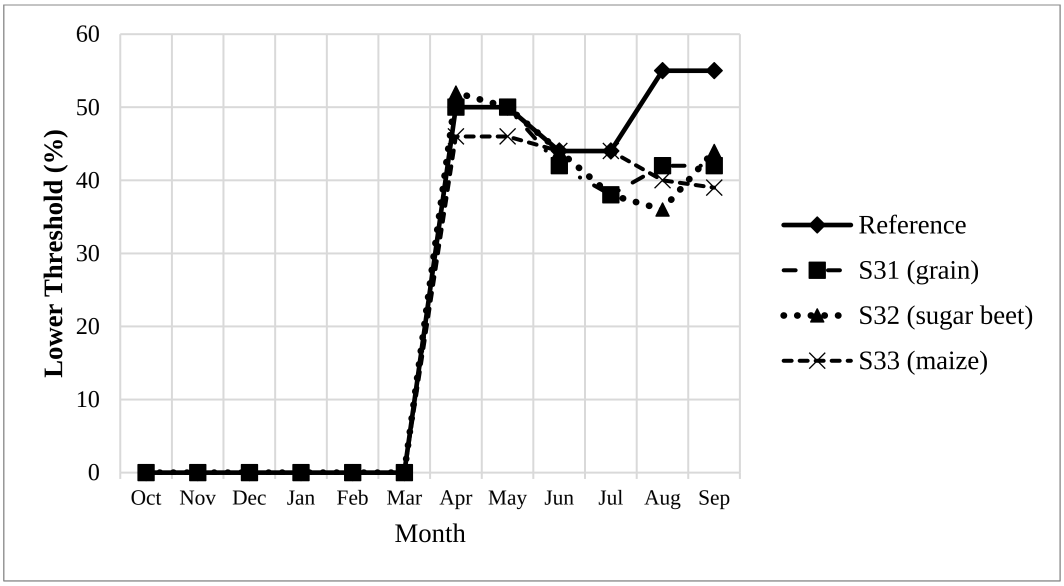
S21	*S22*	*S23*
alfalfa	alfalfa	alfalfa
grain	forage maize	forage maize
horticulture	horticulture	maize
legume	legume	mixed vegetable
maize	maize	poppy
mixed fruit	mixed fruit	potato
mixed seedling	mixed seedling	sugar beet
mixed vegetable	mixed vegetable	
poplar	poplar	
poppy	poppy	
potato	potato	
sunflower	pumpkin seed	
	sugar beet	
	sunflower	

3.2.5.3 Deficit irrigation scenarios (S3)

By practicing the deficit irrigation program, which exposes the plant to a certain level of water stress, irrigation water efficiency is aimed without significant yield decreases. The periods when the crops are very susceptible to water stress determined by studies (Ünlü et al., 2008); (Süheri et al., 2007) focusing on the crop yield in the deficit irrigation approach are considered in this study. Full irrigation has been practiced in sensitive periods to increase water efficiency without negatively affecting crop yield. In contrast, deficit irrigation has been practiced in relatively tolerant periods of the crops. Deficit irrigation program has been adapted for wheat, maize (incl. forage maize), and sugar beet in the scenarios of S31, S32, and S33, respectively.

Considering the growth stages of wheat, deemed necessary to apply irrigation (Ünlü et al., 2008), in scenario S31, summer wheat is fully irrigated in April and May, at the beginning of the heading and milk stage, and 50% less water has been given in the later growth stages. It is claimed that the water used most efficiently with regards to root and sugar yield is when full irrigation is applied during vegetative growth and ripening stages, whereas 50% deficit irrigation during the root swelling stage (Süheri et al., 2007). Therefore, in scenario S32, 50% less water has been given in July-August, which is the root swelling period of sugar beet, and full irrigation has been applied in other growth stages. Considering the tasselling stage of maize is stated as very sensitive to water stress (Ünlü et al., 2008), in scenario S33, full irrigation has been applied as of June and July during and before the tasselling stage, and 50% deficit irrigation has been applied in other stages.

For the deficit scenario application in the WEAP model, lower and upper threshold parameters are modified to decrease irrigation water by defined rates relative to the reference scenario. Irrigation lower and upper threshold variables are entered into the model as monthly variations provided in Figure 3.23 to decrease the baselined irrigation by 50% over periods where crops are relatively more resistant to water stress. For each scenario, variables are revised to practice deficit irrigation, particularly for the related crops in the entire basin.



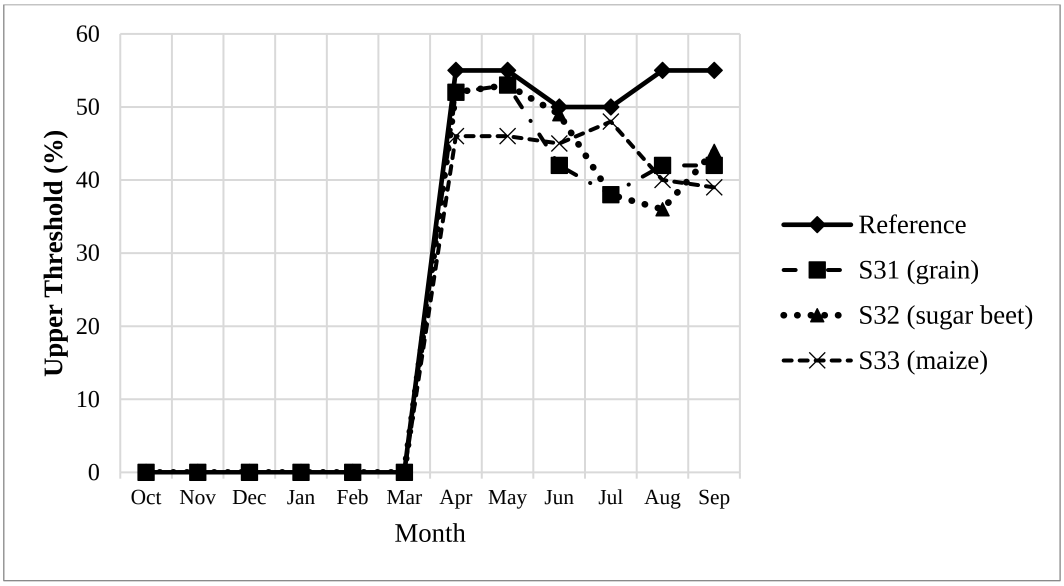


Figure 3.23. Monthly lower and upper threshold values modified for deficit irrigation application

3.2.5.4 Combination scenarios (C1 & C2)

Two selective combinations of the scenarios have been formed aiming at the highest impact on irrigation water use. C1 comprises scenarios S113, S123, S23, and S31, whereas C2 incorporates scenarios S119, S123, S23, and S31.

To implement irrigational water management scenarios, operational parameters that exclusively control the irrigated area and irrigation triggering mechanism in the WEAP model are modified as depicted in Table 3.21.

Table 3.21 Specifications regarding crop, parameter, and the corresponding change in the scenario application

Scenario	*Description*	*Crop(s) of interest*	*Parameter(s)*	*Applied change(s)*
S111	pattern change-forage crops	Alfalfa, vicia	Acreage (ha)	alfalfa: -0.4*alfalfa vicia: +0.4*alfalfa (See also Figure 3.22)
S112	pattern change-forage crops	Alfalfa, vicia, trefoil	Acreage (ha)	alfalfa: -0.66*alfalfa vicia: +0.33*alfalfa trefoil: +0.33*alfalfa (See also Figure 3.22)
S113	pattern change-forage crops	Alfalfa, vicia, trefoil	Acreage (ha)	alfalfa: -1.0*alfalfa vicia: +0.5*alfalfa trefoil: +0.5*alfalfa (See also Figure 3.22)
S114	pattern change-forage crops	Forage maize, vicia	Acreage (ha)	forage maize: -0.4*forage maize vicia: +0.4*forage maize (See also Figure 3.22)
S115	pattern change-forage crops	Forage maize, vicia	Acreage (ha)	forage maize: -0.7*forage maize vicia: +0.7*forage maize (See also Figure 3.22)
S116	pattern change-forage crops	Forage maize, vicia	Acreage (ha)	forage maize: -1.0 *forage maize vicia: +1.0*forage maize (See also Figure 3.22)
S117	pattern change-forage crops	Alfalfa, forage maize	Acreage (ha)	alfalfa: -0.4*alfalfa forage maize: +0.4*alfalfa (See also Figure 3.22)

Scenario	*Description*	*Crop(s) of interest*	*Parameter(s)*	*Applied change(s)*
S118	pattern change- forage crops	Alfalfa, forage maize	Acreage (ha)	alfalfa: -0.7*alfalfa forage maize: +0.7*alfalfa (See also Figure 3.22)
S119	pattern change- forage crops	Alfalfa, forage maize	Acreage (ha)	alfalfa: -1.0*alfalfa forage maize: +1.0*alfalfa (See also Figure 3.22)
S121	pattern change- oilseeds	Sunflower, safflower	Acreage (ha)	sunflower: -0.4*sunflower safflower: +0.4* sunflower (See also Figure 3.22)
S122	pattern change- oilseeds	Sunflower, safflower	Acreage (ha)	sunflower: -0.7*sunflower safflower: +0.7*sunflower (See also Figure 3.22)
S123	pattern change- oilseeds	Sunflower, safflower	Acreage (ha)	sunflower: -1.0*sunflower safflower: +1.0 sunflower (See also Figure 3.22)
S21	Improved irrigation- surface to sprinkler	See Table 3.20	Upper & lower thresholds	min, max (0.55, 0.95)*lower threshold min, max (0.80, 0.95)*upper threshold
S22	Improved irrigation- surface to drop	See Table 3.20	Upper & lower thresholds	min, max (0.55, 0.95)*lower threshold 1*upper threshold (i.e., no change)
S23	Improved irrigation- sprinkler to drop	See Table 3.20	Upper & lower thresholds	min, max (0.65, 0.93)*lower threshold 1*upper threshold (i.e., no change)
S31	Deficit irrigation- grain	Grain	Upper & lower thresholds	See Figure 3.23
S32	Deficit irrigation- sugar beet	Sugar beet	Upper & lower thresholds	See Figure 3.23
S33	Deficit irrigation- maize	Maize	Upper & lower thresholds	See Figure 3.23

Scenario	*Description*	*Crop(s) of interest*	*Parameter(s)*	*Applied change(s)*
C1	Combined set 1	See scenarios: S113, S123, S23, S31	Acreage (ha), upper & lower thresholds	Applied changes for the scenarios S113, S123, S23, S31
C2	Combined set 2	See scenarios: S119, S123, S23, S31	Acreage (ha), upper & lower thresholds	Applied changes for the scenarios S119, S123, S23, S31

CHAPTER 4

RESULTS AND DISCUSSION

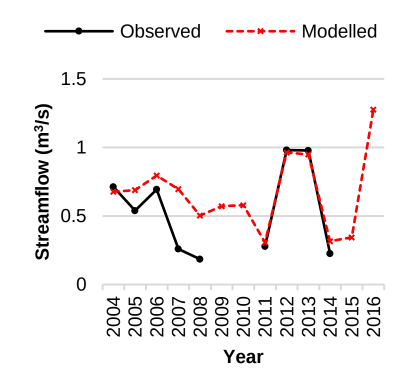
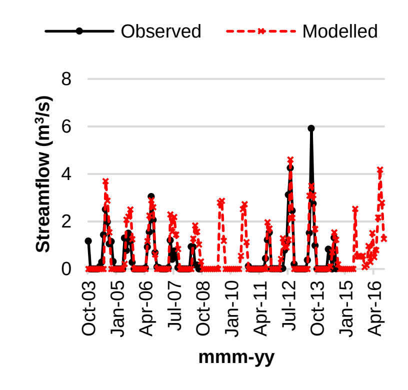
4.1 Calibration and Verification

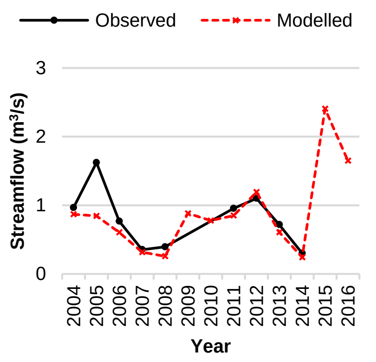
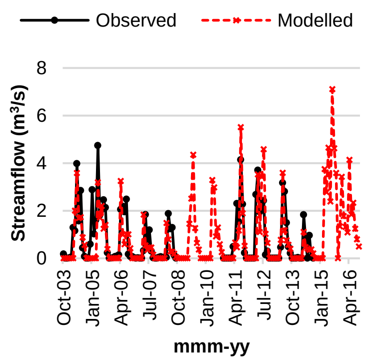
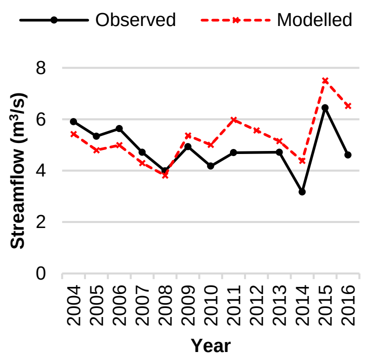
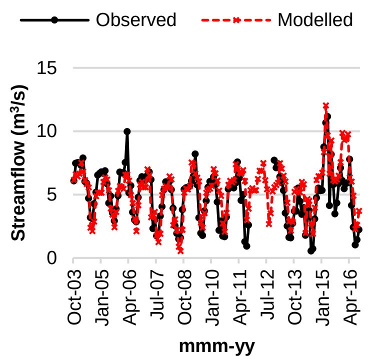
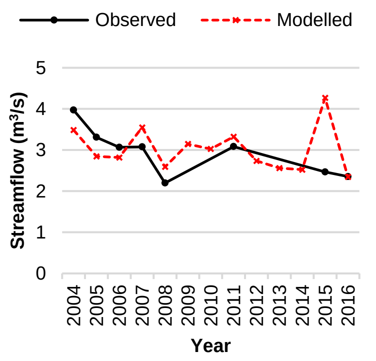
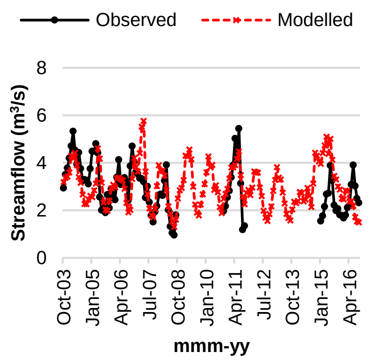
The model has been manually calibrated for 2004-2012 and validated in the period 2013-2016. For the model performance evaluation, five gauging stations located at the outlets of three sub-basins (Aktaş, Ayvalı, and Aydınlı) and the outlets of two dams (Çatören and Kunduzlar) are selected. The soil parameters embedded into expressions of hydrological processes that involve streamflow generation have been used for the WEAP model calibration (Table 4.1). The model performance has been evaluated for Nash Sutcliffe Efficiency (NSE) coefficient, PBIAS, R^2, and RMSE. The model evaluation statistics have been calculated for the calibration and validation periods based on the observed and modeled streamflow (Figure 4.1).

As demonstrated in Figure 4.1, a general agreement regarding trends modeled and observed streamflow follows a similar pattern. Except for the gauges at dam outlets (D12A192 and D12A184), calibration results are proved better than the validation results. The plot results indicate that baseflows are replicated throughout the calibration period yet are overestimated in the validation period. On the other hand, flood peak estimates perform relatively better regarding timing than magnitude. Within the scope of this study, model performance is needed satisfactory for low flows because demand-management scenarios will have the most impact in dry periods when the irrigation that crops need is not available. In periods when flow peaks, the impact of the scenarios will not be effective that much compared to dry periods since most of the irrigation water needs will be met even under normal conditions.

Table 4.1 The WEAP model calibration parameters

Variable	*Default Value*	*Unit*	*Calibrated Value (in range)*
Runoff Resistance Factor	2.00	-	1-80
Preferred Flow Direction	0.15	-	0.07-0.2
Soil Water Capacity	1000	mm	150-950
Deep Water Capacity	1000	mm	30,000-300,000
Root Zone Conductivity	20	mm/month	100-200
Deep Conductivity	20	mm/month	1-16
Initial Z1	30	%	30-65
Initial Z2	30	%	30-50
Freezing Point	-5	^oC	-5 to -10
Melting Point	5	^oC	0 to 10

	Stats	Annual	Monthly Time Series
D12A192 (Çatören dam outlet)	Calibration NSE= 0.44 PBIAS= -26.94 R^2= 0.80 RMSE= 0.64 Validation NSE= 0.70 PBIAS= -5.05 R^2= 0.84 RMSE= 0.71		

	Stats	Annual	Monthly Time Series
D12A184 (Kunduzlar dam outlet)	<u>Calibration</u> NSE= 0.47 PBIAS= 19.83 R^2= 0.74 RMSE= 0.84 <u>Validation</u> NSE= 0.75 PBIAS= 16.67 R^2= 0.87 RMSE= 0.45		
E12A024 (Aktaş sub-basin outlet)	<u>Calibration</u> NSE= 0.60 PBIAS= -0.71 R^2= 0.79 RMSE= 1.19 <u>Validation</u> NSE= 0.45 PBIAS= -24.68 R^2= 0.84 RMSE= 1.79		
D12A159 (Aydınlı sub-basin outlet)	<u>Calibration</u> NSE= 0.30 PBIAS= 0.51 R^2= 0.61 RMSE= 0.88 <u>Validation</u> NSE= -3.71 PBIAS= -31.97 R^2= 0.08 RMSE= 1.46		

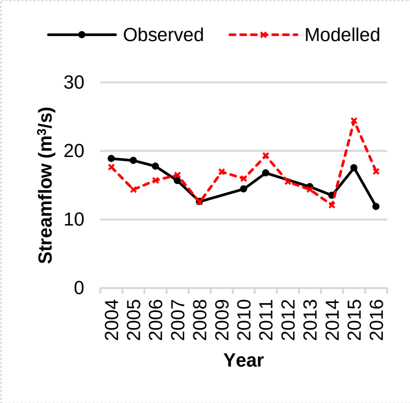
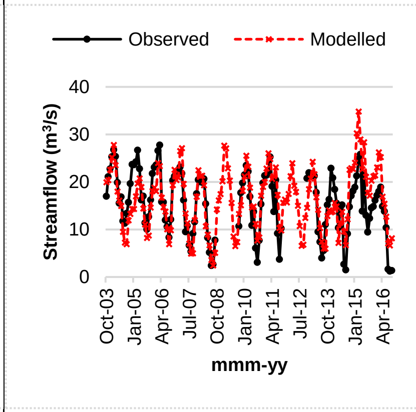
	Stats	Annual	Monthly Time Series
E12A052 (Ayvalı sub-basin outlet)	<u>Calibration</u> NSE= 0.73 PBIAS= 2.40 R^2= 0.86 RMSE= 3.40 <u>Validation</u> NSE= 0.31 PBIAS= -18.39 R^2= 0.76 RMSE= 5.39		

Figure 4.1. The WEAP model calibration and validation results

4.2 Water Budget

Within the scope of this study, water budgets that are incorporating inflows and outflows of the basin are interpreted for an overall evaluation of the current state concerning pressures on available water resources and contributions to the catchment. In order to regard the impacts of hydrological conditions on water resources, water budget calculations are based on the model outputs averaged for;

i) the modeling period of 2004-2016,

ii) the normal years,

iii) and the dry years.

In order to characterize the hydrological drought, the Streamflow Drought Index (SDI) is computed using observed streamflow data at the gauging station Ayvalı (E12A052) over the period 1989-2016. For this study, the states defined in Table 4.2 are a basis for classifying normal and dry years. For the water budget assessment, normal years correspond to states 0 or 1, and dry years correspond to states 3 or 4. There is no state two that occurred throughout the modeling period.

Table 4.2 State description of hydrological drought based on SDI (Nalbantis & Tsakiris, 2009)

State	*Description*	*Criterion*
0	Non-drought	SDI ≥ 0.0
1	Mild drought	-1.0 ≤ SDI < 0.0
2	Moderate drought	-1.5 ≤ SDI < -1.0
3	Severe drought	-2.0 ≤ SDI < -1.5
4	Extreme drought	SDI < -2.0

Since the Upper Sakarya WEAP model application distinguishes water resources from each other as surface water and groundwater, the water budget components are associated with the related resource. All of the results are given for the corresponding resource. For the water budget evaluation, various tables are prepared for the three cases beforementioned (i, ii, iii).

At first, inflows and outflows of related resources are given separately in the SW budget and GW budget tables. The SW budget has been evaluated within the scope of the river boundaries. Streams feeding the stream, discharges, water allocations made from streams and ponds located on it, evaporation and volume change amounts of dams and water transmission loss in the irrigation network constitute the components of the SW budget. The difference between the SW budget inputs and outputs gives average streamflow at the Upper Sakarya basin outlet. The GW budget has been evaluated within the scope of aquifer boundaries (GW plains). GW budget input is the total aquifer recharge amount. Outputs consist of allocations made from GW resources.

Later, sector-based water withdrawals are given as percent of share in (1) total water withdrawal, (2) water potential and (3) water availability. Sector-based contributions are determined via the following computations using the results obtained from budget tables:

(1) Sector-based withdrawal/Total water withdrawal*100

(2) Withdrawal/Total Input*100

(3) Withdrawal/(Total Input- Total Output)*100

Finally, all hydrologic processes of the basin are outlined for catchment, river, reservoir, aquifer components in a summary table. Unlike the SW and GW budget tables, storage amounts of the available resources at the beginning of the model are considered. Initial reservoir storage is the sum of water stored in all dams, ponds and lakes; the initial groundwater storage is the sum of the water stored in all aquifers in the basin. In order to calculate available water regarding surface water and groundwater resources, the inflows of each resource are subtracted from the outflows; after, the initial storage of resources has been added to this amount.

4.2.1 Water budget for the modeling period (2004-20016)

The SW and GW budget calculations are provided in Table 4.3 and Table 4.4, respectively; contributions of sector-based water allocations to total withdrawal, potential and availability are given in Table 4.5; and the outline of overall catchment processes of the hydrologic components is provided in Table 4.6.

According to the SW budget given in Table 4.3, the streamflow trend is mostly driven by the interflow with 55%. More than half of the surface water originates from interflow, and the contribution of baseflow and runoff to the river is relatively less. In the model concept, no connection was established between surface and groundwater. The recharge flow reaching the aquifers was introduced to the model as direct inputs, and the catchment component generates baseflow. It is not easy to accurately simulate the partition balance of runoff, interflow and baseflow, without more information about the natural processes between surface and groundwater (Hughes et al. 2020).

Irrigation allocation from the river makes a 58.4% contribution to the outputs of the SW budget, which means there is a high dependency on river flow in supplying irrigation demand. As a total, surface water withdrawn for the irrigation has an 83.5% portion of outflows in the water budget.

The total natural recharge in the Upper Sakarya basin is 913.2 hm^3 in a year, as depicted in the GW budget given in Table 4.4. Likewise, in the SW budget, the highest pressure on the groundwater resources is the irrigation water allocations with a 58.4% share.

As seen in Table 4.5, agriculture has a total share of 84.3% of all water allocations. 11.0% of the total water allocations are used by the urban sector, whereas 2.8% and 1.9 % by the livestock and industrial sectors, respectively. Comparable results are obtained for the water potential and water availability.

Hydrologic components of the study area are summarized in Table 4.6. The yearly average surface water and groundwater availability are determined as 619 hm^3 and 1371 $hm^{3,}$ respectively. Precipitation provides a significant input to surface flow. On the other hand, natural recharge is the major input to groundwater. Although there is a significant amount of SW inputs, GW availability is higher than SW availability due to the large portion of evapotranspiration loss and decrease in soil moisture.

Table 4.3 Surfacewater budget (2004-2016)

Inputs (Surfacewater)	**(hm^3/year)**	**% of Total Inputs**
Surface runoff	0.6	0.1
Interflow	437.5	55.0
Baseflow	210.8	26.5
Çatören dam head flow*	22.0	2.8
Kunduzlar dam head flow*	28.7	3.6
Çavuşçu dam head flow*	65.4	8.2
WWTP discharge	17.9	2.2
Untreated urban water	11.4	1.4
The net change in reservoir storage	1.2	0.2
Total Inputs	***795.4***	***100.0***
Outputs (Surfacewater)	**(hm^3/year)**	**% of Total Outputs**

Irrigation water supply (from river)	159.2	58.4
Irrigation water supply (from pond)	28.2	10.3
Livestock water supply* (from river)	11.4	4.2
Domestic water supply* (from river)	3.7	1.4
Transmission loss of irrigation water	40.0	14.7
Transmission loss of domestic water	1.5	0.5
Reservoir surface evaporation	28.4	10.4
Total Outputs	***272.4***	***100.0***
Available surface-water for allocation (at the outlet)	***523.0***	

*Direct inputs entered into the model

Table 4.4 Groundwater budget (2004-2016)

Inputs (Groundwater)	**(hm^3/year)**	**% of Total Inputs**
Natural recharge*	913.2	100
Total Inputs	***913.2***	***100***
Outputs (Groundwater)	**(hm^3/year)**	**% of Total Outputs**
Irrigation water supply	215.2	78.8
Domestic water supply*	34.4	12.6
Industrial water supply*	10.0	3.7
Transmission loss of domestic water	13.4	4.9
Total Outputs	***273.1***	***100.0***
Available groundwater for allocation	***640.1***	

*Direct inputs entered into the model

Table 4.5 Percentage of sector-based withdrawals in terms of total withdrawal, water potential and water availability (2004-2016)

		Agriculture (%)	**Urban (%)**	**Livestock (%)**	**Industrial (%)**	***Total (%)***
Water Withdrawal	SW	90.3	3.8	5.8	0.0	*100.0*
	GW	78.8	17.5	0.0	3.7	*100.0*
	SW + GW	84.3	11.0	2.8	1.9	*100.0*
Water Potential	SW	28.6	1.2	1.8	0.0	*31.6*
	GW	23.6	5.2	0.0	1.1	*29.9*
	SW + GW	25.9	6.4	1.8	1.3	*35.4*
Water Availability	SW	43.5	1.8	2.8	0.0	*48.1*
	GW	33.6	7.5	0.0	7.5	*48.6*

Table 4.6 Hydrologic components of the basin (2004-2016)

(hm^3/year)	**SW**			**GW**
	Catchment	River	Reservoir	Aquifer
Initial Storage			94	731
INPUTS				
Precipitation	7628			
Irrigation	403			
Decrease in Snow (Melt)	331			
Headflow*		116		
Discharge		29		
The net change in reservoir storage			1	
Natural Recharge*				913
Total (SW / GW)		***8603***		***1644***
OUTPUTS				
Evapotranspiration	4812			
Increase in Snow	331			
The net change in soil moisture	2567			
Irrigation supply		159	28	215

(hm^3/year)		**SW**		**GW**
	Catchment	River	Reservoir	Aquifer
Livestock supply*		11		
Urban supply*		4		34
Industrial supply*				10
Irrigation water transmission loss			40	
Urban water transmission loss			1	13
Net evaporation for reservoir			28	
Total (SW / GW)		***7983***		***273***
INPUTS-OUTPUTS		***619***		***1371***

*Direct inputs entered into the model

4.2.2 Water budget for normal years

Considering the surface-water budget given in Table 4.7 on a yearly average, 51.2 hm^3 of more water is available for allocation relative to the modeling period average. In addition, the average yearly change in reservoir storage increases from -1.2 hm^3 to 38.5 hm^3 compared to the modeling period average. However, the total share of the irrigation water output decreases by 10%. This situation can result from the precipitation generated more in normal years so that less irrigation is needed. Likewise, irrigation water supply from groundwater resources decreases by 2.1%, as shown in the GW budget (Table 4.8) and contributions of the irrigation sector for all parameters decline by considerable rates (Table 4.9). Due to the reasons stated above, available surface and groundwater increased by comparable rates, as shown in Table 4.10.

Table 4.7 Surface-water budget (for normal years)

Inputs (Surface-water)	**(hm^3/year)**	**% of Total Inputs**
Surface runoff	0.8	0.1
Interflow	489.5	56.1
Baseflow	208.4	23.9
Çatören dam head flow	25.9	3.0

Kunduzlar dam headflow	33.8	3.9
Çavuşçu dam head flow	84.4	9.7
WWTP discharge	17.9	2.1
Untreated urban water	11.4	1.3
Total Inputs	***872.1***	***100.0***
Outputs (Surfacewater)	**(hm^3/year)**	**% of Total Outputs**
Irrigation water supply (from river)	150.0	50.4
Irrigation water supply (from pond)	26.4	8.9
Livestock water supply (from river)	11.4	3.8
Domestic water supply (from river)	3.7	1.3
Transmission loss of irrigation water	37.5	12.6
Transmission loss of domestic water	1.5	0.5
Reservoir surface evaporation	28.8	9.7
The net change in reservoir storage	38.5	12.9
Total Outputs	***297.8***	***100.0***
Available surface-water for allocation (at the outlet)	***574.2***	

Table 4.8 Groundwater budget (for normal years)

Inputs (Groundwater)	**(hm^3/year)**	**% of Total Inputs**
Natural recharge	913.2	100.0
Total Inputs	***913.2***	***100.0***
Outputs (Groundwater)	**(hm^3/year)**	**% of Total Outputs**
Irrigation water supply	202.3	77.8
Domestic water supply	34.4	13.2
Industrial water supply	10.0	3.8

Transmission loss of domestic water	13.4	5.1
Total Outputs	***260.1***	***100.0***
Available groundwater for allocation	***653.1***	

Table 4.9 Percentage of sector-based withdrawals in terms of total withdrawal, water potential and water availability (for normal years)

		Agriculture (%)	**Urban (%)**	**Livestock (%)**	**Industrial (%)**	**Total (%)**
Water Withdrawal	SW	89.8	4.0	6.2	0.0	100.0
	GW	77.8	18.4	0.0	3.8	100.0
	SW + GW	83.5	11.5	3.0	2.0	100.0
Water Potential	SW	12.3	0.6	0.8	0.0	13.7
	GW	22.2	5.2	0.0	1.1	28.5
	SW + GW	15.7	3.1	0.8	0.6	20.2
Water Availability	SW	37.2	1.7	2.6	0.0	41.5
	GW	31.0	7.3	0.0	7.3	45.6

Table 4.10 Hydrologic components of the basin (for normal years)

(hm^3/year)	**SW**			**GW**
	Catchment	River	Reservoir	Aquifer
Initial Storage			94	731
INPUTS				
Precipitation	8342			
Irrigation	379			
Decrease in Snow (Melt)	310			
Headflow		144		
Discharge		29		
Natural Recharge				913
Total (SW / GW)		***9299***		***1644***
OUTPUTS				

(hm^3/year)	SW			GW
	Catchment	River	Reservoir	Aquifer
Evapotranspiration	5013			
Increase in Snow	310			
The net change in soil moisture	3007			
Irrigation supply		150	26	202
Livestock supply		11		
Urban supply		4		34
Industrial supply				10
Irrigation water transmission loss		38		
Urban water transmission loss		1		13
Net evaporation for reservoir			29	
The net change in reservoir storage			38	
Total (SW / GW)		***8628***		***260***
INPUTS-OUTPUTS		***671***		***1384***

4.2.3 Water budget for dry years

As it can be concluded from the surface-water budget given in Table 4.11 on a yearly average, 58.5 hm^3 of less water is available for allocation relative to the modeling period average. In addition, the net change in reservoir storage decreases by -31 hm^3/yr compared to the modeling period average. Despite the decrease in the surface water inflows, the total share of the irrigation water output increases by 1%. This situation can be associated with the fact that less precipitation is received in dry years to more irrigation. Likewise, irrigation water supply from groundwater resources increases by 1.1%, as shown in the GW budget (Table 4.12), and contributions of the irrigation sector for all parameters raise by comparable rates (Table 4.13). Due to the reasons stated above, available surface and groundwater decreased by considerable rates, as shown in Table 4.14.

Table 4.11 Surface-water budget (for dry years)

Inputs (Surface-water)	**(hm^3/year)**	**% of Total Inputs**
Surface runoff	0.4	0.1
Interflow	377.5	50.3
Baseflow	215.2	28.7
Çatören dam head flow	18.5	2.5
Kunduzlar dam headflow	23.5	3.1
Çavuşçu dam head flow	54.6	7.3
WWTP discharge	17.9	2.4
Untreated urban water	11.5	1.5
The net change in reservoir storage	32.1	4.3
Total Inputs	***751.1***	***100.0***
Outputs (Surfacewater)	**(hm^3/year)**	**% of Total Outputs**
Irrigation water supply (from river)	172.1	60.0
Irrigation water supply (from pond)	26.3	9.2
Livestock water supply (from river)	11.4	4.0
Domestic water supply (from river)	3.7	1.3
Transmission loss of irrigation water	43.2	15.1
Transmission loss of domestic water	1.5	0.5
Reservoir surface evaporation	28.3	9.9
Total Outputs	***286.6***	***100.0***
Available surface-water for allocation (at the outlet)	***464.5***	

Table 4.12 Groundwater budget (for dry years)

Inputs (Groundwater)	**(hm^3/year)**	**% of Total Inputs**
Natural recharge	913.2	100.0
Total Inputs	***913.2***	***100.0***
Outputs (Groundwater)	**(hm^3/year)**	**% of Total Outputs**
Irrigation water supply	230.2	79.9
Domestic water supply	34.4	12.0
Industrial water supply	10.1	3.5
Transmission loss of domestic water	13.4	4.6
Total Outputs	***288.1***	***100.0***
Available groundwater for allocation	***625.1***	

Table 4.13 Percentage of sector-based withdrawals in terms of total withdrawal, water potential and water availability (for dry years)

		Agriculture (%)	**Urban (%)**	**Livestock (%)**	**Industrial (%)**	**Total (%)**
Water Withdrawal	SW	90.8	3.6	5.5	0.0	100.0
	GW	79.9	16.6	0.0	3.5	100.0
	SW + GW	85.2	10.4	2.7	1.8	100.0
Water Potential	SW	32.2	1.3	2.0	0.0	35.4
	GW	25.2	5.2	0.0	1.1	31.5
	SW + GW	28.3	6.8	2.0	1.3	38.4
Water Availability	SW	52.0	2.1	3.2	0.0	57.3
	GW	36.8	7.7	0.0	7.7	52.1

Table 4.14 Hydrologic components of the basin (for dry years)

(hm^3/year)	**SW**			**GW**
	Catchment	River	Reservoir	Aquifer
Initial Storage			94	731
INPUTS				

(hm^3/year)		**SW**		**GW**
	Catchment	River	Reservoir	Aquifer
Precipitation	6985			
Irrigation	429			
Decrease in Snow (Melt)	345			
Headflow		97		
Discharge		29		
The net change in reservoir storage			32	
Natural Recharge				913
Total (SW / GW)		***8011***		***1644***
OUTPUTS				
Evapotranspiration	4514			
Increase in Snow	345			
The net change in soil moisture	2305			
Irrigation supply		172	26	230
Livestock supply		11		
Urban supply		4		34
Industrial supply				10
Irrigation water transmission loss			43	
Urban water transmission loss			1	13
Net evaporation for reservoir			28	
Total (SW / GW)		***7450***		***288***
INPUTS-OUTPUTS		***561***		***1356***

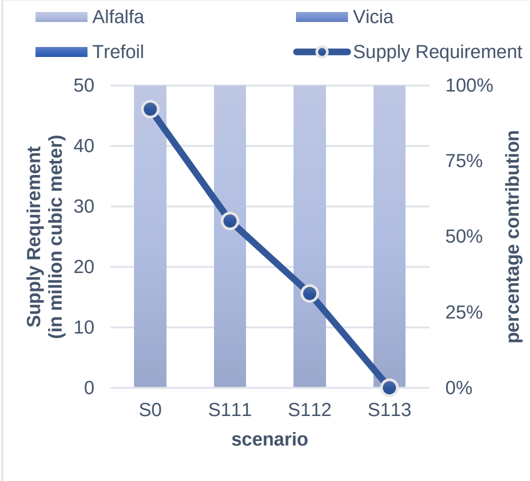
4.3 Scenario Analysis

Figure 4.2 demonstrates the scenario results in terms of supply requirement and irrigation shortfall. Supply requirement is calculated incorporating water demand and losses (e.g., evaporative, leakage). Catchment irrigation shortfall is defined as the portion of the actual demand for crop evapotranspiration not fulfilled by irrigation. The figure also demonstrates the relevant crop's contribution to the output provided for each scenario group, including the reference. Since there is no irrigation need or deficit in unirrigated crops, only the contribution of irrigated crops is shown in the graphics. According to the plots given in Figure 4.2, the highest contribution is achieved by implementing selective measures in water requirement and deficit magnitude, as expected. Furthermore, S31 has proved the most efficient individual scenario in decreasing irrigation demand and shortage.

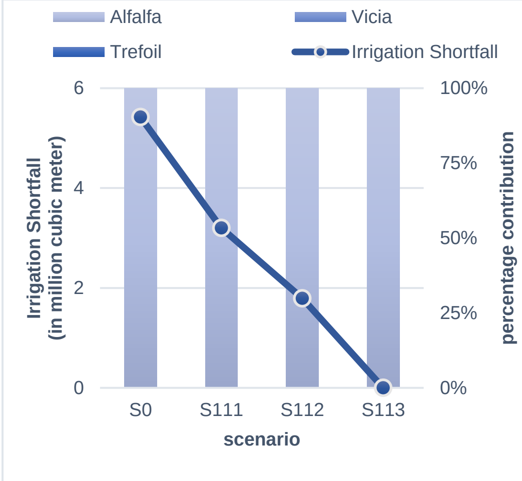
An overall table is provided to compare results in terms of demand, supply, deficit, and reliability in terms of difference relative to the historical scenario (Table 4.15). The efficiency is concluded as the highest in terms of deficit compared with demand and supply, besides the pattern change scenarios within alfalfa and forage maize (i.e., S117, S118, and S119). By combining the selective alternatives, C1 proposes an approximately 45% decline in supply requirement. Furthermore, Mehta et al. (2013) illustrated that by implementing diversified cropping patterns and improvements in irrigation technology, requirement decreases to nearly 12% less than the historical mean under the climate change sequence.

Figure 4.3 indicates the Demand Site Reliability in terms of surface water. In the WEAP model, reliability is computed as the percent of the timesteps in which a water demand is fully satisfied for a demand site (Sieber & Purkey, 2015). In this case, reliabilities for demand sites that rely on the groundwater are 100% (i.e., groundwater supply requirement was fulfilled at all months in 2005-2016). However, as demonstrated in Figure 4.3, surface water reliability might vary between 51-99% depending on the relevant scenario and corresponding demand site. Sub-basins located in upstream locations (i.e., 72-92% for Aktas, 91-99% for Aydınlı) result in relatively higher reliability than downstream locations. (i.e. Ayvalı 51-60%). That can be relevant considering the impact of upstream uses on the available resources downstream. While considering the net change in reliability in Table 4.15, C1 and C2 significantly impact the surface water reliability for all demand sites. Also, scenarios S31, S123, S21, S23 are promising. Regarding this issue, Esteve et al., 2015 further suggested that adapting crop pattern optimization might have a % seven contribution to the demand reliability under climate change conditions.

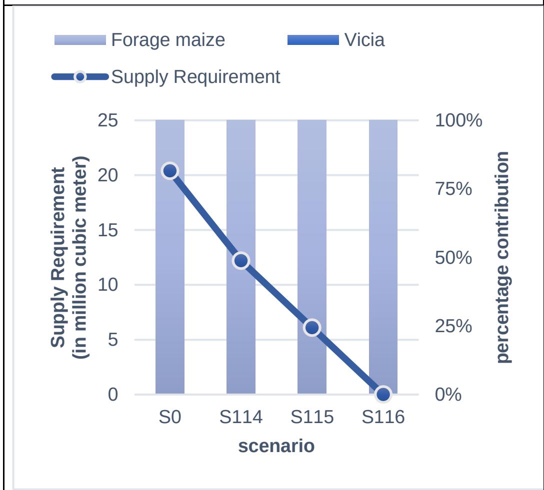
Supply Need (average, 2005-2016)	*Irrigation Shortfall (average, 2005-2016)*



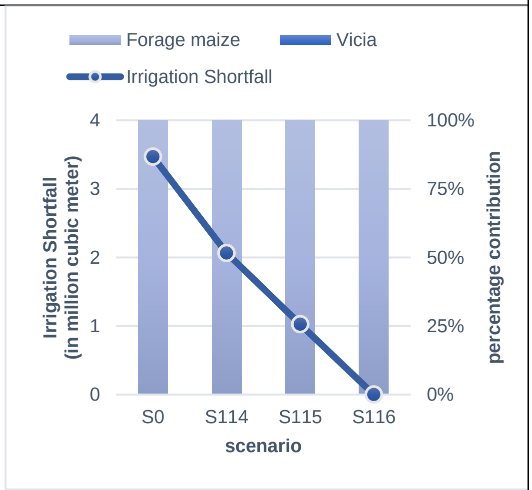
(a1. S111-S113)



(b1. S111-S113)

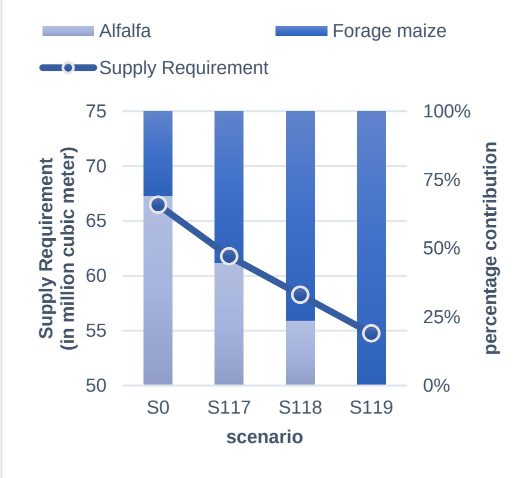


(a2. S114-S116)

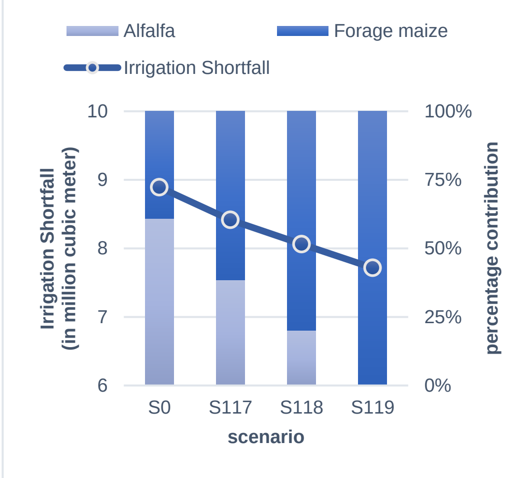


(b2. S114-S116)

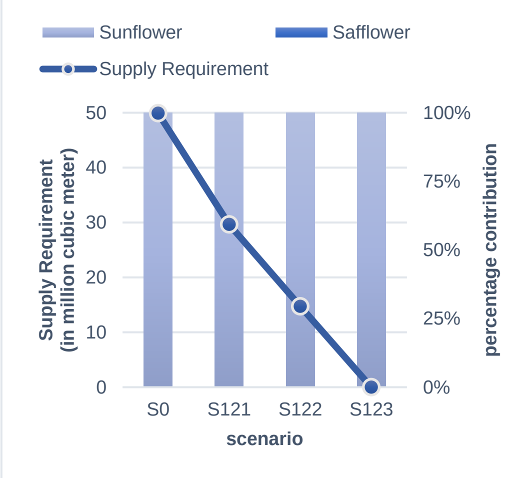
Supply Need (average, 2005-2016)	*Irrigation Shortfall (average, 2005-2016)*



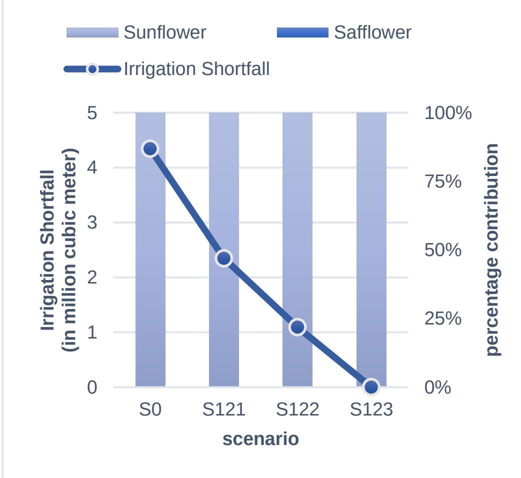
(a3. S117-S119)



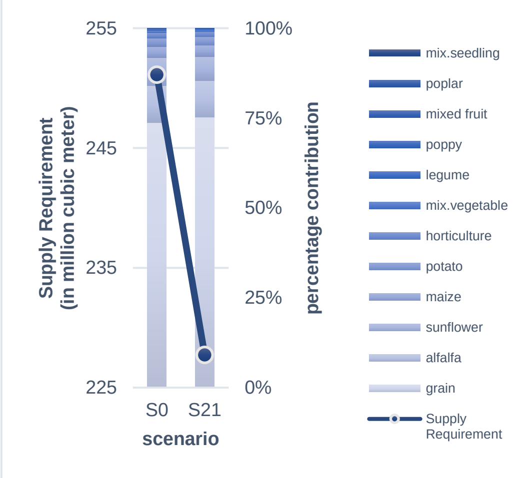
(b3. S117-S119)

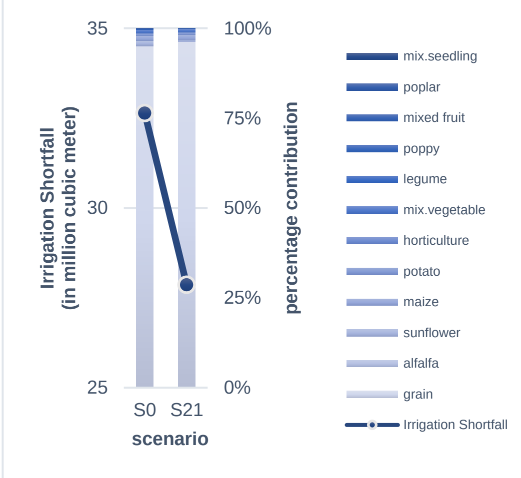


(a4. S121-S123)

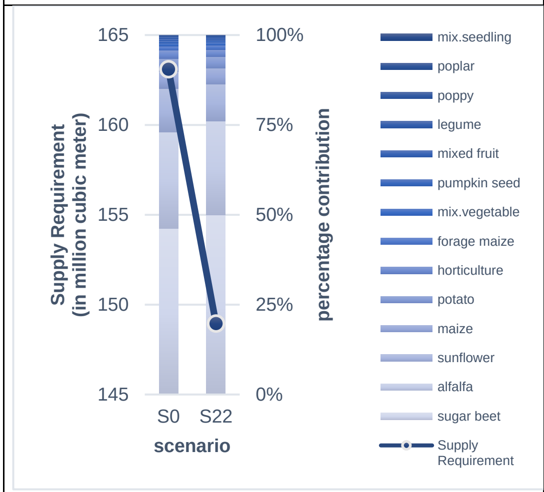


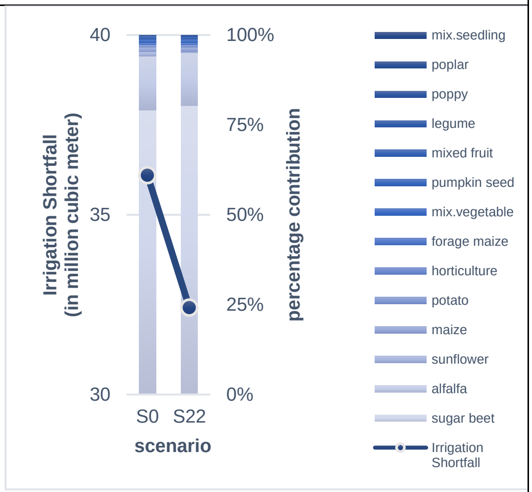
(b4. S121-S123)



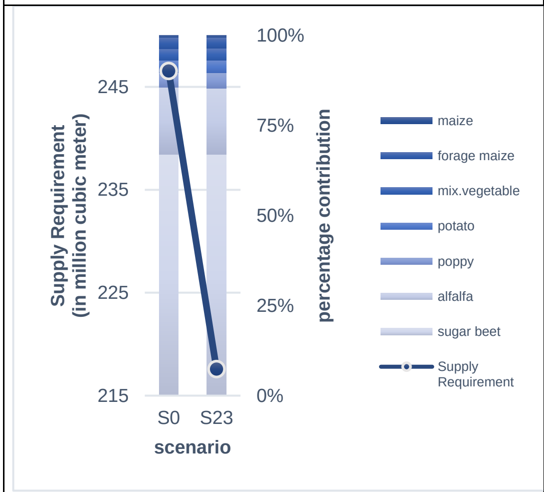


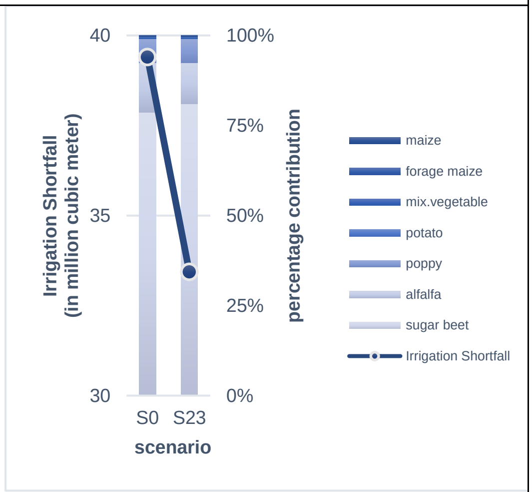
Supply Need (average, 2005-2016)	*Irrigation Shortfall (average, 2005-2016)*
(a5. S21)	(b5. S21)





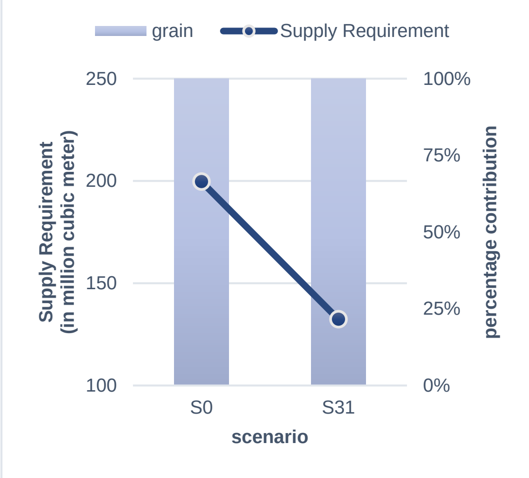
(a6. S22)	(b6. S22)



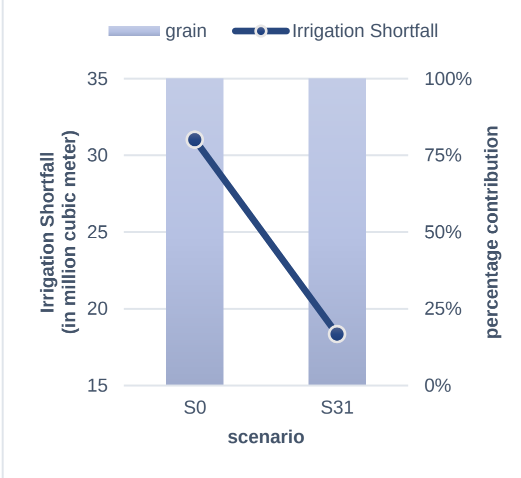


(a7. S23)	(b7. S23)

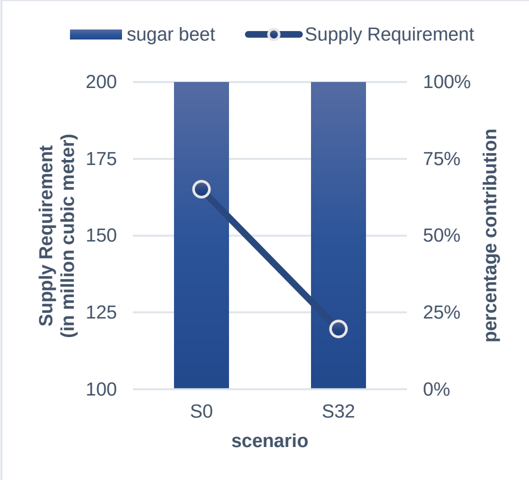
Supply Need (average, 2005-2016)	*Irrigation Shortfall (average, 2005-2016)*



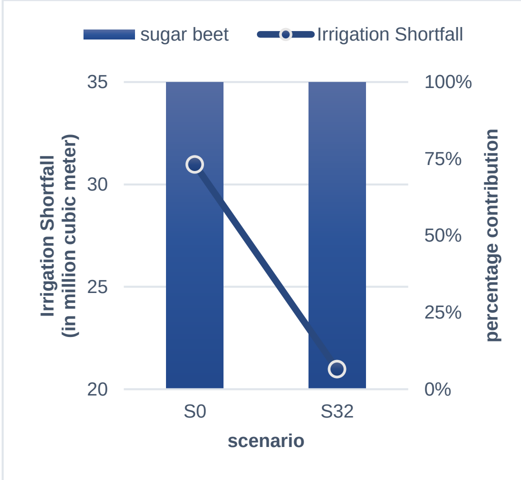
(a8. S31)



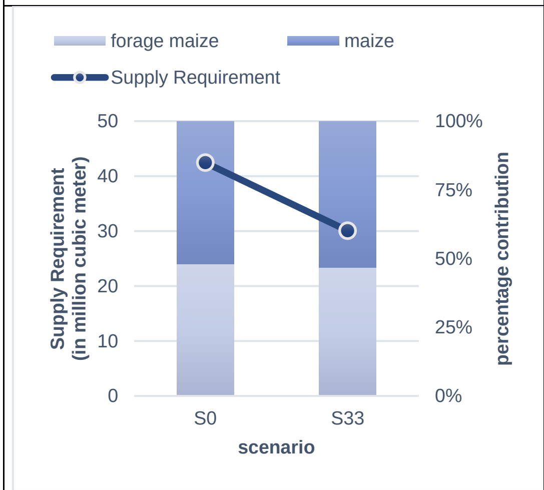
(b8. S31)

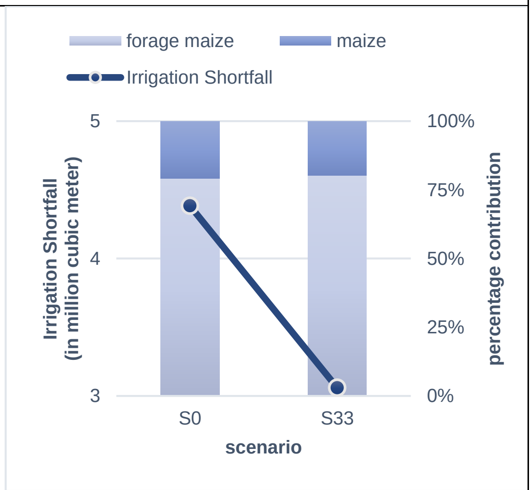


(a9. S32)

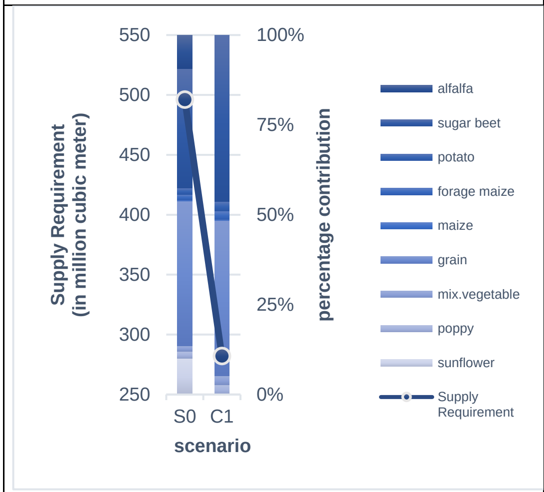


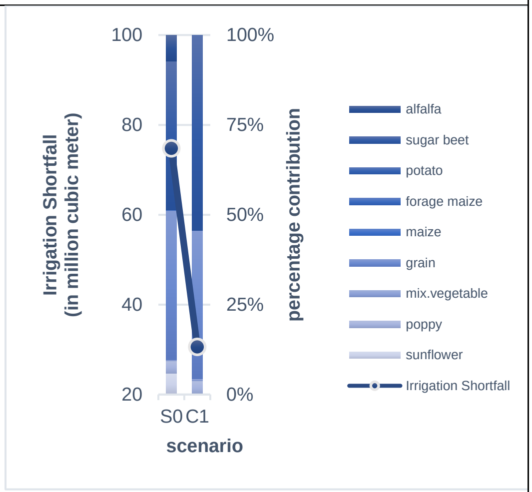
(b9. S32)



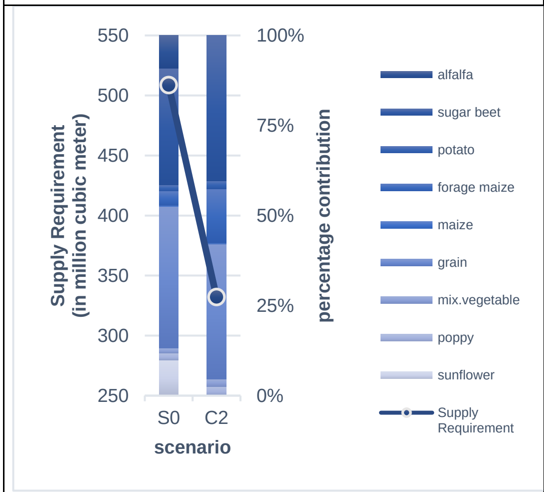


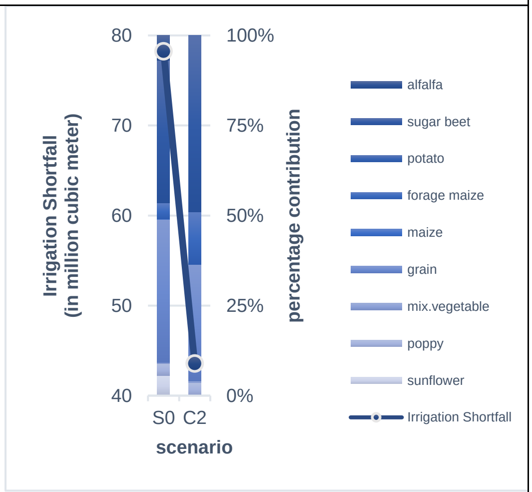
Supply Need (average, 2005-2016)	*Irrigation Shortfall (average, 2005-2016)*
(a10. S33)	(b10. S33)





(a11. C1)	(b11. C1)





(a12. C2)	(b12. C2)

Figure 4.2. Average supply requirement and irrigation shortfall (2005-2016)

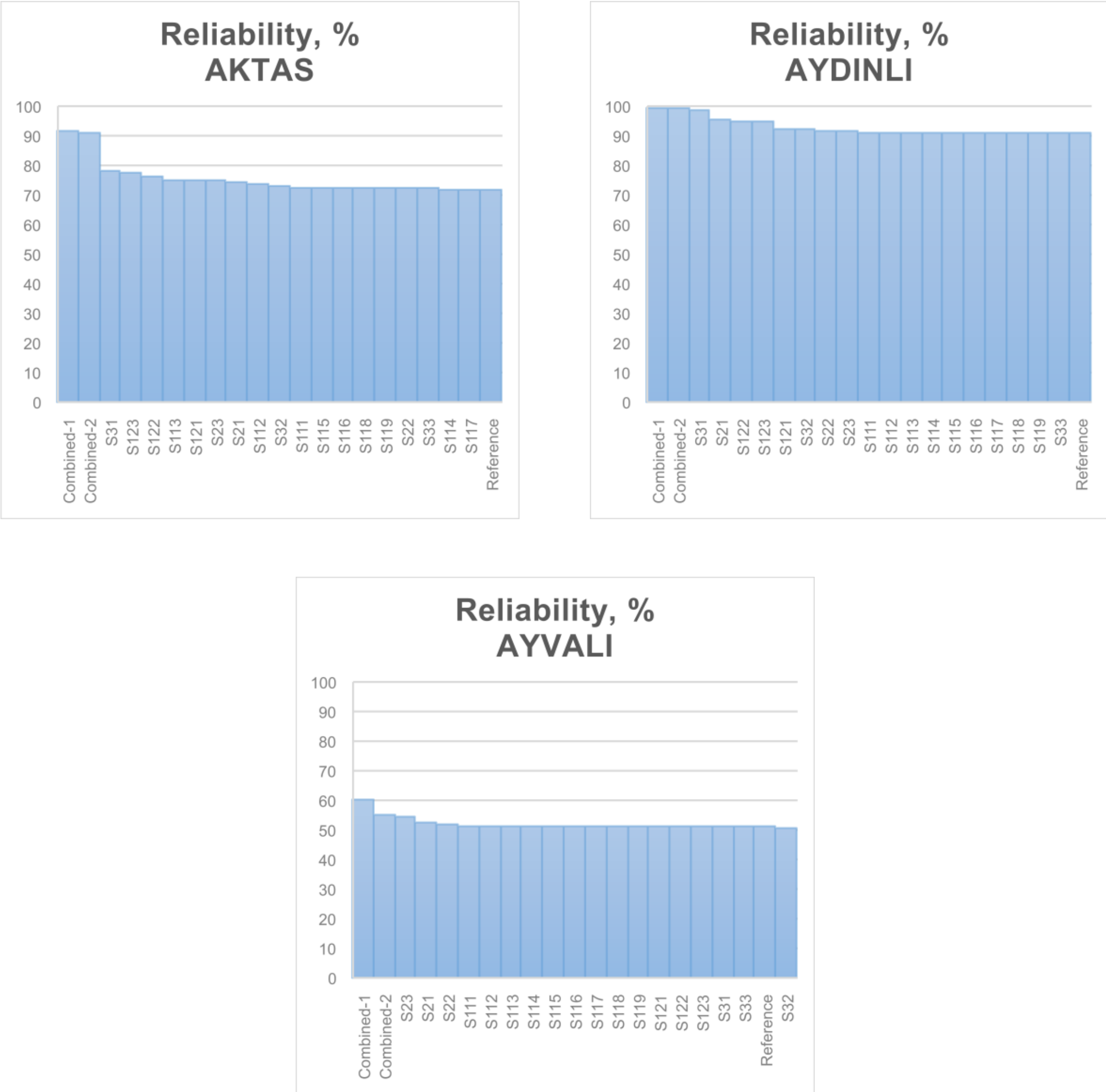


Figure 4.3. Surface water reliability for irrigation demand (2005-2016)

Table 4.15 Comparing results for demand, supply, deficit, and reliability in terms of % change* (2005-2016)

Scenario	*Supply Required*	*Irrigated*	*Shortfall*	*Reliability*		
				AKTAS	*AYDINLI*	*AYVALI*
S111	-40.1	-39.9	-41.0	0.6	0.0	0.0
S112	-66.1	-65.9	-66.9	1.9	0.0	0.0
S113	-100.0	-100.0	-100.0	3.2	0.0	0.0
S114	-40.1	-39.9	-40.5	0.0	0.0	0.0

Scenario	*Supply Required*	*Irrigated*	*Shortfall*	*Reliability*		
				AKTAS	*AYDINLI*	*AYVALI*
S115	-70.1	-69.9	-70.5	0.6	0.0	0.0
S116	-100.0	-100.0	-100.0	0.6	0.0	0.0
S117	-7.1	-8.5	-5.4	0.0	0.0	0.0
S118	-12.4	-14.8	-9.3	0.6	0.0	0.0
S119	-17.6	-21.2	-13.2	0.6	0.0	0.0
S121	-40.6	-39.4	-46.0	3.2	1.3	0.0
S122	-70.5	-69.6	-74.8	4.5	3.8	0.0
S123	-100.0	-100.0	-100.0	5.8	3.8	0.0
S21	-9.3	-11.3	-14.6	2.6	4.5	1.3
S22	-8.7	-15.1	-10.2	0.6	0.6	0.6
S23	-11.8	-15.9	-15.1	3.2	0.6	3.2
S31	-33.7	-29.4	-40.9	6.4	7.7	0.0
S32	-27.6	-25.6	-32.3	1.3	1.3	-0.6
S33	-29.2	-28.7	-30.2	0.6	0.0	0.0
C1	-43.2	-39.2	-59.1	19.9	8.3	9.0
C2	-34.7	-31.8	-44.3	19.2	8.3	3.8

*Net change in irrigation water supply need, actual supply and shortfall relative to the reference scenario

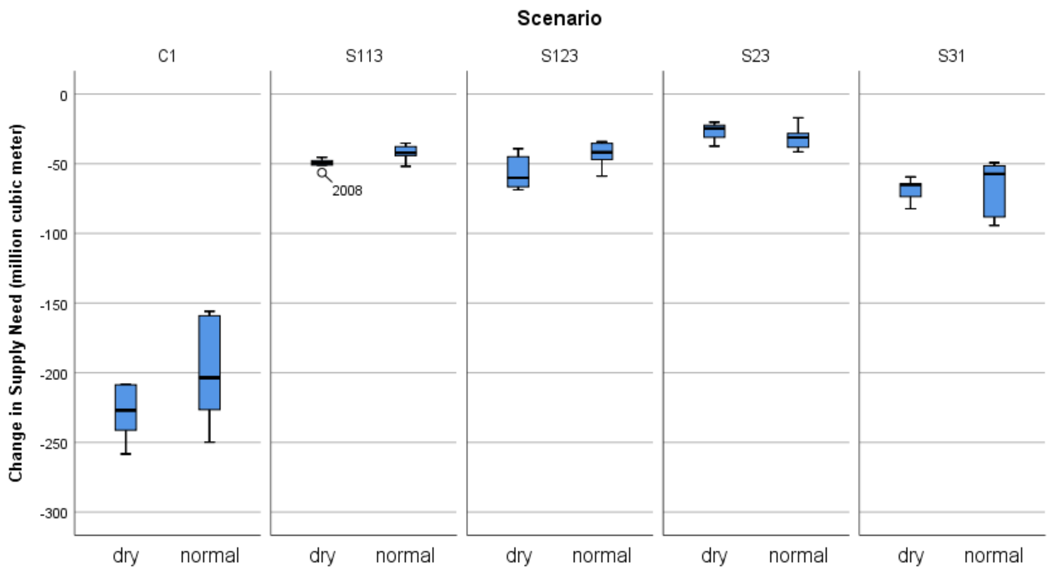
As seen in the supply need column of Table 4.15, scenarios that resulted in the highest net impact on irrigation water supply over their groups are S113, S123, S23, S31 and C1. In terms of supply need, irrigation supply and shortfall parameters, C1 has the highest impact since it is the combination scenario that implements all other scenarios on the figure simultaneously. On the other hand, particular S-group scenarios are close to each other in a narrow band regarding the net effect in output parameters. However, scenario outputs have demonstrated minor variations considering the hydrologic conditions.

For statistical analysis, box and whisker plots, as seen in Figure 4.4, are obtained for the scenarios that have been proved most effective in terms of irrigation water use.

In general, S113 and S123 have a relatively higher impact in dry years than the normal years. Furthermore, few outliers have been observed in Figure 4.4 under severe drought conditions in 2008 regarding the change in supply need and irrigation shortfall parameters. Likewise, an outlier is observed regarding the shortfall in 2007, where the mild drought condition prevails most strongly in the normal group. In this case, it can be clearly stated that crop pattern change practice is most effective in dry periods. This situation might occur because less precipitation is received in dry periods, and thus more irrigation is needed to compensate for the evapotranspiration loss. This situation is also interpreted in Section 4.2.3; relatively higher irrigation has been observed in the current dry state than the normal period, whereas less inflow has been acquired. Since the irrigation supplies from surface water and groundwater are much higher in dry periods, switching to non-irrigated crops in S113 (vicia and trefoil) and S123 (safflower) is more effective concerning irrigation water efficiency.

Similarly, in the S31 scenario, as seen in Figure 4.4, the net change in the supply need and irrigation shortfall parameters is higher in dry years than in normal years. However, the net change in the irrigation amount parameter is calculated to be close to each other in dry and normal periods. In addition, the S31 scenario shows the net change in the amount irrigated in 2014, which is the least dry. After the detailed analysis of the results, it is determined that the grain to which the scenario applied in the Aydınlı sub-basin is irrigated 20% more than the reference scenario. Due to the insufficient flows in the Gökpınar creek located in the Aydınlı basin, the 3.7 times more irrigation compared to the reference in July 2014 contributed significantly to this outlier observed in 2014.

The S23 is the scenario with the least net change compared to the reference when evaluated among the other most effective alternatives, as seen in Figure 4.4. At the same time, when this scenario is evaluated under hydrological drought conditions, it is seen that it causes different effects in different parameters. These effects might be related to the variety of products to which the scenario is practiced and the competition between the products that the scenario is not applied. It is observed that the net change in Irrigation demand and supply parameters in normal years is more than in dry years. In the Irrigation shortfall output, it is determined that there is more water deficit in the normal period compared to the reference. Especially in the normal years 2009, 2011, the 2015 sugar beet has more water deficit than the reference. The reason for this situation has been investigated with detailed analysis. In the further study, it is noticed that during the dry periods of 2008, 2010 and 2014, there is more irrigation requirement for grain than normal years within the scope of the study area (Figure 4.5). However, this product is not included in the S23 scenario as the transition to drip irrigation is not applicable in the grain. Therefore, while this high irrigation requirement is met for grain during dry periods, the irrigation deficit of sugar beet in normal years following the dry years could not be compensated. As shown in Figure 4.5, competing water demand is available, especially in 2011, since the irrigation needs of both crops are the same. However, in scenario S23, the irrigation demand of this product is met as the irrigation efficiency of the grain is not reduced. At the same time, the water deficit of sugar beet increased due to the competing water use between those crops.



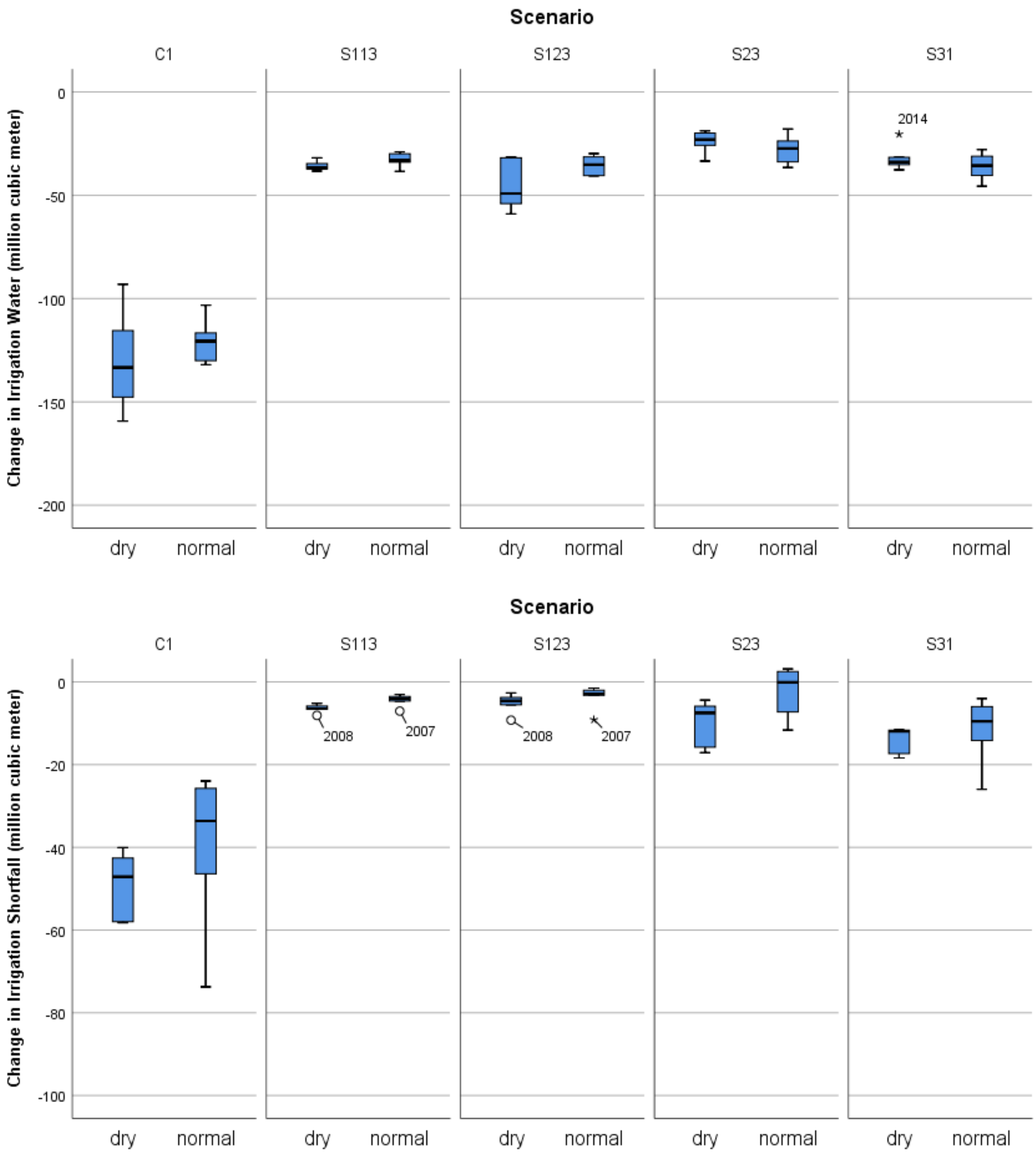


Figure 4.4. Box and whisker plots by the most effective scenarios (2005-2016)

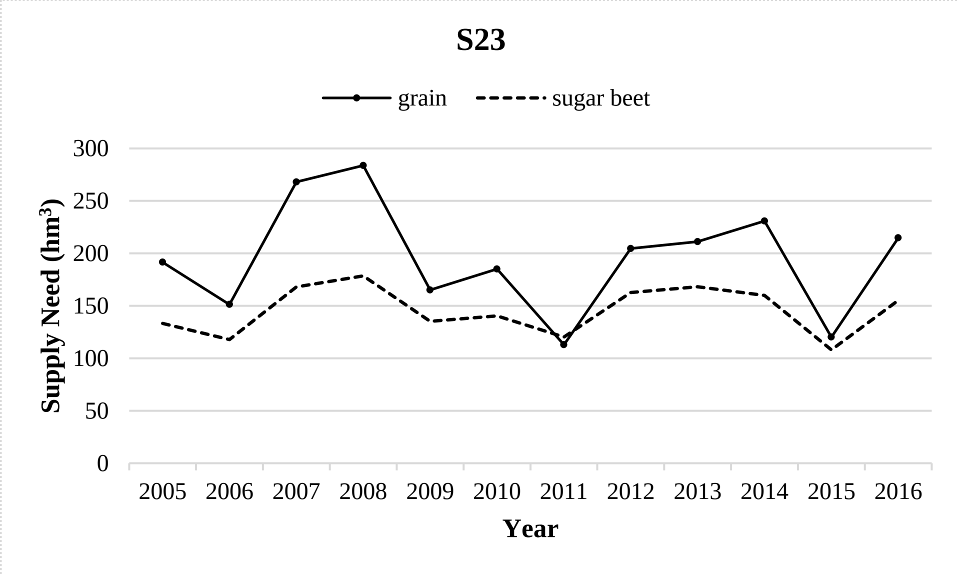


Figure 4.5. Irrigation supply needs of grain and sugar beet for scenario S23

Alp et al. (2021) conducted further evaluation concerning economic aspects of demand-oriented management scenarios included in the Upper Sakarya WEAP model application. Economic analysis of the scenarios was done to see how the producer would be affected in economic terms if the scenarios are implemented. Scenarios under economic evaluation include crop pattern change (S1) and deficit irrigation practices (S3). S2 scenarios could not be evaluated in economic terms due to the uncertainty caused by the fact that many different parameters are needed to calculate economic inputs and outputs for improving irrigation techniques. Thus, different results may yield according to the region, product and producer. Economic evaluations were carried out for the last year of the model period (i.e. 2016) to represent the most current condition.

The data used in these evaluations were obtained from different sources. The production areas and production quantities required for the general economic analysis of agricultural production in the basin were obtained from the Turkish Statistical Institute (TurkStat, 2019). Prices and costs were obtained from the Provincial Directorates of Agriculture and Forestry, several irrigation unions and cooperatives, and various data from the farmers in the region. (Alp et al., 2021).

Within the scope of economic analysis, production costs were calculated considering all the expenses made for the periods between soil preparation to harvesting. Gross Production Values (GPV) are calculated over the selling price and average yield of the products. The net income of the farmer is calculated by subtracting the production costs from the GPV. Net income shows the producer's income from a particular product if the relevant scenario is implemented. It is very important from the point of view of the producers on these applications. On the other hand, considering that water resources are limited, the net income to be obtained by using 1 m^3 of irrigation water is an important parameter in sustainable planning based on both the producer's income and the efficient allocation of water resources. Therefore, the optimum alternative should be determined in sustainability by considering the net income per 1 m^3 of water (Alp et al., 2021).

As seen in Figure 4.6., the results obtained from the economic analysis of the scenarios are evaluated in terms of farmer's net income per 1m^3 of irrigation water used. Significant contributions to the farmer's income by 20-50 TL per m^3 of water use compared to reference scenario can be achieved by scenarios S113 (shifting forage crop pattern from alfalfa to vicia and trefoil), S123 (shifting oilseeds pattern from sunflower to safflower) and S116 (shifting forage crop pattern from maize to vicia). Deficit irrigation practices have a 3TL/m^3 contribution at most in scenarios S31-S33. In contrast, a negative impact on the net income is observed for shifting the forage crop pattern from alfalfa to maize in scenarios S117-S119. While considering the decrease in irrigation water use provided in Figure 4.7, options that have considerable support to the economic gain besides serving to protect water resources are S113 and S123.

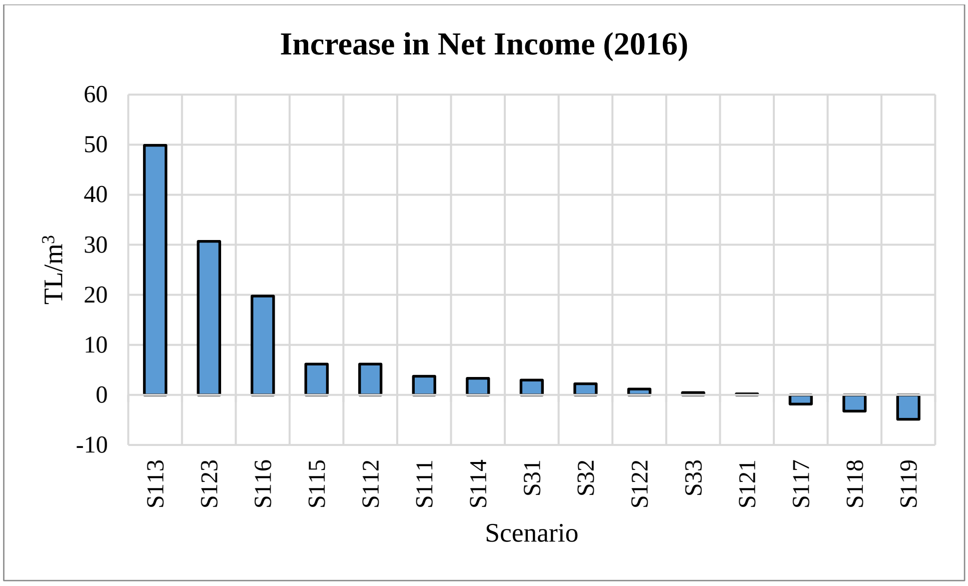


Figure 4.6. Increase in the net income value relative to the reference scenario (Alp et al., 2021)

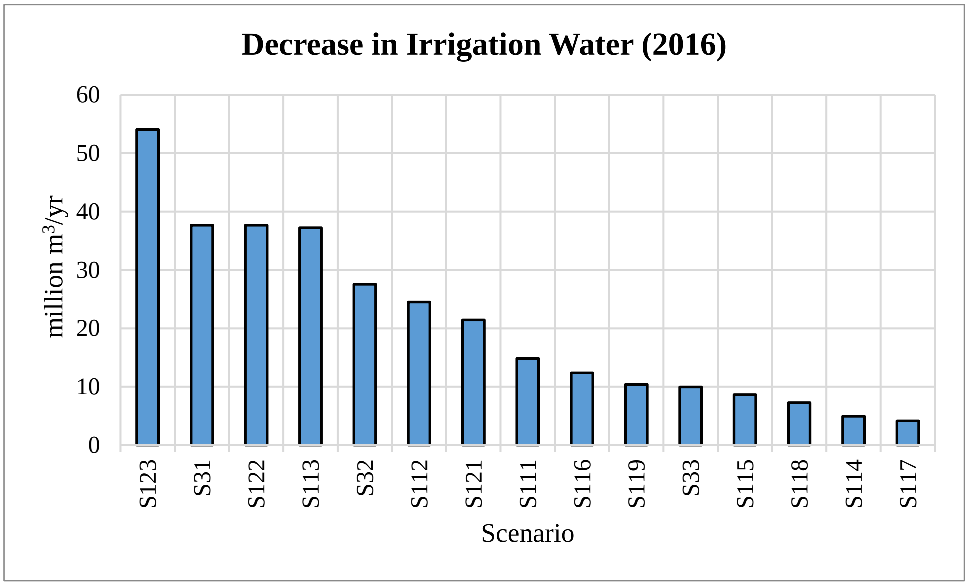


Figure 4.7. Decrease in the irrigation water supply relative to the reference scenario

Furthermore, stakeholders were consulted obtain feedback about the scenarios evaluated in this study. Representatives from several stakeholders, including 3. Regional Directorate of State Hydraulic Works in Eskişehir, Eskişehir Directorate of Provincial Agriculture and Forestry, Seyitgazi Municipality and irrigation associations (Sakaryabaşı and Eskişehir). An overview of stakeholder opinions on best management alternatives is provided as follows;

Shifting forage cropping pattern from alfalfa to vicia or trefoil (S113):

- The yield of alfalfa, a perennial plant, is quite high compared to vicia and trefoil.
- In terms of forage crops, alternative crops being more profitable facilitates their adoption by farmers.
- An R&D project is currently carried out to encourage relatively low yielding alternative forage crops instead of alfalfa by partially or completely covering the farmers' financial losses.

Shifting oilseeds cropping pattern from sunflower to safflower (S123):

- Since safflower has good quality with its rich content and several health benefits, its use has become widespread, especially in recent years. An increase has been observed in the cultivation areas.
- Safflower is a very good alternative for especially arid lands not suitable to grow a sunflower.
- Safflower has a relatively low yield, and it has sales problems due to a lack of industry.

Improving irrigation method from sprinkler to drip (S23):

- Installation and maintenance in drip irrigation are more laborious and costly compared to sprinkler irrigation.
- There is 50% government support for drip irrigation installation.
- Sprinkler irrigation is less than drip irrigation in terms of product yield. In drip irrigation, the product yield is increased by applying a small amount of water to the plant's roots.
- In drip irrigation applications, less fertilizer is needed by adding fertilizer to the irrigation water.
- Drip irrigation becomes widely practiced, especially for maize.

Practicing deficit irrigation on grain (S31):

- Deficit irrigation is currently practiced for grain.
- Restrictions were imposed on the export and import of wheat.
- The grain yield decreased due to the lack of precipitation. In order to increase the yield, especially in wheat and barley, the need for irrigation has occurred during dry periods.
- A type of bread wheat called "reis," which has a relatively higher yield in dry farming than wheat, can be considered an alternative.

Further suggestions:

- For irrigation systems with canal structures in the ground, 40% of the water allocated for irrigation is lost by infiltrating the soil. Projects were prepared to install closed systems rather than open canal systems but could not be realized due to a lack of funds.
- Considering various parameters (plant water need, meteorology, soil structure, transmission and field application efficiency), optimizing irrigation water distribution system with the remote sensing method is suggested as a state-of-the-art method to provide an appropriate amount of water suitable time for the crop.

An overall summary weighing the advantages and limitations of best management options is provided in Table 4.16 to aid the authorities' decision-making.

Table 4.16 An overview incorporating advantages and limitations of best management alternatives

	Advantages	*Limitations*
S113 (crop pattern change: from alfalfa to vicia & trefoil)	1. The highest contribution to the net income 2. Significant decrease in irrigation water use 3. Trefoil grows on arid, weak and gravelly soils that are not suitable for alfalfa cultivation 4. Trefoil is funded equally to alfalfa under forage crop production support 5. R&D to compensate financial losses of farmers 6. Trefoil is a perennial like alfalfa	1. Alfalfa has a higher yield than vicia or trefoil 2. Vicia has less fund than alfalfa
S123 (crop pattern change: from sunflower to safflower)	1. A significant contribution to the net income 2. The highest decrease in irrigation water use 3. Safflower has a wide range of uses, rich in content and high quality 4. Safflower is drought and cold resistant, suitable for arid land	1. Low yield 2. Sales problems due to lack of industry 3. No available government subsidies
S23 (improved irrigation: from sprinkler to drip)	1. The government loan is available for drip irrigation as well as sprinkler 2. Product yield increases proportionally to irrigation efficiency 3. The suitable method to apply water with fertilizer	1. Not practicable to install largely cultivated lands due to higher effort & cost compared to sprinkler
S31 (deficit irrigation: grain)	1. Already practiced widely by farmers 2. Alternative wheat type is suitable for dry periods	1. Risk of yield decreases & crop loss 2. Restrictions on the export & import of wheat 3. Negative impacts of climate change on grain yield

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CHAPTER 5

CONCLUSION

Current state and alternative scenarios are investigated with the focus on sustainable water governance for agricultural production. Impacts of agricultural management on dynamics in demand and supply are evaluated upon each technical measure. From the water - food (agriculture) nexus perspective, alternative scenarios considered efficient irrigation water use with alterations in the current crop patterns, irrigation technologies, and programs. Pressurized irrigation techniques such as sprinkler and drip irrigation are preferred wherever practicable as an alternative to surface irrigation. Furthermore, alternative forage crops (vicia or trefoil) and oilseeds (safflower) are promoted instead of those irrigated multiple times in one season (alfalfa, forage maize, sunflower). Last but not least, more conservative irrigation programs have been suggested for grain, sugar beet, and maize.

Scenario analysis has shown that when more efficient irrigation techniques, deficit irrigation programs are embraced, and less water-intensive crops are favored, demand and supply decline in proportion to each other. In contrast, reliability rises with a relatively lower rate. For instance, promoting sprinkler and drip irrigation techniques suggests a 10% and 15% decrease in demand and supply, respectively, while increasing reliability by nearly 1-5% compared to a historic baseline scenario.

For statistical analysis, the scenarios that have been proved most effective in irrigation water use have been evaluated further. Each scenario that resulted in the highest impact on irrigation water supply over their groups is S113, S123, S23, S31 and C1. In terms of supply need, irrigation supply and shortfall parameters, C1 has the highest impact since it is the combination scenario that implements all other scenarios on the figure simultaneously. Scenarios S113 and S123 have a relatively higher impact in dry years than the normal years. This situation might occur because less precipitation is received in dry periods, and thus more irrigation is needed to compensate for the evapotranspiration loss. The S23 has the least net change relative to the historic baseline scenario compared to the other most effective alternatives. These situations are suggested to be related to the water competition between sugar beet to which crop the scenario is applied and the grain disregarded from the scope of the related scenario.

Furthermore, economic evaluations are considered in scenario analysis. Producers aim to obtain maximum net income from the product they grow and plan their product patterns accordingly. However, due to the negative effects of climate change for many years, the production balance has been adversely affected. For Turkey, which is not rich in water, it is critical for sustainable agriculture to plan agricultural irrigation, where water resources are widely used by taking into account the economic gain. S113 and S123 are the most profitable options for economic gain besides serving to protect water resources.

Final recommendations on best management options are provided to encourage decision-makers to implement measures represented in the scenario analysis and to achieve sustainable agricultural management goals in the basin.

S113 (crop pattern change; from alfalfa to vicia & trefoil): Trefoil should be encouraged under conditions that are not suitable in terms of land or climate for the cultivation of alfalfa. Alternative forage crops profitable facilitates their adoption by farmers. In this regard, current research for compensating financial losses of the farmers is of great concern in encouraging alternative forage crops instead of alfalfa.

S123 (crop pattern change; from sunflower to safflower): While emphasizing the importance of this crop, government subsidies should be provided to encourage its farming and industry, and R&D studies should be increased.

S23 (improved irrigation; from sprinkler irrigation to drip): Although drip method is not deemed practicable over large fields due to the high cost and effort needed for installation and maintenance, emphasizing the benefits of increasing crop yield and reducing fertilizer use, as well as improving government incentives, will make a significant contribution to farmers' adoption of this method.

S31 (deficit irrigation; grain): In terms of deficit irrigation in grain, the periods that will cause the least yield loss should be investigated before practice, thus preserving the product yield and water efficiency. Furthermore, acknowledging the alternative wheat type suitable for dry periods can mitigate the negative impacts of climate change on grain yield.

The transmission of agricultural waters to the fields through open channels causes almost half of the allocated water to be lost. Furthermore, transmission losses can lead to a shortage of drinking water to be allocated from the same source and agricultural water shortage. Upgrading the irrigation conveyance system to closed channels would be a good measure to reduce the water loss through the infiltration to soil. Ensuring the necessary investments in this regard is of critical importance.

In conclusion, there are pressures and risks regarding the water and food resources and related ecosystem processes. However, such challenges can be addressed by promoting conservative agricultural practices that assure water and food security. Altering crop patterns, modifying irrigation methods and schedules makes it highly achievable to ensure water and food (agriculture) sustainability. Best management practices should be determined with an integrated approach, considering technical outputs, stakeholder views, economic and ecological evaluations. It is believed that the agricultural practices researched in this study can be adopted and applied widely by the farmers without difficulty, and can make significant contributions to sustainable agriculture in the future, provided that sufficient incentives are provided and necessary measures are taken by considering the recommendations provided regarding critical issues by the decision-makers.

REFERENCES

Aboelnga, H. T., Khalifa, M., McNamara, I., Ribbe, L., & Sycz, J. (2018). *The Water-Energy-Food Security Nexus: A review of Nexus literature and ongoing Nexus initiatives for policymakers.* Bonn: Nexus Regional Dialogue Programme (NRD).

Ahmadaali, J., Barani, G.-A., Qaderi, K., & Hessari, B. (2018). Analysis of the Effects ofWater Management Strategies and Climate Change on the Environmental and Agricultural Sustainability of Urmia Lake Basin, Iran. *Water, 10*. doi:10.3390/w10020160

Al Zayed, I. S., & Elagib, N. A. (2017). Implications of non-sustainable agricultural water policies for the water-food nexus in large-scale irrigation systems: A remote sensing approach. *Advances in Water Resources*, 1-15.

Albaji, M., Golabi, M., Nasab, S. B., & Zadeh, F. N. (2015). Investigation of surface, sprinkler and drip irrigation methods based on the parametric evaluation approach in Jaizan Plain. *Journal of the Saudi Society of Agricultural Sciences*, 1-10.

Albrecht, T. R., Crootof, A., & Scott, C. A. (2018). The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. *Environmental Research Letters, 13*(4). doi:https://doi.org/10.1088/1748-9326/aaa9c6

Alfarra, A., Kemp-Benedict, E., Hötzl, H., Sader, N., & Sonneveld, B. (2012). Modeling Water Supply and Demand for Effective Water Management Allocation in the Jordan Valley. *Journal of Agricultural Science and Applications, 1*(1), 1-7.

Al-Omari, A. S., Al-Karablieh, E. K., Al-Houri, Z. M., Salman, A. Z., & Al-Weshah, R. A. (2015). Irrıgation Water Management in the Jordan Valley under Water Scarcity. *Fresenius Environmental Bulletin, 24*(4), 1176 - 1188.

Al-Omari, A., Al-Bakri, J., Hindiyeh, M., Al-Houri, Z., Farhan, I., & Jibril, F. (2018). Integrated Hydrologic and Quality Model for Zarqa River Basin in Jordan. *Fresenius Environmental Bulletin, 27*(7), 4637-4647.

Alp, E., Kentel, E., Aydınalp Köksal, M., Demir, Y., Başkan, O., Yakut, M., (2021). *Su, Enerji ve Gıda İlişkisinin Sakarya Havzasında Değerlendirilmesi.* METU, Environmental Engineering Department. Ankara 2017-2021: funded by TÜBİTAK 116Y166.

Amisigo, B. A., McCluskey, A., & Swanson, R. (2015). Modeling Impact of Climate Change on Water Resources and Agriculture Demand in the Volta Basin and other Basin Systems in Ghana. *Sustainability, 7*, 6957-6975. doi:10.3390/su7066957

Aras, İ. (2006). Damla Sulama Yöntemi. *Toprak Gübre Ve Su Kaynakları Merkez Araştırma Enstitüsü*, 49-60.

Armstrong, D., O'Donnell, D., & Thompson, C. (2001). *Irrigation Equipment and Techniques.* Wise Watering Irrigation Management Course.

Assaf, H., & Saadeh, M. (2008). Assessing water quality management options in the Upper Litani Basin, Lebanon, using an integrated GIS-based decision support system. *Environmental Modelling & Software, 23*, 1327–1337. doi:10.1016/j.envsoft.2008.03.006

Bhatti, G. H., & Patel, H. M. (2015). Irrigation Scheduling Strategies for Cotton Crop in Semi-Arid Climate Using WEAP Model. *Journal of Indian Water Resources Society, 35*(1).

Biggs, E. M., Bruce, E., Boruff, B., Duncan, J. M., Horsley, J., Pauli, N., . . . Imanari, Y. (2015). Sustainable development and the water–energy–food nexus:. *A perspective on livelihoods*, 389–397.

Blanco-Gutiérrez, I., Varela-Ortega, C., & Purkey, D. R. (2013). Integrated assessment of policy interventions for promoting sustainable irrigation in semi-arid environments: A hydro-economic modeling approach. *Journal of Environmental Management*, *128*, 144-160.

Boutraa, T. (2010). Improvement of Water Use Efficiency in Irrigated Agriculture: A Review. *Journal of Agronomy*, 1-8.

Brindha, K. (2017). International virtual water flows from agricultural and livestock products of India. *Journal of Cleaner Production*, 922-930.

Çakmak, B., & Beyribey, M. (2003). Sakarya Havzası Sulamalarında Sistem Performansının Değerlendirilmesi. *Tarım Bilimleri Dergisi*, *9*(1), 116–124.

Chartres, C., & Sood, A. (2013). The water for food paradox. *Aquatic Procedia*, 3-19.

Cook, C., & Bakker, K. (2012). Water security: Debating an emerging paradigm. *Global Environmental Change*, 94–102.

Copernicus. (2012). *CLC 2012*. Retrieved February 26, 2018, from Land Monitoring Service: https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

da Silva, V., de Oliveira, S., Braga, C., Brito, J., de Sousa, F., de Holanda, R., . . . de Araújo, L. (2016). Virtual water and water self-sufficiency in agricultural and livestock products in Brazil. *Journal of Environmental Management*, 465-472.

Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., . . . Yang, Q. (2018). Water-energy nexus: A review of methods and tools for macro-assessment. *Applied Energy*, *210*, 393-408. doi:https://doi.org/10.1016/j.apenergy.2017.08.243

Damerau, K., Patt, A. G., & Van Vliet, O. P. (2016). Water saving potentials and possible trade-offs for future food and energy supply. *Global Environmental Change*, 15–25.

Darani, H. R., Kohansal, M. R., Ghorbani, M., & Saboohi, M. (2017). An Integrated Hydro-Economic Modeling to Evaluate Marketing Reform Policies of Agricultural Products. *Bulgarian Journal of Agricultural Science, 23*(2), 189–197.

Dehghanipour, A. H., Zahabiyoun, B., Schoups, G., & Babazadeh, H. (2019). A WEAP-MODFLOW surface water-groundwater model for the irrigated Miyandoab plain, Urmia lake basin, Iran: Multi-objective calibration and quantification of historical drought impacts. *Agricultural Water Management, 223*. doi:https://doi.org/10.1016/j.agwat.2019.105704

Descheemaeker, K., Amede, T., & Haileslassie, A. (2010). Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, 579-586.

DSİ. (2016a). *Sakarya Havzası Master Planı Tarımsal Ekonomi Nihai Raporu.* Eskişehir: T.C. Orman Ve Su İşleri Bakanlığı Devlet Su İşleri Genel Müdürlüğü 3. Bölge Müdürlüğü.

DSİ. (2016b). *Sakarya Havzası Master Planı Halk Sulamaları Nihai Raporu.* Eskişehir: T.C. Orman Ve Su İşleri Bakanlığı Devlet Su İşleri Genel Müdürlüğü 3. Bölge Müdürlüğü.

DSİ. (2017). *Sakarya Havzası Master Plan Nihai Raporu.* Eskişehir: T.C. Orman Ve Su İşleri Bakanlığı Devlet Su İşleri Genel Müdürlüğü 3. Bölge Müdürlüğü.

Esteve, P., Varela-Ortega, C., Blanco-Gutiérrez, I., & Downing, T. E. (2015). A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture. *Ecological Economics, 120*, 49-58. doi:http://dx.doi.org/10.1016/j.ecolecon.2015.09.017

FAO. (2008). *AQUASTAT. Global Water Information System. Country Fact Sheet. Turkey*. Retrieved February 16, 2020, from AQUASTAT - FAO's Global Information System on Water and Agriculture:

http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/TUR

FAO. (2014). *The Water-Energy-Food Nexus. A new approach in support of food security and sustainable agriculture.* Rome: Food and Agriculture Organization of the United Nations.

FAO. (2017). *Water for Sustainable Food and Agriculture. A report produced for the G20 Presidency of Germany.* Rome: Food and Agriculture Organization of the United Nations.

FAO. (2018). *Water-Energy-Food Nexus for the review of SDG 7. POLICY Br. #9.* FAO. Retrieved from https://sustainabledevelopment.un.org/content/documents/17483PB_9_Draft.pdf

Fasel, M., Bréthaut, C., Rouholahnejad, E., Lacayo-Emery, M. A., & Lehmann, A. (2016). Blue water scarcity in the Black Sea catchment: Identifying key actors in the water-ecosystem-energy-food nexus. *Environmental Science & Policy journal*, 140–150.

Fowe, T., Nouiri, I., Ibrahim, B., Karambiri, H., & Paturel, J. E. (2015). OPTIWAM: An Intelligent Tool for Optimizing Irrigation Water Management in Coupled Reservoir–Groundwater Systems. *Water Resources Management, 29,* 3841–3861. doi:https://doi.org/10.1007/s11269-015-1032-9

Godfray, H. C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., . . . Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5967), 812-818.

Golfam, P., Ashofteh, P.-S., & Loáiciga, H. A. (2019). Evaluation of the VIKOR and FOWA Multi-Criteria Decision Making Methods for Climate-Change Adaptation of Agricultural Water Supply. *Water Resources Management, 33*, 2867–2884. doi:https://doi.org/10.1007/s11269-019-02274-z

Green, S. R., Kirkham, M. B., & Clothier, B. E. (2006). Root uptake and transpiration: From measurements and models to sustainable irrigation. *Agricultural Water Management*, 165-176.

Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy*, 365–377.

Hoff, H. (2011). *Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus.* Stockholm: Stockholm Environment Institute.

Howell, T. A. (2001). Enhancing Water Use Efficiency in Irrigated Agriculture. *Agronomy Journal*, 281-289.

Howell, T. A. (2003). Irrigation Efficiency. *Encyclopedia of Water Science*, 467-472.

Hughes, D., Mantel, S., & Farinosi, F. (2020). Assessing development and climate variability impacts on water resources in the Zambezi River basin: Initial model calibration, uncertainty issues and performance. *Journal of Hydrology: Regional Studies*.

Ibarrola-Rivasa, M. J., Granados-Ramírez, R., & Nonhebel, S. (2017). Is the available cropland and water enough for food demand? A global perspective of the Land-Water-Food Nexus. *Advances in Water Resources*.

IWMI. (2007). *Summary Water for Life Water for Food: A Comprehensive Assessment of Water Management in Agriculture.* International Water Management Institute. London: Earthscan.

Jackson, L. E. (2012). *Adaptation Strategies for Agricultural Sustainability in Yolo County, California.* California Energy Commission.

Jiang, Y., Xu, X., Huang, Q., Huo, Z., & Huang, G. (2016). Optimizing regional irrigation water use by integrating a two-level optimization model and an agro-hydrological model. *Agricultural Water Management*, 76-88.

Joyce, B. A., Mehta, V. K., Purkey, D. R., Dale, L. L., & Hanemann, M. (2011). Modifying agricultural water management to adapt to climate change in California's central valley. *Climatic Change, 109*, 299-316. doi:10.1007/s10584-011-0335-y

Kaddoura, S., & El Khatib, S. (2017). Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. *Environmental Science & Policy, 77*, 114-121. doi:https://doi.org/10.1016/j.envsci.2017.07.007

Kang, S., Hao, X., Du, T., Tong, L., Su, X., Lu, H., . . . Ding, R. (2017). Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. *Agricultural Water Management*, 5-17.

Karabulut, A., Egoh, B. N., Lanzanova, D., Grizzetti, B., Bidoglio, G., Pagliero, L., . . . Mubareka, S. (2016). Mapping water provisioning services to support the ecosystem–water–food–energy nexus in the Danube river basin. *Ecosystem Services*, 278–292.

Karagöz, D. E., & Fidan, H. (2011). Ankara İli Polatlı İlçesinde Sulama Kooperatiflerine Ortak Olan Tarım İşletmelerinin Ekonomik Analizi*. *Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 1*(4), 83–90.

Karamouz, M., Ahmadi, B., & Zahmatkesh, Z. (2013). Developing an Agricultural Planning Model in a Watershed Considering Climate Change Impacts. *Journal of Water Resources Planning and Management, 139*(4), 349-363. doi:10.1061/(ASCE)WR.1943-5452.0000263

Kassam, A., Friedrich, T., & Derpsch, R. (2010). Conservation Agriculture in the 21st Century: A Paradigm of Sustainable Agriculture. *European Congress on Conservation Agriculture.* Madrid.

Kebebe, E. G., Oosting, S. J., Haileslassie, A., Duncan, A. J., & de Boer, I. J. (2014). Strategies for improving water use efficiency of livestock production in rain-fed systems. *Animal*, 908-916.

Leck, H., Conway, D., Bradshaw, M., & Rees, J. (2015). Tracing the Water–Energy–Food Nexus: Description, Theory and Practice. *Geography Compass, 9*(8), 445-460.

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., & Scardigno, A. (2014). Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Agricultural Water Management*, 84-94.

Linke, P. (2014). On the development of strategies for water and energy management in the context of the water- energy-food nexus. *Proceedings of the 8th International Conference on Foundations of Computer-Aided Process Design* (pp. 196-201). Washington: Elsevier B.V.

Mailhol, J. C., Zairi, A., Slatni, A., Ben Nouma, B., & El Amani, H. (2004). Analysis of irrigation systems and irrigation strategies for durum wheat in Tunisia. *Agricultural Water Management*, 19-37.

McNeill, K., Macdonald, K., Singh, A., & Binns, A. D. (2017). Food and water security: Analysis of integrated modeling platforms. *Agricultural Water Management*, 100-112.

Mehta, V. K., Haden, V. R., Joyce, B. A., Purkey, D. R., & Jackson, L. E. (2013). Irrigation demand and supply, given projections of climate and land-use change, in Yolo County, California. *Agricultural Water Management, 117*, 70-82. doi:http://dx.doi.org/10.1016/j.agwat

Meneses, Y. E., Stratton, J., & Flores, R. A. (2017). Water reconditioning and reuse in the food processing industry: Current situation and challenges. *Trends in Food Science & Technology*, 72-79.

Merdun, H. (2004). Comparison of irrigation performance based on the basin, crop pattern, and scheme sizes using external indicators. *Turkish Journal of Agriculture and Forestry, 28*(5), 321–331.

Ministry of Agriculture and Forestry. (1997). *Best Management Guidelines for Sustainable Irrigated Agriculture.* Wellington.

Mishra, B. K., Regmi, R. K., Masago, Y., Fukushi, K., Kumar, P., & Saraswat, C. (2017). Assessment of Bagmati river pollution in Kathmandu Valley: Scenario-based modeling and analysis for sustainable urban development. *Sustainability of Water Quality and Ecology, 9*(10), 67-77. doi:http://dx.doi.org/10.1016/j.swaqe.2017.06.001

Mulligan, M., Fisher, M., Sharma, B., Xu, Z. X., Ringler, C., Mahé, G., . . . Ahmad, M.-u.-D. (2011). The nature and impact of climate change in the Challenge Program on Water and Food (CPWF) basins. *Water International, 36*(1), 96-124. doi:10.1080/02508060.2011.543408

Nalbantis, I., & Tsakiris, G. (2009). Assessment of Hydrological Drought Revisited. *Water Resour Manage*, 881-897.

Oweis, T. (1997). *Supplemental irrigation: a highly water-efficient practice.* Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Owusu-Sekyere, E., Jordaan, H., & Chouchane, H. (2017). Evaluation of water footprint and economic water productivities of dairy products of South Africa. *Ecological Indicators,* 32-40.

Pedersen, S. M., & Lind, K. M. (2017). *Precision Agriculture: Technology and Economic Perspectives.* Cham, Switzerland: Springer International Publishing AG 2017.

Pereira, L. S., Oweis, T., & Abdelaziz, Z. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, 175-206.

Phocaides, A. (2007). *Handbook on Pressurized Irrigation Techniques.* Rome: Food and Agriculture Organization of the United Nations.

Postel, S. L. (1998). Water for Food Production : Will There Be Enough in 2025 ? Boosting the water productivity of world agriculture will be crucial to meeting future food needs. *BioScience*, 629-637.

Purkey, D. R., Joyce, B., Vicuna, S., Hanemann, M. W., Dale, L. L., Yates, D., & Dracup, J. A. (2008). Robust analysis of future climate change impacts on water for agriculture and other sectors: a case study in the Sacramento Valley. *Climatic Change, 87*, 109-122. doi:10.1007/s10584-007-9375-8

Qadir, M., Sharma, B. R., Bruggeman, A., Choukr-Allah, R., & Karajeh, F. (2007). Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agricultural Water Management*, 2-22.

Rai, R. K., Singh, V. P., & Alka, U. (2017). Chapter 10 - Irrigation Methods. In *Planning and Evaluation of Irrigation Projects: Methods and Implementation* (pp. 353-363). Academic Press. doi:https://doi.org/10.1016/B978-0-12-811748-4.00010-8

Ran, Y., van Middelaar, C. E., Lannerstad, M., Herrero, M., & de Boer, I. J. (2017). Freshwater use in livestock production—To be used for food crops or livestock feed? *Agricultural Systems*, 1-8.

Robinson, T., Thornton, P., Franceschini, G., Kruska, R., Chiozza, F., Notenbaert, A., . . . See, L. (2011). *Global livestock production systems.* Rome: Food and Agriculture Organization of the United Nations (FAO) and International Livestock Research Institute.

Rojas-Downing, M. M., Nejadhashemi, P. A., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 145-163.

Ronco, P., Zennaro, F., Torresan, S., Critto, A., Santini, M., Trabucco, A., & Zollo, A. L. (2017). A risk assessment framework for irrigated agriculture under climate change. *Advances in Water Resources*, 1-17.

Salim, Y., Cuceloglu, G., & Ekdal, A. (2019). Estimation of Water Budget Components of the Sakarya River Basin by Using the WEAP-PGM Model. *Water, 11*(271). doi:10.3390/w11020271

Salomón-Sirolesi, M., & Farinós-Dasí, J. (2019). A New Water Governance Model Aimed at Supply–Demand Management for Irrigation and Land Development in the Mendoza River Basin, Argentina. *Water, 11*(3). doi:https://doi.org/10.3390/w11030463

Sampath, D. S., Weerakoon, S. B., Mishra, B., & Herath, S. (2014). Assessments ofIrrigation Water Requirement from DeduruOyaLeft Bank Canal to SupplementDeduruOya Left Bank Irrigation Demand. *ENGINEER*, 17-32.

Sanders, K. T., & Masri, S. F. (2015). The energy-water agriculture nexus: The past, present and future of holistic resource management via remote sensing technologies. *Journal of Cleaner Production*, 73-88.

Santikayasa, I. P. (2016). Development of an Integrated Agricultural Planning Model Considering Climate Change. *IOP Conf. Series: Earth and Environmental Science, 31*. doi:10.1088/1755-1315/31/1/012042

Savva, A. P., & Frenken, K. (2002). *Irrigation Manual. Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation.* Harare: Food and Agriculture Organization of the United Nations.

Schultz, B., & Uhlenbrook, S. (2008). Water security: What does it mean, what may it imply? doi:10.1201/9780203878057.pt2

Sezen, S. M. (2012, Ekim 11). *Sulama.* Retrieved from Mustafa Kemal Üniversitesi: http://www.mku.edu.tr/files/898-ce39185a-b293-4530-92ed-488764d07ca4.pdf

Siciliano, G., Rulli, M. C., & D'Odorico, P. (2017). European large-scale farmland investments and the land-water-energy-food nexus. *Advances in Water Resources* , 1-12.

Sieber, J., & Purkey, D. (2015). *Water Evaluation And Planning System; User Guide.* Stockholm Environment Institute. Retrieved from https://www.weap21.org/downloads/WEAP_User_Guide.pdf

Skoulikaris, C., Ganoulis, J., Tolika, K., Anagnostopoulou, C., & Velikou, K. (2017). Assessment of agriculture reclamation projects with the use of regional climate models. *Water Utility Journal*, *16*, 7-16.

Slaughter, A. S., Mantel, S. K., & Hughes, D. A. (2016). Water quality management in the context of future climate and development changes: a South African case study. *Journal of Water and Climate Change, 7*(4), 775-787.

Smidt, S. J., Haacker, E. M., Kendall, A. D., Deines , J. M., Pei, L., Cotterman, K. A., . . . Hyndman, D. W. (2016). Complexwater management in modern agriculture: Trends in the water-energy-food nexus over the High Plains Aquifer. *Science of the Total Environment*, 988–1001.

Sridharan, V., Ramos, E. P., Zepeda, E., Boehlert, B., Shivakumar, A., Taliotis, C., & Howells, M. (2019). The Impact of Climate Change on Crop Production in Uganda—An Integrated Systems Assessment with Water and Energy Implications. *Water*, *11*. doi:10.3390/w11091805

Strzepek, K., & Boehlert, B. (2010). Competition for water for the food system. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 2927-2940.

Süheri, S., Topak, R., & Yavuz, D. (2007). Farklı Sulama Programlarının Şeker Pancarı Verimine Ve Su Kullanım Randımanına Etkisi. *Selçuk Üniversitesi Ziraat Fakültesi Dergisi, 21*(43), 37-45.

Sutton, W. R., Srivastava, J. P., & Neumann, J. E. (2013). *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia. Directions in Development.* Washington: World Bank. doi:10.1596/978-0-8213-9768-8

Taban, S., Özcan, H., & Koç, Ö. (2000). Orta Anadolu'da Çeltik Tarımı Yapılan Toprakların Potasyum Durumu ve Adsorpsiyonu. *Tarım Bilimleri Dergisi, 6*(3), 62–67.

TAGEM, & DSİ. (2017). *Türkiye'de Sulanan Bitkilerin Bitki Su Tüketim Rehberi.* Ankara.

TurkStat. (2019). *Merkezi Dağıtım Sistemi Bitkisel Üretim İstatistikleri*. Retrieved from Türkiye İstatistik Kurumu Veritabanları: https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr

U.S. Geological Survey. (2000). FS. 083-00. Retrieved 11 3, 2018, from Earth Explorer: https://earthexplorer.usgs.gov/

United Nations. (2015a). *Transforming our world: the 2030 Agenda for Sustainable Development.* Resolution. Retrieved from https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

United Nations. (2015b). *Paris Agreement.* Paris. Retrieved from https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

United Nations. (2020, May). *United Nations Conference on Sustainable Development, Rio+20*. Retrieved from Sustainable Development Goals Knowledge Platform: https://sustainabledevelopment.un.org/rio20

Ünlü, M., Kanber, R., Kapur, B., Koç, D. L., & Tekin, S. (2008). Water Saving in Agricultural Irrigation: Deficit Irrigation Concept. *5. Dünya Su Forumu Bölgesel Hazırlık Süreci. DSİ Yurtiçi Bölgesel Su Toplantilari. Sulama – Drenaj Konferansı Bildiri Kitabı* (pp. 81-95). Adana: State Hydraulic Works.

Uygan, D., & Çetin, Ö. (2004). Bor'un Tarımsal ve Çevresel Etkileri: Seydisuyu Su Toplama Havzası. *II. Uluslararası Bor Sempozyumu.*

Uygan, D., & Çetin, Ö. (2015). Eskişehir ve Sakarya İlleri'nde Kurulu Bazı Damla Sulama Sistemlerinde Performans Göstergelerinin Değerlendirilmesi Damla sulama sistemlerinde performans göstergeleri. *Toprak Su Dergisi*, *4*(1), 27–35.

Uygan, D., Öztürk, N., & Çetin, Ö. (2001). Sulama Sularında Kirlilik ve Önemi": Eskişehir-Seyitgazi-Kırka Yöresinde Bor Kirliliği. *Eskişehir İli'nin Tarımsal Potansiyeli, Sorunları ve Çözüm Yolları (Bitki, Toprak, Su, İklim İlişkileri) - 5. Sempozyum Bildirileri.* Eskişehir. doi:10.13140/2.1.4765.7765

Van den Abeele, L., Smets, T., Derden, A., Huybrechts, D., & Nevens, F. (2017). Feasibility study for the food processing industry in Flanders (Belgium) to become water neutral by 2030. *Journal of Cleaner Production*, 1376-1390.

Vanham, D. (2016). Does the water footprint concept provide relevant information to address the water-food-energy-ecosystem nexus? *Ecosystem Services*, 298-307.

Vanham, D., Mak, T. N., & Gawlik, B. M. (2016). Urban food consumption and associated water resources: The example of Dutch cities. *Science of the Total Environment*, 232–239.

Varis, O., Keskinen, M., & Kummu, M. (2017). Four dimensions of water security with a case of the indirect role of water in global food security. *Water Security*, 36–45.

Vicuña, S., McPhee, J., & Garreaud, R. D. (2012). Agriculture Vulnerability to Climate Change in a Snowmelt-Driven Basin in Semiarid Chile. *Journal of Water Resources Planning and Management, 138*(5), 431-441. doi:10.1061/(ASCE)WR.1943-5452.0000202

Weindl, I., Bodirsky, B. L., Rolinski, S., Biewald, A., Lotze-Campen, H., Müller, C., . . . Popp, A. (2017). Livestock production and the water challenge of future food supply: Implications of agricultural management and dietary choices. *Global Environmental Change*, 121-132.

Winter, J. M., Young, C. A., Mehta, V. K., Ruane, A. C., Azarderakhsh, M., Davitt, A., . . . Rosenzweig, C. (2017). Integrating water supply constraints into irrigated agricultural simulations of California. *Environmental Modelling & Software, 96*, 335-346.

World Bank. (2017). *Lesotho WEAP Manual.* doi:https://doi.org/10.1596/26026

World Economic Forum. (2011). *Global Risks 2011 Sixth Edition An initiative of the Risk Response Network.* Cologny/Geneva.

World Economic Forum. (2011). *Water security : the water-food-energy-climate nexus : the World Economic Forum water initiative.* Washington: Island Press.

WWAP. (2015). *The United Nations World Water Development Report 2015: Water for a Sustainable World.* Paris: UNESCO. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000231823

Xue, J., & Ren, L. (2016). Evaluation of crop water productivity under sprinkler irrigation regime using a distributed agro-hydrological model in an irrigation district of China. *Agricultural Water Management*, 360-365.

Yates, D. N., Miller, K. A., Wilby, R. L., & Kaatz, L. (2015). Decision-centric adaptation appraisal for water management across Colorado's Continental

Divide. *Climate Risk Management, 10,* 35-50. doi:http://dx.doi.org/10.1016/j.crm.2015.06.001

Yu , G., Yang, Y., Tu, Z., Jie, Y., Yu, Q., Hu , X., . . . Wang, H. (2016). Modeling the water-satisfied degree for production of the main food crops in China. *Science of the Total Environment*, 215–225.

Zhang, J., Campana, , P. E., Yao, T., Zhang, Y., Lundblad, A., Melton, F., & Yan, J. (2017). The water-food-energy nexus optimization approach to combat agricultural drought: A case study in the United States. *Applied Energy*, 1-16.

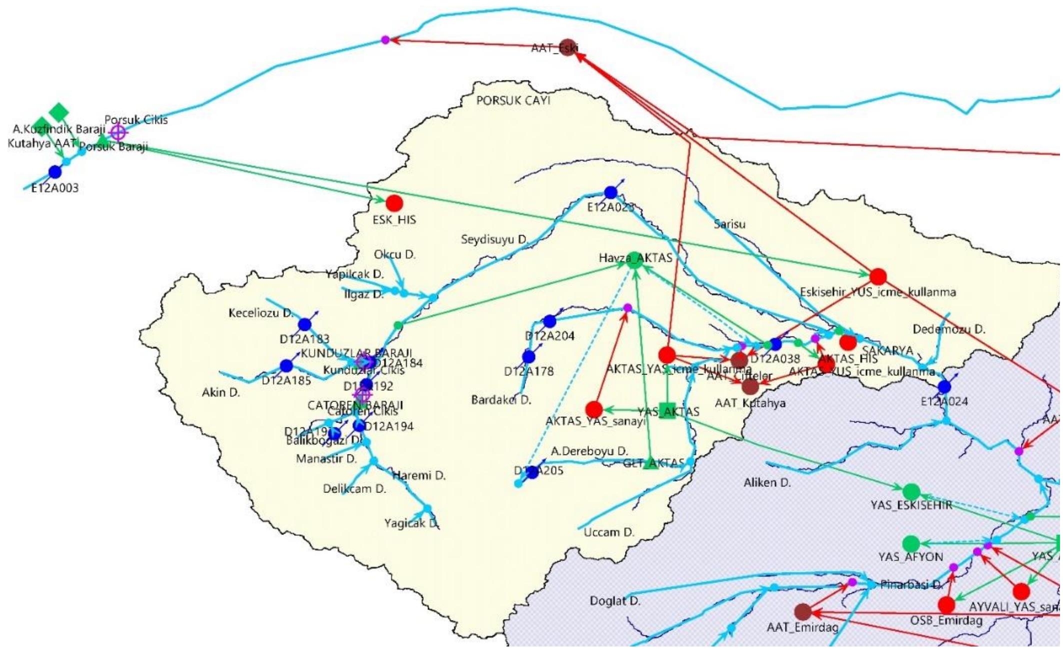
APPENDICES

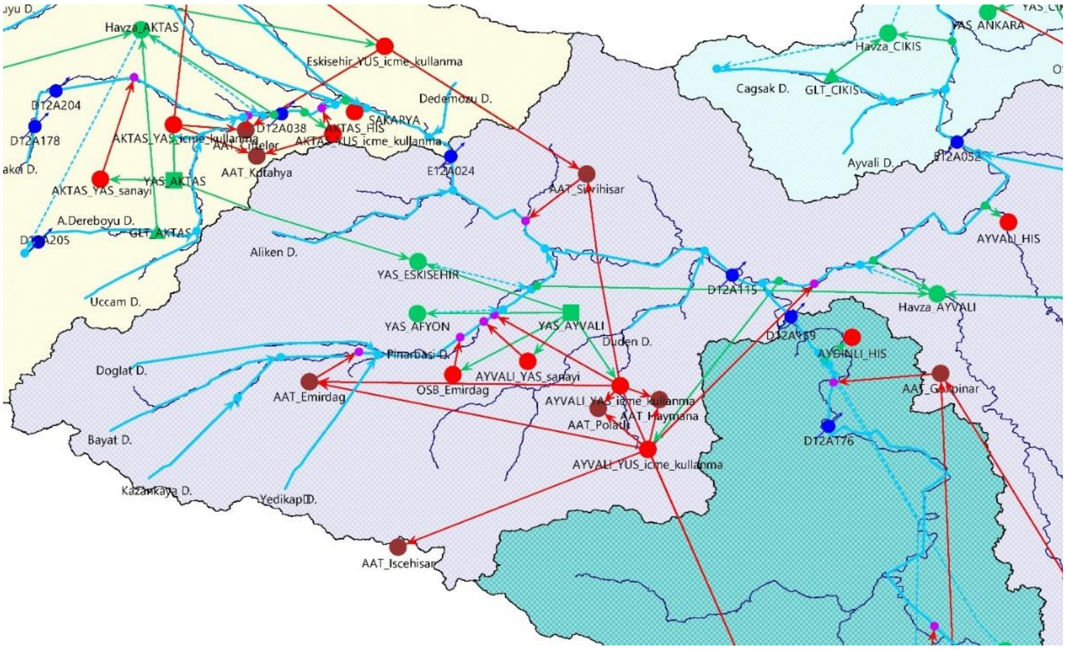
A. Properties of Nexus Methods (Adapted from Dai et al., 2018)

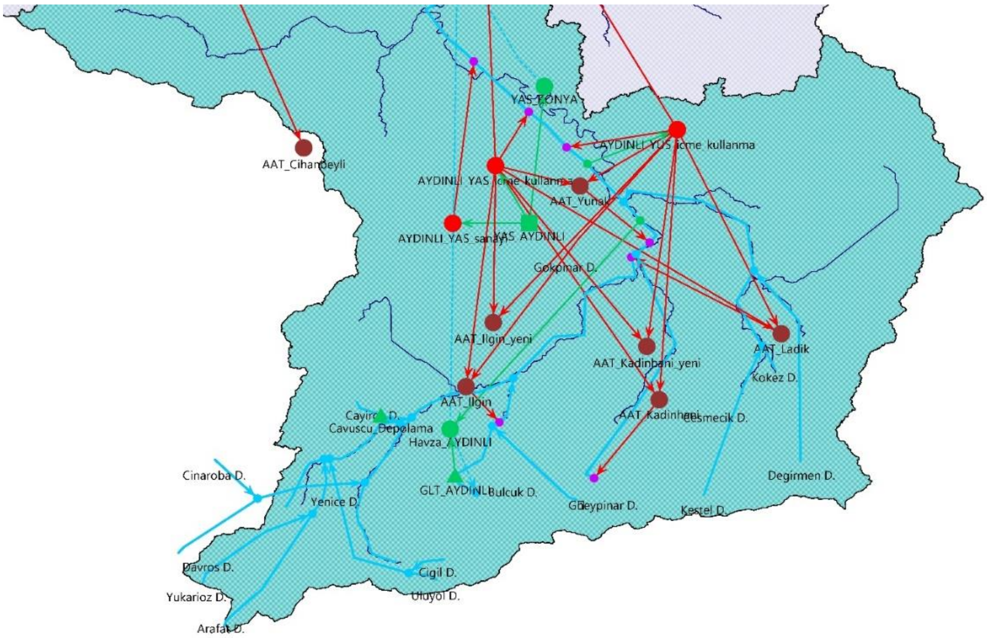
Nexus Scope	Method	Model Type	Scale	Level
Water-Energy	El	Quantitative analysis	City	Understanding
Water-Energy	Jordan's framework	Integrated	National	Governing
Water-Energy	Linkage analysis	Quantitative analysis	City	Understanding
Water-Energy	MRNN	Quantitative analysis	City and regional	Understanding
Water-Energy	System dynamic approach	Integrated	Regional	Understanding
Water-Energy	UWOT	Quantitative analysis	City	Understanding
Water-Energy-Ecosystem	Integrated CGE	Simulation	National	Governing
Water-Energy-Ecosystem	CMDP	Simulation	National	Understanding
Water-Energy-Ecosystem	GLEW	Simulation	Regional	Understanding
Water-Energy-Ecosystem	RRP	Integrated	Multi-scales	Understanding
Water-Energy-Ecosystem	MA	Quantitative analysis	National	Understanding
Water-Energy-Ecosystem	Modified AQAL	Integrated	Regional and national level	Implementing
Water-Energy-Ecosystem	Mixed-unit MRIO	Quantitative analysis	National and transboundary	Understanding
Water-Energy-Ecosystem	REWSS	Quantitative analysis	Regional	Understanding
Water-Energy-Ecosystem	SPATNEX-WE	Integrated	National	Implementing
Water-Energy-Ecosystem	TIAM-FR	Integrated	National and transboundary	Understanding
Water-Energy-Ecosystem	UWtoA	Quantitative analysis	City	Understanding
Water-Energy-Ecosystem	WATER	Quantitative analysis	Multi-scales	Understanding
Water-Energy-Ecosystem	WCCEM	Simulation	National or global	Understanding
Water-Energy-Ecosystem	WEAP-LEAP	Integrated	Multi-scales	Governing
Water-Energy-Ecosystem	WESTWeb	Quantitative analysis	City	Understanding

Nexus Scope	Method	Model Type	Scale	Level
Water-Energy-Food	DEA	Quantitative analysis	Multi-scales	Understanding
Water-Energy-Food	IAD-NAS	Quantitative analysis	National	Governing
Water-Energy-Food	Nexus Assessment 1.0	Quantitative analysis	Regional and national	Governing
Water-Energy-Food	WEF Nexus Tool 2.0	Simulation	National	Governing
Water-Energy-Food	WEFO	Integrated	Multi-scales	Governing
Water-Energy-Food	ZeroNet DSS	Integrated	Regional	Governing
Water-Energy-Food-Ecosystem	MuSIASEM	Integrated	National and regional	Governing
Water-Energy-Food-Ecosystem	Modified SWAT	Integrated	Transboundary	Understanding
Water-Energy-Food-Ecosystem	MSA	Quantitative analysis	City	Understanding
Water-Energy-Food-Ecosystem	TRBNA	Integrated	Transboundary	Implementing
Water-Energy-Land Use-Climate	CLEWS	Integrated	Multi-scales	Implementing
Water-Energy-Land Use-Climate	Foreseer	Integrated	National and transboundary	Understanding
Water-Energy-Land Use-Climate	GCAM-USA	Integrated	Regional	Governing
Water-Energy-Land Use-Climate	PRIMA	Integrated	Regional and national level	Implementing

B. Schematic View of WEAP Model Application of Upper Sakarya



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AAT_Kadinhani_yeni
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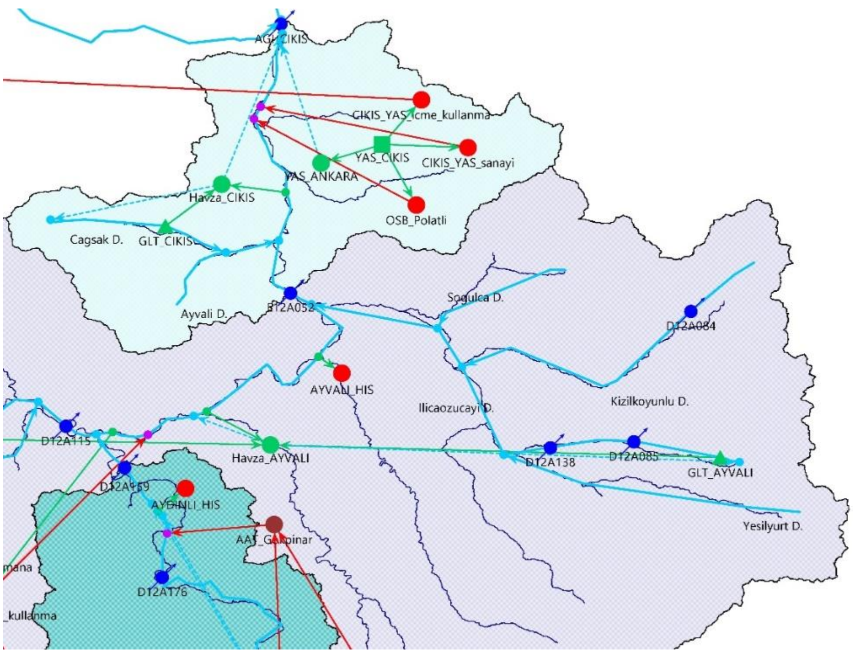
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GLT_CIKIS
Ayvali D.
DT2A052
Sogulca D.
DT2A084
AYVALI_HIS
Ilicaozucayi D.
Kizilkoyunlu D.
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Havza_AYVALI
DT2A138
DT2A085
GLT_AYVALI
Yesilyurt D.
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C. Data Requirement for Catchment Simulation Methods (Adapted from Sieber & Purkey, 2015)

Method	Section	Input	Description
Simplified Coefficient Method	Land Use	Area	Land area
Simplified Coefficient Method	Land Use	Kc	Crop coefficient relative to the reference crop
Simplified Coefficient Method	Land Use	Effective Precipitation	% of precipitation available for evapotranspiration
Simplified Coefficient Method	Climate	Precipitation	Monthly total precipitation amount
Simplified Coefficient Method	Climate	Etref	The monthly reference evapotranspiration
Simplified Coefficient Method	Irrigation	Irrigated	Binary digit entry to define either the area is irrigated or not
Simplified Coefficient Method	Irrigation	Irrigation Fraction	% of supplied water available for evapotranspiration
Simplified Coefficient Method	Loss and Reuse	Reuse Rate	% of water reused within demand site, resulting in a decrease in supply requirement
Simplified Coefficient Method	Yield	Potential Yield	Maximum potential yield
Simplified Coefficient Method	Yield	Yield Response Factor	Parameter that defines how the yield changes when actual evapotranspiration is less than potential evapotranspiration
Simplified Coefficient Method	Yield	Market Price	Market price per kilogram of crop
Simplified Coefficient Method	Yield	Planting Date	Month of planting
Simplified Coefficient Method	Yield	Harvest Date	Month of harvest
Soil Moisture Method	Land Use	Area	Land area
Soil Moisture Method	Land Use	Kc	Crop coefficient relative to the reference crop
Soil Moisture Method	Land Use	Soil Water Capacity	Effective water holding capacity of the upper soil layer
Soil Moisture Method	Land Use	Deep Water Capacity	Effective water holding capacity of the lower soil layer
Soil Moisture Method	Land Use	Runoff Resistance Factor	Parameter used to control surface runoff response
Soil Moisture Method	Land Use	Root Zone Conductivity	Root zone conductivity rate at full saturation
Soil Moisture Method	Land Use	Deep Conductivity	Conductivity rate of the deep layer at full saturation
Soil Moisture Method	Land Use	Preferred Flow Direction	Parameter used to partition the flow between interflow and percolation
Soil Moisture Method	Land Use	Initial Z1	Initial value of the water content given as a percentage of the storage at the upper soil layer

Method	Section	Input	Description
Soil Moisture Method	Land Use	Initial Z2	Initial value of the water content given as a percentage of the storage at the lower soil layer
Soil Moisture Method	Climate	Precipitation	Monthly total precipitation amount
Soil Moisture Method	Climate	Temperature	The weighted mean of high and low temperature monthly
Soil Moisture Method	Climate	Humidity	The average monthly relative humidity.
Soil Moisture Method	Climate	Wind	The average monthly wind speed.
Soil Moisture Method	Climate	Cloudiness Fraction	Fraction of daytime hours with no clouds (0.0=completely overcast, 1.0=no clouds)
Soil Moisture Method	Climate	Latitude	The latitude in degrees.
Soil Moisture Method	Climate	Freezing Point	Solid water threshold for snow accumulation
Soil Moisture Method	Climate	Melting Point	Liquid water threshold for snowmelt
Soil Moisture Method	Climate	Albedo Lower Bound	Lower threshold ratio used in the calculation of albedo
Soil Moisture Method	Climate	Albedo Upper Bound	Upper threshold ratio used in the calculation of albedo
Soil Moisture Method	Climate	Albedo	Parameter used to set value and override default calculation for albedo
Soil Moisture Method	Climate	Initial Snow	The initial value for snow accumulation at the beginning of the first month of the simulation
Soil Moisture Method	Climate	Snow Accumulation Gauge	Historical data of snow accumulation (snowpack), to be used in calibration
Soil Moisture Method	Irrigation	Irrigated Area	Definition of the area as either irrigated or not
Soil Moisture Method	Irrigation	Lower Threshold	Soil moisture lower bound below which the irrigation starts
Soil Moisture Method	Irrigation	Upper Threshold	Soil moisture upper bound at which the irrigation stops
Soil Moisture Method	Irrigation	Irrigation Use of Runoff	% of catchment's runoff can be used for irrigation internally
Soil Moisture Method	Flooding	Minimum Depth	Minimum required depth of above-ground storage
Soil Moisture Method	Flooding	Maximum Depth	Maximum depth of above-ground storage
Soil Moisture Method	Flooding	Target Depth	Target depth of above-ground storage
Soil Moisture Method	Flooding	Release Requirement	Amount of water released to be replaced with new supply
Soil Moisture Method	Flooding	Fraction Flooding Received	Share of flood flow to be partitioned within the land uses of the catchment
Soil Moisture Method	Flooding	Flood Return Fraction	% of water above Maximum Depth that flows out
Soil Moisture Method	Flooding	Volume Area Elevation Curve	Relationship of volume to surface area and elevation
Soil Moisture Method	Flooding	Initial Surface Depth	Initial value for surface depth
Soil Moisture Method	Yield	Potential Yield	Maximum potential yield

Method	Section	Input	Description
Soil Moisture Method	Yield	Yield Response Factor	Parameter that defines how the yield changes when actual evapotranspiration is less than potential evapotranspiration
Soil Moisture Method	Yield	Market Price	Market price per kilogram of crop
Soil Moisture Method	Yield	Planting Date	Month of planting
Soil Moisture Method	Yield	Harvest Date	Month of harvest
MABIA Method	Land Use	Area	Land area
MABIA Method	Land Use	Crops	Definition of crop type and planting date
MABIA Method	Land Use	Surface Layer Thickness	Depth of surface layer subject to drying by evaporation
MABIA Method	Land Use	Total Soil Thickness	Combined depth of the first two buckets
MABIA Method	Land Use	Soil Water Capacity	Available water capacity as a % of the volume
MABIA Method	Land Use	Maximum Infiltration Rate	Water amount that can infiltrate into the soil over one day
MABIA Method	Land Use	Maximum Percolation Rate	Water amount that can percolate from soil to groundwater over one day
MABIA Method	Land Use	Effective Precipitation	% of precipitation available for evapotranspiration
MABIA Method	Land Use	Fraction Covered	Effective fraction of soil surface covered by vegetation
MABIA Method	Land Use	Direct Recharge to GW	% of precipitation not available for evapotranspiration and goes to groundwater
MABIA Method	Land Use	Initial Bucket 1 Depletion	Initial value of soil moisture depletion for the top bucket
MABIA Method	Land Use	Initial Bucket 1 Depletion	Initial value of soil moisture depletion for the bottom bucket
MABIA Method	Climate	Precipitation	Daily total precipitation amount
MABIA Method	Climate	ETref	Evapotranspiration from the reference surface, the so-called reference crop evapotranspiration or reference evapotranspiration, denoted as ET_0
MABIA Method	Climate	Min. Temperature	Minimum daily temperature
MABIA Method	Climate	Max. Temperature	Maximum daily temperature
MABIA Method	Climate	Latitude	Latitude of the climate station
MABIA Method	Climate	Altitude	Altitude of the climate station
MABIA Method	Climate	Min. Humidity	Minimum daily relative humidity
MABIA Method	Climate	Max. Humidity	Maximum daily relative humidity
MABIA Method	Climate	Average Humidity	Average daily relative humidity
MABIA Method	Climate	Wind	Average daily wind speed

Method	Section	Input	Description
MABIA Method	Climate	Wind speed measurement height	For the calculation of evapotranspiration, wind speed measured at 2 m above the surface is required
MABIA Method	Climate	Solar Radiation	Daily solar radiation
MABIA Method	Climate	Sunshine Hours	Actual number of daytime hours with no clouds
MABIA Method	Climate	Cloudiness Fraction	Fraction of daytime hours with no clouds (0.0=completely overcast, 1.0=no clouds)
MABIA Method	Climate	Krs	Adjustment coefficient for Hargreaves radiation formula
MABIA Method	Irrigation	Irrigation Schedule	Definition of irrigation methods and schedule
MABIA Method	Irrigation	Fraction Wetted	Fraction of soil surface wetted by the irrigation system
MABIA Method	Irrigation	Irrigation Efficiency	% of supplied water available for evapotranspiration
MABIA Method	Irrigation	Loss to Groundwater	% of supplied water that infiltrates to groundwater
MABIA Method	Irrigation	Loss to Runoff	% of supplied water that runs off to surface water
MABIA Method	Irrigation	Irrigation Use of Runoff	% of catchment's runoff can be used for irrigation internally
MABIA Method	Flooding	Minimum Depth	Minimum required depth of above-ground storage
MABIA Method	Flooding	Maximum Depth	Maximum depth of above-ground storage
MABIA Method	Flooding	Target Depth	Target depth of above-ground storage
MABIA Method	Flooding	Release Requirement	Amount of water released to be replaced with new supply
MABIA Method	Flooding	Initial Surface Depth	Initial value for surface depth
MABIA Method	Yield	Potential Yield	Maximum potential yield
MABIA Method	Yield	Market Price	Market price per kilogram of crop
Plant Growth Model	Land Use	Area	Land area
Plant Growth Model	Land Use	Crops	Definition of crop type, planting, and harvest dates
Plant Growth Model	Land Use	Surface Layer Thickness	Depth of surface layer subject to drying by evaporation
Plant Growth Model	Land Use	Soil Layers	Definition of the number and thickness of the soil layers
Plant Growth Model	Land Use	Soil Water Capacity	Available water capacity as a % of the volume
Plant Growth Model	Land Use	Soil Albedo	Parameter used in the calculation of average surface albedo
Plant Growth Model	Land Use	Soil Moisture Limit for Evaporation	Soil moisture limit to which soil dries, as a fraction of wilting point
Plant Growth Model	Land Use	Saturated Hydraulic Conductivity	Measure of soil's ability to transmit water when subjected to the hydraulic gradient
Plant Growth Model	Land Use	Plant Update Compensation Factor	Factor that enables deeper root zone layers to meet transpiration demand if upper layers are too dry

Method	Section	Input	Description
Plant Growth Model	Land Use	Initial Soil Water Content	Initial value of the soil moisture content
Plant Growth Model	Land Use	Depth to Groundwater	Parameter used to estimate the contribution of a shallow water table to crop transpiration and bare soil evaporation
Plant Growth Model	Climate	Precipitation	Daily precipitation amount
Plant Growth Model	Climate	Min Temperature	Minimum daily temperature
Plant Growth Model	Climate	Max Temperature	Maximum daily temperature
Plant Growth Model	Climate	Latitude	Latitude in decimal degrees
Plant Growth Model	Climate	Altitude	Altitude of the climate station
Plant Growth Model	Climate	Dew Point	Dew point temperature
Plant Growth Model	Climate	Min Humidity	Minimum daily relative humidity
Plant Growth Model	Climate	Max Humidity	Maximum daily relative humidity
Plant Growth Model	Climate	Wind	Average daily wind speed
Plant Growth Model	Climate	Solar Radiation	Daily solar radiation
Plant Growth Model	Climate	CO2	Atmospheric concentration of carbon dioxide
Plant Growth Model	Irrigation	Irrigation Schedule	Definition of irrigation methods and schedule
Plant Growth Model	Irrigation	Distribution Uniformity	Measure of application uniformity of irrigation
Plant Growth Model	Irrigation	Irrigation Rate	Measure of application rate of irrigation
Plant Growth Model	Irrigation	Irrigation Use of Runoff	% of catchment's runoff can be used for irrigation internally

D. Data Requirement for Supply & Resources (Adapted from Sieber & Purkey, 2015)

Supply & Resources Component	Section	Input	Description
River	Inflows and Outflows	Head flow	Average monthly inflow at the head of the river
River	Inflows and Outflows	Maximum Diversion	Maximum monthly diversion due to physical or other constraints
River	Inflows and Outflows	Fraction Diverted	% fraction of flow diverted from the main river
Reaches	Inflows and Outflows	Surface Water Inflow	Monthly surface water inflow to reach
Reaches	Inflows and Outflows	Groundwater Inflow	Monthly groundwater inflow to reach
Reaches	Inflows and Outflows	Groundwater Outflow	Monthly outflow to groundwater (as % of river flow)
Reaches	Inflows and Outflows	Evaporation	Monthly evaporation (as % of river flow)
Reaches	Inflows and Outflows	River Flooding Threshold	River flow rate at which flooding starts
Reaches	Inflows and Outflows	River Flooding Fraction	River flooding threshold that goes to catchment (as % of river flow above)
Reaches	Inflows and Outflows	Reach Length	Horizontal length of the interface between reach and linked groundwater
Reaches	Physical	Distance Marker	Distance marker for top of each reach
Reaches	Physical	Flow Stage Width	River stage and width to flow
Reservoirs	Physical	Storage Capacity	Total storage capacity of the reservoir
Reservoirs	Physical	Initial Storage	Initial amount of water stored in the reservoir
Reservoirs	Physical	Volume Elevation Curve	The relationship between reservoir volume and elevation
Reservoirs	Physical	Net Evaporation	Evaporation excluding the precipitation on the reservoir surface
Reservoirs	Physical	Maximum Hydraulic Outflow	Maximum reservoir outflow due to hydraulic constraints
Reservoirs	Physical	Loss to Groundwater	Seepage from the reservoir to groundwater
Reservoirs	Physical	Observed Volume	Monthly measured reservoir storage data
Reservoirs	Operation	Top of Conservation	Maximum volume of water in the reservoir
Reservoirs	Operation	Top of Buffer	Volume below which releases are constrained
Reservoirs	Operation	Top of Inactive	Volume in the reservoir not available for allocation
Reservoirs	Operation	Buffer Coefficient	Fraction of water in buffer zone available each month for the release
Reservoirs	Hydropower	Max. Turbine Flow	Maximum turbine flow up to which hydropower is generated
Reservoirs	Hydropower	Tailwater Elevation	Reservoir elevation excluding the working water head on the turbine is the tailwater elevation
Reservoirs	Hydropower	Plant Factor	% of each month that hydropower plant is working

Supply & Resources Component	Section	Input	Description
Reservoirs	Hydropower	Generating Efficiency	Electricity generated divided by hydropower input
Reservoirs	Hydropower	Hydropower Priority	Supply priority at which Energy Demand will be satisfied
Reservoirs	Hydropower	Energy Demand	Target monthly hydropower production needs
Reservoirs	Priority	Priority	Priority of filling reservoir for supply (relative to other demands)
Reservoirs	Priority	Buffer Priority	Optional priority for filling buffer-zone of the reservoir for supply (relative to other demands)
Run of River Hydro	Hydropower	Max Turbine Flow	Maximum turbine flow up to which hydropower is generated
Run of River Hydro	Hydropower	Plant Factor	% of each month that hydropower plant is working
Run of River Hydro	Hydropower	Generating Efficiency	Electricity generated as per hydropower input
Run of River Hydro	Hydropower	Fixed Head	Head difference for hydropower generation
Run of River Hydro	Hydropower	Hydropower Priority	Supply priority at which Energy Demand will be satisfied
Run of River Hydro	Hydropower	Energy Demand	Target monthly hydropower production needs
Flow Requirements	Water Use	Minimum Flow Requirement	Minimum average monthly instream flow needs for environmental or social purposes
Flow Requirements	Water Use	Priority	Priority of flow requirement for supply (relative to other demands)
Streamflow Gauges	Inflows and Outflows	Streamflow Data	Monthly measured streamflow data
Groundwater	Physical	Storage Capacity	Maximum theoretical capacity of the aquifer
Groundwater	Physical	Initial Storage	Initial amount of water stored in the aquifer
Groundwater	Physical	Maximum Withdrawal	Monthly maximum volume available for withdrawal from the aquifer
Groundwater	Physical	Natural Recharge	Monthly inflow to the groundwater source
Groundwater	Physical	Method	Method for determining GW-SW interactions
Local Reservoirs	Physical	Inflow	Monthly inflow to the non-river reservoir
Local Reservoirs	Physical	Storage Capacity	Total storage capacity of the reservoir
Local Reservoirs	Physical	Initial Storage	Initial amount of water stored in the reservoir
Local Reservoirs	Physical	Volume Elevation Curve	The relationship between reservoir volume and elevation
Local Reservoirs	Physical	Net Evaporation	Evaporation excluding the precipitation on the reservoir surface
Local Reservoirs	Physical	Maximum Hydraulic Outflow	Maximum reservoir outflow due to hydraulic constraints
Local Reservoirs	Physical	Loss to Groundwater	Seepage from the reservoir to groundwater
Local Reservoirs	Physical	Observed Volume	Monthly measured reservoir storage data
Local Reservoirs	Operation	Top of Conservation	Maximum volume of water in the reservoir
Local Reservoirs	Operation	Top of Buffer	Volume below which releases are constrained
Local Reservoirs	Operation	Top of Inactive	Volume in the reservoir not available for allocation

Supply & Resources Component	Section	Input	Description
Local Reservoirs	Operation	Buffer Coefficient	Fraction of water in buffer zone available each month for the release
Local Reservoirs	Hydropower	Max. Turbine Flow	Maximum turbine flow up to which hydropower is generated
Local Reservoirs	Hydropower	Tailwater Elevation	Reservoir elevation excluding the working water head on the turbine is the tailwater elevation
Local Reservoirs	Hydropower	Plant Factor	% of each month that hydropower plant is working
Local Reservoirs	Hydropower	Generating Efficiency	Electricity generated divided by hydropower input
Local Reservoirs	Hydropower	Hydropower Priority	Supply priority at which Energy Demand will be satisfied
Local Reservoirs	Hydropower	Energy Demand	Target monthly hydropower production needs
Local Reservoirs	Priority	Priority	Priority of filling reservoir for supply (relative to other demands)
Local Reservoirs	Priority	Buffer Priority	Optional priority for filling buffer-zone of the reservoir for supply (relative to other demands)
Other Supplies	Inflows and Outflows	Inflow	Monthly inflow to local supply or amount generated by local supply
Transmission Links	Linking Rules	Maximum Flow: Volume	Maximum flow as volume, due to physical or other constraints
Transmission Links	Linking Rules	Maximum Flow: Percent of Demand	Maximum flow as % of total demand, due to physical or other constraints
Transmission Links	Linking Rules	Supply Preference	Preference of a demand site for each source of water
Transmission Links	Losses	Loss from System	Losses that disappear from the system due to evaporation and leakage (as % of flow passing through the link)
Transmission Links	Losses	Loss to Groundwater	Losses that flow to specified groundwater due to leakage (as % of flow passing through the link)
Return Flows	Inflows and Outflows	Return Flow Routing	% of the total outflow
Return Flows	Inflows and Outflows	Loss from System	Losses that disappear from the system due to evaporation and leakage (as % of flow passing through the link)
Return Flows	Inflows and Outflows	Loss to Groundwater	Losses that flow to specified groundwater due to leakage (as % of flow passing through the link)
Return Flows	Inflows and Outflows	Gain from Groundwater	Monthly infiltration from groundwater into return flow link

E. List of Irrigation Fields in Upper Sakarya

Irrigation Facilities

Sub-basin	Name	Net Area (hectare)	Gross Area (hectare)	Operation	Resource
Aktaş	Fethiye	73	84	2009	Fethiye Pond
Aktaş	Karaören	124	138	1971	Karaören Pond
Aktaş	Yapıldak	197	218	1993	Yapıldak Pond
Aktaş	Seyitgazi	13000	14518	1987	(Çatören & Kunduzlar Dams)
Aktaş	Çifteler	6200	7170	1969	Eminekin Regulator
Aktaş	Kaymaz	370	420	1978	Kaymaz Dam
Aktaş	Ayvalı-I	71	77	1994	Ayvalı-I Pond
Aktaş	Çatmapınar	708	837	1994	Çatmapınar Pond
Aktaş	Yukarı Söğüt	60	73	1988	Yukarı Söğüt Pond
Aktaş	Aslanbeyli	40	50	1988	Aslanbeyli Pond
Aktaş	Hanköy Kayı	170	200	1985	Hanköy Kayı Pond
Aktaş	Üççam	326	347	2006	Üççam Pond
Aktaş	Sarıcaova	126	144	2015	Sarıcaova Pond
Aydınlı	Deştiğin	150	177	1999	Deştiğin Pond
Aydınlı	Doğanhisar	229	244	1995	Doğanhisar Pond
Aydınlı	Osmancık	186	220	1988	Osmancık Pond
Aydınlı	Mecidiye	463	547	1986	Mecidiye Pond
Aydınlı	Ladik	214	228	1999	Ladik Pond
Aydınlı	Ilgın Ovası (Pumped)	5214	5547	1992	Çavuşçu Reservoir
Aydınlı	Ilgın Atlantı	10230	12092	1970	Çavuşçu Reservoir
Aydınlı	Argıthanı	550	650	2011	Argıthanı Regulator
Aydınlı	Bulcuk	595	595	1995	Bulcuk Dam
Aydınlı	Beykavağı (Kestel)	308	498	2010	Beykavağı Dam
Aydınlı	Yukarıçiğil	117	130	2013	Yukarıçiğil Pond
Aydınlı	Aşağıçiğil	306	306	2007	Aşağıçiğil Pond
Aydınlı	Ayaşlar	237	290	2009	Ayaşlar Dam
Aydınlı	Konakkale	63	75	2014	Konakkale Pond

Sub-basin	Name	Net Area (hectare)	Gross Area (hectare)	Operation	Resource
Aydınlı	Bahçesaray	107	119	2015	Bahçesaray Pond
Aydınlı	Ertuğrul	31	31	2015	Ertuğrul Şehit Mehmet Çolak Pond
Aydınlı	Balkı	145	160	2015	Balkı Pond
Aydınlı	Belekler	103	103	2016	Belekler Pond
Aydınlı	Başköy	397	469	1985	Başköy Pond
Aydınlı	Yazlıca	294	348	1984	Yazlıca Pond
Aydınlı	Yenice	523	618	1993	Yenice Pond
Aydınlı	Çınaroba (Çetme)	124	147	1993	Çınaroba Pond
Aydınlı	Başlamış	60	60	-	Başlamış Pond
Ayvalı	Bayat	184	211	1992	Bayat Pond
Ayvalı	Asarcık	965	1105	2000	Asarcık Pond
Ayvalı	Derbent	179	205	2013	Derbent Dam
Ayvalı	Kemerkaya	379	417	2017	Kemerkaya Dam
Ayvalı	Yedikapı	467	535	2014	Yedikapı Dam
Ayvalı	Çıldırım Regulator	2800	3400	1987	Çıldırım Regulator
Ayvalı	Göktepe Regulator	95	100	2007	Göktepe Regulator
Ayvalı	Soğulca	1110	1110	2011	Soğulca Pond
Ayvalı	Kızılkoyun Pond	83	83	-	Kızılkoyun Pond
Ayvalı & Outlet	Yaralı (Gravity)	2972	3513	1984	Yaralı Regulator
Ayvalı & Outlet	Yaralı (Pumped)	2775	2498	2017	Yaralı Regulator
Outlet	Koçaş	100	117	1990	Koçaş Pond

Irrigation Cooperatives

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Afyon	Emirdağ	Ağılcık	135	303
Afyon	Emirdağ	Alibeyce	80	257
Afyon	Emirdağ	Aşağıpiribeyli 1. Kısım	80	130
Afyon	Emirdağ	Aşağıpiribeyli 2. Kısım		
Afyon	Emirdağ	Aşağıpiribeyli 3. Kısım		
Afyon	Emirdağ	Aydınyaka	80	259
Afyon	Emirdağ	Bademli	70	266
Afyon	Emirdağ	Bağlıca	50	255
Afyon	Emirdağ	Camili	150	212
Afyon	Emirdağ	Çiftlik	310	310
Afyon	Emirdağ	Dağılgan	65	302
Afyon	Emidağ	Davulga	60	218
Afyon	Emirdağ	Ekizce	50	202
Afyon	Emirdağ	Elhan 1. Kısım	115	208
Afyon	Emirdağ	Elhan 2. Kısım	210	210
Afyon	Emridağ	Eskiakören 1. Kısım	330	330
Afyon	Emirdağ	Eskiakören 2. Kısım		
Afyon	Emirdağ	Gömü 1. Kısım	610	610
Afyon	Emirdağ	Gömü 2. Kısım		
Afyon	Emirdağ	Hamzahacılı	90	90
Afyon	Emirdağ	Karaağaç 1. Kısım	255	255
Afyon	Emirdağ	Karaağaç 2. Kısım		
Afyon	Emirdağ	Kılınçlar	70	214
Afyon	Emirdağ	Kurucaköy	125	215
Afyon	Emirdağ	Salihler	150	150
Afyon	Emirdağ	Suvermez	50	290
Afyon	Emirdağ	Tabaklar	35	314
Afyon	Emirdağ	Toklucak	170	194
Afyon	Emirdağ	Türkmenakören 1. Kısım	220	220
Afyon	Emirdağ	Türkmenakören 2. Kısım		
Afyon	Emirdağ	Yeniköy	270	270

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Ankara	Polatlı	Hacıosmanoğlu	187	300
Ankara	Polatlı	Uzunbeyli	262	300
Ankara	Polatlı	Yüzükbaşı	219	300
Eskişehir	Çifteler	Eminekin 1. Kısım	88	208
Eskişehir	Çifteler	Hayriye 1. Kısım	675	686
Eskişehir	Çifteler	Hayriye 2. Kısım		
Eskişehir	Çifteler	Orhaniye 1. Kısım	176	176
Eskişehir	Çifteler	Yıldızören 1. Kısım	307	341
Eskişehir	Günyüzü	Çardaközü 1. Kısım	118	118
Eskişehir	Günyüzü	Gümüşkonak 1. Kısım	312	471
Eskişehir	Günyüzü	Gümüşkonak 2. Kısım		
Eskişehir	Günyüzü	Kayakent 1. Kısım	283	334
Eskişehir	Günyüzü	Kuzören 1. Kısım	62	117
Eskişehir	Günyüzü	Mercan 1. Kısım	34	75
Eskişehir	Mahmudiye	Doğanca 1. Kısım	206	206
Eskişehir	Mahmudiye	Fahriye ve Işıkören 1. Kısım	268	268
Eskişehir	Mahmudiye	Güllüce 1. Kısım	371	375
Eskişehir	Mahmudiye	Güllüce 2. Kısım	88	88
Eskişehir	Mahmudiye	İsmetpaşa 1. Kısım	473	473
Eskişehir	Mahmudiye	Kaymazyayla 1. Kısım	138	138
Eskişehir	Mahmudiye	Kaymazyayla 2. Kısım		
Eskişehir	Mahmudiye	Mesudiye 1. Kısım	203	203
Eskişehir	Mahmudiye	Şerefiye 1. Kısım	210	210
Eskişehir	Mahmudiye	Türkmenmecidiye 1. Kısım	1309	1309
Eskişehir	Mahmudiye	Türkmenmecidiye 2. Kısım		
Eskişehir	Mahmudiye	Yeniköy 1. Kısım	200	200
Eskişehir	Odunpazarı	İmişehir 1. Kısım	256	456
Eskişehir	Odunpazarı	Kalkanlı 1. Kısım	700	700
Eskişehir	Odunpazarı	Karatepe 1. Kısım	212	236
Eskişehir	Odunpazarı	Kıravdan 1. Kısım	102	240
Eskişehir	Odunpazarı	Türkmentokat 1. Kısım	700	700
Eskişehir	Odunpazarı	Türkmentokat 2. Kısım	310	310
Eskişehir	Odunpazarı	Yahnikapan 1. Kısım	310	310

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Eskişehir	Seyitgazi	Akın	181	181
Eskişehir	Seyitgazi	Aslanbeyli 1. Kısım	58	125
Eskişehir	Seyitgazi	Ayvalı 1. Kısım	75	189
Eskişehir	Seyitgazi	Beykışla 1. Kısım	195	195
Eskişehir	Seyitgazi	Büyükdere 1. Kısım	736	736
Eskişehir	Seyitgazi	Değişören 1. Kısım	288	288
Eskişehir	Seyitgazi	Değişören 2. Kısım	81	223
Eskişehir	Seyitgazi	Gümüşbel 1. Kısım	219	219
Eskişehir	Seyitgazi	Kırka 1. Kısım	171	183
Eskişehir	Seyitgazi	Örencik 1. Kısım	79	195
Eskişehir	Seyitgazi	Sarayören 1. Kısım	99	153
Eskişehir	Seyitgazi	Yenikent 1. Kısım	375	375
Eskişehir	Sivrihisar	Aşağı Kepen 1. Kısım	92	210
Eskişehir	Sivrihisar	Aydınlı 1. Kısım	650	650
Eskişehir	Sivrihisar	Aydınlı 2. Kısım	480	480
Eskişehir	Sivrihisar	Bahçecik 1. Kısım	186	200
Eskişehir	Sivrihisar	Ballıhisar 1. Kısım	122	127
Eskişehir	Sivrihisar	Beyyazı 1. Kısım	112	112
Eskişehir	Sivrihisar	Dinek 1. Kısım	175	175
Eskişehir	Sivrihisar	Gerenli 1. Kısım	171	198
Eskişehir	Sivrihisar	Göktepe 1. Kısım	1005	1005
Eskişehir	Sivrihisar	Göktepe 2. Kısım		
Eskişehir	Sivrihisar	Göktepe 3. Kısım		
Eskişehir	Sivrihisar	Hamamkarahisar 1. Kısım	95	175
Eskişehir	Sivrihisar	İstiklalbağı 1. Kısım	50	88
Eskişehir	Sivrihisar	Kadıncık 1. Kısım	108	108
Eskişehir	Sivrihisar	Kaymaz	355	355
Eskişehir	Sivrihisar	Koçaş 1. Kısım	250	266,4
Eskişehir	Sivrihisar	Memik	167	167
Eskişehir	Sivrihisar	Selimiye 1. Kısım	335	335
Eskişehir	Sivrihisar	Sığırcık 1. Kısım	889	889
Eskişehir	Sivrihisar	Sivirhisar Merkez 1. Kısım	133	429
Eskişehir	Sivrihisar	Yaverören 1. Kısım	335	335

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Konya	Çeltik	Çeltik Merkez 1. Kısım	1699	1699
Konya	Çeltik	Çeltik Merkez 2. Kısım		
Konya	Çeltik	Çeltik Merkez 3. Kısım		
Konya	Çeltik	Çeltik Merkez 4. Kısım		
Konya	Çeltik	Doğanyurt 1. Kısım	219	711
Konya	Çeltik	Doğanyurt 2. Kısım		
Konya	Çeltik	Gökpınar 1. Kısım	3300	3300
Konya	Çeltik	Gökpınar 2. Kısım		
Konya	Çeltik	Gökpınar 3. Kısım		
Konya	Çeltik	Gökpınar 4. Kısım		
Konya	Çeltik	Gökpınar 5. Kısım		
Konya	Çeltik	Gökpınar 6. Kısım		
Konya	Çeltik	Kaşören 1. Kısım	1038	1038
Konya	Çeltik	Kaşören 2. Kısım		
Konya	Çeltik	Küçükhasan 1. Kısım	112	276
Konya	Çeltik	Mevlütlü 1. Kısım	325	350
Konya	Çeltik	Torunlar 1. Kısım	450	466
Konya	Doğanhisar	Başköy 1. Kısım	75	240
Konya	Doğanhisar	Doğanhisar Merkez 1. Kısım	175	300
Konya	Doğanhisar	Konakkale 1. Kısım	19	60
Konya	Doğanhisar	Uncular	235	235
Konya	Ilgın	Argıthanı 1. Kısım	310	198
Konya	Ilgın	Argıthanı 2. Kısım		290
Konya	Ilgın	Argıthanı 3. Kısım		276
Konya	Ilgın	Boğazkent 1. Kısım	60	150
Konya	Ilgın	Çavuşçugöl 1. Kısım	700	400
Konya	Ilgın	Çavuşçugöl 2. Kısım		500
Konya	Ilgın	Harmanyazı 1. Kısım	170	170
Konya	Ilgın	Kapaklı 1. Kısım	212	310
Konya	Ilgın	Olukpınar 1. Kısım	75	150
Konya	Ilgın	Orhaniye 1. Kısım	120	150
Konya	Kadınhanı	Afşarlı 1. Kısım	150	200
Konya	Kadınhanı	Afşarlı 2. Kısım		200

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Konya	Kadınhanı	Alabağ (Koşmar) 1. Kısım	150	300
Konya	Kadınhanı	Başkuyu 1. Kısım	1016	1016
Konya	Kadınhanı	Başkuyu 2. Kısım		
Konya	Kadınhanı	Hacımehmetli 1. Kısım	260	1050
Konya	Kadınhanı	Hacımehmetli 2. Kısım		
Konya	Kadınhanı	Kabacalı 1. Kısım	200	200
Konya	Kadınhanı	Kamışlıözü 1. Kısım	250	340,8
Konya	Kadınhanı	Karahisarlı 1. Kısım	230	230
Konya	Kadınhanı	Kolukısa 1. Kısım	444	582
Konya	Kadınhanı	Kolukısa 2. Kısım		
Konya	Kadınhanı	Konurören 1. Kısım	100	550
Konya	Kadınhanı	Meydanlı 1. Kısım	210	339
Konya	Kadınhanı	Saçıkara 1. Kısım	229	370
Konya	Sarayönü	Gözlü 1. Kısım	812	550
Konya	Sarayönü	Gözlü 2. Kısım		532
Konya	Sarayönü	Karatepe 1. Kısım	285	285
Konya	Sarayönü	Karatepe 2. Kısım		
Konya	Sarayönü	Kuyulusebil	570	570
Konya	Sarayönü	Ladik 1. Kısım	209	209
Konya	Sarayönü	Özkent 1. Kısım	250	436
Konya	Sarayönü	Sarayönü	336	336
Konya	Yunak	Başhöyük	490	490
Konya	Yunak	Biçer	108	108
Konya	Yunak	Dümrek	124	124
Konya	Yunak	Eğrikuyu 1. Kısım	160	372
Konya	Yunak	İshakuşağı 1. Kısım	520	420
Konya	Yunak	İshakuşağı 2. Kısım		168
Konya	Yunak	Karayayla 1. Kısım	350	430
Konya	Yunak	Kıllar 1. Kısım	808	1162
Konya	Yunak	Kıllar 2. Kısım		
Konya	Yunak	Kıllar 3. Kısım		
Konya	Yunak	Koçyazı 1. Kısım	87	216
Konya	Yunak	Kuzören 1. Kısım	165	278

Province	District	Name	Net Area (hectare)	Gross Area (hectare)
Konya	Yunak	Saray 1. Kısım	440	440
Konya	Yunak	Turgut 2. Kısım	305	305
Konya	Yunak	Yavaşlı 1. Kısım	100	600
Konya	Yunak	Yığar 1. Kısım	360	360
Konya	Yunak	Yunak Merkez 1. Kısım	355	535
Konya	Yunak	Yunak Merkez 2. Kısım		
Konya	Yunak	Yunak Merkez 4. Kısım		

Public Irrigations

Name	Resource	Area			
		Pumped	***Gravity***	***Bore***	***Total***
No.1 (Çifteler)	Sakarya	30	0	0	30
No.1A (Hamidiye)	Seydi Creek	1106.5	393.5	0	1500
No.2 (Sadıroğlu)	Sakarya	120	0	0	120
No.3 (Ova Deresi- Sincan)	Spring Water	0	0	80	80
No.4 (Aliken)	Başkurt Springs	2000	0	0	2000
No.5 (Aktaş)	Sakarya Stream	788.8	62.9	348.3	1200
No.6 (Buzluca)	Sakarya	197.2	15.7	87.1	300
No.7 (Buzluca yan dere)	Buzluca Stream	59	21	0	80
No.8 (Buzluca karşısı)	Sakarya	88.5	31.5	0	120
No.9 (Paşa Alagöz)	Sakarya	590.1	209.9	0	800
No.10 (Ahiler)	Sakarya	590.1	209.9	0	800
No.11 (Kaldırım)	Tributary	737.7	262.3	0	1000
No.12 (Göktepe)	Tributary	147.5	52.5	0	200
No.13 (Yenidoğan)	Sakarya	150	0	0	150
No.14 (İlyaspaşa Karşısı)	Sakarya	1200	0	0	1200
No.15 (Çakmak)	Sakarya	1600	0	0	1600
No.16 (Torunlar)	Gökpınar Stream	590.1	209.9	0	800
No.17 (Tüfekçioğlu)	Sakarya	737.7	262.3	0	1000
No.18 (Yaralı)	Ilıcaözü Stream	1643.4	131.1	725.5	2500
No.19 (Yaralı 2)	Katrançayı Stream	788.8	62.9	348.3	1200
No.20 (İzler)	Tributary	737.7	262.3	0	1000
No.20/A (Kirazoğlu)	Tributary	295.1	104.9	0	400
No.21 (Karailyas)	Sakarya	3286.7	262.2	1451.1	5000
No.22 (Karacaahmet)	Sakarya	394.4	31.5	174.1	600
No.23 (Gürsöğüt)	Sakarya	1314.7	104.9	580.4	2000
No.24 (Şabanözü)	Alacalıözü Stream	328.7	26.2	145.1	500
No.25 (Tatlıkuyu)	Yarözü Stream	657.3	52.6	290.1	1000

F. Crop Patterns of Upper Sakarya

Crop Patterns in Irrigated Agriculture (Surface Water-Sourced Irrigation Group)

Catchment/ Sub-basin	Crop	Area (hectare)												
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
AKTAS	alfalfa	447.6	515.6	547.5	574.9	534.1	518.6	441.9	483.8	453.6	544.4	493.7	425.3	489.3
AKTAS	maize	623.7	393.1	357.5	334.9	340.0	333.3	378.3	440.6	441.2	435.1	540.8	327.8	774.0
AKTAS	forage maize	278.7	315.3	332.5	347.2	325.3	316.9	275.7	298.2	282.0	330.8	303.5	266.8	301.2
AKTAS	grain	6925.6	9563.1	7110.0	8855.7	7855.0	5801.3	6541.7	4018.6	4588.3	5312.4	6560.5	6760.8	6156.8
AKTAS	horticulture	160.2	185.5	394.0	653.7	801.0	767.5	1509.9	1103.3	773.5	828.5	1174.8	757.4	1167.2
AKTAS	legume	149.5	106.4	140.1	109.3	20.5	107.3	103.8	37.9	280.9	129.6	51.0	263.1	145.5
AKTAS	mixed fruit	0.0	5.0	7.0	0.0	1.0	7.7	1.3	0.9	2.1	0.6	0.7	0.2	0.9
AKTAS	mixed seedling	7.0	5.0	7.0	20.0	23.0	6.6	8.5	8.2	10.0	12.6	10.0	10.6	10.4
AKTAS	mixed vegetable	7.6	11.6	20.0	10.2	12.0	51.9	19.8	12.3	8.2	7.5	6.8	11.1	5.9
AKTAS	off-season	0.0	0.0	0.0	0.0	623.0	0.0	260.5	18.4	726.5	166.0	0.0	0.0	0.0
AKTAS	olive	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AKTAS	onion-garlic	55.3	22.0	58.0	47.1	48.0	42.6	106.2	256.4	189.9	138.3	37.3	122.6	115.4
AKTAS	poplar	14.5	12.4	7.0	2.1	1.0	11.7	13.3	5.9	5.2	10.2	10.2	10.2	12.8
AKTAS	poppy	0.0	0.0	0.0	1.0	22.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
AKTAS	potato	300.9	307.5	563.0	597.1	447.0	413.8	562.3	865.7	612.8	391.0	283.5	593.0	362.5
AKTAS	pumpkin seed	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
AKTAS	sugar beet	1724.9	1954.6	1683.5	1395.2	1470.1	1904.3	1786.7	1892.4	1789.1	1930.0	1505.4	1832.8	1985.6
AKTAS	sunflower	2047.6	1755.2	2460.0	1590.5	2478.0	1745.6	1516.8	1257.4	2270.7	2974.5	1583.0	1584.9	2207.6
AKTAS	vineyard	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
AYDINLI	alfalfa	11.4	16.8	11.4	72.7	56.0	89.4	45.3	41.4	41.9	123.4	96.7	102.6	138.9
AYDINLI	banana	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AYDINLI	maize	2534.5	106.7	186.6	207.2	122.8	76.6	64.7	139.8	315.3	672.5	221.1	380.2	617.1
AYDINLI	forage maize	12.0	17.7	12.1	76.9	59.2	94.7	47.9	43.8	44.3	130.6	102.3	108.6	147.1
AYDINLI	grain	5855.8	6901.4	3992.2	9162.0	7704.3	5072.8	6238.1	2848.6	7160.1	5646.8	4909.8	6043.1	6386.0
AYDINLI	grassland	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	47.6	0.0	0.0	0.0	0.0

Catchment/ Sub-basin	Crop	Area (hectare)												
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
AYDINLI	horticulture	67.3	10.0	0.0	42.3	7.8	7.1	3.9	6.2	0.1	0.0	0.0	0.8	0.0
AYDINLI	legume	60.9	45.0	43.7	61.1	87.4	14.3	18.3	10.5	7.3	57.9	47.6	160.1	92.3
AYDINLI	mixed fruit	26.2	33.5	51.8	28.2	31.4	109.2	374.0	103.8	108.3	111.9	214.7	209.8	178.9
AYDINLI	mixed seedling	0.0	3.4	0.0	7.8	5.5	32.5	22.0	22.0	12.6	58.5	37.0	0.0	0.0
AYDINLI	mixed vegetable	145.2	138.1	99.6	113.7	145.6	147.2	85.0	73.3	85.5	105.5	116.3	137.3	224.4
AYDINLI	off-season	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1000.0	703.5	961.8	645.5	1309.8
AYDINLI	onion-garlic	19.5	15.0	4.0	51.3	12.5	0.0	6.9	11.3	16.9	0.5	1.3	2.0	0.0
AYDINLI	peanut	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.0
AYDINLI	poplar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.2	1.4	1.4
AYDINLI	poppy	51.3	79.0	30.0	15.0	141.6	194.6	409.1	104.0	118.7	392.7	292.0	483.6	393.9
AYDINLI	potato	40.0	21.6	15.0	32.9	41.5	43.8	128.2	147.7	157.9	113.7	74.4	84.8	71.1
AYDINLI	strawberry	5.0	5.0	6.0	7.0	7.0	3.0	32.0	38.0	21.0	28.0	23.8	45.0	81.4
AYDINLI	sugar beet	2357.1	1552.4	1419.7	1222.3	1492.2	1647.3	1502.8	1327.8	1784.2	1880.6	1050.5	1467.1	2411.1
AYDINLI	sunflower	1155.6	200.5	510.4	2139.1	1106.4	2040.7	123.9	1094.9	2760.2	3704.3	360.7	2180.0	3345.2
AYDINLI	vineyard	3.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
AYVALI	alfalfa	875.5	973.5	894.9	965.8	1107.2	1010.4	956.9	980.1	1027.7	1081.1	1081.7	1052.9	1066.4
AYVALI	maize	30.0	76.3	38.9	48.5	121.0	60.7	73.8	100.6	120.0	132.9	120.7	202.5	136.9
AYVALI	forage maize	806.7	827.6	810.8	825.9	856.0	835.4	824.0	829.0	839.1	850.5	850.6	844.5	847.3
AYVALI	grain	6091.2	8576.7	6333.5	9084.7	8706.2	7797.2	8411.5	7709.7	8649.9	8189.5	9305.9	7568.6	8233.4
AYVALI	grassland	100.0	100.0	100.0	155.0	107.0	117.0	120.0	120.0	35.0	20.0	45.0	90.0	90.0
AYVALI	horticulture	479.4	839.4	482.4	949.4	1185.4	776.0	763.5	833.9	643.2	592.0	645.8	634.5	641.5
AYVALI	legume	0.0	32.0	0.0	38.0	41.0	47.7	31.3	37.9	32.0	32.1	40.0	0.0	21.0
AYVALI	mixed fruit	13.0	46.8	64.5	61.0	1.0	47.0	72.0	10.0	71.4	75.7	28.1	37.9	80.8
AYVALI	mixed seedling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	0.0	0.0	0.0	0.0	0.0
AYVALI	mixed vegetable	5.0	33.0	17.9	20.9	43.0	57.4	49.0	21.6	43.0	34.2	59.5	112.8	112.1
AYVALI	off-season	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.2	2.4	0.0
AYVALI	onion-garlic	923.1	1009.1	923.1	1186.1	1265.1	1178.5	1278.8	1474.5	1192.4	1202.0	1138.7	1244.5	1323.3
AYVALI	poplar	0.0	6.3	0.0	2.9	61.0	2.7	4.5	42.8	1.5	2.1	55.2	28.9	42.3
AYVALI	poppy	699.5	801.5	693.5	973.5	819.5	1074.8	1338.1	1016.3	707.1	835.1	756.0	984.6	785.5
AYVALI	potato	1.0	0.8	9.4	27.6	19.0	12.0	43.0	86.3	125.0	39.8	52.2	202.8	96.7
AYVALI	pumpkin seed	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3	609.3
AYVALI	sugar beet	5127.2	5680.3	4927.8	5427.8	5781.2	5753.7	5682.0	5606.4	5723.5	5789.3	5798.8	5642.2	5806.7

Catchment/ Sub-basin	Crop	Area (hectare)												
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
AYVALI	sunflower	495.8	565.8	538.3	584.0	575.8	514.3	569.5	519.7	506.9	523.1	541.0	513.5	523.9
AYVALI	vineyard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
OUTLET	alfalfa	3.6	3.6	4.3	4.3	4.3	5.0	6.4	3.6	6.8	3.6	3.6	5.0	5.0
OUTLET	maize	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	2.5	0.0	2.5	3.0	3.0
OUTLET	forage maize	36.9	36.9	37.2	37.2	37.2	37.5	38.1	36.9	38.2	36.9	36.9	37.5	37.5
OUTLET	grain	2063.4	2058.4	2058.4	2058.4	2058.4	2058.4	2073.5	2058.4	2058.4	2058.4	2058.4	2058.4	2058.4
OUTLET	horticulture	425.8	425.8	425.8	425.8	425.8	425.8	425.8	425.8	425.8	425.8	428.3	425.8	425.8
OUTLET	legume	0.0	0.0	0.0	0.0	0.0	3.0	4.0	5.0	3.5	0.0	2.1	20.0	20.0
OUTLET	mixed seedling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	3.0	3.0
OUTLET	mixed vegetable	5.0	10.0	8.0	8.0	3.0	3.0	0.0	2.0	4.5	10.0	2.5	0.0	0.0
OUTLET	onion-garlic	425.8	425.8	425.8	425.8	425.8	425.8	425.8	432.8	425.8	425.8	430.8	425.8	425.8
OUTLET	poppy	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
OUTLET	pumpkin seed	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3	248.3
OUTLET	sugar beet	1070.7	1064.7	1067.7	1067.7	1064.7	1066.2	1064.7	1064.7	1064.7	1064.7	1064.7	1064.7	1064.7

Crop Patterns in Irrigated Agriculture (Groundwater-Sourced Irrigation Group)

Catchment/ Province	Crop	Area (hectare) 2004-2016
AFYON	alfalfa	346.6
AFYON	chickpea	383.0
AFYON	maize	75.5
AFYON	forage maize	70.5
AFYON	fallow	448.9
AFYON	grain	517.1
AFYON	grain k.	1242.8
AFYON	mixed fruit	60.5
AFYON	mixed vegetable	27.6
AFYON	potato	77.0
AFYON	sugar beet	580.6
ANKARA	maize	100.1
ANKARA	forage maize	21.8
ANKARA	grain	1322.1
ANKARA	horticulture	349.7
ANKARA	mixed vegetable	166.9
ANKARA	onion	296.1
ANKARA	pumpkin seed	223.5
ANKARA	sugar beet	1040.5
ANKARA	sunflower	107.4
ESKİŞEHİR	alfalfa	1472.6
ESKİŞEHİR	maize	964.6
ESKİŞEHİR	forage maize	1382.2
ESKİŞEHİR	grain	3705.9
ESKİŞEHİR	horticulture	708.5
ESKİŞEHİR	mixed fruit	417.4
ESKİŞEHİR	mixed vegetable	1017.8
ESKİŞEHİR	onion	740.8
ESKİŞEHİR	potato	634.7
ESKİŞEHİR	pumpkin seed	33.4
ESKİŞEHİR	sugar beet	4340.9
ESKİŞEHİR	sunflower	1474.3
KONYA	alfalfa	2628.1
KONYA	bean	1882.5
KONYA	maize	2091.6
KONYA	grain	2744.3
KONYA	horticulture	1795.3
KONYA	mixed fruit	1038.1
KONYA	potato	1318.9
KONYA	sugar beet	2388.0
KONYA	sunflower	2728.8
KONYA	vineyard	751.4

Crop Patterns in Non-irrigated Agriculture

Catchment/ Sub-basin	Crop	Area (hectare)				
		2004-2012	**2013**	**2014**	**2015**	**2016**
AKTAS	barley	13757.1	24400.0	19739.3	19620.0	20742.0
AKTAS	chickpea	1397.0	2881.1	1975.0	1905.0	1596.7
AKTAS	fallow	37136.0	46475.9	58956.6	64489.1	54045.5
AKTAS	lentil	6.0	0.0	0.0	1.0	1.0
AKTAS	oat	227.2	636.4	639.7	685.4	693.8
AKTAS	safflower	561.3	726.6	260.0	119.5	79.5
AKTAS	sunflower	406.8	158.8	158.8	158.8	158.8
AKTAS	triticale	5.4	5.2	8.6	7.1	62.7
AKTAS	vicia	1044.2	1044.2	1044.2	1044.2	1044.2
AKTAS	wheat	34322.2	43275.1	40096.6	37227.3	42500.1
AYDINLI	barley	76210.0	69563.9	70067.1	68942.2	56725.0
AYDINLI	bean	162.0	165.3	165.0	162.0	152.0
AYDINLI	canola	270.0	58.0	39.3	39.3	0.0
AYDINLI	chickpea	4802.6	5148.6	4678.9	4735.0	4933.8
AYDINLI	fallow	131171.0	134748.4	150307.2	147602.2	104901.1
AYDINLI	lentil	202.5	253.7	239.0	256.0	146.0
AYDINLI	oat	2316.0	2292.6	1860.6	1866.9	2090.9
AYDINLI	safflower	494.3	652.8	882.0	883.3	889.0
AYDINLI	sunflower	854.3	854.3	854.3	854.3	854.3
AYDINLI	triticale	120.0	113.7	148.8	137.1	137.9
AYDINLI	vicia	5397.5	5397.5	5397.5	5397.5	5397.5
AYDINLI	wheat	137651.6	148398.2	155795.8	149324.1	137338.9
AYVALI	barley	88851.0	82279.9	83221.0	81637.6	82337.8
AYVALI	bean	55.0	53.6	55.3	50.3	51.3
AYVALI	chickpea	5967.6	6491.7	5225.0	4705.0	4735.0
AYVALI	fallow	112843.7	121171.3	148532.7	156614.6	154327.9
AYVALI	lentil	1123.5	929.8	736.3	698.3	646.9
AYVALI	oat	4697.5	4609.5	4393.6	4276.6	4274.9
AYVALI	safflower	1161.3	2832.4	2451.4	2415.6	2378.8
AYVALI	sunflower	9.4	0.0	0.0	0.0	0.0
AYVALI	triticale	85.0	76.3	63.2	71.8	50.4
AYVALI	vicia	892.5	892.5	892.5	892.5	892.5
AYVALI	wheat	143743.2	154800.0	157601.9	160204.7	159206.7
OUTLET	barley	2500.0	3000.0	1999.9	2200.0	2200.0
OUTLET	chickpea	400.0	550.0	700.0	350.0	180.0
OUTLET	fallow	16976.5	13433.1	15320.4	15581.7	16800.2
OUTLET	lentil	45.0	59.0	80.0	75.0	50.0
OUTLET	oat	0.0	95.6	110.5	150.0	430.0
OUTLET	safflower	5.0	21.9	17.6	15.0	13.5
OUTLET	sunflower	10.0	10.0	10.0	10.0	10.0
OUTLET	wheat	3611.2	5220.9	4499.6	5924.0	6500.0