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Calculation of Water Used for Agricultural Purposes at the Downstream Point in Hydroelectric Power Plant Projects with TAGEM-SuET Software and Water Transmission: The Case of Sarıgüzel HPP

HES Projelerinde Mansaba Bırakılan Tarımsal Amaçlı Su

Miktarının TAGEM-SuET Yazılımı ile Hesaplanması ve Su İletimi: Sarıgüzel HES Örneği

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Abstract: Although hydroelectric power plants are ideal sources for electricity generation, the diversion of water from its natural course and its transportation through transmission lines can have various environmental impacts. While aiming to prevent or minimize these impacts, it is necessary to calculate the amount of water that will be left for natural life, human use and agricultural purposes during the design phase of the plant. This study aims to calculate the agricultural water usage to be left for irrigation, estimate plant water consumption, and ensure the effective management of water resources, plan irrigation programs, and design transmission lines. In the calculation of plant water consumption, soil characteristics, climate parameters, and plant characteristics are used. In both the world and our country, computer models can perform these operations quickly and accurately. Using the TAGEM-SuET software, plant water consumption, irrigation scheduling, and irrigation module calculations were made, followed by the provision of technical design parameters for the piped irrigation network. Some data collection and calculation efforts have benefited from GIS and public institutions. TAGEM-SuET could be a good tool for calculating the agricultural water usage left for irrigation and water management in such areas. Additionally, it was concluded that the introduction of a piped irrigation network could reduce irrigation water use while enabling modern irrigation techniques that increase agricultural productivity.

Keywords: Sarıgüzel HPP, TAGEM-SuET, Irrigation water, Irrigation module, Irrigation network

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Öz: Hidroelektrik Santralleri elektrik üretimi için ideal kaynaklar olmakla birlikte suyun yatağından saptırılarak iletim hatları içinde taşınması sonucu çevreye çeşitli etkileri olabilmektedir. Bu etkilerin engellenmesi ya da en aza indirilmesi hedeflenirken santralin projelendirme aşamasında mansaba bırakılacak doğal yaşam, insanlar ve tarımsal kullanım amaçlı suyun hesaplanması gerekmektedir. Bu çalışmada, mansaba bırakılacak tarımsal amaçlı kullanılan suyun hesaplanması, bitki su tüketimi tahmini yapılarak su kaynaklarının etkin yönetilmesi, sulama programı ve iletim hatlarının planlanması amaçlanmıştır. Bitki su tüketimi hesaplamalarında toprak özellikleri, iklim parametreleri ve bitki özellikleri kullanılmaktadır. Dünyada ve ülkemizde bu işlemleri bilgisayar modelleri hızlı ve doğru yapabilmektedir. TAGEM-SuET yazılımı kullanılarak bitki su tüketimi, sulama programlaması ve sulama modül hesaplamaları yapılmış ve sonrasında borulu sulama şebekesi ile ilgili teknik tasarım parametreleri verilmeye çalışılmıştır. Bazı veri toplama ve hesaplama çalışmalarında CBS ve kamu kurumlarından faydalanılmıştır. TAGEM-SuET'in konu edilen bu tür sahalardaki mansaba bırakılacak tarımsal amaçlı kullanılan suyun hesaplanmasında ve su yönetimi için iyi bir araç olabileceği düşünülmektedir. Ayrıca borulu sulama şebekesinin getirilmesi ile sulama suyu kullanımının azaltılabileceği hem de tarımsal verimi arttıran modern sulama tekniklerine olanak sağlayacağı sonucuna varılmıştır.

Anahtar Kelimeler: Sarıgüzel HES, TAGEM-SuET, Sulama suyu, Sulama modülü, Sulama şebekesi

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INTRODUCTION

In the last few decades, the demand for renewable energy sources such as hydro, solar, and wind has been rapidly increasing with the increase in environmental problems and the onset of the depletion of fossil fuels. A study by the World Energy Council (WEC) shows that hydroelectric energy which is a clean and continuous energy source and accounts for approximately 71% of all renewable energy production. It also meets 19% of the world's energy needs (Kurulekar et al., 2021). As the end of 2021, 743 hydroelectric power plants have been commissioned in Turkey through cooperation between the public and private sectors (DSI, 2022). Based on the most recent updated figures, Turkey's total installed capacity has reached 115.144 MW. The distribution of this capacity by energy sources is as follows: 28% hydropower, 21.4% natural gas, 19% coal, 10.9% wind, 16.8% solar, 1.5% geothermal, and 2.3% other sources (Electricity - Ministry of Energy and Natural Resources, 2025). These figures indicate that hydroelectric power plants (HEPPs) are one of the most heavily invested renewable energy sources in Turkey. In terms of hydroelectric energy resources, Turkey has numerous rivers of both low and high flow rates, as well as its topographical and morphological diversity, is among the countries that can be considered quite rich.

The construction of hydroelectric power generation facilities has been fully transferred to the private sector under the provisions of the "Electricity Market Law" as a result of recent regulations. The Environmental Impact Assessment (EIA) Regulation (no. 25318) was developed to control potential environmental changes and damages, applies both prior and after construction. The regulation is of critical importance for the sustainable use of natural resources and organizes processes such as project site selection, implementation, monitoring, and control according to specific rules (Başayiğit and Uçar, 2018). In this context, environmental flow assessments defined as the flow required to minimize environmental impacts specific to the characteristics and ecosystem of each river's catchment area are taken into consideration. One of the key aspects of minimizing the environmental impact of HEPPs is allocating water to the downstream flow point. This release is variously referred to as vital water, or environmental flow. As this water also supports downstream drinking and agricultural water needs, total demand must be considered when determining its volume. However, all these demands progressively alter the flow volume and pattern of the river over time. The flow regime of river changes when water is diverted from the riverbed or stored in higher regions. If water is not partially released into the riverbed during accumulation periods, this results in a decrease in downstream water flow. Conversely, if water is suddenly released during high-flow periods, the flow regime downstream is disrupted. In particularly, the construction of large dams is directly associated with changes in the river's flow regime, which consequently affects the ecosystems dependent on the downstream water (Bunn and Arthington, 2002). Although the effects of river modifications cannot be entirely prevented, they can be managed and kept within certain limits (Davis and Hırji, 2003).

To determine the amount of water used for agricultural purposes at the downstream point, it is necessary to identify watershed boundaries, water resources, land use patterns, vegetation cover, climate data, and some soil characteristics. These data can be obtained through field studies, maps, reports, and meteorological records. One of the most significant parameters is crop evepotranspiration (ETc). ETc is essential for various applications such as precipitation and the irrigation water demand, planning of water storage and diversion structures, planning and operation of irrigation systems, and water budget calculations based on watershed. Nowadays, Remote Sensing and Geographic Information Systems (GIS) are utilized to generate spatial data for calculating the amount of water allocated for agriculture. Additionally, technological advancements and the widespread use of technology in many sectors, including agriculture, have increased the need for software that can perform standard algorithm-based calculations, which can be described as expert systems for scientists, engineers, technical personnel, and producers. Software programs such as CROPWAT model, IRSIS, and AGROS are examples of such tools. These programs are developed to determine the optimum irrigation timing for plants, irrigation schedules and crop evapotranspiration. By utilizing these software programs (Cai et al., 2007; López-Urrea et al., 2012; Memon and Jamsa, 2018; Köksal, 2018; Kartal et al., 2019), it is possible to calculate the aforementioned parameters in a short time, based on different climatic conditions, soil properties, and the sufficiency of the water source to be used (İstanbulluoğlu and Şişman, 2004). TAGEM-SuET is tailored to local conditions and effectively integrates national datasets. Its functionalities are comparable to internationally recognized tools such as CROPWAT (FAO) and AquaCrop. CROPWAT estimates basic crop water requirements but lacks integrated pipeline and GIS-based analysis capabilities. AquaCrop effectively simulates crop yield under water stress but is not directly compatible with water transmission infrastructure models. TAGEM-SuET bridges this gap by linking water demand estimation with infrastructure planning. It supports water resources management and remains applicable even under limited meteorological data. Its development in Turkish enhances accessibility and relevance for national academic, public and private agricultural stakeholders. With this perspective, the “Irrigation Management and Crop Evapotranspiration Calculation System” (TAGEM-SuET) developed by TAGEM was utilized in this study. Using the SuET irrigation module calculation tool, the following calculations can be made for a given crop pattern at agricultural enterprises or large irrigation areas: i) irrigation module, ii) flow rate in water transmission line, and iii) seasonal total volumetric water requirement.

A regulation and inventory, including the “Mansap Water Rights Report”, which takes into account the quantity and timing of water not allocated to facilities such as storage structures, upstream public irrigation, drinking and domestic use, and water mills, should be prepared and carefully monitored after the hydroelectric power plant (HEPP) energy production. Additionally, the 'Post-Tailwater Water Rights Report' should be prepared for the area located at the tailwater discharge point following the energy production of the HEPP. Specifically, public irrigation projects should be planned by determining vegetation cover, plant water requirements, and irrigation areas. After that the required irrigation water is provided in accordance with the concept of a welfare state. In line with the above objectives, the Sarıgüzel HEPP has been examined as a case study. The study aims to determine the amount of water used for agriculture at the downstream point, assess water structures (hydrants), evaluate irrigation systems, and provide a useful example for the literature.

MATERIAL AND METHOD

Geographical and Topographical Properties

The Sarıgüzel Dam and HEPP which is part of the Kandil Energy Group are located within Kahramanmaraş. Hacınınoğlu HEPP is also located at the downstream of the Menzelet Dam on the Ceyhan River within The north of Kahramanmaraş and the south of Elbistan District. The Sarıgüzel HEPP is located downstream of the Hacınınoğlu HEPP2. The catchment area is situated in the Upper Ceyhan Basin, which serves as a transitional region between the Central Anatolia, Eastern Anatolia, Southeastern Anatolia and Mediterranean regions. After the branches that form the Ceyhan River merge, the river flows through a deep valley (Figure 1).

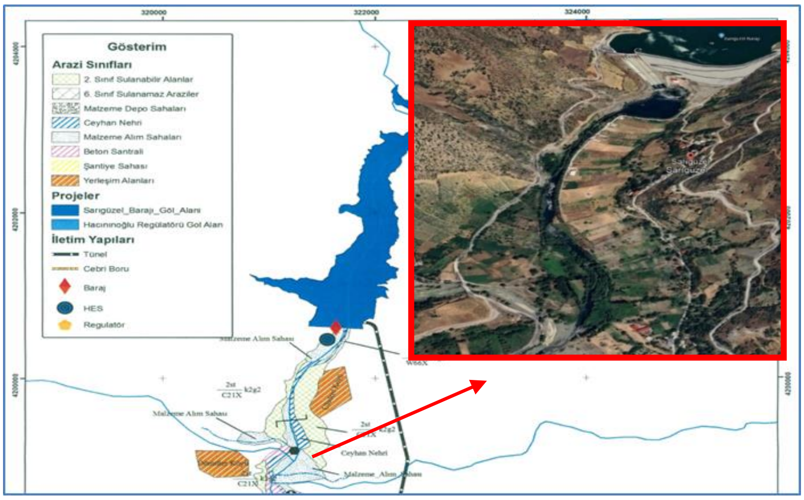

Figure 1. Map and location of the Sarıgüzel Dam and study area (Google Earth).

Şekil 1. Harita ve konum olarak Sarıgüzel Barajı ve çalışma alanı (Google Earth).

The water stored in the Sarıgüzel Dam is both turbinated at the Sarıgüzel HEPP through the transmission tunnel and released downstream from the Sarıgüzel Dam as "life water" (vital water). The Sarıgüzel Dam is designed at an elevation of 795 m on the bed of the Ceyhan River. The average elevation of the agricultural land in the project area is 797 m. The UTM coordinates are recorded as 37° 55′ 31.46′′ (N) / 36° 57′ 58.84′′ (E). The general layout of the dam and the HEPP central building along with covered areas are shown in Figure 1.

Climate Characteristics

Kahramanmaraş Province is located in an area where three distinct geographical regions (the Mediterranean, Eastern Anatolia, and Southeastern Anatolia) come closest together. In contrast to the climate of Kahramanmaraş city center, the climate becomes more continental as one moves northward with increasing elevation. The annual average temperature in Kahramanmaraş is 16.6 °C, while it drops to 10.7 °C in Elbistan. The lowest average monthly temperatures occur in January, with 4.7 °C in Kahramanmaraş and -3 °C in Elbistan. The highest monthly average temperatures occur in August, with 28.1 °C in Kahramanmaraş and 23.4 °C in July in Elbistan. The average temperatures exceed 23 °C for four months of the year. With this trend, the center is influenced by the Mediterranean thermal regime type, while the north and northeast are under the influence of the continental thermal regime. Precipitation values vary significantly throughout the year, with July, August, and September being the months with the least rainfall.

Crop Pattern in the Irrigated Project Area

Corn, cereals, and fruit are produced in the Sarıgüzel Dam and HEPP project area along the banks of the Ceyhan River, mainly for the local population's own needs. The current crop pattern and distribution percentages are presented in Table 1.

Table 1. Crop pattern and distribution.
Çizelge 1. Bitki deseni ve dağılımı.

Crop	Left bank		Right bank	
	Planted area (ha)	Distribution (%)	Planted area (ha)	Distribution (%)
Orchard crops (walnut, apple)	3.5	20	1.6	30
Vegetable garden crops (tomato, pepper)	7	40	1.1	20
Field crops (corn, wheat, barley and alfalfa)	7	40	2.7	50
Total	17.5	100	5.5	100

The life water (vital water) released from the dam was taken as the reference path in the studies conducted for approximately 23 hectares of agricultural land located on the downstream side of the "Sarıgüzel Dam and HEPP". The total area of 17.5 hectares (ha), consisting of plots ranging from 0.4 ha to 0.8 ha, was determined on the left bank (eastern section). In this area, 3.5 ha (20%) is planted with agricultural crops (walnuts and apples), 7 ha (40%) is used for vegetable farming (tomatoes, peppers), and 7 ha (40%) is used for field crops (corn, barley, wheat, alfalfa). On the right bank (western section), a total area of 5.5 ha with individual plots ranging from 0.3 ha to 0.5 ha is used for farming with the distribution of these areas being 1.6 ha (30%), 1.1 ha (20%), and 2.7 ha (50%) respectively, as shown in Table 1.

On both the right and left banks, for the total 23 ha of land: 20% (1.03 ha) of the planted agriculture areas are irrigated by drip irrigation, while 80% (4.12 ha) use surface irrigation. In the vegetable farming area, 30% (2.43 ha) is irrigated by drip irrigation, while 70% (5.67 ha) uses surface irrigation. For the field crop areas, 5% (0.49 ha) is irrigated by sprinkler systems, and 95% (9.26 ha) uses surface irrigation systems.

Method

Data production for the study area was carried out, followed by the calculation of water needs based on these data. Laboratory work, field studies, and office work were conducted to determine the characteristics of the study area. Archived satellite images were used via Google Earth. In addition, topographic maps and land cover, provincial soil maps produced by the General Directorate of Village Services were utilized. Field checks were conducted to verify the area's features. For this purpose, GPS was used for navigation. The cultivable land, main vegetation patterns and other water-related elements were identified with coordinates. Furthermore, face-to-face interviews were conducted with local residents and farmers to gather more detailed information. In the office work, reports related to the study area and literature were reviewed. Using the irrigation module of the TAGEM-SuET software, calculations were made based on the crop pattern of the study area, additionally the flow rate in the water transmission line and the seasonal total volumetric water requirement were determined. The flow chart of metodology is shown in Figure 2.

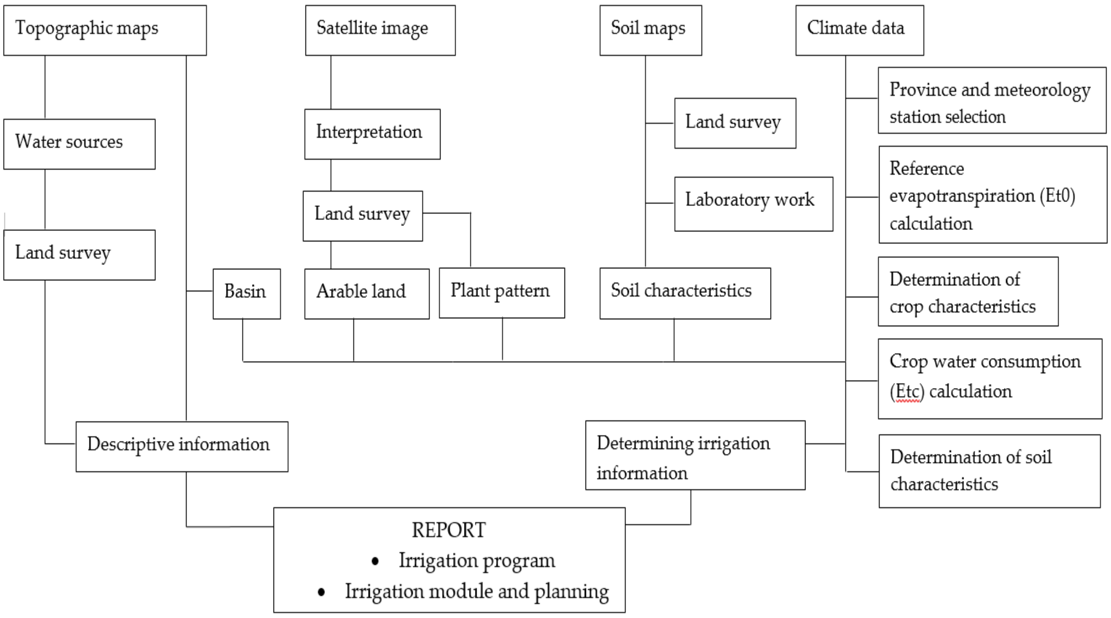

Figure 2. The flow chart of metodology.
Şekil 2. Metodolojinin akış diyagramı.

TAGEM-SuET Software

The software is designed to assist in the calculation of reference crop evapotranspiration (ETo) and potential crop evapotranspiration (ETc). In addition to the data included in the "Guide to Crop Water Consumptions of Irrigated Plants in Turkey" which is available in the SuET database, the software also includes some new and updated data related to plants, soils and irrigation systems which are necessary for irrigation management. The climate data used spans a 30-year period. SuET, with its flexible and customizable database structure, provides the capability to perform calculations for (1) Reference Evapotranspiration (ETo), (2) Crop Evapotranspiration (ETc), (3) Irrigation Scheduling, and (4) Irrigation Module Calculations. It offers seven different methods as alternatives: (Standardized Penman-Monteith, Blaney Criddle, Makking, Pristley-Taylor, Jensen-Haise, Hargreaves, and Turc).

The calculation of reference crop evapotranspiration is based on the Standardized FAO Penman-Monteith method in the program, as shown in Equation 1.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

In the equation:
Rn = Net radiation calculated for the plant surface (MJ m^{-2} day^{-1}),
G = Soil heat flux (MJ m^{-2} day^{-1}),
T = Daily average air temperature, measured at a height between 1.5 and 2.5 meters (°C),
u2 = Daily average wind speed, measured at a height of 2.0 meters (m s^{-1}),
es = Saturation vapor pressure, calculated for a height between 1.5 and 2.5 meters (kPa),
ea = Actual vapor pressure, calculated for a height between 1.5 and 2.5 meters (kPa),
Δ = Slope of the saturation vapor pressure-temperature curve (kPa $°C^{-1}$),
γ = Psychrometric constant (kPa $°C^{-1}$).
Crop evapotranspiration is calculated using Equation 2.

$$ET_c = k_c \times ET_0 \quad (2)$$

In the equation:
ETc = Crop evapotranspiration (mm),
kc = Crop coefficient,
ET0 = Reference crop evapotranspiration (mm).
The model can also make suggestions for irrigation methods, irrigation schedules under different irrigation conditions and evaluating the impact of rainfall conditions or adequate irrigation conditions on crop yield. The SuET software input parameters consist of climate, plant, and soil parameters. Climate parameters include: Maximum temperature (Tmax), minimum temperature (Tmin), maximum relative humidity (RHmax), minimum relative humidity (RHmin), wind speed (u), solar radiation (Rs), local atmospheric pressure (P), and planting-harvesting dates; Plant parameters include: crop coefficient (kc), effective root depth, and water-yield response factor (Ky); Soil parameters include: soil texture, available soil water, soil infiltration rate, TK and SN values, and amount of soil water at the time of planting.

Data Input

Climate Data

Turkey's climatic regions and available climate station data are included in the software (Figure 3). The Kahramanmaraş-Elbistan climate station menu was selected from the database for study area and the software used 30 years of meteorological data which were calculated as the average of multi-year.

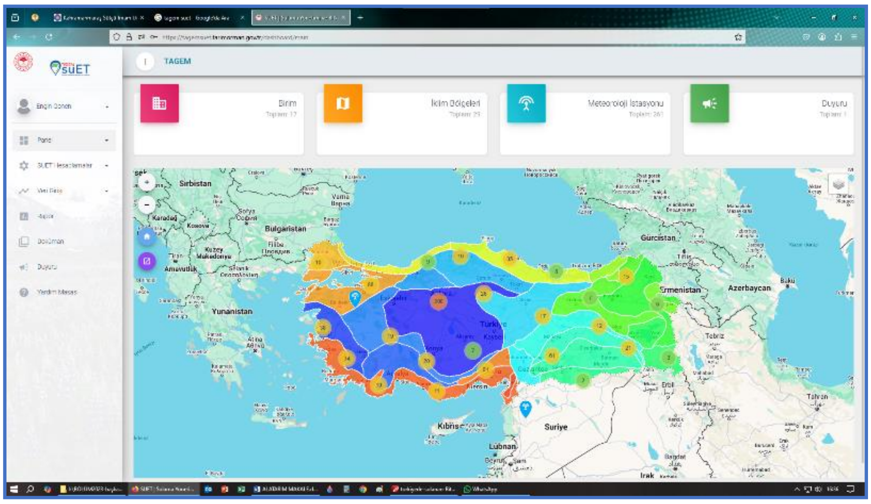

Figure 3. Climatic regions of Turkey and station locations.
Şekil 3. Türkiye iklim bölgeleri ve istasyon yerleşimleri.

Soil Characteristics of the Study Area

The soil physical properties were determined at 90 cm soil profile and it was found to have a loamy (L) soil texture. The soil's sand content was calculated to be 40.5%, silt content 41.5%, and clay content 18%. Field capacity (FC) and wilting point (WP) were determined as 348 mm m^{-1} and 152 mm m^{-1}, respectively. From these values, the available water retention capacity was calculated with 196 mm m^{-1}, additionally soil bulk density was found as 1.52 g cm^{-3}. Soil infiltration rate was also taken the value provided by the program for loamy soils (Figure 4).

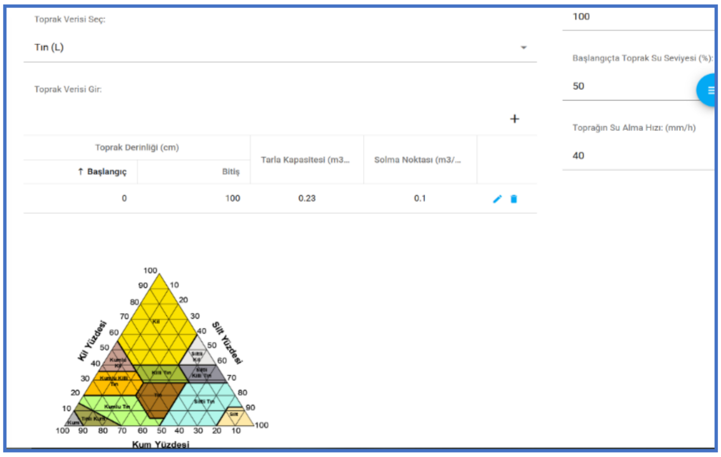

Figure 4. Soil characteristics interface in the SuET irrigation program calculation section.
Şekil 4. SuET sulama programı hesaplama bölümü toprak özellikleri ara yüzü.

Plant Characteristics

The crop coefficient values which divided according to climatic regions were entered into the program for the initial, middle, and final stages. In the same interface, the lengths of the initial, development, middle, and final stages, as well as the effective root depths of the crops grown in the study area were entered into the system. Also critical level value and Ky factor were considered. The corresponding file was prepared for ETc and irrigation scheduling. The planting dates of crops were also entered (Figure 5). These data were developed by using the "Plant Water Consumption Guide for Irrigated Crops in Turkey" section from the program interface. The crops considered in this study include walnut, apple, tomato, pepper, corn, wheat, barley, and alfalfa (Table 1).

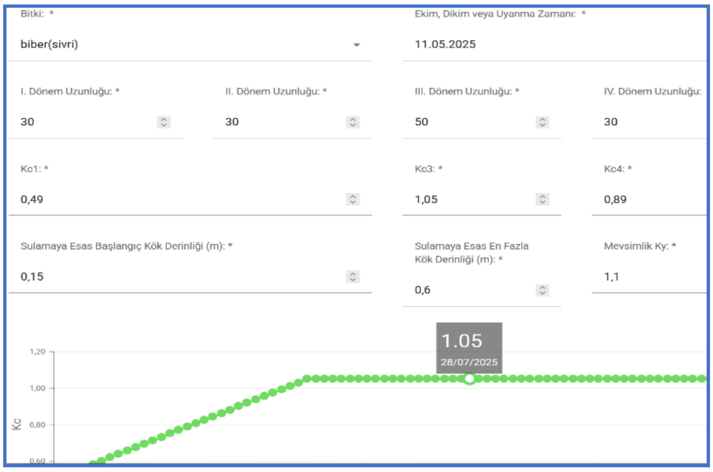

Figure 5. SuET irrigation program calculation section: plant characteristics interface.
şekil 5. suet sulama programı hesaplama bölümü bitki özellikleri ara yüzü.

Each data set has been transferred to the corresponding module in database format under the expertise of irrigation engineering (e.g., irrigation efficiencies selected based on irrigation methods, irrigation sceudule, etc.). Subsequently, crop evapotranspiration, irrigation water requirements and irrigation module were calculated (in 10-day periods). Values that need to be considered during the design of irrigation network and suitable water transmission pipelines were identified. Finally, an analysis was made by comparing research outputs with the previous conditions.

RESULTS AND DISCUSSION

Crop Evapotranspiration and Irrigation Program

The crop evapotranspiration (ETc) values are an important parameter in determining irrigation water requirements, preparing irrigation programs, conducting feasibility studies for irrigation projects and topics related to soil, plant physiology, meteorology, and agricultural practices (Kodal, 1982; Köksal, 2018; Altınbılek and Kızıl, 2024). ETc can vary depending on climatic regions, plant physiology, developmental stages, and agricultural practices. Looking at the total seasonal ETc values for plants grown in study area, crop with the highest ETc was found to be walnut, while barley had the lowest water consumption. Peak period values were found as follows: 186.6 mm for walnut (July), 162.6 mm for apple (July), 192.7 mm for tomato (July), 176.0 mm for pepper (July), 201.0 mm for corn (July), 144.6 mm and 137.2 mm for wheat and barley (May), and 156.7 mm for alfalfa (July).

With the SuET, irrigation programs can be made based on the region's climatic and soil conditions, crop characteristics, farmer preferences and irrigation system for any crop grown at the parcel level. Irrigation schedule and frequency under both full and deficit irrigation can be made. The results of the irrigation programs for mentioned crops under average rainfall and optimal planning conditions are given in Table 2. According to the results, the number of irrigations for crops grown in the study area was as follows: walnut (9), apple (7), tomato (14), pepper (20), corn (10), wheat (4), barley (3), and alfalfa (9). The highest number of irrigations was pepper, with a total irrigation water amount of 486.5 mm, while the least irrigation water was 254.2mm for barley. The highest irrigation water amount was found to be 1527.9 mm for walnut. Variability in irrigation water amounts can be attributed to factors such as the irrigation method efficiency, the area cultivated, the ETc calculation methods and plant growth periods (Tülücü, 2003).

Additionally, irrigation schedules for different crops grown in various soil types can be planned with fixed or specific irrigation intervals/amounts. Under adequate irrigation conditions, optimal irrigation programs can be developed, while deficit irrigation programs can be considered inadequate irrigation conditions. Figure 6 shows the optimal irrigation program for walnut. SuET is derived under conditions where surface irrigation efficiency is 55%, the soil texture is loamy, the initial soil water level is 50%, the permissible available capacity ratio (Ry) is 0.70 and the irrigated area is 100% for 21 da.

Table 2. Optimal irrigation programs for crops grown in the left bank of the study area, produced from the SuET irrigation program menu.

Çizelge 2. SuET sulama programı menüsünden üretilmiş araştırma alanı sol sahilde yetiştirilen bitkilere ait ≈en uygun sulama programları.

Irrigation planning results						
Plant name	Irrigation method	Number of irrigations	Total irrigation water applied (mm)	Crop evapotranspiration ETc (mm)	Shortest irrigation interval (day)	Yield rate (%)
Walnut	Surface	9	1527.9	928.1	16	100
Apple	Surface	7	1174.1	683.4	18	100
Tomato (local)	Drip	14	529.5	618.8	8	100
Pepper (pointed)	Drip	20	486.5	568.1	5	100
Corn (grain)	Drip	10	488.6	622.2	8	100
Wheat (winter)	Sprinkler	4	364.2	571.8	14	100
Barley (winter)	Sprinkler	3	254.2	449.8	12	100
Alfalfa	Sprinkler	9	888.5	824.8	14	100

When planning irrigation programs, the irrigation interval shortens as the Ry value decreases, and conversely, it lengthens as Ry increases depending on plant and irrigation method. Increased yield and quality can be achieved through frequent irrigation with drip irrigation. Indeed, SuET program provided the highest number of irrigations for tomato, pepper, and corn under drip irrigation in this study (Table 2). Moreover, SuET software considers the Ry value when predicting yield loss. It is recommended that Ry entered between 35% and 100%. For crops planted with a row spacing of less than 50 cm, or those planted in a more densely packed manner, it is deemed appropriate to use an irrigated area ratio of 100%. This ratio can be between 50-70% with row spacing of 70-100 cm and it can range from 35-50% with row spacing exceeding 100 cm such as orchards and vineyards. Under optimal irrigation conditions, the ratio of actual water consumption to maximum water consumption being 1 indicates that the actual yield (Ya) is equal to the maximum yield (Ym). As the number of irrigations decreases, the total irrigation water amount also decreases. Furthermore, when the applied restriction ratio under deficit irrigation conditions increases, the trend or percentage of yield reduction also increases (Çakmak and Kendirli, 2002).

No reduction was applied water for the left bank irrigation area of Sarıgüzel as an example. Therefore, optimal irrigation programs were arranged under sufficient conditions (Table 2).

Figure 6. An example for optimum irrigation plan in SuET irrigation program module.
Şekil 6. SuET sulama programı modülünde örnek bitki uygun sulama planı.

By planning irrigation timing under different conditions, water losses can be minimized while irrigation efficiency and the availability of plant nutrients can be increased. Additionally, greater utilization of rainfall, successful management of weeds and diseases, reduced fertilizer application costs, and equitable water distribution among farmers can be achieved (Gürgülü, 2007). With the SuET program used in this study, it seems feasible to provide recommendations for appropriate water usage conditions in small-scale family agricultural fields in the region. Moreover, models such as SuET can help predict the impacts of changes in irrigation practices on downstream ecosystems and water quality, thereby providing critical data for Integrated Water Resources Management (IWRM).

One key finding of this study is the influence of irrigation methods on water use. Drip irrigation systems, require less irrigation water compared to surface methods as shown in international studies (Asadi et al., 2024). The use of advanced systems can reduce water consumption and help prevent downstream water depletion. This also supports ecosystem services. These outcomes are highlighted in river basin irrigation studies (Chaves et al., 2023).

Irrigation Module and Planning

In the planning stage of irrigation networks, the calculated irrigation module is used in the dimensioning of irrigation systems and transmission line, considering the chosen operating method and flexibility coefficient (Koç et al., 2016). When the previous water transmission line of the research area was dimensioned, surface irrigation methods were considered in irrigation module. Therefore, surface irrigation parameters such as water application efficiency were also used in calculating water requirements. If drip or sprinkler irrigation methods are applied in these areas, it is expected that the required water volume will be lower than the calculated value for surface irrigation due to the higher irrigation efficiency of pressurized irrigation systems. In other words, the water requirement calculated for surface irrigation represents the maximum water needed for irrigation.

Transitioning from traditional irrigation methods to drip or sprinkler systems in the project area could reduce water losses by an estimated 25–40% (FAO, 2017). However, this rate may vary depending on crop type and irrigation schedule. Although the initial investment costs of modern irrigation systems are relatively high, they offer substantial long-term savings by reducing water and energy use. For instance, a study conducted in Turkey showed that farmers who switched to drip irrigation experienced up to a 30% decrease in annual water costs per hectare (Çevik et al., 2019). From an environmental perspective, this transition enables more efficient water allocation and reduces erosion risks. Consequently, it alleviates pressure on downstream ecosystems and water resources.

In this program, the irrigation module was calculated with an irrigation efficiency of 55% and a daily irrigation time of 20 hours for research area. According to the results, the highest irrigation module for both irrigation areas (left and right banks) was calculated as 1.25 and 1.15 L s^{-1} ha^{-1}, respectively, at the second period of July (Table 3). In previous calculations (year of 2022) for the study area, the water transmission lines were dimensioned based on this value of 1.30 L s^{-1} ha^{-1}. The value used in the project was considered sufficient according to the findings of this study. The flow rates ranged from a minimum of 0.05 L s^{-1} to a maximum of 21.86 L s^{-1} on the left bank, and from 0.02 L s^{-1} to 6.32 L s^{-1} on the right bank. The total water requirements for left bank and right bank were determined as 149.18×10^3 m^3 and 44.84×10^3 m^3, respectively. Additionally, the total water requirement calculated by the SuET program for the left bank was reduced to 129.72×10^3 m^3 due to the existing plant pattern and irrigation methods (surface, drip and sprinkler irrigation) used in the project year. This finding is consistent with several international case studies that underscore the necessity of upgrading irrigation infrastructure to achieve sustainable water use (Ali et al., 2022).

Table 3. Data for the study area's left and right banks for 10-day periods generated from the SuET irrigation module and planning menu.

Çizelge 3. SuET sulama modülü ve planlama menüsünden üretilmiş araştırma alanı sol ve sağ sahil için 10 günlük dönemlerdeki veriler.

	Left bank			Right bank		
Irrigation period	Irrigation module- q (L s^{-1} ha^{-1})	Flow rate - Q (L s^{-1})	Water requirement (×10^3 m^3)	Irrigation module- q (L s^{-1} ha^{-1})	Flow rate - Q (L s^{-1})	Water requirement (×10^3 m^3)
March -II	0.00	0.05	34.17	0.00	0.02	13.43
March -III	0.00	0.06	40.60	0.00	0.02	15.95
April -I	0.02	0.28	204.94	0.02	0.11	80.51
April -II	0.06	1.10	794.34	0.08	0.45	321.87
April -III	0.10	1.69	1214.19	0.12	0.68	487.83
May -I	0.13	2.33	1679.09	0.17	0.95	684.95
May -II	0.24	4.16	2995.14	0.27	1.46	1049.54
May -III	0.39	6.84	4923.41	0.41	2.24	1615.58
June -I	0.50	8.81	6341.25	0.53	2.91	2097.02
June -II	0.64	11.24	8091.42	0.66	3.62	2607.37

Table 3. Continue.
Çizelge 3. Devamı.

	Left bank			Right bank		
Irrigation period	Irrigation module- q (L s^{-1} ha^{-1})	Flow rate - Q (L s^{-1})	Water requirement (×10^3 m^3)	Irrigation module- q (L s^{-1} ha^{-1})	Flow rate - Q (L s^{-1})	Water requirement (×10^3 m^3)
June -III	0.93	16.33	11757.06	0.89	4.89	3523.89
July -I	1.14	19.88	14316.08	1.05	5.77	4155.69
July -II	**1.25**	**21.86**	**15738.29**	**1.15**	**6.32**	**4553.08**
July -III	1.24	21.73	15643.20	1.12	6.17	4440.07
August -I	1.15	20.08	14454.10	1.06	5.81	4181.65
August -II	1.03	18.09	13023.13	0.94	5.15	3710.62
August -III	1.08	18.86	13577.18	0.98	5.41	3894.52
September -I	0.84	14.68	10572.47	0.78	4.28	3082.18
September -II	0.60	10.49	7555.17	0.55	3.02	2173.93
September -III	0.37	6.45	4640.58	0.35	1.91	1374.44
October -I	0.11	1.88	1350.08	0.15	0.82	587.12
October -II	0.02	0.42	299.01	0.03	0.18	130.52
October -III	0.01	0.14	97.47	0.01	0.05	38.29
November -II	0.00	0.05	37.82	0.00	0.02	14.86
December -I	0.00	0.00	1.73	0.00	0.00	0.68
Total:			149.38			44.84

The highest irrigation module which is calculated using the total irrigation water requirement is expected to occur in either July or August. Başayiğit and Uçar (2018) stated that the peak value could occur in different months due to variability in the cultivated area and the month with the highest water consumption depending on crop diversity in their study. In contrast, Koç et al. (2016) found that the irrigation modules calculated for July in the research area of the Aydın Plain located in the Büyük Menderes Basin were consistent with the planning module.

Irrigation Transmission Line

The irrigation water requirement and hydraulic design, pipe diameter of transmission line is determined based on the highest irrigation module during the project period with taking into account project safety. This planning assumes that all hydrants are open during the specified period. The flow rates for the main and lateral branches of the system are statistically determined under the assumption that they are available at every point of the network. Each hydrant may have one, two, three or four outlets with each farming operation receiving one outlet. The farmer uses the designated outlet for irrigation. Drip and sprinkler systems are connected to hydrants to deliver irrigation water to the crops. Reducing the number of structural elements and their costs is related to the pipe diameters and usage of irrigation area. Determining pipe diameters in irrigation networks and ensuring the most economical network design is crucial. The pipe diameters designed appropriately with reducing the flow rate in terms of cost and hydraulics during network optimization (Marım et al., 2018). The pipe diameter in transmission lines is determined considering load losses, flow rate and recommended speed limits. A key criterion is that the load losses during transmission should not exceed the current load. The local load losses are considered negligible in the calculation of load losses in long transmission lines; therefore, continuous load losses are only taken into account. Additionally, linear programming is commonly used to design the pipe lines for project safety, economic feasibility and hydraulics based on total flow.

Under the above planning criteria, the parameters calculated for the irrigation transmission infrastructure based on the methods used by Dal (2014) and Yıldırım (2005) are presented in Table 4. According to the calculations, the pipe length for the left bank irrigation transmission line is 1400 m with a diameter of 160 mm, while the right bank figures are 1400 m and 110 mm. According to previous project planning, 5 hydrants were installed for 5.5 hectares of land on the right bank, and 10 hydrants were installed for 17.5 hectares on the left bank. However, considering that the average service area per hydrant in Turkey is 6.1 ha, it can be concluded that the number of hydrants in the previous design was excessive. This result is influenced by the fact that a hydrant can have a maximum of 4 outlets and is affected by the distribution, size and number of farmer parcels in the research area.

Table 4. Technical datas at the left and right banks calculated for transmission pipeline in the research area.
Çizelge 4. Araştırma alanındaki iletim boru hattı için hesaplanan sol ve sağ sahil teknik verileri.

Parameters	Left Bank Transmission Pipeline	Right Bank Transmission Pipeline
Planned pipe type	P100 PN10 coil	P100 PN10 coil
Outer diameter	160 mm	110 mm
Hydraulic length	1400 m	1400 m
Pressure class	PN10-10 atm-100 mvc	PN10-10 atm-100 mvc
Number of pipelines	1	1
Main pipe flow rate	23 L s^{-1}	7.5 L s^{-1}
Number of hydrants	10	5
F factor	0.41	0.37
Friction loss	47.22 mvc	43.75 mvc
Corrected friction loss	17.47 mvc	17.94 mvc
Slope direction and percentage	North/South slope down, 0.70%	North/South slope down, 0.70%
Inlet pressure	18.82 mvc	19.18 mvc
Outlet pressure	11.14 mvc	11.04 mvc
Difference	7.68 mvc	8.14 mvc
Pipe diameter compliance	7.68 mvc <10 mvc Suitable	8.14 mvc <10 mvc Suitable

Water Rights Framework

The effectiveness of irrigation networks extends beyond physical infrastructure. Legal frameworks governing downstream water rights are vital for fair distribution and environmental sustainability. For instance, legal disputes over downstream water rights have been central to debates in the Murray-Darling Basin (Australia) and Nile Basin (Africa), where water availability for agriculture is directly impacted by upstream water use (Grafton et al., 2018; Sadoff et al., 2020). This highlights the necessity of adopting an integrated water management approach.

It is crucial to ensure that upstream irrigation practices do not negatively impact downstream ecosystems. The adverse effects of excessive irrigation water use on river flow and ecosystem services such as fish migration and water quality have been thoroughly documented in various international studies (DeAngelis et al., 2010; Geleta et al., 2023). Modeling downstream flow in river basins helps identify potential negative impacts on water quality and aquatic biodiversity, and support sustainable agricultural planning. Furthermore, legal frameworks that regulate water rights are essential. They ensure equitable access for agriculture while safeguarding ecological functions.

CONCLUSION

In this study, the calculation of water allocated for agricultural purposes to be released downstream which constitutes a part of the planning process for hydroelectric power plants (HEPs) was performed along with irrigation scheduling, estimation of crop water consumption (ETc), and irrigation module calculations using the TAGEM-SuET software. Subsequently, the effective management of water resources and the planning of irrigation pipelines were carried out for determining the number of hydrants, the appropriate pipe diameter, and the length of the pipeline. The total water requirement for approximately 23 hectares of agricultural land located on the downstream side of the "Sarıgüzel Dam and HEP" was calculated to be 194.22×10^3 m^3. The highest ETc value was found to be 928.1 mm for walnut with the FAO-Penman Monteith method. The highest irrigation modules in July were determined to be 1.25 L s^{-1} ha^{-1} on the left side and 1.15 L s^{-1} ha^{-1} on the right side. This was achieved within the expected period. The design criteria of water intake structures in irrigation pipeline were found to be within the correct limits; additionally, the DSI linear programming technique could be recommended for this process. According to the results and planning process, while 16.5% of the agricultural land in the region currently uses pressurized pipe irrigation systems and 83.5% uses surface irrigation, it is expected that the adoption of pressurized irrigation techniques throughout the area would reduce water losses and increase agricultural productivity and farmer income. However, agricultural water use must be balanced with the protection of downstream ecosystems, and future water management strategies should be developed accordingly.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

DECLARATION OF AUTHOR CONTRIBUTION

The authors contributed equally to each stage of the study.

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