

HYDROLOGICAL AND WATER QUALITY MODELING OF KÜÇÜK MENDERES RIVER BASIN AND MANAGEMENT SCENARIOS

by

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B.Sc. in Environmental Engineering, İstanbul University, 2018

Submitted to the Institute of Environmental Sciences
in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Sciences

Boğaziçi University

2023

ACKNOWLEDGEMENTS

In the arduous journey of completing this master's thesis, marked by numerous financial and moral challenges, there are several individuals whom I deeply appreciate and wish to acknowledge. Foremost, I extend my heartfelt gratitude to my thesis advisor, İrem Daloğlu Çetinkaya, whose unwavering support and wealth of knowledge were invaluable throughout this academic endeavor. I am also indebted to my undergraduate thesis advisor, Atakan Öngen, whose encouragement prompted me to embark on this challenging path. To my beloved family, Emre and Ashı, whose patience endured my occasional fits of frustration not only during this process but in general, your enduring support has been my rock. To my dear friends, Simla and Semanur, whose belief in me often exceeded my own, I am profoundly grateful for your unwavering faith. And lastly, but certainly not least, I wish to express my deepest gratitude to myself, for summoning the strength and resilience to persist through every difficulty and obstacle, ultimately bringing this dissertation to fruition. This accomplishment is a testament to the power of determination and the unwavering support of those who stood by my side.

ABSTRACT

HYDROLOGICAL AND WATER QUALITY MODELING OF KÜÇÜK MENDERES RIVER BASIN AND MANAGEMENT SCENARIOS

This study aims to investigate the water quantity and quality in the Küçük Menderes Basin, where agricultural activities are intense, and which observe the effects of different agricultural practices. We used the SWAT model. The model outputs, which were simulated between 2001-2019 with a 5-year warm-up period, were evaluated with monthly flow, sediment, NO_2^- , NO_3^- , NH_4^+ , and TN variables. We calibrated the model simultaneously for flow, sediment, and nutrient variables, using the SWAT-CUP SUFI-2 algorithm. 1500 simulations and 114 parameters were used in the calibration. Although the calibration and validation intervals vary for each station and the calibration period ranges between 2006 and 2014 and the validation period ranges between 2009 and 2018. Ten observation stations were used for flow, two for sediment, and one for quality. Calibration results were evaluated using R^2 , NSE, and PBIAS objective functions, p-factor and r-factor uncertainty analyses, global sensitivity analysis, and graphical visualizations. Satisfactory results were obtained for flow calibration, with an overall NSE score of 0.65, whereas sediment calibration failed. Good values were obtained from total nitrogen for quality, but the number of data was insufficient. Validation results also vary between stations with 0.5 - 0.8 for R^2 . A scenario analysis was carried out with three different agricultural applications: a 30 % reduction in irrigation amount, a 30 % reduction in fertilizer amount, and the application of both. The scenario results showed a reduction of 18.8 % for the annual average nitrate load when fertilizer amounts were reduced by 30 % and a reduction of 17.2 % for the annual average nitrate load when irrigation and fertilizer amounts were reduced. No major differences were seen for other variables.

ÖZET

KÜÇÜK MENDERES HAVZASI'NIN HİDROLOJİK VE SU KALİTESİ MODELLEMESİ VE YÖNETİM SENARYOLARI

Bu çalışma, tarımsal faaliyetlerin yoğun olduğu Küçük Menderes Havzası'ndaki su miktarının ve kalitesinin araştırılmasını ve farklı tarımsal uygulamaların etkilerinin gözlemlenmesini amaçlamaktadır. Çalışmada SWAT modeli kullanılmıştır. 2001-2019 yılları arasında simüle edilen ve 5 yıllık ısınma periyodu kullandığımız model çıktıları aylık akış, sediman, NO_2^- , NO_3^- , NH_4^+ ve TN değişkenleri ile değerlendirildi. Model SWAT-CUP SUFI-2 algoritmasını kullanarak sırasıyla akış, sediman ve besin değişkenleri için aynı anda kalibre edildi ve kalibrasyonda 1500 simülasyon ve 114 parametre kullanıldı. Kalibrasyon ve validasyon aralıkları her bir istasyon için farklılık göstermekte ve buna göre kalibrasyon dönemi 2006-2014, doğrulama dönemi ise 2009-2018 yılları arasında değişmektedir. Akış için on, sediman için iki ve kalite için bir gözlem istasyonu kullanıldı. Kalibrasyon sonuçları, R^2 , NSE ve PBIAS objektif fonksiyonları, p faktörü ve r faktörü belirsizlik analizleri, global duyarlılık analizi ve grafiksel görselleştirmeler kullanılarak değerlendirildi. Akış kalibrasyonu için toplamda 0,65 NSE ile tatmin edici sonuçlar elde edilirken, sediman kalibrasyonu başarısız oldu. Kalite için toplam azottan iyi değerler elde edildi, ancak veri sayısı yetersizdi. Validasyon sonuçları da istasyonlar arasında değişiklik göstermektedir, farklı objektif fonksiyonları için farklı sonuçlar gözlemlenirken sonuçlar R^2 için 0.5 - 0.8 aralığında değişmektedir. Çalışma sonunda sulama miktarında % 30 azalma, gübre miktarında % 30 azalma ve her ikisinin uygulanması olarak üç farklı tarımsal uygulama ile senaryo çalışması yapıldı. Senaryo sonuçları, gübre miktarları % 30 oranında azaltıldığında yıllık ortalama nitrat yükü için % 18,8'lik bir azalma, sulama ve gübre miktarları % 30 oranında azaltıldığında ise yıllık ortalama nitrat yükü için % 17,2'lik bir azalma olduğunu göstermiştir. Diğer değişkenler için büyük farklılıklar görülmemiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

ARS	Agricultural Research Service
BMPs	Best management practices
CFRG	The Cover and Management Factor
CFSR	Climate Forecast System Reanalysis
CLC	CORINE Land Cover
CORINE	The Coordination of Information on The Environment
DEM	The Digital Elevation Model
DSI	The General Directorate of State Hydraulic Works
EİE	Elektrik İşleri Etüt İdaresi
ET	Evapotranspiration
EU	The European Union
FAO	Food and Agriculture Organization of the United Nations
GCM	General Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GLUE	Generalized Likelihood Uncertainty Estimation
HRU	Hydrologic Response Units
IWRM	Integrated Water Resources Management
KGI	Quality Gauge Station
LOADEST	Load Estimator
M.Sc.	Master of Science
MCMC	Markov chain Monte Carlo
MENA	East Asia, North America, and the Middle East and North Africa
MGM	The General Directorate of Meteorology
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent bias
PET	Potential Evapotranspiration

Ph.D.	Doctor of Philosophy
PO_4^{3-}	Orthophosphate
PSO	Particle Swarm Optimization
R^2	Coefficient of Determination
RBMP	River Basin Management Plan
RCP	Representative Concentration Pathway
SRTM	The Shuttle Radar Topography Mission
SS	Suspended Solid
SUFI 2	Sequential Uncertainty Fitting
SWAT	The Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Programs
SYGM	The General Directorate of Water Management
TAGEM	The General Directorate of Agricultural Research and Policies
TN	Total Nitrogen
TP	Total Phosphorus
TUIK	Turkish Statistical Institute
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	The United States Department of Agriculture
USGS	United States Geological Survey
USLE	The Universal Soil Loss Equation
WFD	The Water Framework Directive
WGEN	Weather Generator

1. INTRODUCTION

Water is necessary not only for the vital functions of living things but also for all human activities. For instance, many sectors, such as beverage or agriculture, depend on water as a primary input. As the most crucial resource for all living, water is vulnerable to external factors, such as climate change, land use, agricultural activities, industrial activities, etc. The number of people, which reached over 8 billion in 2023, with an increase of 5 billion since 1960, is expected to reach 10 billion in 2058 (United Nations Population Fund, 2023). Unfortunately, it is well known that overpopulation also negatively affects the quantity and quality of water, especially when water is not managed effectively.

The UN World Water Development Report 2023 highlighted six severe findings. According to the report, 46 % of people have difficulty accessing safe water, vast amounts of natural wetlands have already been lost, and some countries have lost 6 % of their gross domestic product (GDP) due to water scarcity. Between 2000 and 2019, floods and droughts affected 1.65 billion and 1.43 billion people, respectively. It has been determined that by 2050, 2.4 billion people in urban areas will face water scarcity, and although I have many transboundary resources, about half of them are not cooperatively managed (UNESCO, 2023b).

Only 3 % of the water is freshwater, and most of the freshwater is locked in the glaciers (Gleick, 1993). On the other hand, water use continues to increase by nearly 1 % every year and is expected to be so by 2050. Nevertheless, many countries already have water shortages when I compare the water amounts with the requirement (UNESCO, 2023). Turkey is a country that is experiencing water scarcity, with 1,400 m³ per capita annually. The national water plan reported that water consumption increased by 40 % in the last twenty years in Turkey (Su Yönetimi Genel Müdürlüğü, 2019c).

As it has been known for a long time, the majority of water use in the world, with a rate of 70 %, is still in irrigation and agricultural activities (Samimi et al., 2020). In Turkey, the total water potential is 112 m³, and it is used for irrigation (74 %), drinking use (13 %), and industry (13 %) (Su Yönetimi Genel Müdürlüğü, 2019c). Irrigation schedule and method significantly affect these high water use amounts (Samimi et al., 2020).

Besides the quantity problems, countries are also at risk of water quality caused by a lack of wastewater treatment plans or agricultural activities, depending on income levels (UNESCO, 2023). Water pollution is caused by two primary source types: point sources and nonpoint sources. Due to the determination challenges, controlling and managing nonpoint sources such as livestock and agricultural activities is more demanding than point sources such as industrial and wastewater treatment plant discharges.

Since the continuity of humans, flora, and fauna depend on clean water entities, it has to be managed delicately (Fan & Shibata, 2015). The European Union (EU) took action in December 2000 with the enforcement of the Water Framework Directive (WFD). The directive is mainly based on the idea of seeing water not as a commercial product but as a heritage and implementing an effective policy for the protection of water resources (EU, 2000). Regarding the implementation of WFD, plans for sustainable water, which is called Integrated Water Resources Management (IWRM), have started at watershed scales by EU countries (Moroglu & Yazgan, 2008).

The directive, which is also on the agenda of Turkey as an EU candidate country, aims to improve water quantity and chemical and ecological quality (Malagó et al., 2017a; Moroglu & Yazgan, 2008). The leading authorities responsible for water management in Turkey are The Ministry of Agriculture and Forestry, The Ministry of Environment, Urbanization and Climate Change. The General Directorate of Water Management (SYGM) and The General Directorate of State Hydraulic Works (DSI) are the sub institutions of The Ministry of Agriculture and Forestry. The Ministry of Agriculture and Forestry of Turkey accomplished watershed protection action plans for 25 river basins and has been doing river basin management plans recently. While the institution also does drought and flood management plans, master plans, and sectoral allocation plans, The Ministry of Environment, Urbanization, and Climate Change is responsible for climate change action plans and wastewater action plans. (Su Yönetimi Genel Müdürlüğü, 2019c).

With these water management initiatives, water resource management approaches have evolved over the past two decades, and the need for different management tools is increasing (Terry et al., 2022). One of these tools, computer modeling systems, has been developed to establish actions against water pollution and to provide integrated management support on aquatic systems with less time and money consumption (Malagó et al., 2017b). Water hydrology and quality models continue to be developed with varied features and objectives. Dealing with specific environmental conditions,

addressing needs with different model structures, and applying alternative scenarios have taken water management policies to the next level (Gassman et al., 2014).

One of these models is the Soil and Water Assessment Tool (SWAT) model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS) and has had widespread usage recently. Because of its open-source code, many publications, and supporting software, SWAT was and continues to be applied for basin-scale water hydrology and quality model studies by too many researchers. SWAT models have varied objectives due to the basin or watershed needs. While it is used to understand climate change effects on hydrology, it also can be used for management practice options (Gassman et al., 2014; Neitsch et al., 2011).

Although people worldwide have widely used the SWAT model, 69 % of the studies are related to hydrology in Turkey (Peker & Cüceoğlu, 2022). This is understandable when considering that the water needs of some river basins exceed the potential of the resources in Turkey, which is located in a semi-arid region of the world. However, on the other hand, there are many polluted basins from diffuse sources in Turkey due to excessive livestock and agricultural activities. The Küçük Menderes River Basin, which has the second smallest area in Turkey, is one of these basins.

The main objective of the thesis is to show how applicable the SWAT model is in Turkey's watershed in water quality parameters and sediment, as well as to help improve the management activities at the watershed scale. In addition to this, understand the changes in hydrology and water quality under different management practices. I have chosen the Küçük Menderes Basin because although it has a relatively small area, agricultural activities are active, and thus the effects of irrigation and fertilizer use can be seen more easily. With this study, I aim to help authorities to develop water management policies and to give a successful example of SWAT modeling in a different basin scale.

This study starts with a literature review about hydrological and water quality modeling and using SWAT for Watershed modeling. After that, it continues with a detailed section to explain and define the study area features, and introduces the previous studies done in the watershed. Materials and methods included SWAT Model Theory, Data Collection, Evaluation and Preparation, SWAT Model Set-up, Calibration, Validation, and Management Scenarios The results of the modeling effort is provided in the Results section followed by the discussion of the results and concluding remarks.

2. LITERATURE REVIEW

2.1. Hydrological and Water Quality Modeling

Hydrology and water quality models that focus on the representation of natural processes are practical tools to simulate and estimate water budgets, loads, and transport of pollutants in water bodies. Due to the massive number of chemicals, water quality models have the benefits of saving time and costs for experiments. In addition, the option to measure variables in the field is not always available. (Wang et al., 2013). The importance of hydrology and water quality models continues to increase daily, and their use is rapidly becoming widespread by researchers and policymakers to support many elements such as water management, risk analysis, and scenario analyses used for different purposes (Fu et al., 2019). External conditions such as climate change and land use significantly affect surface water resources' quality and quantity. Various model approaches have been developed to track and protect these open ecosystems worldwide (Fan & Shibata, 2015). With technological developments, the numbers and diversity of the models have improved (Yuan et al., 2020).

Model types are evaluated for different criteria according to their input and parameters. One of them is lumped and distributed models based on the spatial and temporal variability of inputs. Although lumped models treat a basin as one whole area, distributed models distinguish the area into small units according to some parameters; therefore, the inputs and outputs of distributed models vary spatially (Devia et al., 2015). The other classification among models is stochastic and deterministic. In this classification, the difference is a variety of model outputs for a single set of inputs. While the deterministic model produces the same outcomes, the stochastic model gives various values. Also, models are distinct from their time factor as an event-based static model and a dynamic model that is a continuous process. Since static models don't consider time parameters, it produces outputs only for a specific time, whereas continuous models give serial results.

Models have another important classification and are divided into three empirical (metric), conceptual (parametric), and physically based (mechanistic) models. Empirical models, also called metric models or black-box models, are established within boundaries, and do not consider physical processes but are created only through observation and existing data. However, conceptual, or parametric models use semi-empirical equations to consider processes such as rainfall, runoff, and

evapotranspiration. Physically based models or mechanistic models, SWAT is an example, are based on spatial distribution and evaluate parameters according to their physical characteristics (Devia et al., 2015).

Hydrological models based on water occurrence, circulation, and distribution are water quantity related. Although each model developed has a different approach, they are used to find variations in the hydrologic cycle. Literature has many examples of hydrological models such as SWAT, MIKE SHE, HBV model, ANN, etc. (Devia et al., 2015).

There are also water quality models used to assess environmental pollution problems. Environmental management practices have diversified with the improvement of water quality models and model software (Wang et al., 2013). Water quality models are interested in water components and their interactions. The water quality models, which are stated to have passed through three stages such as the primary stage, improvement stage, and broadening stage, started with the Streeter – Phelps models (S-P models) and evolved into modeling diffuse source pollution with the economic developments in the world (Gao & Li, 2014). The examples of models interested in various parameters and results are QUAL 2K, WASP 6, QUASAR, MIKE 21, and SWAT (Wang et al., 2013).

2.2. SWAT Model Theory

SWAT is a continuous-time model that simulates various physical processes at a river basin or watershed scale (Gassman et al., 2007; Neitsch et al., 2011). SWAT as a physically based model, requires inputs such as topography, soil, land use, weather, agricultural management, and point source information to predict the impacts of these processes (Neitsch et al., 2011). Since many studies in literature explain the SWAT model, I will summarize the theory as much as possible and tailor it to the needs of this study.

As shown in Figure 2.1 and Figure 2.2, respectively, the land and routing phases are two divisions for the hydrologic cycle used by SWAT. The former is about the amount of water and accumulation of sediment, nutrient, and pesticide in the main channel, and the latter is about the movement of water, sediment, and nutrient from the channel network to the outlet of the watershed. Climate, hydrology, nutrients/pesticides, erosion, land cover/plant, management practices, main channel processes, and water bodies are the eight main sections included in the model (Neitsch et al., 2011).

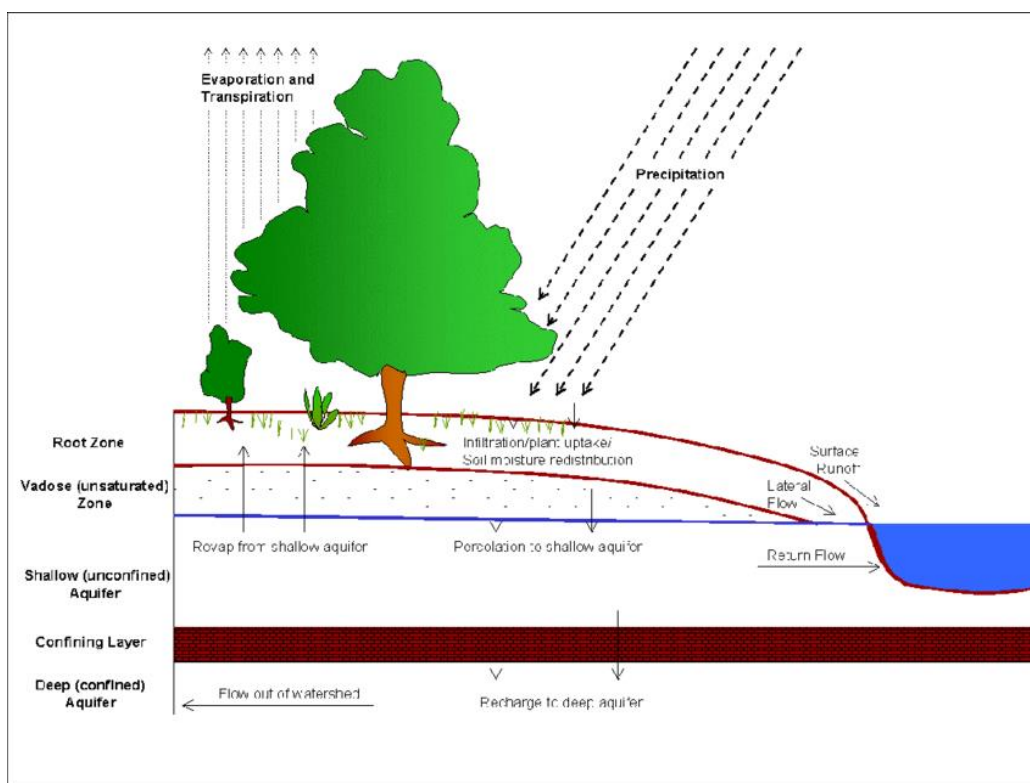


Figure 2.1. Schematic representation of the hydrologic cycle (Neitsch et al., 2011).

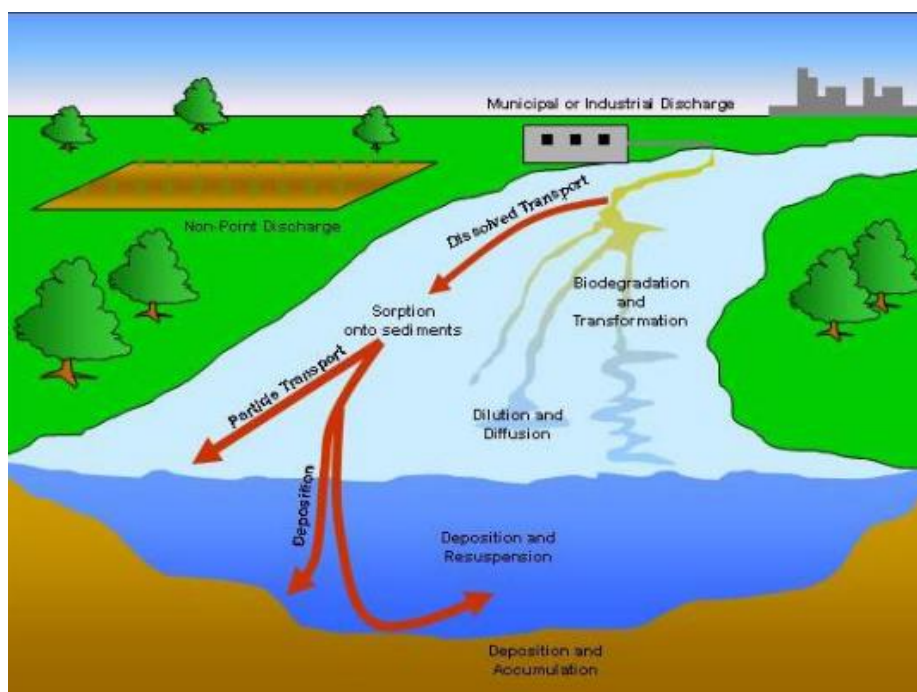


Figure 2.2. In-stream processes modeled by SWAT (Neitsch et al., 2011).

SWAT starts with partitioning the basin into sub-basins and then small units called Hydrologic Response Units (HRU). HRUs represent one particular unit with unique soil type, slope, and land

cover, but unlike sub-basins, they do not have spatiality. The creation of different areas aims to assess the impact of hydrology separately according to land use, soil types, and slope characteristic; thus, water, sediment, and nutrient transformations and losses will be evaluated for each hydrologic response unit at the sub-basin level (Fan & Shibata, 2015). The sub-basin delineation of the Lake Fork Watershed is shown in Figure 2.3 as an example (Neitsch et al., 2011).

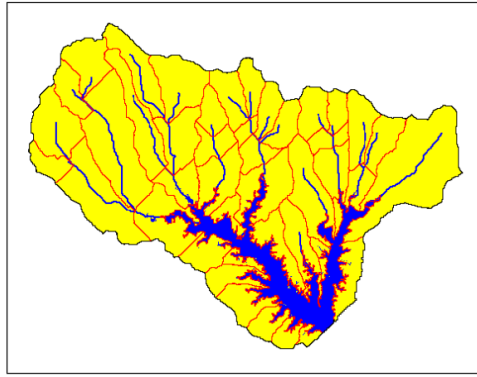


Figure 2.3. Sub-basin delineation of the Lake Fork Watershed (Neitsch et al., 2011).

The hydrologic cycle is the essential parameter used in SWAT to accurately assume the land phase's pesticides, sediments, or nutrients (Neitsch et al., 2011). (2.1 shows the equation used to calculate water balance.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (2.1)$$

“Where SW_t is the final soil water content (mm H₂O), SW_0 is the initial soil water content on day i (mm H₂O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H₂O), Q_{surf} is the amount of surface runoff on day i (mm H₂O), E_a is the amount of evapotranspiration on day i (mm H₂O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H₂O), and Q_{gw} is the amount of return flow on day i (mm H₂O) (Neitsch et al., 2011). “

SWAT uses a modified universal soil loss equation (2.2) to calculate erosion and sediment yield for each HRU (Neitsch et al., 2011).

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0.56} \times K \times C \times P \times LS \times CFRG \quad (2.2)$$

“Where Sed is sediment yield per day (tons), Q_{surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m³/s), $area_{hru}$ is the area of the HRU (ha), K is the soil erodibility factor, LS

is the universal soil loss equation (USLE) topographic factor, C is the cover and management factor, P is the USLE support practice factor, and CFRG is the coarse fragment factor”

SWAT is powerful in nutrient modeling as well. The nitrogen and phosphorus cycles are determinants to track the transformation and movement of nitrogen and phosphorus. The nitrogen and phosphorus cycles are shown in Figure 2.4 and Figure 2.5, respectively. The approach is supply and demand for plant use when estimating nutrients for each HRU. Surface runoff and lateral subsurface flow are the driving forces for the transportation of nutrients (Neitsch et al., 2011).

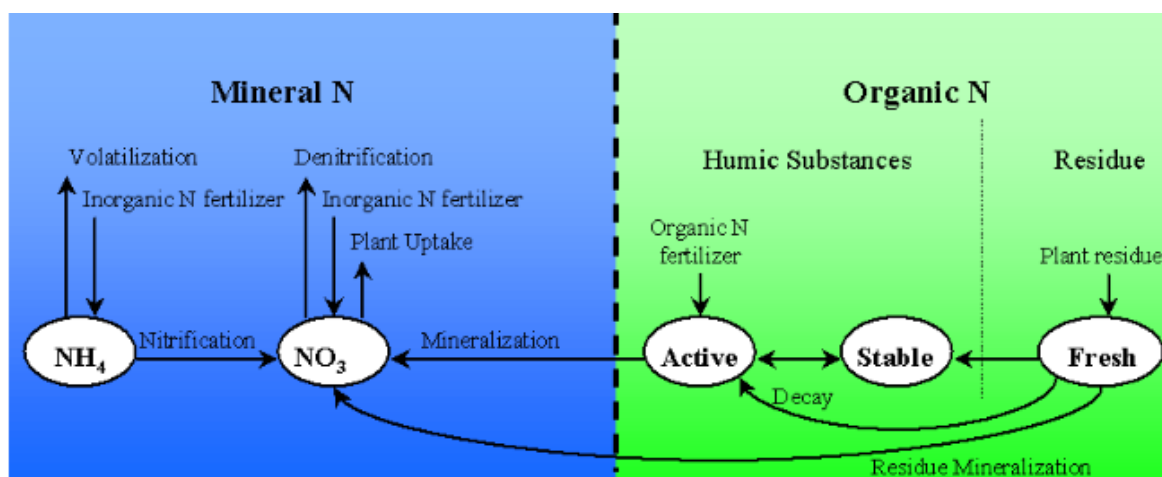


Figure 2.4. Partitioning of Nitrogen in SWAT (Neitsch et al., 2011).

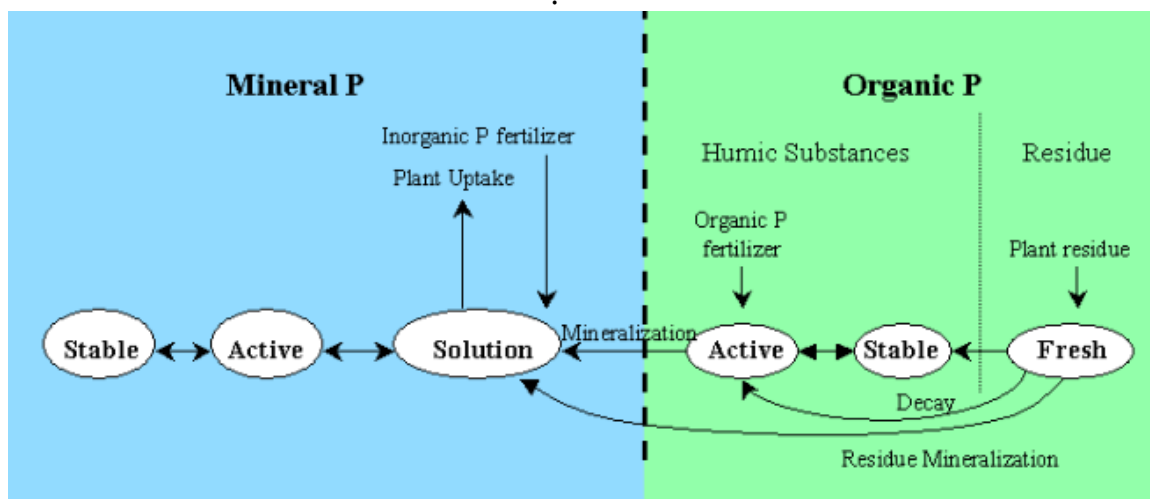


Figure 2.5. Partitioning of Phosphorus in SWAT (Neitsch et al., 2011).

2.3. Using SWAT for Watershed Modeling

In addition to its general applications, SWAT, which is used for particular subjects or specific regions, is one of the most widely used ecohydrological models, and therefore, there are many studies on SWAT in the literature (Tan et al., 2020). Water quantity and quality, floods and droughts, crop yield estimation, management practices applications, and climate change effects are examples of the application of SWAT for varied situations. Studies generally concentrate on East Asia, North America, the Middle East, and North Africa, besides the other parts of the world. While the SWAT is used for hydrology, water quality, and crop growth modeling of a watershed, it gives outputs under the main five categories: surface water, soil water, groundwater, water quality, and crop growth (Samimi et al., 2020).

SWAT is most commonly used in the field of hydrology modeling, so the vast majority of examples focus on hydrology and hydrology scenarios (Samimi et al., 2020). Hydrologic processes that SWAT used for the analysis are surface runoff, ET, groundwater flow, lateral flow, and percolation (Swain et al., 2020). While SWAT can successfully model shallow aquifers and surface waters, it does not model below the percolation layer, the bottom layer of groundwater and assume is lost out of the system. Such constraints of the SWAT model are one of the reasons why I see it widely used in integration with other models; e.g. MODFLOW and SWAT integration. (Guzman et al., 2015). Another example is the integration of the CE-QUAL model, which is a two-dimensional hydrodynamic and water quality model used to determine the reservoir water quality, which is frequently used in the literature, with the SWAT model (Mateus et al., 2014).

One of the most important outputs of the use of SWAT in the field of hydrology is that the quality of the precipitation data used when establishing the model directly affects the flow (Guamel & Lee, 2020). However, it has also been proven that the SWAT model gives successful results with good calibration, even in the data-scarce basins (Nyeko, 2015). Researchers usually evaluate model performance in SWAT applications by comparing it with daily, monthly, or annual flow data; the most commonly used are daily and monthly flow (Moriasi et al., 2007). On the other hand, studies have been carried out regarding the fact that the calibration is not performed only with streamflow and that multi-variable calibration provides more reliable results (Shah et al., 2021).

Another frequent objective of using the SWAT model is climate change scenarios. Climate change severely impacts water quantity and quality due to extreme weather events and temperature

changes. When parameters such as precipitation and evapotranspiration change, increases or decreases happen in water quality; therefore, they can cause problems such as floods or inadequate water supply (Arain, 2011). The SWAT model uses GCMs for constructing future scenarios by changing precipitation, maximum temperature, minimum temperature, wind speed, solar radiation, and relative humidity. When the studies which are focused on climate change effects using with SWAT model are assessed, it can be seen that besides the scenarios such as GFDL- ESM2M, HadGEM-ES, IPSL-CM5A-LR, the researcher used different methods like increases and decreases of the temperature or precipitation (Song & Zhang, 2012). Since the temperature and precipitation impact streamflow and nonpoint source pollution, scenarios will be used for assessing the change in these parameters (Li & Kim, 2019). While the effects of climate change mainly on hydrology, atmospheric CO₂ concentration is also reported by the researchers (Ficklin et al., 2009; Yang et al., 2019). The expected outcomes in future scenarios are streamflow, sediment, and nutrient export increases (Yang et al., 2019). Moreover, studies frequently mention considering the management practices that will be affected by climate change (Ficklin et al., 2009; Haro-Monteagudo et al., 2020; Yang et al., 2019).

It is known how applicable SWAT model in agricultural watersheds after many studies. The SWAT model, which has many successful applications in modeling the pollution loads and transports caused by the use of fertilizers and pesticides, which are the most important causes of agricultural pollution, integrates the applications carried out in agricultural basins into the model with daily scheduling or a heat unit scheduling (Neitsch et al., 2011). The SWAT model is applied for various purposes in agricultural basins. Along with studies investigating the effects of agricultural practices on hydrology and sediment (Benaman et al., 2005), there are studies focusing on pollution loads from fertilizer use (Malagó et al., 2017b) and pesticide use (Cambien et al., 2020), or discussing the effects of practices on plant growth (Chen et al., 2021). Studies are generally since the model is successful in practice, but they also frequently discuss the difficulties experienced in the application of the model, such as the redundancy of data required for model setup and calibration difficulties. Variables used as agricultural pollution scale in applications are generally nitrate (NO_3^-), total nitrogen (TN), and total phosphorus (TP) (Malagó et al., 2017b), but variables such as nitrite (NO_2^-) (Kansara & Lakshmi, 2021), ammonium (NH_4^+), orthophosphate (PO_4^{3-}) are also used (Bouraoui et al., 2005).

There are illuminating results regarding the application of the SWAT model in agricultural watersheds and the effects of good agricultural practices, land use or crop rotation on hydrology and water quality. Jiang et al. (2021) used reallocating scenarios between hay and corn-soybean and

reported decreasing average annual TN, TP, and sediment load. Chen et al. (2021) studied the effects of irrigation depths with 14 different scenarios for corn, sorghum, and wheat, and found that greater irrigation depths caused an increase in soil water content and runoff while reducing irrigation amounts. P. Chen et al. (2021) assessed the impact of land use on water quality, changing grassland to different crops, and observed increasing TN and TP loads at the watershed outlet. On the other hand, researchers reported the challenges and limitations of SWAT for this specific use. Benaman et al. (2005), used SWAT in an agricultural watershed in Upstate New York, got the good results from hydrology calibration, however, mentioned the difficulties of sediment calibration.

Best management practices (BMPs) are often applied to assess the effects of the model in agricultural watersheds. Naseri et al. (2021) implemented SWAT and the NSGA-II evolutionary algorithm to estimate optimal BMPs impacts on streamflow and sediment and found that sediment yield is more affected than streamflow. Merriman et al. (2019) investigated the 74 BMPs; results showed that sediment and nutrient decrease with the implantations of BMPs and highlighted that multiple BMPs are more effective. Daloğlu et al. (2014), investigated effects of agricultural conservation practices in Lake Erie, implementing a stylized agent-based model (ABM) to understand farmers decisions impacts on water quality.

Although the SWAT model is frequently applied in small or large-scale basins, there is also a continental scale applications. Abbaspour et al. (2015) build and calibrate the SWAT model in Europe. In the study, different water components, crop yield and water quality are investigated, and data availability is discussed.

Because the SWAT has been used for modeling for a long time in the literature, many examples exist in Turkey besides worldwide. SWAT applications continue to gain momentum in Turkey and Turkish researchers have widely used the M.Sc. or Ph.D. thesis as the model for hydrology, water quality, and sediment modeling. Besides the dissertations, many articles have been published in recent years to demonstrate the applications and challenges of the SWAT model. Peker & Cüceoğlu, 2022 reviewed the studies accomplished by SWAT in Turkey and found that while most of the articles (69 %) focused on hydrology, only 31 % of them were interested in water quality. On the other hand, Samimi et al., 2020 studied arid/semi-arid irrigated agricultural watersheds, revealing that Turkey and the world have equivalent outcomes. Their research comprises several parts of the world, and the water quantity is still the most imposed subject on the SWAT model in East Asia, North America, and the Middle East and North Africa (MENA).

In studies conducted within the context of Turkey, the acquisition of data sets indispensable for the development of a Soil and Water Assessment Tool (SWAT) model predominantly relies on consistent sources. Specifically, the Digital Elevation Model (DEM), land use data, and soil maps primarily draw upon the resources provided by SRTM, CORINE, and FAO, respectively. Meteorological stations, together with the quantity and quality observation stations, are chiefly obtained from the General Directorate of Meteorology and the State Hydraulic Works (Peker & Cüceoğlu, 2022).

Studies that have been done in different geographical parts of Turkey have varied objectives. (Baltacı, 2019; Karakoyun, 2022; Yıldırimer, 2018) focused on the sediment pollution in İnebolu Basin, Murat River Basin, and Borçka Reservoir Basin, respectively. All used the SWAT-CUP SUFI-2 algorithm, primarily used for the studies, to calibrate the SWAT models. Baltacı, 2019 and Karakoyun, 2022 used the LOADEST program to return daily suspended solid to monthly suspended solids, while Yıldırimer, 2018 mentioned they used measured suspended solid values for the research. Three of them used the same objective functions, which are R^2 , NSE, and PBIAS, and reported satisfactory results. However, Yıldırimer, 2018, mentioned that they did not get good results from one of the points for the monthly sediment calibration and explained that it was caused because of the hydroelectric power plants close to the stream.

Four studies specifically focused on water quality modeling using the SWAT model have been done in Turkey, Tuzla (Palas) Lake Watershed, Gürdük Watershed, Ergene River Basin, and Lake Mogan Watershed. While two of them were interested in agricultural pollution (Kabal, 2019; Özcan, 2016), in the study in the Tuzla (Palas) Basin (Azgın, 2015), climatic and land use changes were reported. On the other hand, due to the Ergene River Basin requirements where industrialization is concentrated, industrial discharges are used as point sources in the model (Paçal, 2017). Like the previous studies, researchers used the SWAT-CUP program SUFI 2 algorithm for the calibration process except for Azgın, 2015 who did not mention the calibration algorithm. In addition, Paçal, 2017 used manual calibration for nutrient data; also, they could not validate it because of data scarcity. Özcan, 2016, on the other hand, solved this problem using different monitoring stations for the calibration and validation processes.

Three studies preferred to use R^2 and NSE as objective functions, which are frequently used in modeling research. Özcan, 2016 and Kabal, 2019 used PBIAS beside the two. However, Azgın, 2015 adopted RMSE and correlation coefficient in their study. While streamflow, nitrate (NO_3^-), and total

nitrogen (TN) were the typical variables among the researchers, Özcan, 2016 and Kabal, 2019 also used sediment, and except for Azgin, 2015 , others used total phosphorus (TP) to calibrate or compare their models' results.

While Azgin, 2015 and Özcan, 2016 implemented a one-at-a-time sensitivity analysis, Paçal, 2017 performed a global sensitivity analysis. Kabal also used global sensitivity analysis, which was done in another study. Özcan, 2016 also mentioned that they performed a one-at-a-time sensitivity analysis after calibration. Before the calibration, they also used parameters from literature. Researchers selected one (Azgin, 2015 and Özcan, 2016) and two years (Paçal, 2017) of warm-up periods.

At the end of the study, while results for monthly streamflow were in good agreement, daily streamflow was acceptable, and nutrients were also adequate for the study done by Paçal, 2017. The researcher explained the difference between daily and monthly results as data scarcity in the Ergene River Basin. Özcan, 2016 also reported their outcomes as satisfactory and added that their model slightly overestimates flow. Azgin, 2015 also assessed the calibration results of streamflow as satisfactory even though the results were affected by hydrological and meteorological data scarcity. In Kabal, 2019 study, streamflow calibration succeeded for two stations, but one was not for NSE and PBIAS. Their explanation was intense human activity in the watershed and modelers' errors.

Kabal, 2019 sediment outcomes failed for NSE and R^2 but were satisfactory only for PBIAS. Özcan, 2016, who used the same objective functions with Kabal, 2019, on the other hand, did not get good results in any of them. Two reasons were discussed in the latter for the unsuccessful results; discrepancy in streamflow calibration and sediment observation months mainly belong to winter. Kabal, 2019 commented the failure was mostly with the higher sediment yield values, and more data can cause more promising results.

When the studies' results for quality variables were assessed, it can be seen that the most challenging part was here, and some of the results were unsatisfactory. Azgin, 2015 only implemented graphical comparison and did not calibrate quality parameters. In the study correlation coefficient was found as inadequate according to the literature. Özcan, 2016 reported the calibration results of NO_3^- and TP as unsatisfactory except for PBIAS. When Kabal, 2019 found satisfactory results for PBIAS and R^2 , NSE failed. Paçal, 2017 did manual calibration for quality and, like Azgin, 2015 , compared them on the graphs. As an objective function of R^2 , their result was satisfactory.

Although the common argument was data scarcity among the researchers, some other problems were suggested for water quality. For instance, Özcan, 2016 explained the NO_3^- overestimation caused by the fertilizer type used in the model setup. The significant highlight was that researchers continued to apply scenarios despite unsatisfactory sediment and water quality results.

2.4. SWAT-CUP Applications and Parameter Selection

As can be seen from many applications, the SWAT-CUP program is often used to calibrate the SWAT model. Therefore, researchers discussed many problems and improved recommendations about SWAT and SWAT-CUP programs. Although the primary sources are the programs' manuals, specific studies are primarily used in literature and this study. Two were done in Thur Watershed and Europe to model hydrology and water quality by Abbaspour et al. (2007) and Abbaspour et al. (2015), respectively. The other is the study that offered calibration guidelines for SWAT-CUP (Abbaspour et al., 2017).

Due to the number of parameters that affect the streamflow, sediment, and water quality, and the number of parameters significantly impact the calibration time, modelers should be careful about the parameter selection. For this reason, Abbaspour et al. (2015) suggested specific parameters according to the initial models' requirements. If the model has a pattern such as overestimating baseflow, underestimating runoff peaks, or higher nitrate loads, recommended parameters can increase or decrease as needed, and satisfactory results can be reached without time consumption. Abbaspour et al. (2007), on the other hand, suggested parameter sets to use in the calibration processes of different variables because some parameters impact only streamflow; for instance, some of them impact streamflow and sediment simultaneously. When considering the recommendations about respective simulations in the literature, as first streamflow, then sediment, and the nutrient, this study offers a point of view on the parameter selection for this issue. While CN2 and SOL_AWC are the common parameters for streamflow, RCN is the common parameter for nitrate.

In addition to parameter selection, it is essential to consider the model's non-uniqueness, which means the same result can be obtained from diverse parameter sets; therefore, choosing any of them causes incorrect interpretation due to inaccuracy. For the solution, calibration uncertainty analysis, calculated with the p-factor and r-factor in the SWAT-CUP, should be taken into account. Indeed, Abbaspour et al. (2015) emphasizes consideration of p-factor and r-factor rather than objective functions representing the percentage of data within the 95 PPU band and the thickness of the band,

respectively. More than 0.7 and less than 1.5 are the intervals suggested for p-factor and r-factor in the literature correspondingly (Abbaspour et al., 2015).

3. STUDY AREA

Küçük Menderes River Basin is one of the 25 hydrological basins in Turkey, which is located in the western part of Turkey. The total precipitation area of the basin is 6963 km², and the annual average flow is 0.54 hm³. The mainstream with the average length of 129 km, called Küçük Menderes, flows into the Aegean Sea; therefore, the basin has open characteristics. The basin covers primarily İzmir city and also some of Kuşadası, the district of Aydın city. Küçük Menderes Basin is surrounded by mountains Karadağ, Beydağ, Kümeli Dağı Bozdağ, and Kesme Mountains, on the other hand, İzmir Bay and the Aegean shoreline. In the Küçük Menderes Basin, typical features of the Mediterranean climate, hot and dry summers, and warm and rainy winters are observed. The vegetation that develops due to the Mediterranean climate characteristics in the basin consists of dwarf plants at low elevations, mixed-type tree communities towards higher elevations, and coniferous forests.

Küçük Menderes, the mainstream rising in the Kiraz Plain, is fed by many tributaries, forms a delta in the Pamucak Region, and then flows into the Aegean Sea. Although the river floods and marshes occur in the winter, many tributaries dry in the summers. As surface resources, a few lakes are in the basin. The largest lakes are Belevi and Çatal, which are situated downstream. Barutçu and Gebekirse lakes also occurred after the transportation of Küçük Menderes River's alluvion.

The General Directorate of State Hydraulic Works determined five sub-basins in the watershed, considering features such as surface precipitation area, groundwater recharge area, geological, hydrogeological, and aquifer structures, and this study will focus on the Küçük Menderes sub-basin, which has the mainstream and most extensive area (Figure 3.1). The Kuşadası Sub-basin does not have a surface water body (Devlet Su İşleri Genel Müdürlüğü, 2016).

The agricultural land covers 44.8 % of the basin, and 52 % of this area is classified as arable land, while the rest is classified as dry land (Su Yönetimi Genel Müdürlüğü, 2018). Essential products are olives, corn, cotton, tobacco, wheat, tomatoes, watermelon, clover, forage turnip. Cotton and tobacco production has been decreasing in time with the regulations in the basin (Gülersoy & Çelik, 2014). The study, which focused on agricultural land use, determined that agricultural areas were used in accordance with their purpose for now. It also recommended continuing use for agriculture

as their purpose instead of using it as residential or industrial areas in the future because wrong land use significantly affects the quality of agriculture (Güzdüzoğlu & Çukur, 2019).

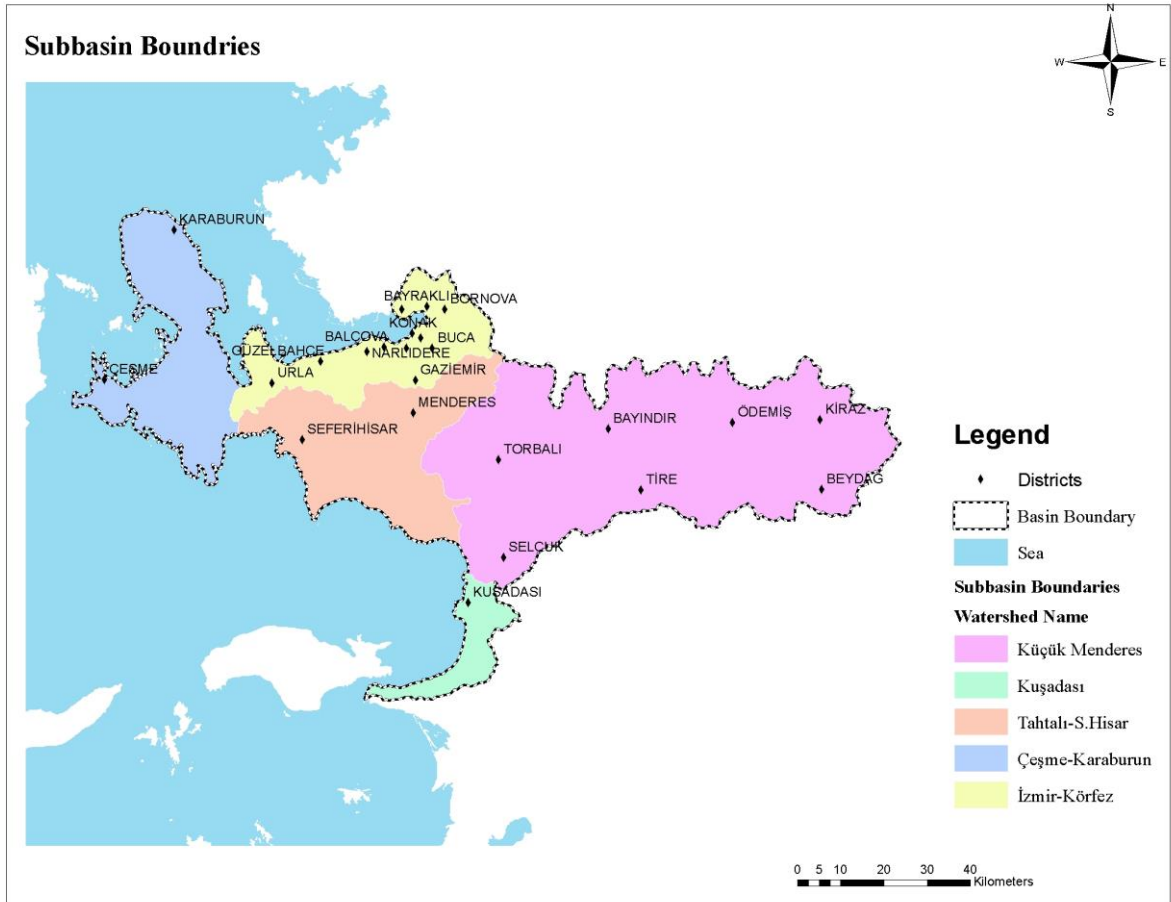


Figure 3.1. Küçük Menderes River Basin's sub-basins.

In the basin, the Ministry of Agriculture and Forestry has done a lot of important projects under the Water Framework Directive until now (Table 3.1). These projects have different focuses and valuable results for this study. The leading five projects are going to be elaborated below. After that, their outcomes will be discussed to determine discrepancies.

Table 3.1. Main projects accomplished in the basin.

Project Name	Year
Küçük Menderes River Basin Management Plan	2019
Kuzey Ege, Gediz and Küçük Menderes River Basins Flood Management Plan	2019
Küçük Menderes River Basin Sectoral Water Allocation Action Plan	2019
Küçük Menderes River Basin Drought Management Plan	2018
Küçük Menderes River Basin Master Plan	2016

The Ministry of Agriculture and Forestry did the first project, namely Watershed Protection Action Plan, in 2010; after that, they renewed it in 2019 as River Basin Management Plan. This study evaluated point sources of domestic and industrial activities in Küçük Menderes Basin and investigated diffuse pollutants. The study discusses in detail septic tanks, irregular dumps, agricultural resources, fertilizer use, land use, livestock activities, mining activities, transportation, and air pollutants. The findings indicate that livestock activities play a significant role in causing nitrogen and phosphorus pollution, which are considered within the scope of diffuse pollution. Küçük Menderes River Basin Management Plan climate projection results show temperature increases are between 1.9-3.2 °C for RCP 4.5 and 3.9 – 5.3 °C for RCP 8.5 at 2100 in the basin. (Su Yönetimi Genel Müdürlüğü, 2019b)

Another study focused on water resources in Küçük Menderes River Basin, Master Plan Project, was accomplished in 2016. The workers calculated the water potentials and the actual and future water consumption of the Küçük Menderes River Basin according to sub-basins. Per the project outcomes, the yearly average surface water potential is 624 hm³, and the average annual precipitation is 693 mm. Considering agricultural, industrial, and human uses of surface water and groundwater, the total water consumption is 1220,58 hm³, and water needs in the future were calculated as 1408,04 hm³. In addition to the water quantity, the water quality from various sources is the well-informed outcome of the project. Not only domestic, industrial, waste, and geothermal polluters as known for point sources but also diffuse pollution from land use livestock and agriculture have been the subjects of the research. As a result, they found surface water quality classes according to Surface Water Quality Regulation. While fourteen water bodies were determined in class three, six were in class four. Suggestions about the plants in the basin, such as irrigation, energy, drinking water, and flood, were other project outcomes. Transferring from the Gediz Basin to the Küçük Menderes Basin to supply the need for drinking water in İzmir City is one of the suggestions that can affect the water amount.

Also, the Drought Management Project was published in 2018 in three sections: drought analysis, water budget works, and the action plan. The first section includes a literature review of the Basin. Settlements, geography, topography, population, water resources, hydrogeology, and climatic situation of the Basin were discussed. This study delineated the Basin into six sub-basins, unlike the others. Integration of the two sub-basins, Upper Menderes and Lower Menderes, compose the Küçük Menderes Sub-basin, which is this study's focus. Drought analysis was performed using seven indexes, and three climate scenarios were implemented. In the second section, they did water budget

studies for surface and groundwater resources. 624 hm³/year and 716,78 hm³/year water potential were determined for surface and groundwater, respectively. For RCP 4.5 and RCP 8.5 scenarios, surface water potential has a decreasing trend in 2018-2098, according to the study. Contrary to the surface water potential, groundwater potential has an increasing trend for the same period in both scenarios. The third section includes the vulnerability analysis of sectors and the decreasing capacity of the drought effects. The results showed that the most water consumption was used in Upper Menderes Sub-basin, and the water was used mainly for agricultural purposes. Vulnerability for agriculture was found more likely in the Upper and Lower Menderes Basins. The study recommended that the focus on dry farming strategies and improvement of irrigated agriculture should be considered in these sub-basins.

Sectoral Water Allocation Action Plan is another critical study in the Küçük Menderes River Basin in 2019. This study has focused on the water needs of 12 sectors: agriculture, energy, tourism, industry, mining, etc., between 2021-2025. In addition to this, drought scenarios and water budgets were studied in the basin. The results demonstrated that surface water potential changes between regular and drought periods from 77.70 hm³/year to 31.25 hm³/year, respectively. Groundwater potential, on the other hand, has a decreasing trend with the increasing drought severity between 250 hm³/year to 100 hm³/year in the Küçük Menderes Sub-basin. Researchers also indicated that the severity of the drought will increase all around the basin by 2071. The water needs of Küçük Menderes sub-basin are significantly from the agriculture sector, as mentioned in the study. The results clearly show that, even though this demand can be met for now, in the future, with increasing severity of drought, water potential will be inadequate to meet this demand. Researchers recommended reusing wastewater after treatment for agricultural activities and optimizing planting patterns.

The Flood Management Plan Project was the other study implemented in the basin. Similar to the other studies, firstly, this study examined the basin features such as socioeconomic situation, water resources, geology, and topography. After the literature review, flood risk assessment, management methods, and cost-benefit analysis were discussed. In this study, which was carried out according to the districts in the basin, the most sensitive provinces were Bornava, Konak, and Tire. It has been determined that Menderes and Torbalı settlements, as districts with arable land, may be particularly affected by floods. The suggested precautions are divided into three before, during, and after the flood. Flood control reservoirs and river reclamation can be used before the flood, coordination, and

evacuation can be used during the flood, and improvement and restructuring can be used after the flood.

Table 3.2. Features of the Küçük Menderes River Basin (Master Plan (2016))

Area (km ²)	6,963
Average annual flow (hm ³)	0.54
Average annual flow (m ³ /s)	17.16
Average annual precipitation (mm)	727
Average annual temperature (°C)	16.8
Average evapotranspiration (mm)	1,525
The length of the Küçük Menderes River (km)	129
Average annual surface water potential (hm ³)	624
Average flow efficiency (l/s/km ²)	2.4
Rate of average flow/precipitation	0.1
Groundwater recharge (hm ³)	716.5
Water consumption (hm ³)	1220.58
Population	3,569,806
Sub-basins number	5

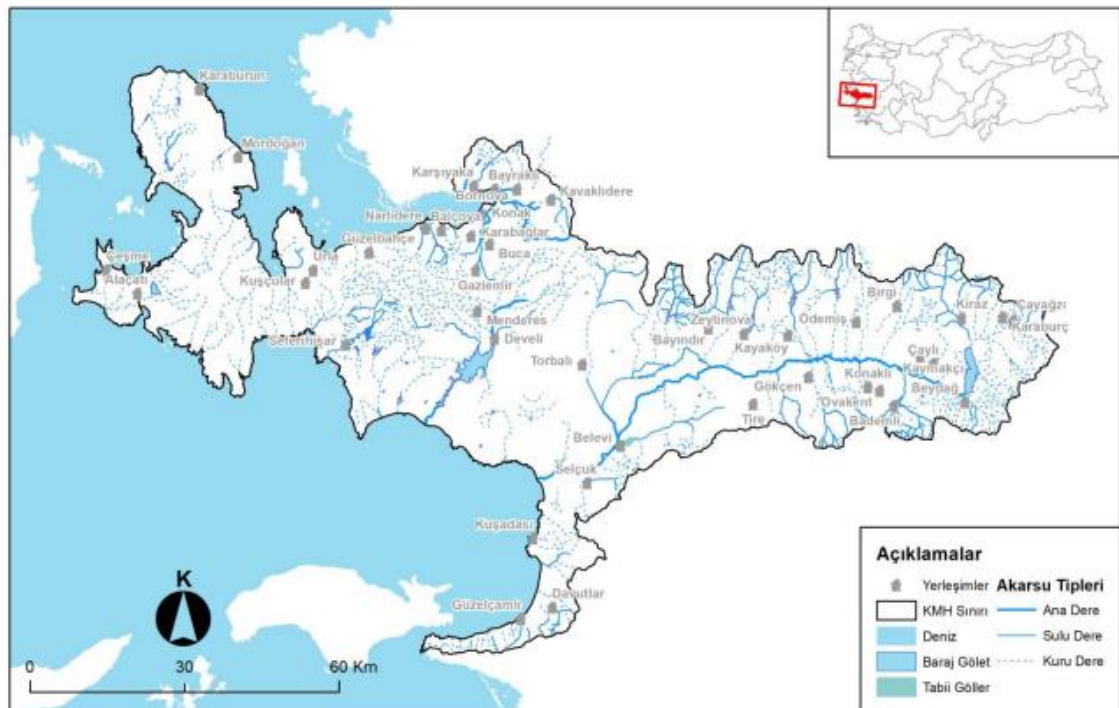


Figure 3.2. Küçük Menderes River Basin Drainage Network (Su Yönetimi Genel Müdürlüğü, 2019a).

According to a study by the Republic of Turkey Ministry of Agriculture and Forestry, Impacts of the Climate Change on Water Sources Project (2016), the average temperature will increase in the basin. They used three climate projections which are HadGEM2-ES, MPI-ESM-MR, and CNRM-CM5.1. The result shows that the highest temperature increase prediction was the HadGEM2-ES

model, and the lowest forecast was the MPI-ESM-MR model RCP4.5 scenario. Considering all models and scenarios, temperatures are expected to increase by more than 2°C after 2050, and the highest temperature increase will be seen in the period 2091-2100 with results up to 5.2°C.

When total precipitation projections in Küçük Menderes River Basin are assessed, the HadGEM2-ES model RCP 8.5 scenario shows that the frequency and severity of negative anomalies will increase. In the MPI-ESM-MR model, the RCP4.5 and RCP8.5 scenarios reveal that highly significant decreases in precipitation are expected in the entire basin. According to the results of the CNRM-CM5.1 model RCP8.5 scenario, it is predicted that there will be a lack of rainfall in the basin. The critical outcome of the study is that according to the effects of models, in both scenarios, the water demand in the basin cannot be supplied (GDWM, 2016).

As mentioned above, Küçük Menderes Watershed is the largest sub-basin of the Küçük Menderes Basin, with an area of 3491 km². The watershed contains nine districts of İzmir: Menderes, Torbalı, Selçuk, Bayındır, Kemalpaşa, Tire, Ödemiş, Beydağ, and Kiraz. Although Buca, Salihli, Turgutlu, Nazilli, Sultanhisar, and Köşk, which are the districts of İzmir, Manisa, and Aydın, fall into the watershed boundaries, the areas within the boundaries are negligible. In this study, the area will be limited to Küçük Menderes Watershed, which involves the mainstream and has denser agricultural activities.

4. MATERIALS AND METHODS

In this part, the required data sets will be explained. After that, the steps of the model set-up will be described, and then calibration, validation, and sensitivity analysis will be detailed. As a result, discussions and recommendations will be made about the research outcomes. The stages of this study are visualized in Figure 4.1. This study will use the SWAT model to investigate the water quantity and quality in the Küçük Menderes Basin.

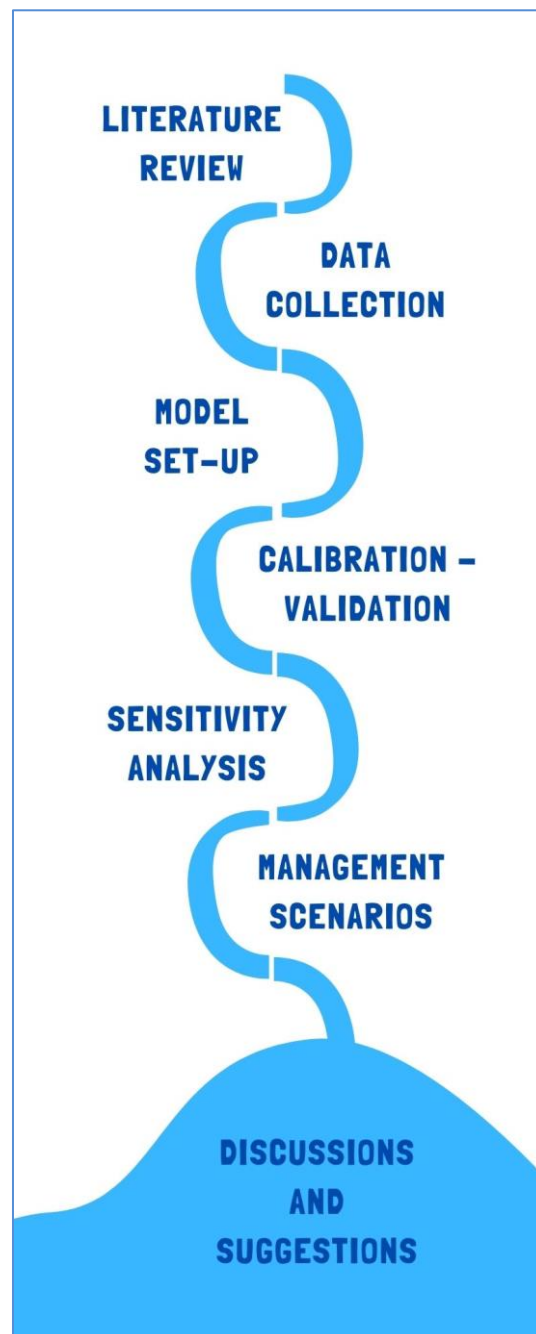


Figure 4.1. Visualizing the stages of the research.

4.1. Data Collection, Evaluation and Preparation

SWAT requires various data sets to calculate the processes in the watershed. While some data sets are compulsory to start a simulation, some can vary according to the study's needs. Input data, their descriptions, and sources required and obtained for this study are given in Table 4.1. After the required data sets are obtained, they should be prepared as SWAT input data. In the below sections, arrangements for each data set are explained.

Table 4.1. Input data for SWAT Model.

DATA TYPE	DATA DESCRIPTION	SOURCE
Topography	Digital Elevation Model (DEM) (elevation, slope, 30mx30m resolution)	USGS
LULC	Corine 2012 Land Cover Map / Land use and classification (agricultural land, pasture, forest etc.)	European Environment Agency CORINE Land Cover (CLC) inventory
Soil	Global Soil Map / Soil properties (soil hydrologic group, maximum rooting depth, fraction of porosity etc.)	FAO – UNESCO
Meteorology	Daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data	Turkish State Meteorological Service
Agricultural Management	Information on main cultivated products, agricultural management schedule and fertilizer usage information	Literature review, and face to face interviews
Calibration/Validation	Discharges, Water quality	The General Directorate of State Hydraulic Works (DSI)

4.1.1. Digital Elevation Model and Stream Network

A DEM (Digital Elevation Model) file is required as topographic data for the Küçük Menderes River Basin to evaluate the slope, length of the slope, stream network characterization, and delineation (Nyeko, 2015; Kabal., 2019). USGS official website provides Digital Elevation Model data (<https://earthexplorer.usgs.gov/>), accessible freely worldwide. The data set is called SRTM 1 Arc Second Global Data with a resolution of 30m x 30m (accessed on 1/29/2023).

Users can select maps on the website either with a watershed boundary or using a specified rectangular option, so approximately the watershed is selected and downloaded from the website. After a delineation trial in ArcGIS, DEM was clipped according to the boundaries of the watershed. In the study area, elevation varies between -5 m to 2139 m (Figure 4.2).

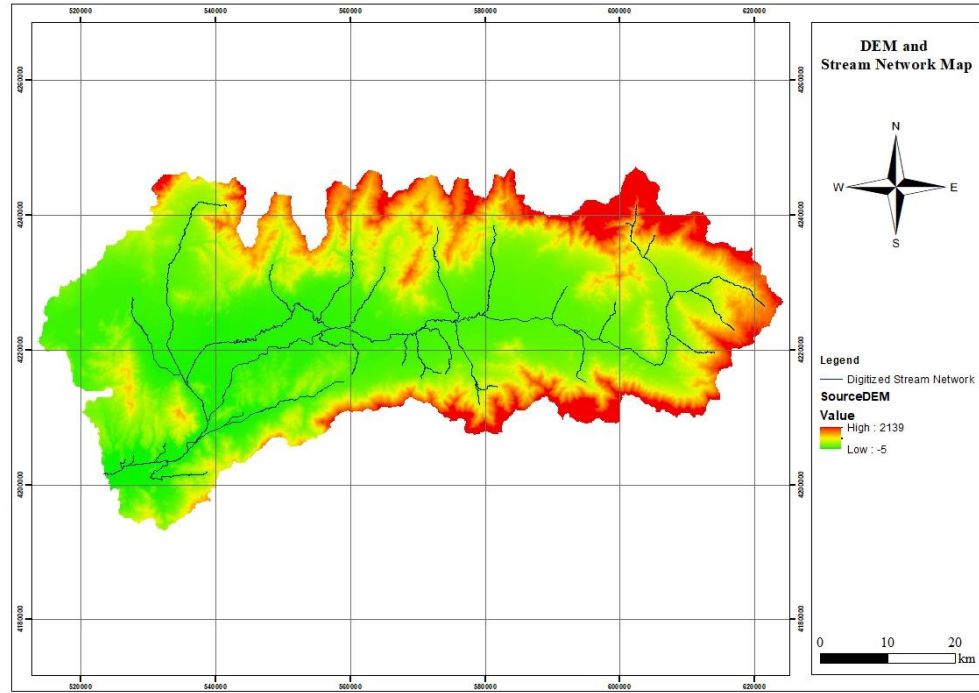


Figure 4.2. DEM and digitized stream network map of the Küçük Menderes Watershed.

4.1.2. Reservoirs, Ponds, and Lakes

I examined two previous plans conducted by the Ministry of Agriculture and Forestry; Küçük Menderes River Basin Management Plan and Küçük Menderes River Basin Master Plan (see Section 2.4.). Additionally, I used one internet page administered by The General Directorate of State Hydraulic Works to determine reservoirs and their features in the Küçük Menderes (<https://bolge02.dsi.gov.tr/Sayfa/Detay/861>). According to these studies, five reservoirs and eight ponds are in the watershed, and Table 4.2 shows their characteristics. Ergenli and Rahmanlar reservoirs and Dereli and Akalan ponds are in construction as of 2023. As seen in Table 4.2, except for Beydağ Barajı, many are new, considering the focus of the study years, and have small areas and low flow. Besides the reservoirs, there are three leading natural lakes in the watershed. Gebekirse, Barutçu, and Çatal lakes are close to the downstream on the southwestern part of the watershed. Another lake generally classified as a wetland is Eleman. Because they will not be used at the modeling phase, only the largest two are demonstrated in Figure 4.3.

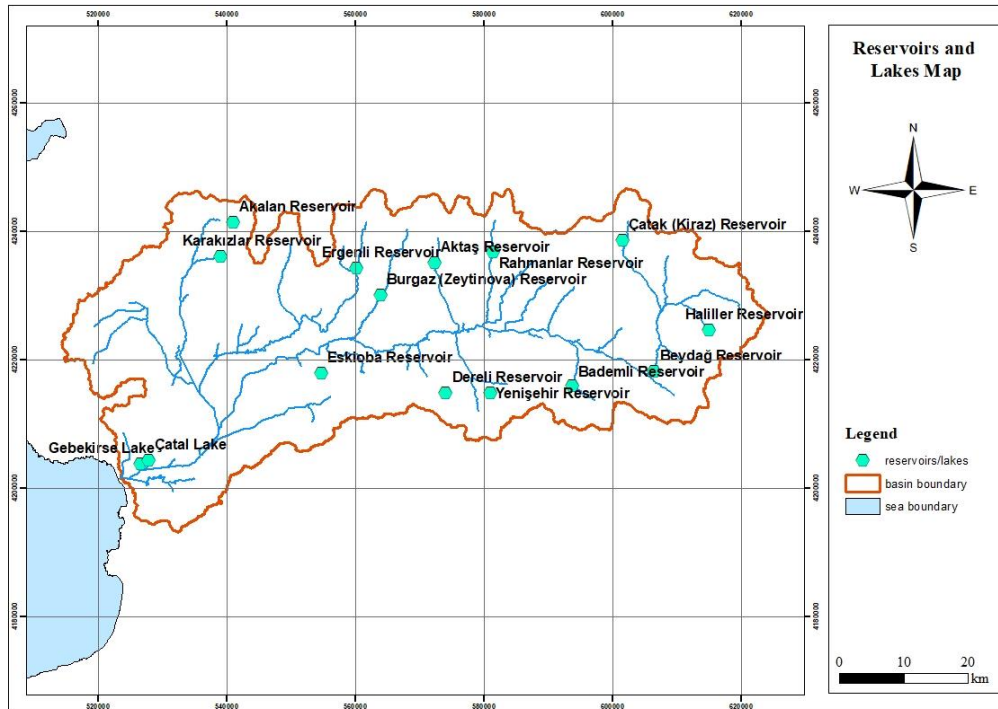


Figure 4.3. Reservoirs and lakes 2012 in the Küçük Menderes Watershed.

Table 4.2. Characteristics of the reservoirs and ponds in the watershed.

Name of the reservoir/pond	DSI	MASTER PLAN (2016)						
	Current Situation	Flow (hm ³ /year)	Area (ha)	The year of reservoir become operational	Normal water level (m)	Max water level (m)	Min water level (m)	Precipitation area (km ²)
Beydağ Reservoir	In operation	50.64	1452.27	2008	221.2	224.11	182.55	444
Aktaş Reservoir	In operation	8.33	175.71	-	391	392.94	328	58.7
Burgaz (Zeytinova) Reservoir	In operation	17.53	135.11	2013	180	183.01	115	91.2
Ergenli Reservoir	In construction	21.64	108.36	-	242.5	244.1	174	55.8
Rahmanlar Reservoir	In construction	20.75	89.07	-	256.7	259.62	200.63	65.2
Bademli Pond	In operation	24.42	33.23	2015	289.5	292.14	262.5	39
Haliller Pond	In operation	6.02	12.42	2014	452.75	454.08	438.7	17.4
Eskioba Pond	In operation	0.336 +0.289	7.67	2015	88	88.73	68	3.7
Karakızlar Pond	In operation	-	7.49	2014	236	237.75	221	21.8
Yenişehir Pond	In operation	0.797	7.12	2013	391	392.49	379.8	13.5
Çatak (Kiraz) Pond	In operation	-	4.95	2015	598	599	584	18.4
Dereli Pond	In construction	-	9.33	-	310.59	311.49	290.94	-
Akalan Pond	In construction	-	7.81	-	368.33	369.23	354.14	-

4.1.3. Land Use-Land Cover Data

In this study, CORINE was used as Land Use-Land Cover data. CORINE has 3 hierarchic class levels as level 1, 2, and 3 (Figure 4.4). There are five main classes in level 1: artificial areas, agricultural areas, forest and semi-natural areas, wetlands, and water bodies. Level 1 has five main classes: artificial fields, agricultural fields, forest, and semi-natural areas, wetlands, and water bodies. Classes at level 1 are then divided into separate classes, each in itself; this is called level 2. Similarly, the classes specified in Level 2 also differentiate among themselves in more detail and form Level 3 classes.



Figure 4.4. CORINE land cover classes (Copernicus, 2023).

The data was downloaded from the official website (<https://land.copernicus.eu/pan-european/corine-land-cover>). There are 5 data sets for 1990, 2000, 2006, 2012, and 2018; therefore, for demonstration of the temporal variation all data sets are used. The comparison was made with level 1 classification.

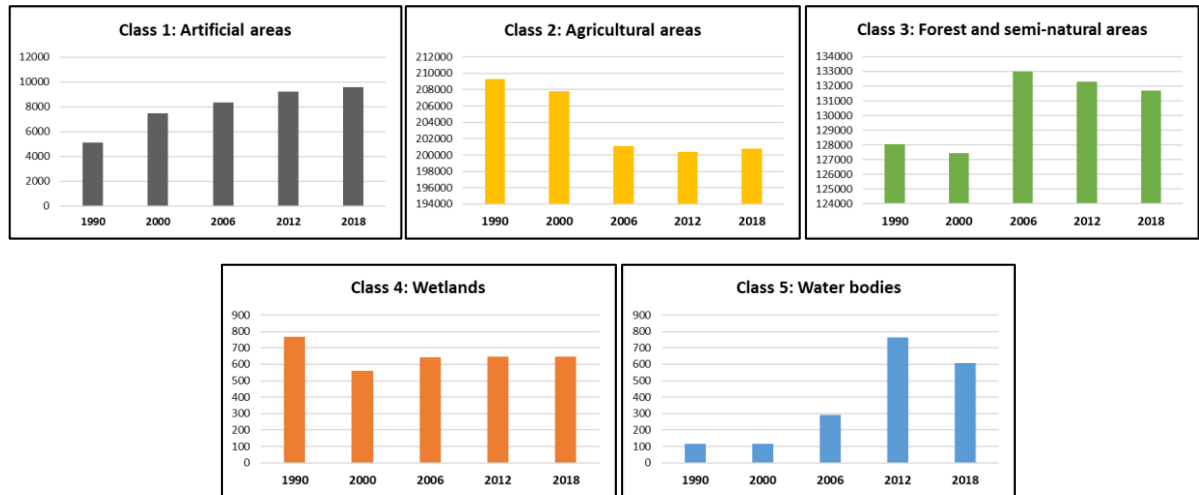


Figure 4.5. CORINE Land Cover (ha) comparison by year for the Küçük Menderes Watershed (data source: CORINE 2012).

As illustrated in Figure 4.5, agricultural areas, forest cover and semi-natural areas demonstrated the highest temporal variation in area from 2000 to 2006. The changes in the water bodies were due to the construction of new reservoirs which started to operate after 2006, and this area can be disregarded since it was so small in the total area. As the model integrated weather data from selection in 2001-2020, the 2012 Corine Land Cover data set was chosen to represent the simulation period.

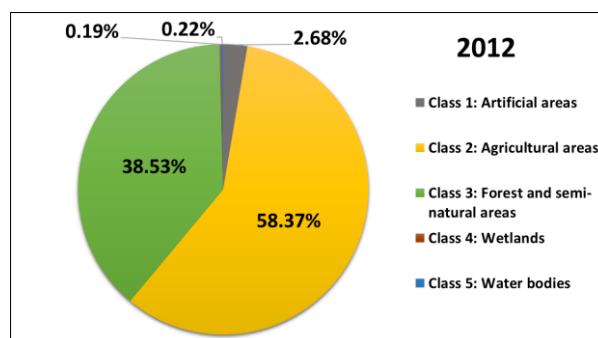


Figure 4.6. CORINE Land Cover distribution by classes in the Küçük Menderes Watershed (data source: CORINE 2012).

In addition, the look-up table was prepared to match up CORINE codes and SWAT codes using level 3 classification. From the literature review, I observed that not every study uses the same coding

protocol. For example, one study may map permanently irrigated land to the AGRR SWAT code, while another study may use AGRL instead. When the look-up table was prepared, I used the CLC illustrated nomenclature guidelines and the SWAT manual, and two studies conducted in Turkey (Cüceloğlu, 2019; Saddiqi, 2019). Since these study focuses are not on agricultural activities, they did not differentiate all agricultural land uses. However, I had to use different classes for different agricultural areas to implement the management practices only for permanently irrigated land. Therefore, I assessed this study's necessities and prepared a look-up table according to SWAT Input/Output Documentation. Table 4.3 compares CORINE codes and definitions and SWAT codes and definitions.

Table 4.3. CORINE and SWAT comparison for land cover.

CLC3	CORINE Definition	Code	SWAT Definition
111	Continuous urban fabric	URHD	Residential-High Density
112	Discontinuous urban fabric	URMD	Residential-Medium Density
121	Industrial or commercial units	UIDU	Industrial
122	Road and rail networks and associated land	UTRN	Transportation
124	Airports	UTRN	Transportation
131	Mineral extraction sites	UIDU	Industrial
132	Dump sites	UIDU	Industrial
133	Construction sites	UIDU	Industrial
142	Sport and leisure facilities	URLD	Residential-Low Density
211	Non-irrigated arable land	WWHT	Winter Wheat
212	Permanently irrigated land	AGRR	Agricultural Land-Row Crops
221	Vineyards	GRAP	Vineyard
222	Fruit trees and berry plantations	ORCD	Orchard
223	Olive groves	OLIV	Olives
231	Pastures	PAST	Pasture
242	Complex cultivation patterns	AGRC	Agricultural Land-Close-grown
243	Land principally occupied by agriculture, with significant areas of natural vegetation	AGRL	Agricultural Land-Generic
311	Broad-leaved forest	FRSE	Forest-Evergreen
312	Coniferous forest	FRSD	Forest-Deciduous
313	Mixed forest	FRST	Forest-Mixed
321	Natural grasslands	RNGE	Range-Grasses
323	Sclerophyllous vegetation	RNGE	Range-Grasses
324	Transitional woodland-shrub	RNGE	Range-Grasses
331	Beaches, dunes, sands	SWRN	Southwestern US (Arid) Range
332	Bare rocks	SWRN	Southwestern US (Arid) Range
333	Sparsely vegetated areas	SWRN	Southwestern US (Arid) Range
411	Inland marshes	WETF	Wetlands-Forested
512	Water bodies	WATR	Water
523	Sea and ocean	WATR	Water

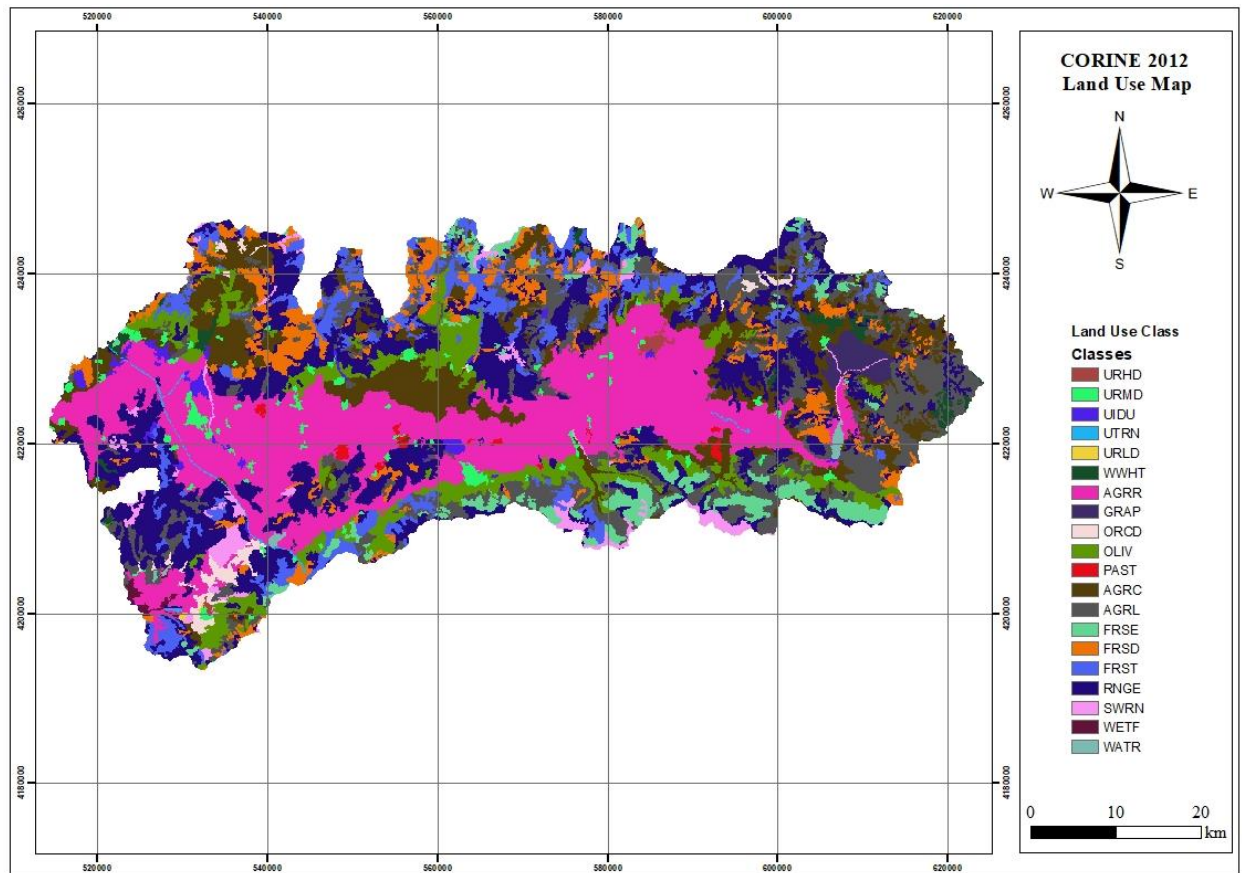


Figure 4.7. Corine 2012 land use map for the Küçük Menderes Watershed.

4.1.4. Soil Data

I obtained the soil map from The Food and Agricultural Organization (FAO) database. A soil map determines runoff and water quality processes, while the land cover map determines runoff, nutrient loads, and erosion rates (Li & Kim, 2019; Kabal., 2019). Three different soil types are observed in the watershed, belonging to hydrologic group D, and hydrologic group C. Other features of the soils are shown in Table 4.4. Figure 4.8, on the other hand, shows the distribution of the soil types in the watershed. When using FAO soil classes and maps, there is a need for the changing user-

soil table in the SWAT2012 access database. Also, a look-up table was prepared to introduce the soil types to the model.

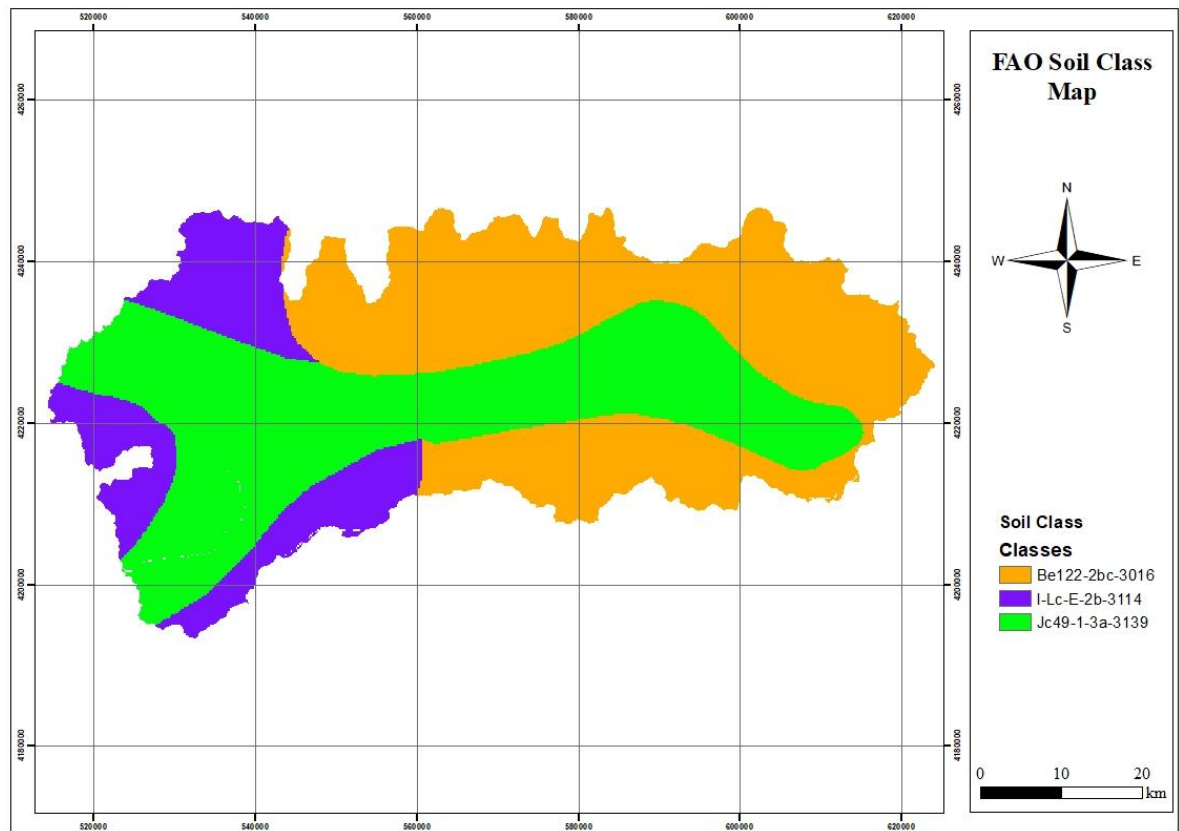


Figure 4.8. FAO soil class map for the Küçük Menderes Watershed.

Table 4.4. Soil features obtained from FAO.

FAO Code	Layers	Hyd_gr p	Sol_Zmx	Anion_Excl	Sol_Crk	Texture
Be122-2bc-3016	2	C	790	0.5	0.5	Loam
I-Lc-E-2b-3114	2	D	460	0.5	0.5	Loam
Jc49-1-3a-3139	2	C	1000	0.5	0.5	Loam

4.1.5. Weather Data

SWAT requires different weather data sets depending on the calculation methods used for evapotranspiration calculations. There are three methods to calculate evapotranspiration, which require different inputs. While the Penman-Monteith method needs varied data sets, Priestley-Taylor needs fewer than that, and Hargreaves method needs the least. Precipitation and minimum-maximum temperature data are Hargreaves' only needs. The Priestly Taylor method requires precipitation,

minimum-maximum temperature, solar radiation, and relative humidity. Penman-Monteith requires precipitation, minimum-maximum temperature, solar radiation, relative humidity, and wind speed.

Many weather data sets can be used for input data for SWAT. In this study, daily observed data was obtained from the General Directorate of Meteorology (Meteoroloji Genel Müdürlüğü, MGM) for January 1980 - October 2021. The General Directorate of Meteorology sent 156 stations' data for maximum-minimum temperature, precipitation (Automatic), precipitation (Manual), solar radiation, wind speed, and relative humidity. Some of them were far from the watershed, and some of them were closed a long time ago.

First of all, I eliminated the stations that were closed before 2021. Also, a 25 km buffer was added to watershed boundaries on ArcMap, as mentioned in the River Basin Management Plan of Küçük Menderes Basin (2019) published by the Ministry of Agriculture and Forestry. Then stations that were on the outside of this line were eliminated too. As a result, 51 stations remained, and only eight out of the 51 were in the watershed.

After the elimination, I accomplished a gap analysis for 51 stations' data. Twenty-three stations were active in 2013 or after that, I had to eliminate these stations as they do not overlap with the simulation period of the model. Three stations had discontinuous precipitation data sets for limited data time intervals (six years for two and four years for others). Four stations had a few years or no precipitation data, as the model cannot operate without the precipitation data, I had to eliminate these sporadic stations as well.

Consequently, 21 stations remained, and only five were in the watershed. These representations are in Table 4.5, Table 4.6, and Figure 4.9.

In addition to MGM data, CFSR (Climate Forecast System Reanalysis) data set (precipitation, minimum-maximum temperature, solar radiation, wind speed, relative humidity) obtained from the SWAT website (<https://swat.tamu.edu/data/cfsr>) for 1979-2014 years in Asia (Table 4.7). CFSR data are daily weather data simulated by imaginary stations using advanced data assimilation techniques; therefore, there are no gaps between the data. Twelve stations are in the 25 km buffer boundary; however, only two contain continuous data. Officers mentioned this problem on the website; however, their only suggestion was to update the site, which did not work.

Table 4.5. Meteorological stations in the 25 km buffer from the Küçük Menderes River Basin.

Station No	Minimum Temperature	Maximum Temperature	Precipitation (Automatic)	Precipitation (Manual)	Solar Radiation	Relative Humidity	Wind Speed
17219	2001-2021	2001-2021	no data	2001-2021	no data	1999-2021	1988-2021
17220	1980-2021	1980-2021	2005-2021	1980-2021	2018-2021	1980-2021	1980-2021
17232	1980-2021	1980-2021	2005-2021	1980-2021	2019-2021	1980-2021	1980-2021
17234	1980-2021	1980-2021	2005-2021	1980-2021	2005-2021 (discontinuous)	1980-2021	1980-2021
17749	2009-2021	2009-2021	2009-2021	no data	2011-2021	2009-2021	2009-2021
17771	2011-2021	2011-2021	2011-2021	no data	2012-2015	2011-2021	2011-2021
17792	1980-2021	1980-2021	2005-2021	1980-2012	no data	1980-2021	1980-2021
17797	2004-2021	2004-2021	2005-2021	no data	no data	2006-2021	2004-2021
17850	1980-2021	1980-2021	2005-2021	1980-2012	no data	1980-2021	1980-2012
17860	1980-2021	1980-2021	2005-2021	1980-2012	no data	1980-2021	1980-2012
17881	2004-2021	2004-2021	2005-2021	no data	no data	1980-2021	2004-2021
18026	2012-2021	2012-2021	2012-2021	no data	2012-2021	2012-2021	2012-2021
18031	2012-2021	2012-2021	2012-2021	no data	2012-2021	2012-2021	2012-2021
18034	2012-2021	2012-2021	2012-2021	no data	2013	2012-2021	2012-2021
18050	2012-2021	2012-2021	2012-2021	no data	2013	2012-2021	2012-2021
18052	2012-2021	2012-2021	2012-2021	no data	2013-2015 (discontinuous)	2012-2021	2012-2021

*Start and finish are included.

Table 4.6. Meteorological stations in the the Küçük Menderes River Basin.

Station No	Minimum Temperature	Maximum Temperature	Precipitation (Automatic)	Precipitation (Manual)	Solar Radiation	Relative Humidity	Wind Speed
17822	1980-2021	1980-2021	2005-2021	1980-2012	2011	1980-2021	1980-2012
17854	1980-2021	1980-2021	2005-2021	1980-2012	no data	1980-2021	1980-2012
18029	2012-2021	2012-2021	2012-2021	no data	2013	2012-2021	2012-2021
18030	2012-2021	2012-2021	2012-2021	no data	2013	2012-2021	2012-2021
18049	2012-2021	2012-2021	2012-2021	no data	2013	2012-2021	2012-2021

*Start and finish are included.

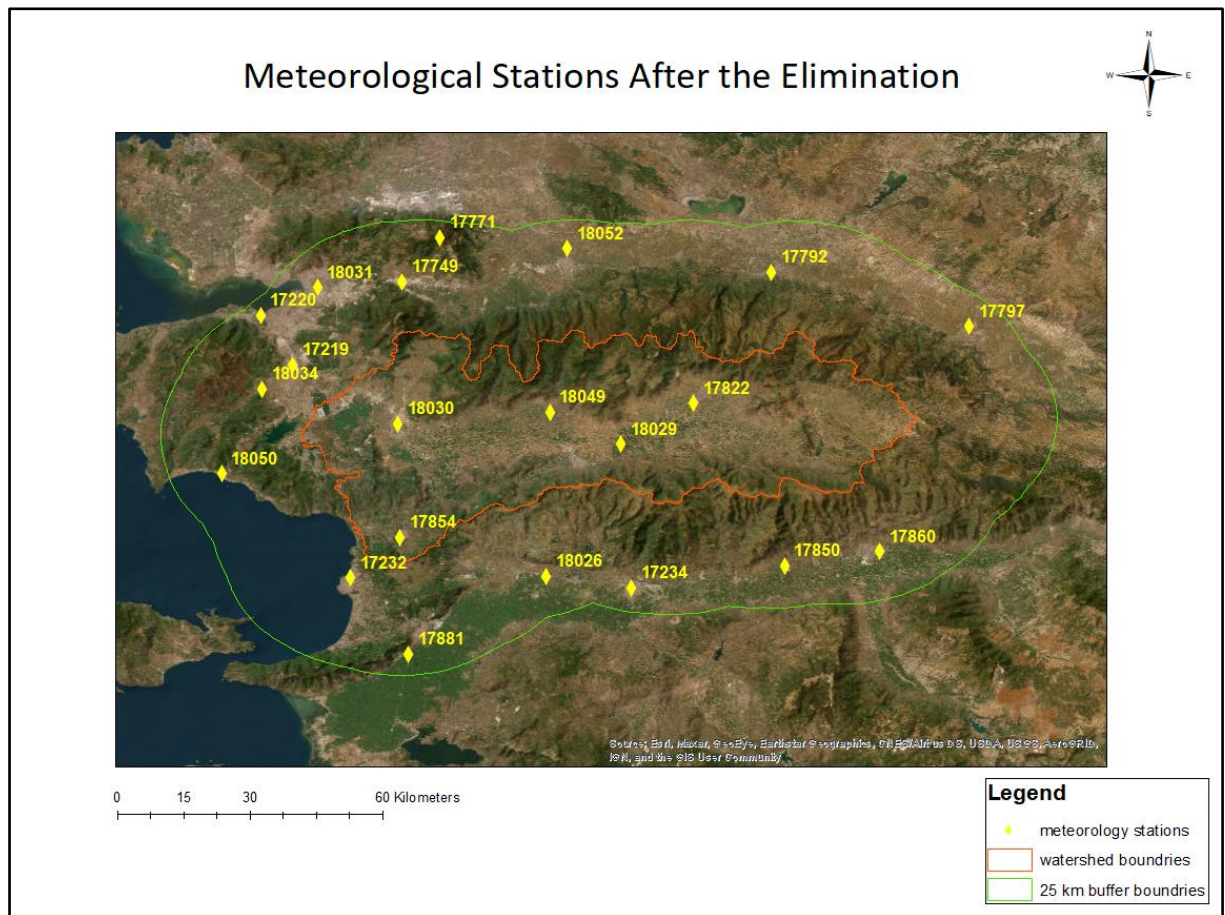


Figure 4.9. Meteorological stations considered for the simulation.

I consulted another website from the University of Guelph, <https://www.uoguelph.ca/watershed/w3s/>, linked to the SWAT official website, to request further data for temperature and precipitation from 2001-01-01 to 2020-03-26 at most. I asked for data as drawn the boundaries around the watershed. They shared precipitation data for 119 locations; however, temperature data was provided only for four stations. Because the borders were drawn by hand, one was outside the 25 km buffer boundary.

Table 4.7. CFSR meteorological stations within the Küçük Menderes Basin.

Year	Station	Latitude	Longitude	Elevation	Temperature	Precipitation	Solar Radiation	Wind Speed	Relative Humidity
2001-2019	tmp27.25_38.25	38.25	27.25	70	Available	Available	No Data	No Data	No Data
2001-2019	tmp27.75_38.25	38.25	27.75	135	Available	Available	No Data	No Data	No Data
2001-2019	tmp28.25_38.25	38.25	28.25	244	Available	Available	No Data	No Data	No Data
1979-2014	382275	38.25	27.50	559	Available	Available	Available	Available	Available
1979-2014	382281	38.25	28.13	583	Available	Available	Available	Available	Available

Because the data is available for only until the third month of 2020, I used the data set until the end of 2019. As can be seen from Table 4.7 two monitoring stations do not match according to their latitude, longitude, and elevation and, therefore, cannot be used together. As a consequence of this,

the data stations for 1979-2014 are inappropriate for simulation. After the elimination, remaining stations for CFSR data are illustrated in Figure 4.10.

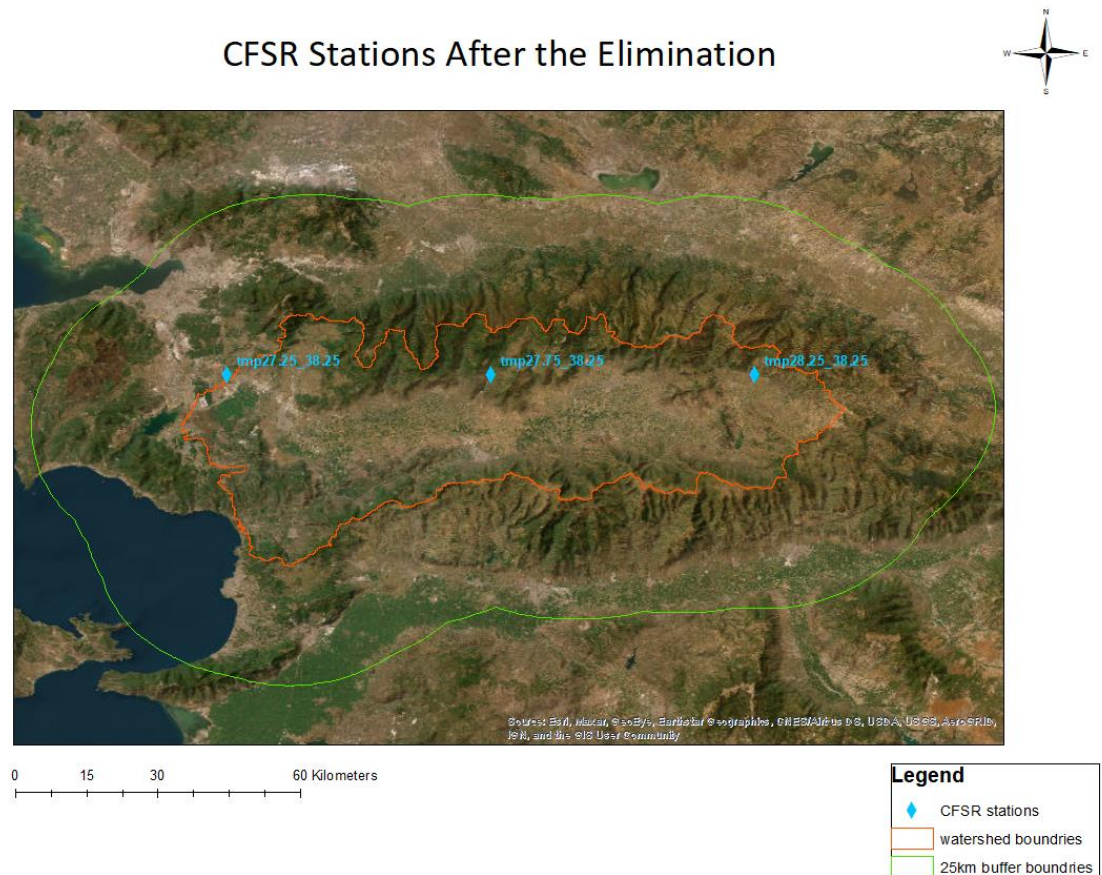


Figure 4.10. CFSR stations after elimination.

When two data sources are compared and examined, both have advantages and disadvantages. For this reason, options were determined with their features taken into account.

As can be noticed from Table 4.6, there is no appropriate solar radiation data in the watershed. On the other hand, Table 4.5 shows most of the solar radiation data do not exist or have only for a few years. Only three stations which are 17749, 18026, and 18031, may be used for the simulation. Relative humidity and wind speed were also checked for three stations, which were considered applicable. As mentioned above, Penman-Monteith and Priestly Taylor require solar radiation data. For this reason, if one of these methods is used, only 17749, 18026, and 18031 stations can be inputs to simulate from 2012 to 2021.

When the Hargreaves method is considered, a few alternative data sets are present according to the time interval, data quality, and closeness. The first option is to choose the most prolonged time

interval between 1980 and 2021. Eight stations can be used for this alternative option, and two are in the watershed; however, their precipitation data are from manual precipitation files. Although data has continued throughout the years, there are many gaps between the days for manual precipitation data.

The second alternative is using an automatic precipitation file for 10 stations between 2005-2021. In this alternative, only two stations are in the watershed and the time interval is shorter than other options.

When data are examined for automatic precipitation data again, but this time in the 2012-2021 interval, it seems more stations can be used as input. Therefore, the third alternative has 20 stations, and five stations are in the watershed. The only disadvantage can be the time interval. When this alternative is chosen, the warm-up period should be kept to a minimum.

The fourth alternative is using only the stations inside the watershed. Due to their standard time interval being between 2012-2021, the time interval can be considered as a disadvantage for this alternative.

Table 4.8. Input options for weather data.

Option	Method	Stations	Time Interval	Disadvantages
1*	Penman Monteith or Priestly Taylor	17749, 18026, 18031	2012-2021	• Closeness • Time interval
1	Hargreaves	17220, 17232, 17234, 17792, 17822 , 17850, 17854 , 17860	1980-2021	• Data scarcity
2	Hargreaves	17220, 17232, 17234, 17797, 17822 , 17850, 17854 , 17860, 17881	2005-2021	• Time interval
3	Hargreaves	17220, 17232, 17234, 17749, 17771, 17792, 17797, 17822 , 17850, 17854 , 17860, 17881, 18026, 18029 , 18030 , 18031, 18034, 18049 , 18050, 18052	2012-2021	• Data scarcity • Time interval
4	Hargreaves	17822 , 17854 , 18029 , 18030 , 18049	2012-2021	• Time interval
5	Hargreaves	17219, 17220, 17232, 17234, 17792, 17822 , 17850, 17854 , 17860	2001-2019	• Data scarcity
6	Hargreaves	tmp.27.25_38.25, tmp.27.75_38.25 , tmp.28.25_38.25	2001-2019	• Only three simulated data stations
7	Hargreaves	17220, 17232, 17234, 17792, 17822 , 17850, 17854 , 17860 tmp.27.25_38.25, tmp.27.75_38.25 , tmp.28.25_38.25	2001-2019	• Data scarcity • Integration problems of 2 data set

*There is one option for Penman-Monteith or Priestly Taylor Methods
Start year and finish year are included.
Bolded stations are in the watershed.

The last three alternatives contain the same scenario in 2001-2019 with eight MGM data stations and three CFSR data stations: using MGM stations only, using CFSR stations only, and using these data sets together, respectively. Despite the time interval being enough, the first and the last have the same disadvantage as they consist of manual precipitation data sets. When CFSR data is used, only three simulated datasets may not represent the watershed. I may consider integrating two data sets, but the literature does not have an example so conclusions can be uncertain. I summarized the options in Table 4.8.

4.1.6. Observed Flow, Sediment and Nutrient Data

Streamflow observation data for basins in Turkey are available on the website of The General Directorate of State Hydraulic Works (DSI). There are two types of stations, managed by DSI and managed by Elektrik İşleri Etüt İdaresi (EİE), and data as yearbooks available for 1959-2015 and 1935-2011, respectively. These are daily streamflow data for each station grouped by basins; however, it does not mean all stations have continuous data. While free yearbooks can be accessed until 2015 for DSI stations; after that, payment is necessary. On the other hand, sediment and nutrient observations are not free for any time duration.

First, I determined streamflow DSI stations in the watershed's boundary and accomplished a gap analysis until 2015 using the yearbooks on the website. Unfortunately, a lot of stations were inactive after 2015. Daily streamflow data for six stations, five stations that had data between 2016-2018 and one station that had data between 2016-2019, were provided from DSI with payment. Data that were bought and downloaded were combined, and also some gaps were filled using the studies done in the Küçük Menderes River Basin Master Plan Project. Datasets were prepared for each station from 1985 to 2019, as the simulation period is mostly dependent on the availability of weather data. Fourteen station information obtained at the end of the gap analysis is shown in Table 4.9.

Water quality data stations were analyzed using the table shown in Küçük Menderes River Basin Management Project. I selected four stations and paid for data from DSI. These datasets included monthly water quality data for many parameters with concentration metrics; however, only some parameters were assessed to calibrate the model according to modeling aims. Also, since outputs of the quality data were not presented as concentration in SWAT, the dataset had to be converted to loads by multiplying with instant flows in the same observation moment. This issue caused the elimination of some observed data because even if more observations were available for a specific

parameter, there was no instant flow measurement for the same month. NH_4^+ , NO_2^- , NO_3^- , Total N, (PO_4^{3-}), Total P, and SS parameters were assessed for four stations. Information about stations and data availability shows only how many months of data are available, and it does not mean that they are continuous, as shown in Table 4.10.

Table 4.9. Flow gauge stations in the watershed.

Station	Latitude	Longitude	Data Availability
D06A001	38.10533	28.212668	1985-2014
D06A011	38.28528	27.929444	1985-2014
D06A012	38.23181	27.834524	1985-2014
D06A013	38.23001	27.74196	1985-2014
D06A025	38.24056	27.553911	1985-2018
D06A026	38.08762	28.066702	1985-2014
D06A027	38.25135	27.685851	1985-2014
D06A033	38.23592	28.198205	1985-2018
D06A034	38.05746	27.90921	1985-2014
D06A035	38.34748	27.419727	2006-2015
D06A042	38.05458	27.9009	1985-2018
D06A045	37.95972	27.416389	2011-2017
D06A046	38.32111	27.475278	2011-2018
D06A048	38.02	27.468889	2013-2019

Table 4.10. Water quality stations in the watershed.

Station	X	Y	Number of months that data were available							
			Q_{ins}	NH_4^+	NO_2^-	NO_3^-	Total N	PO_4^{3-}	Total P	SS
06-02-00- 002	538883	4209738	24	23	15	22	4	17	0	21
06-02-00- 022	578444	4215632	6	6	4	6	0	4	0	5
06-02-00- 016	591503	4228654	28	10	18	27	0	11	0	0
06-02-00- 030	534510	4234776	14	6	5	14	2	5	1	9

As shown in Table 4.10, suspended solid data that will be used to calibrate sediment load are limited. For this reason, another dataset was obtained for a station managed by the EIE between 2006-2007. This station also had an advantage because of its closeness to the downstream of the watershed where no DSI station is present. However, this data set was daily, and the average monthly sediment load was not reported. For this reason, the equation shared in the same report was used to calculate the monthly sediment load from October 2005 to September 2007. The study explained the calculation equation as “The sediment rating curve is evaluated by fitting a curve to the available

observation points, which is of parabolic or power type” (Devlet Su İşleri Genel Müdürlüğü, 2013, page 5).

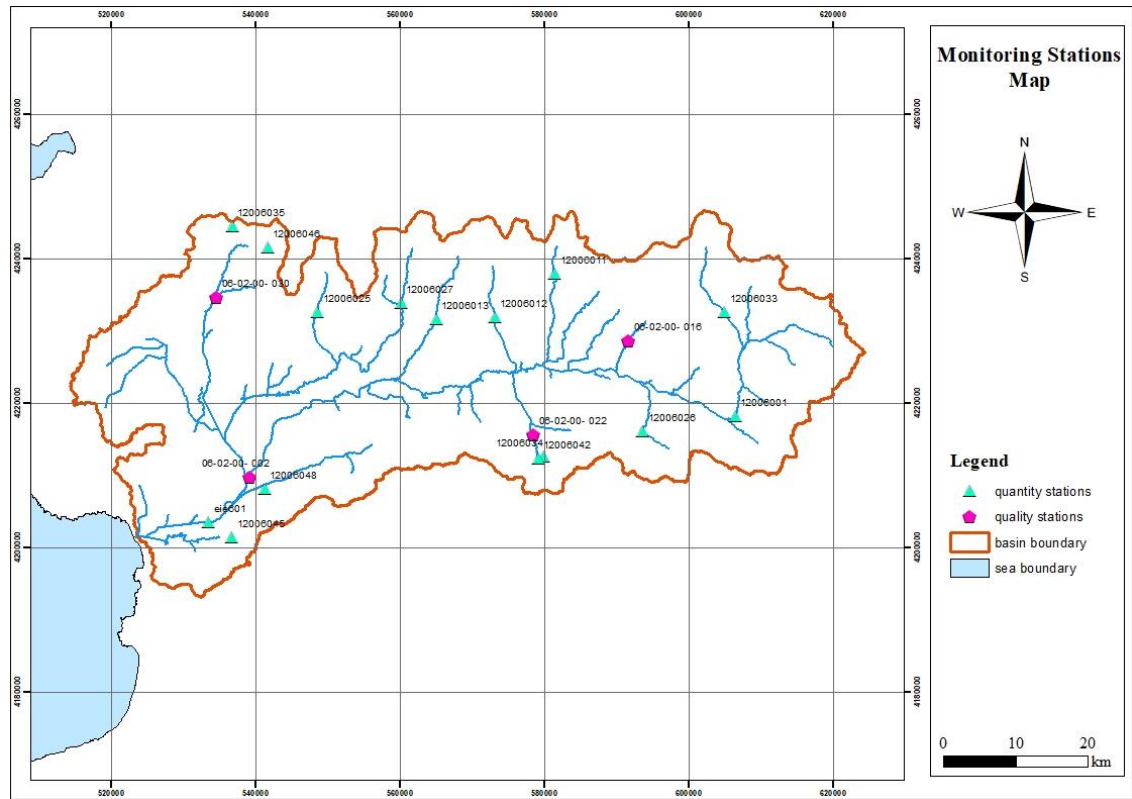


Figure 4.11. Quantity and quality monitoring points map in the Küçük Menderes Watershed.

4.1.7. Management Data

SWAT requires information about operations such as planting, irrigation, fertilizer, tillage, and harvest as input for the management table to simulate crop growing. In this study, I did fieldwork besides a literature review. First of all, to determine the land use of the study area, crop information provided by TÜİK is used. Since TÜİK delivers data at the district level, I downloaded the data after eliminating districts that have an area less than 5000 ha in the watershed. After this step, Torbalı, Beydağ, Bayındır, Tire, Ödemiş, Selçuk, Kiraz, Menderes, and Kemalpaşa districts remain that cover % 98.6 of the watershed. Also, TÜİK provides these data according to the cultivated land area or the crops' weight. I examined both data types from 2004 to 2021 and saw that the dominant crops remain unchanged. I decided to use land area data for 2012 to match with CORINE data and fit the model's time series. The size of the districts remaining in the watershed and the first four crop types with the highest cultivation area are summarized in Table 4.11.

Table 4.11. Areas of districts in the watershed and the most four crops according to their areas.

District	Total area within the watershed (ha)	First crop	Second crop	Third crop	Fourth crop
Ödemiş	78854	potato	corn silage	oil olive	fig
Torbali	56036	oil olive	tomato	corn	corn silage
Tire	55724	oil olive	corn silage	wheat	fig
Bayındır	50434	oil olive	corn silage	wheat	barley
Kiraz	36219	corn silage	barley	tobacco	wheat
Selçuk	24016	oil olive	peach	satsuma	cotton
Beydağ	16312	corn silage	chestnut	fig	oil olive
Menderes	12046	oil olive	wheat	corn	satsuma
Kemalpaşa	7840	cherry	oil olive	grape	grape

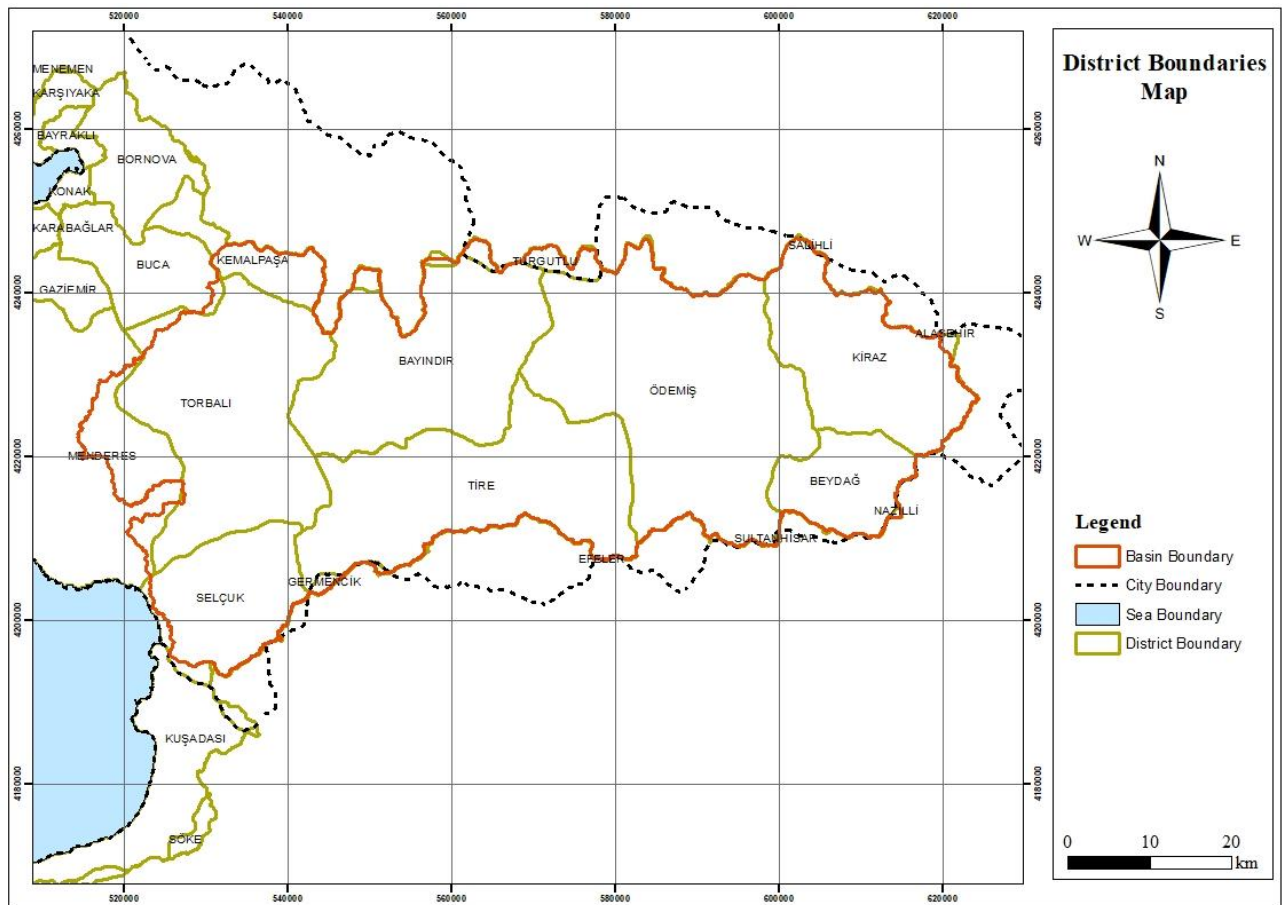


Figure 4.12. District map of the Küçük Menderes Watershed.

After that, I planned a field trip to validate the TÜİK information on crop yields and elaborate more on the in-field management practices data in the watershed. Three districts, Ödemiş, Bayındır, and Tire, which covered most of the area in the watershed, were visited to interview with agricultural organizations and farmers in July 2022. During the interviews, I consulted 12 officers from the District Directorate of Agriculture and Forestry in Ödemiş, Bayındır, and Tire, Chamber of Agriculture in Tire, Bayındır Irrigation Union, officers about the crop types in the region, fertilizer types, and amounts, planting and harvesting dates, irrigation systems, and general agricultural management operations. Besides these interviews, I did an online meeting with a lead farmer whose contact information was received from the District Directorate of Agriculture and Forestry officers in Ödemiş in July 2022.

The interview results with the officers were coherent with each other. Corn silage is the most cultivated crop among the districts as well as potato, wheat, and tomato for paste. Oil olives, figs, satsuma trees, and peach trees are common types of fruit in the watershed. Although farmers had planted cotton and tobacco abundantly in the past, production of these crops declined because of the increasing regulations and lack of incentives leading to economic concerns among the farmers.

The watershed has no fallowing, as I learned from the authorities. Moreover, farmers cultivate twice or three times a year in the same field. Corn silage, as the first crop, is planted in April and harvested in June-July; after that, the second corn silage is planted in August or September. Potatoes have a similar schedule, with planting in May and harvesting in June. Wheat can be cultivated in summer or winter so the planting months can be May or November, depending on the field's crop pattern.

Flood irrigation is a widespread operation type in the area; according to farmer responses, nearly 90 % of the farmers use this system. Farmers also mentioned that drip irrigation has difficulties because the plant height can cause observation challenges, especially for plants like corn silage, so they utilize drip irrigation only for some fruits like tomatoes. Still, the main problem is the level of education and awareness of farmers. The reason I came to this conclusion was the answers I received in our meetings with the farmers and the authorities. Although they had reasons for the difficulty of drip irrigation applications, some stated that they did not believe that irrigation was successful when they did not see it with their eyes. Officials also mentioned that farmers are resistant to making changes and that the number of people who participate in activities such as training and implementing them on their own land is quite low.

While corn silage and potato are irrigated frequently, such as once in three days, wheat and olives are irrigated less regularly, even though irrigation frequency has increased recently. Most water used for irrigation is supplied from groundwater through irrigation wells, and the rest is obtained from surface water sources such as dams and ponds. Officers and farmers mentioned that well depths have declined to approximately 250-300 meters, and if they had financial resources sufficient abstract water from deeper wells, farmers would have irrigated even more.

Fertilization was the only topic with discrepancies in the responses of the Chamber of Agriculture officers and farmers. Although the types of fertilizers do not change, the amounts vary. The standard type is 15.15.15, known as subsoil fertilizer and used for corn silage, potato, and wheat. Application time for this fertilizer to corn silage and potato is just before planting. The farmers, who are economically well, fertilize with an average amount of 70 kg/da and 150 kg/da; in comparison, economically worse farmers fertilize with an average amount of 35 kg/da and 75 kg/da for corn silage and potato, respectively. Also, during the time of weeding, another fertilization is applied by farmers. While corn silage fertilization is 25-50 kg/da urea, potato is fertilized with 40-70 kg/da nitrate. As well as the first fertilization, the second fertilization amounts depend on farmers' welfare. In addition to corn silage and potato, wheat, one of the other most cultivated crops, is fertilized two times before planting and before the first rain. The first, 15.15.15, was utilized as 40 kg/da, and the second, urea, was applied to the soil with 25 kilograms/da. Unlike corn silage, potatoes, and wheat, olive trees are rarely fertilized with manure and urea.

Even though the interviews were quite detailed, the model needs further information on irrigation time, amounts, and tillage schedule. Therefore, another round of literature investigation aimed to fill the gaps in the interview responses. The study about crop water consumption in Turkey, done by DSI and The General Directorate of Agricultural Research and Policies (TAGEM), helped determine the total water consumption for corn silage, potato, and wheat at the Ödemiş station. I distributed the calculated water amounts found in the study to reflect the irrigation operation schedule, i.e., every three days of irrigation. Secondly, the Calendar of Agriculture in İzmir, done by The Ministry of Agriculture and Forestry, provided crops' planting, fertilization, tillage, and irrigation times in İzmir. Finally, Gürgülü & Ul (2017) provided the irrigation schedules for cotton, corn, orange, olive, tomato, and pepper grown in İzmir using the IRSIS software, and I used this study for the irrigation schedule and amount of olive in the watershed. These data were compiled into a management table and served as input to the SWAT model (Table 4.12).

Table 4.12. Crop management in the watershed.

Crop	Wheat (WWHT)		Corn Silage (CSIL)		Potato (POTA)		Olive (OLIV)	
Plant/begin growing	21-Oct		15-Apr		1-Mar		1-Mar	
Fertilizer	20-Oct	20-Nov	14-Apr	10-May	28-Feb	1-Apr	25-Feb	30-Apr
Fertilizer amount (kg/da)	40	25	60	40	100	55	40	25
Fertilizer type	15.15.15	Urea	15.15.15	Urea	15.15.15	Elem-N	Sheep Fr	Urea
Irrigation schedule	November 1 - May 30 (1 in 10 days)		May 15 - June 15 (1 in 3 days)		April 15 - June 15 (1 in 3 days)		June 4 - September 9 (1 in 25 days)	
Total irrigation amount (mm)	393		615		546		818.6	
Tillage	1-Sep		1-Jan		1-Feb		1-Jan	
Harvest and kill	3-Jun		30-Jun		30-Jun		25-Nov	

4.2. SWAT Model Set-up

Although with the technology, modeling systems enhanced recently, the features of computers significantly affect the model run and calibration processes. The laptop I did the SWAT set up and run has 12 GB RAM (Table 4.13.). I also used the versions of ArcMap 10.7 and SWAT 2012 ver. 2020/rev. 681. I had to make one exception at the beginning of the watershed delineation due to the ArcMap version's error, which also other researchers discussed in the SWAT mail group. Burn-in option in the watershed delineation did not work in ArcMap 10.7; therefore, I did only the burn-in part in version ArcMap 10.5 with another laptop.

Table 4.13. Device and Windows specifications.

Processor	Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz 1.80 GHz
Installed RAM	12.0 GB (11.3 GB usable)
System type	64-bit operating system, x64-based processor
Edition	Windows 10 Pro
Version	22H2

There are stringent requirements when building a new SWAT project. For this reason, I utilized ArcSWAT Interface for SWAT User's Guide, Input/Output Documentation, and Theoretical Documentation.

The six main steps that you can see in Figure 4.13 were followed throughout this study. The first was creating the SWAT project. Initially, researchers who use the SWAT model should consider two concerns. Firstly, the project name should be chosen carefully due to the limitations of characters. Secondly, the directory of the project needs enough space for the project.

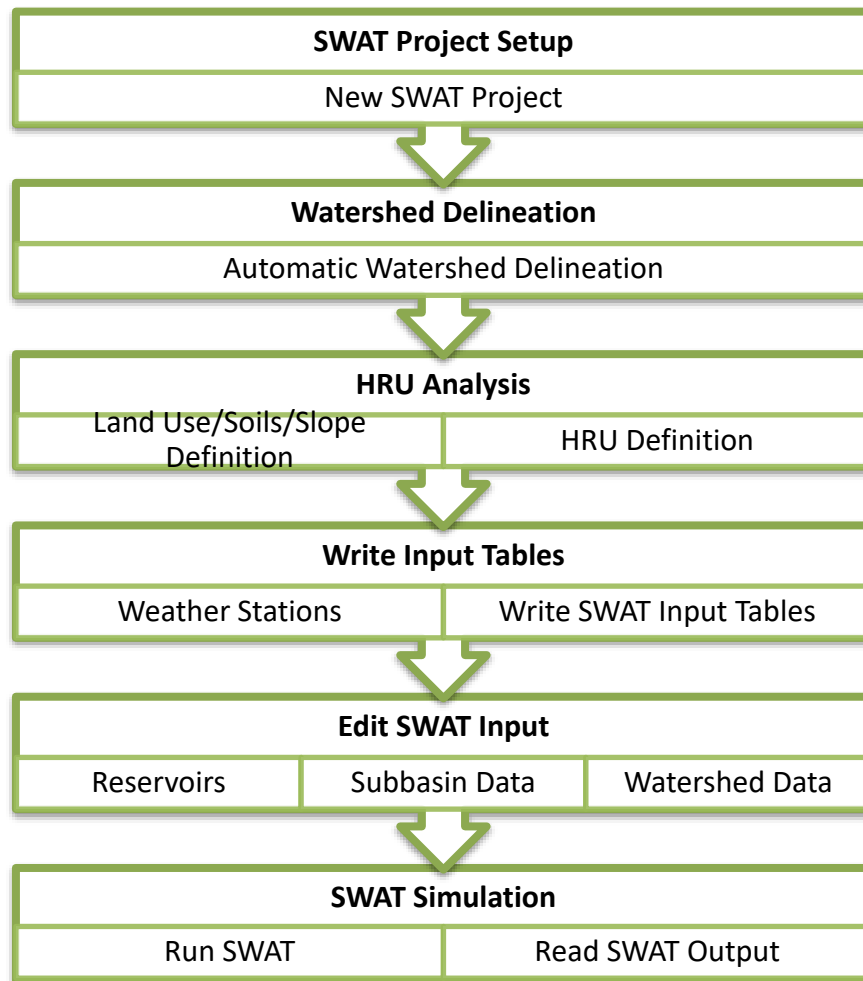


Figure 4.13. Steps used in the study to build up the SWAT model.

To increase model efficiency and depending on the purpose of the model, a number of assumptions were inevitable. Therefore, before model installation, the assumptions listed in Table 4.14 were implemented.

Table 4.14. Assumptions that I have done in the model.

Only three types of soil are in the watershed (due to the FAO data)
All irrigation is done from shallow aquifer
The only crop that cultivated in the watershed is corn silage
Management practices are done only in AGRR land use
Only 1 reservoir is in the watershed (Beydağ Reservoir)
All management practices are the same everywhere in the AGRR land use
There is no point sources in the watershed

4.2.1. Watershed Delineation

On the interface of the SWAT, the first option is watershed delineation after the creation of the new project. This section aims to create sub-basins and HRUs; therefore, Digital Elevation Model was the initial need. After adding the DEM as a raster format, there are two options; mask and burn-in. I did not use the mask option that can help to clip DEM data for the watershed boundaries, so not to have to spend too much time deleting the unnecessary outlets if the DEM was not already clipped, but I used the burn-in option after a few trials since these did not have the realistic results about the stream. Burn in option needs a shapefile of the stream; therefore, I digitized the Küçük Menderes Stream on Google Earth and turned it into the shapefile on ArcMap as mentioned in Section 4.1.1.

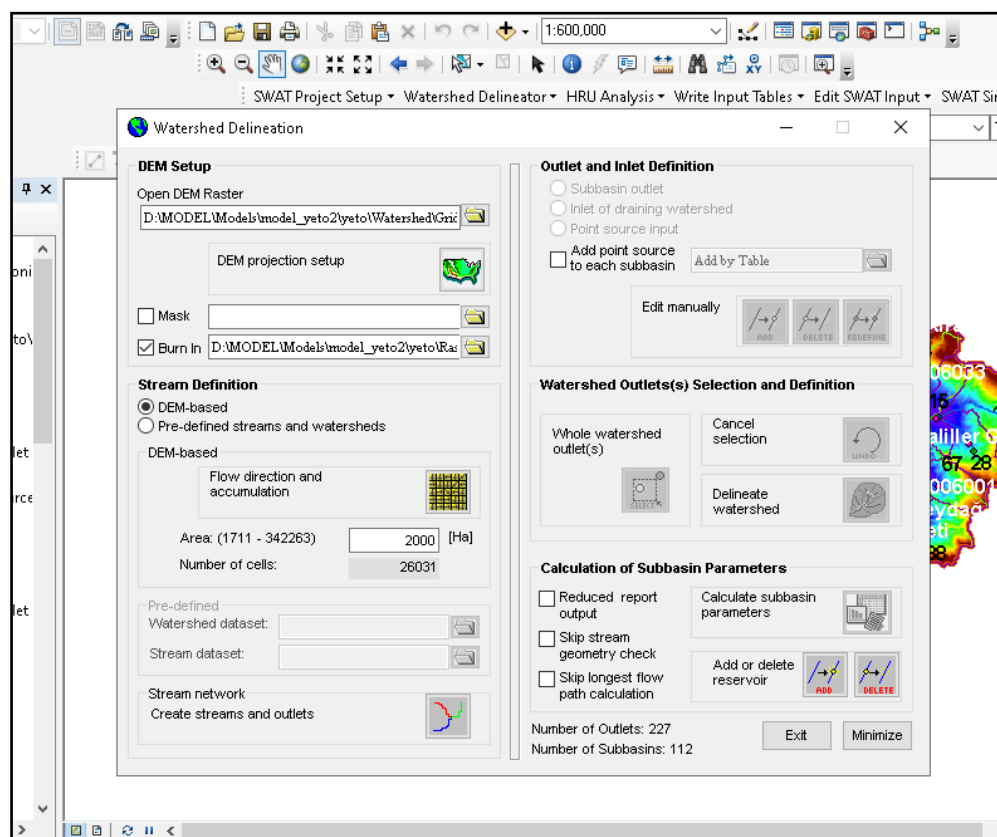


Figure 4.14. Screen capture of the interface of the SWAT watershed delineation part.

Secondly, the stream definition must be done in the watershed delineation section. Two options are there, too; DEM-based or pre-defined streams and watersheds. I did the DEM-based option with the 2000 ha threshold of the area. As this threshold decreases, the number of outputs increases, and this also causes to increase the number of sub-basins and HRUs; however, since these cause meaningful temporal expansion in the continued part of the modeling, especially in the calibration, I

did not decrease the threshold much more. After this, the stream network button was active to create streams and outlets in the watershed.

The third part is outlet and inlet definition, which can correspond to adding outlet, inlet, or point source simultaneously to help manually edit your created outlets. In this part, I put point sources to each sub-basin just in case, although I did not provide the data that are point sources such as domestic and industrial discharge in the watershed. On the other hand, the information of gauge stations was introduced to the model as outlets with the importance of comparing observed and simulated data in the exact same location since the SWAT gives the outputs at the outlets of sub-basins. There is a point here that should not be overlooked and should be emphasized; if the threshold area mentioned in the above paragraph was chosen too large this might lead to an undetailed stream network, and so that the points that you added as outlets cannot be in the appropriate locations. When a tributary is absent, SWAT puts your gauge station as possible as the nearest reach (M. Winchell, R. Srinivasan, M. Di Luzio, 2013).

In our study, even though I made the table with 19 observation stations, five stations had to be eliminated since they could not be put on the right tributary in the stream network. Yet, it was not a problem because not only their datasets had few measurements but also the locations were close to inlets of some sub-basins that do not interact with too many sub-basins. In addition to this, the rest were enough for the calibration process.

After these processes, the Watershed outlet(s) Selection and Definition part was active. SWAT allows you to delineate your watershed into sub-basins after choosing the watershed outlet. I had 112 sub-basins (Figure 4.15) which was a sufficient number of sub-basins when I compared it to another study done by Saddiqi (2019), who examined the differences between the two models that have 60 sub-basins and 266 sub-basins and got satisfactory results for both of them.

The last part of the watershed delineation is calculating the sub-basin parameter and adding reservoirs if you have any. According to the manual, reservoirs, ponds, and wetlands do not differentiate as in reality in terms of their meanings. SWAT considers reservoirs as a reservoir if they only have significant areas on the main channel and classifies them as ponds if reservoirs with a small area cannot affect hydrology too much. As mentioned in section 4.1.2. , five reservoirs and eight lakes are present in the watershed. While the study did not aim to model reservoirs, I added only Beydağ Reservoir, which is in the mainstream and has the most significant precipitation area.

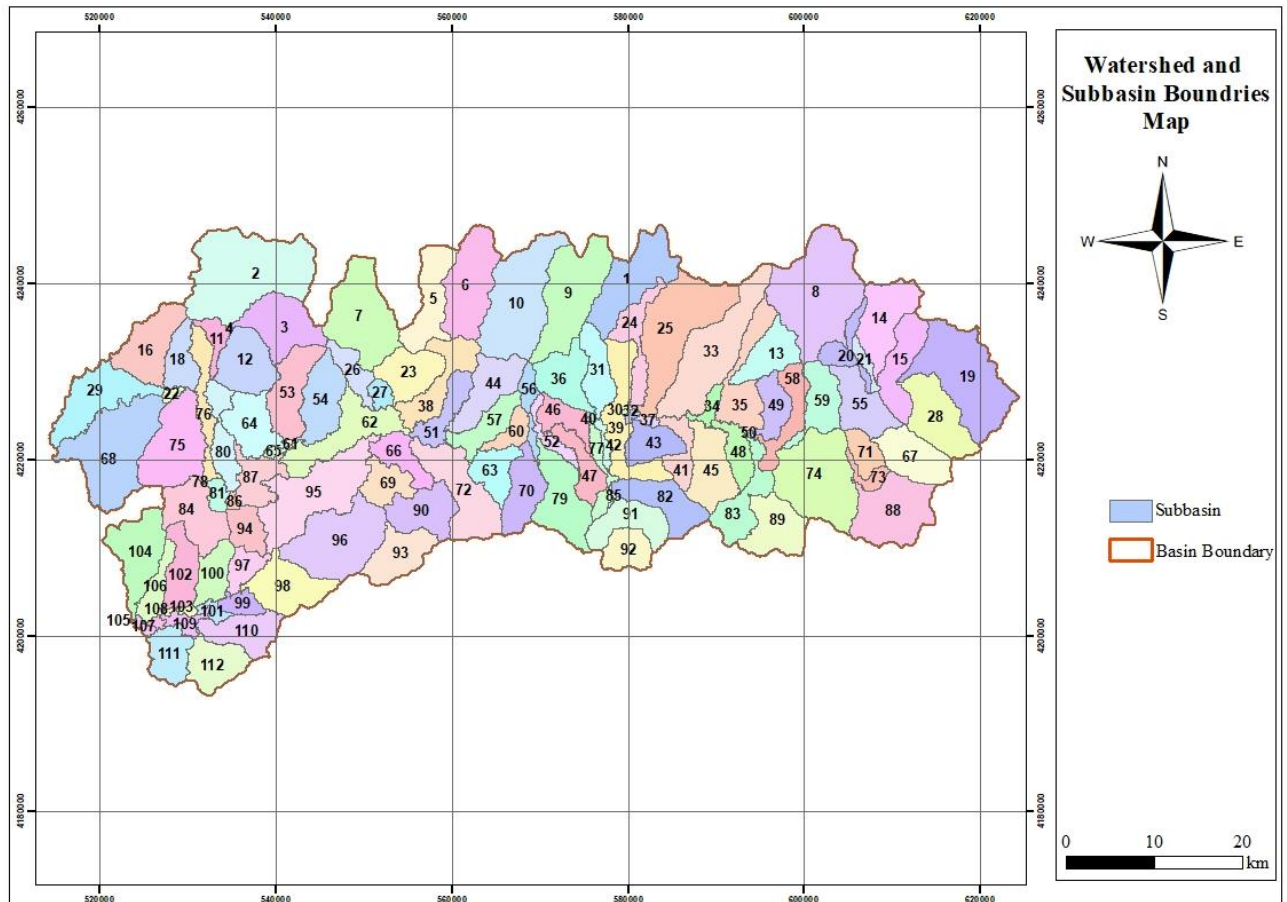


Figure 4.15. Watershed and sub-basin boundaries map of the Küçük Menderes Watershed.

4.2.2. HRU Analysis

The second section in the interface is HRU Analysis. The model divides the basin into Hydrological Response Units (HRUs) using DEM, land use, soil, and slope. For land use and soil, section 4.1.3. (Land Use-Land Cover Data) and 4.1.4. (Soil Data) gives more details on how I obtained the maps. In this part, I used shapefiles of the land use and soil map and look-up tables describing map definitions as inputs. There were two crucial highlights for this part. First was preparing the whole data needed before starting since there was no option to postpone any step, and completing the entire section forthright was compulsory. Secondly, preparing the user soil table before beginning this section and copying it to the model database should be kept in mind.

The third input is defining the number of slope classes and their limits. Although the higher number of classes can contribute to the model's resolution, I chose only two slope classes with the determination of the upper limit as 20.5, which is the mean slope of the watershed. The main reason was the time restriction of the study because defining more slope classes eventually creates more HRUs that significantly impact the simulation time.

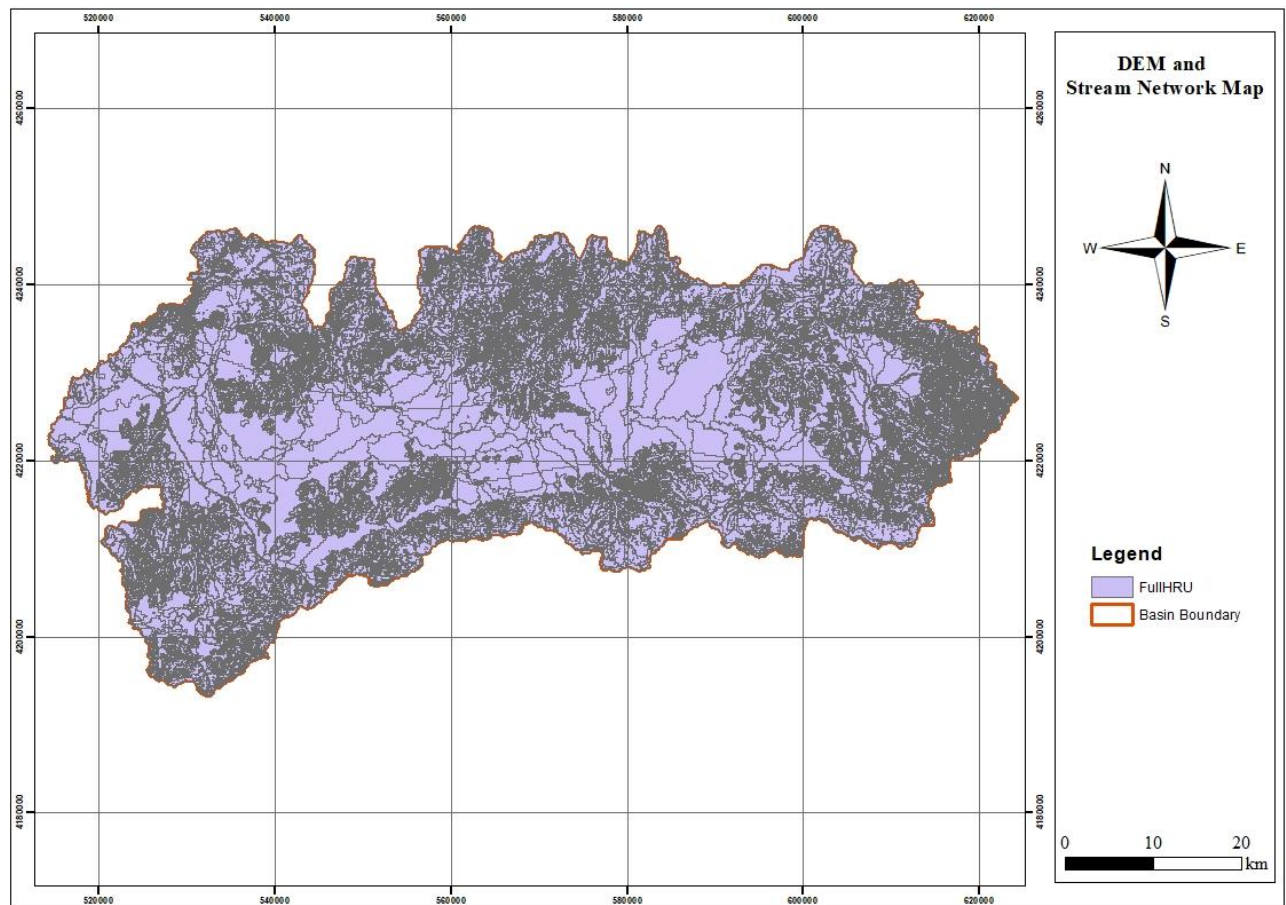


Figure 4.16. HRU map of the Küçük Menderes Watershed.

The HRU Analysis section has a second part for defining HRUs' thresholds. Like the definition of slope, these thresholds also contribute to increased simulation time t . I determine a 10 % limit for land use, soil, and slope, which means SWAT will ignore the HRUs that cover below 10 % of the area. However, I added one exception for AGRR land use which is crucial for the study's focus.

4.2.3. Write Input Tables

The third part of the SWAT interface is Write Input Tables. First of all, weather stations should be introduced to the model. The weather generator table and text files of weather stations' data were prepared as mentioned in section 3.3.5. There are two options for the input files of temperature, rainfall, solar radiation, wind, and humidity data; simulation and gauges. If the simulation option is chosen, SWAT uses the WGEN database; however, if gauge is preferred, text files will be used by SWAT.

In this study, much data was absent; hence I selected the WGEN table for solar radiation, wind, and humidity. On the other hand, I used text files for rainfall and temperature. One caution here as in the soil map, the WGEN user table should change in the model databases before adding inputs. Also, SWAT needs all this data even if the Hargreaves method is chosen to calculate evapotranspiration because it uses solar irradiance, humidity, and wind speed data to calculate crop growth. Therefore, I added these five types of data to the model.

Secondly, Write SWAT Input Tables will activate after weather stations are defined. The only thing is to select all tables and click the Create table button. In the project folder, SWAT created all files in the TxtInOut folder.

4.2.4. Edit SWAT Inputs

The editing section has six options to correct parameters used for databases, point source discharges, inlet discharges, reservoirs, sub-basins, and the watershed, respectively. It is worth noting that SWAT has range tables for parameters in the SWAT 2012 database; therefore, if needed, the option of changing the range is in the databases. However, this should be done very carefully considering the natural conditions. The second emphasis for this section is the option that this editing can be done in the databases. However, it must be remembered that any mistake or deficiency may induce an error in the SWAT run.

Since I did not have data for any point source or inlet, I did not change anything in these files. Firstly, I edited the Beydağ Reservoir information provided in the literature review. I had to edit the range of the reservoir table (resrng) because the reservoir has an immense area that is out of the boundaries of the basin. Due to operational information limitations, only the reservoir's beginning year and its features were used.

Secondly, I revised the PET calculation method in the basin file and chose Hargreaves. The reason behind it, as explained before, is the Hargreaves method needs only rainfall and temperature data to calculate PET. This method is more advantageous when there are many gaps in solar radiation, wind, and humidity datasets.

Finally, I compiled management information that I supplied from the literature review and fieldwork in the management (mgt.) table in the sub-basin editing part. Although the watershed's crop

varies, and I extracted pertinent data about management practices, I utilized corn silage rotation since SWAT does not allow the growth of different crops simultaneously in the same HRU (Bieger et al., 2014). An example of the management operation is given in Table 4.15 and Appendix A.

I did the second range alteration in the management range file (mgt2rng) for the fertilizer application amount (FRT_KG) since the fertilizer usage was out of the default range provided by SWAT as 0-500 kg/ha.

Table 4.15. Crop management schedule added to the model.

Rotation	First		Second	
Crop	Corn Silage (CSIL)		Corn Silage (CSIL)	
Plant/begin growing	15-Apr		1-Aug	
Fertilizer	14-Apr	10-May	30-Jul	1-Sep
Fertilizer amount (kg/da)	60	40	60	40
Fertilizer type	15.15.15	Urea	15.15.15	Urea
Irrigation schedule	May 15 - June 15		Aug 4 – Nov 25	
Total irrigation amount (mm)	(1 in 3 days)		(1 in 3 days)	
Tillage	615		428	
Harvest and kill	1-Jan		30-Nov	

SWAT edit allows you to extend your edits to any sub-basin or HRU; however, this option is applicable if all sub-basins or HRUs have the same value. In our study, this option was advantageous to broaden management parameters to all AGRR HRUs. On the other hand, irrigation sources assumed that every sub-basin irrigates from its shallow aquifer. This information can be edited in the management table to write the sub-basin number, which means extending the edits option will write to all sub-basins the same sub-basin number for the irrigation resource code. Hence, I changed these values in the project database on the mgt2 table by filtering the LANDUSE column with AGRR and copying the SUB-BASIN column to the IRR_NO column after using the extend option for management tables in SWAT Edit.

Finally, after finishing the edit, the Rewrite SWAT Input Files step under SWAT Edit Inputs was done. This crucial step that helps to rewrite your changes should not be skipped after any edits.

4.2.5. SWAT Simulation

After the model construction is done, the next is to run the model. SWAT requires a period of simulation and printout settings in the model simulation menu (Figure 4.17). Despite weather data being available between 2001-2020, I selected the simulation period from 2001 to 2019 due to the availability of observation data. Several studies demonstrated that the warm-up period should be at least two years for hydrology and five years for sediment and nutrient based models to get optimum results from calibration processes (Daggupati et al., 2015). Five years of the warm-up period was chosen considering the study focus.

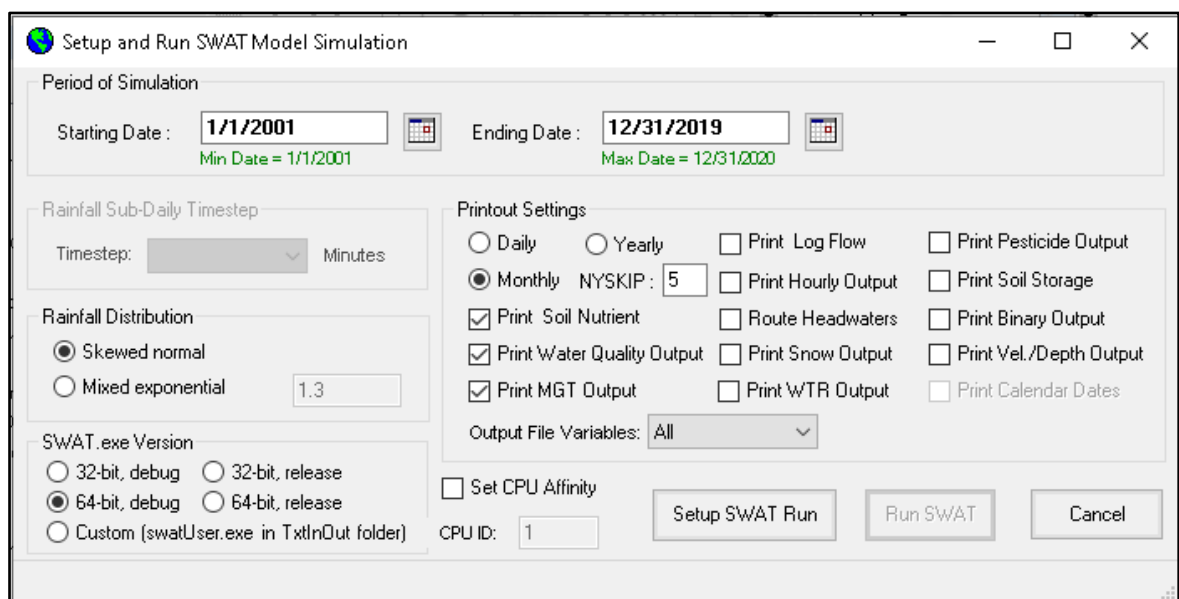
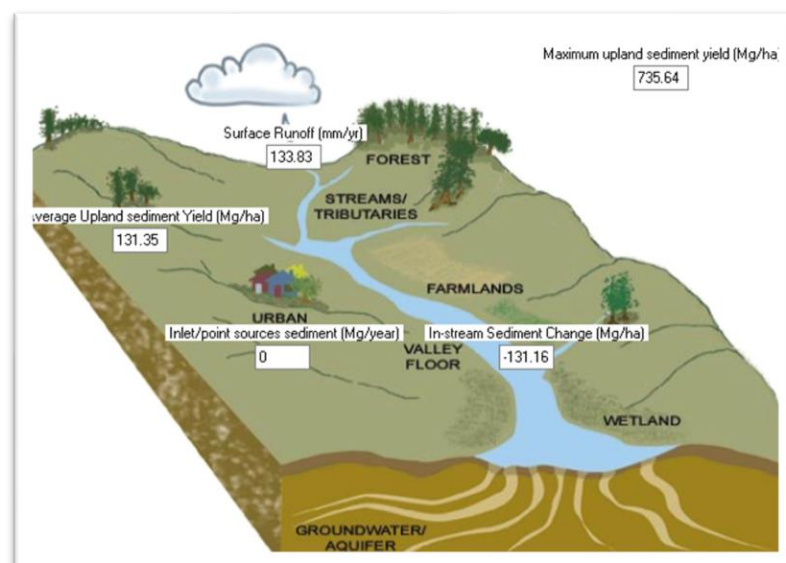


Figure 4.17. Screen capture of the interface of the SWAT run menu.

SWAT has the SWAT Check module that works stand-alone (Moriassi, Zeckoski, et al., 2015). After the SWAT run finished, SWAT outputs summarized by SWAT Check were controlled. SWAT Check can be seen in Figure 4.18 for streamflow and sediment, respectively. It gives us a chance to interpret the results before the calibration. Although every comment on the SWAT Check does not have to be considered by the modelers, valuable insights can be gained. For instance, the annual average precipitation was found as 622.1 mm; however, in the literature, annual precipitation was 716 mm for the Küçük Menderes watershed. So, underestimation in the model for precipitation can be seen effortlessly.



After the simulation, outputs can be found in the project folder as an access database that shows only the selected outcomes in the simulation interface and separate text files. The default simulation was saved as the first simulation because the other simulations will be performed for management practices.

4.3. Calibration

The SWAT calibration and uncertainty programs (SWAT-CUP) sequential uncertainty fitting (SUFI-2) algorithm was used to calibrate streamflow, sediment, and water quality parameters (Li & Kim, 2019). Although the SWAT-CUP program has five different alternative algorithms, SUFI2, PSO, GLUE, ParaSol, and MCMC, that can be used for calibration, validation, uncertainty analysis, and sensitivity analysis processes, I chose SUFI2 because of its reliability and plentiful reporting in the literature (Kouchi et al., 2017).

There are different versions of the SWAT-CUP program, both paid and free. SWAT-CUP-2019 and SWAT-CUP-Premium versions are available to download on the website (<https://www.2w2e.com/home/product>); however, paying for the license is compulsory to use the program features. Also, a parallel processing license, the program's extension that helps drastically decrease the calibration process period, can be obtained from the website for both versions. I did not buy the licenses due to budget inadequacy; therefore, I downloaded the SWAT-CUP-2019 from the website. When the free version is downloaded, and the license is not bought, the program runs the oldest and not updated version of SWAT-CUP, which is SWAT-CUP-2012.

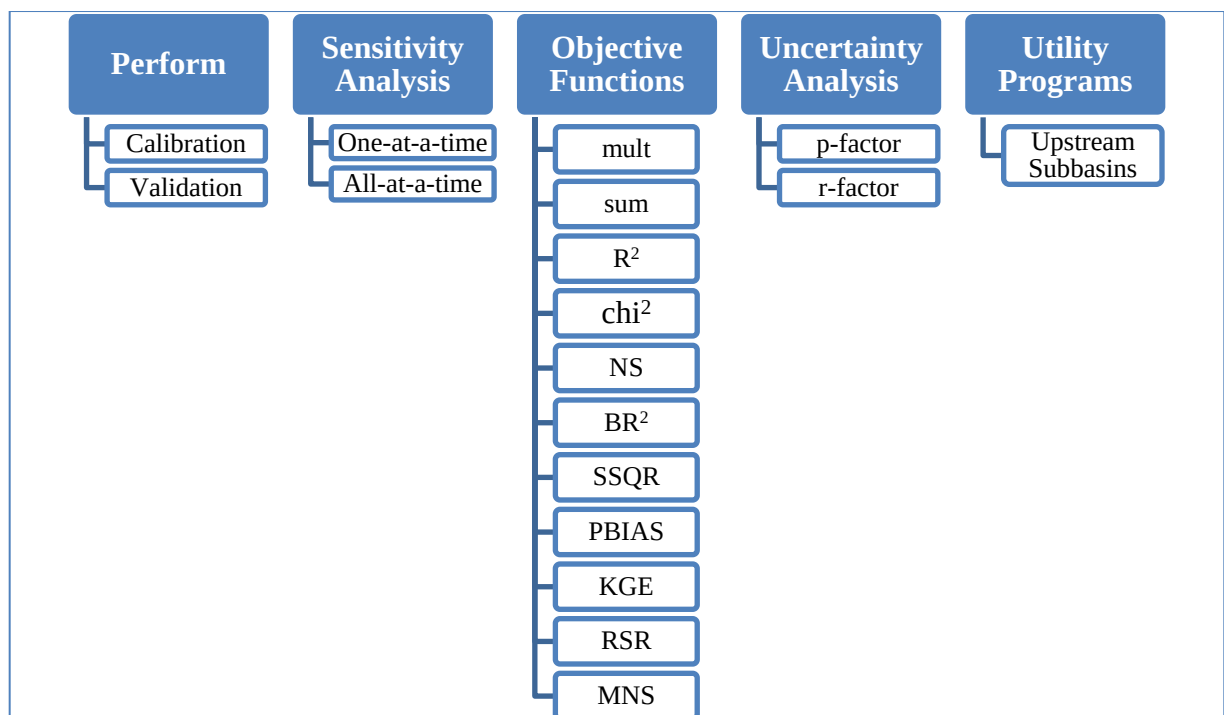


Figure 4.19. Representation of the SWAT-CUP SUFI-2 Algorithm features.

SWAT-CUP has 11 objective functions to model performance criteria: multiplicative form of the square error (mult), the summation form of the square error (sum), coefficient of determination (R^2), Chi-squared distribution (χ^2), Nash-Sutcliffe efficiency (NS), Modified Coefficient of determination (BR^2), Ranked sum of squares (SSQR), Percent bias (PBIAS), Kling-Gupta efficiency (KGE), Ratio of standard deviation of observations to root mean square error (RSR), and Modified Nash-Sutcliffe efficiency (MNS). Although the inputs do not have to change according to objective functions, results change. For this reason, trying a few objective functions to understand which one gives the best results is necessary (Abbaspour, 2010).

In the program, 95PPU, p-factor, and r-factor are used for uncertainty analysis. When the p-factor represents the percentage of the data that includes these parameter sets, in between the 95PPU band, the r-factor represents the thickness of the 95 PPU band area with uncertainty. So, the p-factor changes between 0 to 1, the r-factor changes between 0 to infinite. According to the literature, it is acceptable to obtain a value above 0.7 for the p-factor and a value close to 1 for the r-factor when calibrating the discharge. However, these can be slightly smaller and larger, respectively, for sediment and nutrients. Uncertainty analysis should be emphasized because the importance is more than objective functions. Because the different parameter sets give the same objective function, fitting the parameters is not the best solution. Instead of this, p-factor and r-factor should be considered (Abbaspour, 2010).

Also, two options for sensitivity analysis, all-at-a-time sensitivity analysis (global sensitivity analysis) and one-at-a-time sensitivity analysis (local sensitivity analysis) are available. Sensitivity analysis gives a chance better to understand the importance of processes in the watershed and decreases the time spent for calibration. Therefore, selecting which one is going to use is essential. While the one-at-a-time sensitivity analysis changes one parameter at a time, global sensitivity analysis is performed after one iteration. However, both of them have advantages and disadvantages. In a one-at-a-time analysis, the other parameters are fixed, and only one parameter changes at a time, but it has uncertainty because the other parameters' accuracy cannot be known. On the other hand, in an all-at-a-time sensitivity analysis, all parameters are changed simultaneously, but it needs a more significant number of runs (Abbaspour, 2010).

SWAT-CUP also gives graphical outcomes that can be used to compare observed and simulated data. In addition, graphs show the distance, represented by the r-factor, to understand how significant

the uncertainty is. The area thickening shown on the graph means the model uncertainty increases. The graphs show observed data and the best simulation with a signal (Abbaspour, 2010).

SWAT-CUP also provides utility programs. Elevation bands can be added during the model set-up; however, SWAT-CUP adds a utility to calculate elevation bands and add them to the model after the model runs. Another utility program, Upstream Basins, is used to find nested sub-basins necessary to determine the calibration sequence of the observed data. This extension calculates the nested sub-basin and gives an output of a list of all sub-basins and their nested sub-basins if they are available. The first utility program is not available for SWAT-CUP-2019. Although the SWAT-CUP Premium requires a license to perform other features, Elevation Bands can be used for free with the program's download.

There are three methods for parameterization in SWAT-CUP; absolute (a), replace (v), and relative (r). Absolute change adds the value given in the parameter range to the current value, the replace method directly replaces the value given with the current parameter, and the relative change adds 1 to the given value and multiplies the current value. The importance is to be careful after one iteration for absolute and relative change because the initial data will be changed. Therefore, after every iteration, backup files copy and paste to the calibration file (Abbaspour, 2010).

In addition, SWAT-CUP allows regionalization of parameters by parameter type. In the parameter information file, these descriptions can be entered by selection from the form view page or by typing them in the text view page. The parameter, if separable, can be differentiated by hydrological group, soil type, land use, sub-basin number and slope. However, for example, a parameter in the basin file cannot differ on the basis of sub-basins. Separation of the parameter according to these features can be added sequentially as shown in Figure 4.20 from the view page of the SWAT-CUP interface (Abbaspour et al., 2017).

? Basic Information				Value			Filter Conditions (optional)					
#	Par Name	File Name	File Ext.	Method	Min	Max	Hydro Grp	Soil Texture	Landuse	Subbasins	Slope	Condition..Filt
1	CN2		.mgt	I* Relative	-0.22	0.31				1		

Figure 4.20. SWAT-CUP form view page interface for parameterization.

4.3.1. Objective Functions

The calibration process is used to approach the model results to observed data, which is the natural conditions in the watershed. Validation is also applied for different data sets without a further change with calibration parameters to compare the model results and observed data to see the accuracy of the calibrated parameters. After comparing model results and observed data for calibration and validation, the model performance measures are utilized to define the accuracy between them (Moriassi, Gitau, et al., 2015). For this purpose, statistical or graphical methods can be preferred. Moriassi et al. (2007) divided these techniques into groups as standard regression, dimensionless, and error-index based for statistical methods and direct and derived comparison for graphical methods.

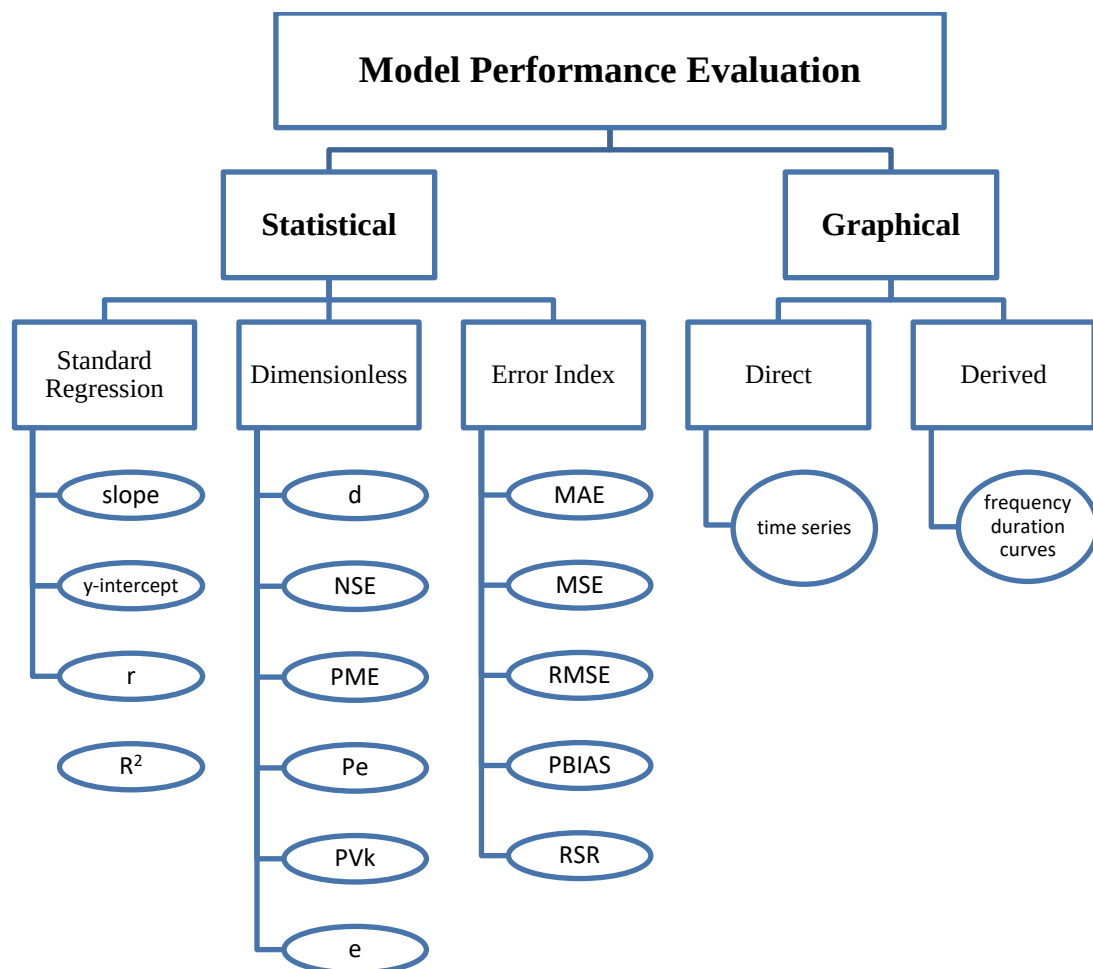


Figure 4.21. Model performance evaluation classification (adapted from: Moriassi et al., 2007).

As I mentioned in Section 4.3. (Calibration), SWAT-CUP uses ten statistical indices for this purpose. Moriassi et al. (2007) recommends three methods based on their analysis, Nash- Sutcliffe

efficiency (NSE), percent bias (PBIAS), and the ratio of the root mean square error to the standard deviation of measured data (RSR) for flow and water quality analysis. Another study by Moriasi et al. (2015) suggests coefficient of determination (R^2), index of agreement (d), and root mean square error (RMSE) in addition to NSE, PBIAS, and RSR. Moriasi, Gitau, et al. (2015) mentioned R^2 , NSE, and RMSE as generally used statistics in literature. Peker & Cüceoğlu (2022) also analyzed 65 global studies and concluded that most commonly used indices for model evaluation are NSE and R^2 .

In literature, the standard recommendation is to utilize multiple objective functions and graphical methods to prevent the magnitude of uncertainty. Mainly for different circumstances, the performance criteria approaches should be selected carefully. For instance, in the situation of a lack of observation points, graphical methods such as scatter plots and time series can be helpful to see how they compromise the data sets (Moriasi, Gitau, et al., 2015). Each objective function gives different sensitive parameters that affect the calibration, therefore; if evaluated on their own, they can produce results that cause misunderstanding about processes in the watershed (Kouchi et al., 2017).

After evaluating literature recommendations and commonly used objective functions, I selected three objective functions: R^2 , NSE, and PBIAS, besides graphical methods to evaluate the model's performance. These are some of the most applied objective functions in studies and are also included in the statistical method classification, standard regression, dimensionless, and error index classifications, respectively. Preferring varied types of methods allows us to see the effects of different methods. Equations 4.3, 4.4, and 4.5 are given below to show the calculation of the objective functions. In the formulas, n stands for the number of observations, $Q_{s,i}$ is the simulated value at time i , $\bar{Q}_s$ is the mean value of simulated streamflow, $Q_{m,i}$ is the measured value at time i , and $\bar{Q}_m$ is the mean measured streamflow (Abbaspour, 2010).

$$R^2 = \frac{[\sum_{i=1}^n (Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)]^2}{\sum_{i=1}^n (Q_{m,i} - \bar{Q}_m)^2 \sum_{i=1}^n (Q_{s,i} - \bar{Q}_s)^2} \quad (4.1)$$

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_{m,i} - Q_{s,i})^2}{\sum_{i=1}^n (Q_{m,i} - \bar{Q}_m)^2} \quad (4.2)$$

$$PBIAS = \frac{\sum_{i=1}^n (Q_{m,i} - Q_{s,i}) * (100)}{\sum_{i=1}^n (Q_{m,i})} \quad (4.3)$$

Model performance statistics are evaluated according to the time step of models described as very good, good, satisfactory, and unsatisfactory. Each evaluation has different intervals for daily, monthly, and yearly simulations and also, they vary between objective functions. In the literature, there are different performance statistics' results for the same objective functions. For instance, while a study recommends to evaluate the model performance as not satisfactory if the PBIAS value $\geq \pm 70$ (Moriassi et al., 2007), other study recommend using the interval $\geq \pm 30$ (Moriassi, Gitau, et al., 2015).

Moriassi et al. (2007) gathered values from studies and summarized them for monthly time steps (Table 4.16). The correlation coefficient (R^2) changes between 0 to 1, and results are evaluated as acceptable if the value is greater than 0.50; however, if it is equal to or smaller than 0.5, results are evaluated as unsatisfactory. Although the Nash Sutcliffe efficiency (NSE) has the same evaluation intervals as the R^2 , it changes between $-\infty$ and 1.00. On the other hand, for PBIAS, changes from $-\infty$ to $+\infty$, necessity is approached to 0; therefore, their intervals include negative and positive values together. Intervals for PBIAS are divided for streamflow, sediment, and N, P by Moriassi et al. (2007). While the values up to ± 10 , ± 15 , and ± 25 are accepted as very good, the values out of ± 25 , ± 55 , and ± 70 are unsatisfactory for streamflow, sediment, and N or P, respectively.

Table 4.16. Performance ratings for monthly time steps (Moriassi et al., 2007).

Performance Rating	NSE	PBIAS		
		Streamflow	Sediment	N, P
Very Good	$0.75 < \text{NSE} \leq 1.00$	$\text{PBIAS} < \pm 10$	$\text{PBIAS} < \pm 15$	$\text{PBIAS} < \pm 25$
Good	$0.65 < \text{NSE} \leq 0.75$	$\pm 10 < \text{PBIAS} < \pm 15$	$\pm 15 < \text{PBIAS} < \pm 30$	$\pm 25 < \text{PBIAS} < \pm 40$
Satisfactory	$0.50 < \text{NSE} \leq 0.65$	$\pm 15 < \text{PBIAS} < \pm 25$	$\pm 30 < \text{PBIAS} < \pm 55$	$\pm 40 < \text{PBIAS} < \pm 70$
Unsatisfactory	$\text{NSE} \leq 0.50$	$\text{PBIAS} \geq \pm 25$	$\text{PBIAS} \geq \pm 55$	$\text{PBIAS} \geq \pm 70$

Moriassi, Gitau, et al. (2015) provided recommendations for R^2 , NSE, and PBIAS for streamflow, sediment, nitrogen, and phosphorus. As mentioned in the study, data were collected from articles, of which more than half were published after 2007, and established model performance evaluation criteria for the specific needs. Although the criteria have a narrower interval than the other studies, I preferred to use these not only due to having all the objective functions I used in this study but also being specified for each variable. Table 4.17 shows the result of the performance rating that I are going to utilize for our study.

Table 4.17. Performance ratings for monthly time steps (Moriassi, Gitau, et al., 2015).

Performance Rating	R^2		
	Streamflow	Sediment	N, P
Very Good	$0.85 < R^2 \leq 1.00$	$0.80 < R^2 \leq 1.00$	$0.70 < R^2 \leq 1.00$
Good	$0.75 < R^2 \leq 0.85$	$0.65 < R^2 \leq 0.80$	$0.60 < R^2 \leq 0.70$
Satisfactory	$0.60 < R^2 \leq 0.75$	$0.40 < R^2 \leq 0.65$	$0.30 < R^2 \leq 0.60$
Unsatisfactory	$R^2 \leq 0.60$	$R^2 \leq 0.40$	$R^2 \leq 0.30$

Performance Rating	NSE		
	Streamflow	Sediment	N, P
Very Good	$0.80 < NSE \leq 1.00$	$0.80 < NSE \leq 1.00$	$0.65 < NSE \leq 1.00$
Good	$0.70 < NSE \leq 0.80$	$0.70 < NSE \leq 0.80$	$0.50 < NSE \leq 0.65$
Satisfactory	$0.50 < NSE \leq 0.70$	$0.45 < NSE \leq 0.70$	$0.35 < NSE \leq 0.50$
Unsatisfactory	$NSE \leq 0.50$	$NSE \leq 0.45$	$NSE \leq 0.35$

Performance Rating	PBIAS		
	Streamflow	Sediment	N, P
Very Good	$PBIAS < \pm 5$	$PBIAS < \pm 10$	$PBIAS < \pm 15$
Good	$\pm 5 < PBIAS < \pm 10$	$\pm 10 < PBIAS < \pm 15$	$\pm 15 < PBIAS < \pm 20$
Satisfactory	$\pm 10 < PBIAS < \pm 15$	$\pm 15 < PBIAS < \pm 20$	$\pm 20 < PBIAS < \pm 30$
Unsatisfactory	$PBIAS \geq \pm 15$	$PBIAS \geq \pm 20$	$PBIAS \geq \pm 30$

4.3.2. Before Calibration

As the literature particularly discourses, datasets should be divided for calibration and validation processes considering the physical criteria of two datasets and controlling their averages and variances (Abbaspour et al., 2017). As Abbaspour et al. (2015) mentioned that two thirds of the data were used for calibration and the rest for validation, so I tried to divide the data considering this. However, when I checked the averages of the calibration and validation periods of the data sets, also with the objective to keep the averages of the calibration and validation sets closer. In certain stations, this objective required us to adjust the time frames of the calibration and validation time series. For example, if the calibration and validation averages are too far from each other at the station that I have separated as guided by Abbaspour et al. (2015) I have made the averages converge by taking a few months' data from calibration to validation or vice versa. Calibration and validation data intervals and numbers of the data points are shown in Table 4.18 and the results' averages and the standard deviations of the calibration and validation period for streamflow are shown in Table 4.19.

Table 4.18. Calibration and validation data intervals and numbers of the data sets.

Station	Sub-basin	Calibration Interval	Number of Data (Calibration)	Validation Interval	Number of Data (Validation)
D06A011	1	1/2006 - 12/2011	72	1/2012 – 12/2014	36
D06A027	6	1/2006 - 12/2011	72	1/2012 – 9/2014	33
D06A025	7	1/2006 - 6/2014	102	7/2014 – 9/2018	51
D06A033	8	1/2006 – 12/2014	83	1/2015 – 6/2018	42
D06A012	9	1/2006 - 12/2011	72	1/2012 – 9/2014	33
D06A013	10	1/2006 - 12/2011	72	1/2012 – 9/2014	33
D06A001	71	1/2006 - 12/2011	72	1/2012 – 9/2014	33
D06A026	89	1/2006 - 12/2011	72	1/2012 – 12/2014	36
D06A042	92	1/2006 - 6/2014	102	7/2014 – 9/2018	51
EİE601	99	1/2006 - 10/2009	46	11/2009 – 9/2011	23

Table 4.19. The comparison of the calibration and validation datasets for streamflow.

Station	Sub-basin	Mean (Calibration)	Mean (Validation)	STD (Calibration)	STD (Validation)
D06A011	1	0.34	0.32	0.53	0.49
D06A027	6	0.28	0.31	0.42	0.37
D06A025	7	0.43	0.45	0.64	0.61
D06A033	8	1.14	1.03	1.50	1.14
D06A012	9	0.26	0.26	0.39	0.35
D06A013	10	0.40	0.45	0.53	0.49
D06A001	71	1.47	1.97	2.00	2.47
D06A026	89	0.62	0.61	1.04	0.92
D06A042	92	0.37	0.30	0.56	0.41
EİE601	99	4.11	5.77	7.84	10.29

As I mentioned, there is not enough measured data for validation in all quality stations. Therefore, I used a single station where I calculated the sediment data from the equation. The station in sub-basin 99 (EİE601) is also used for the streamflow calibration; therefore, the number of data is the same with flow monitoring stations. So, I divided sediment datasets into two thirds as suggested by Abbaspour et al. (2015).

Before the calibration, the initial model must have legitimate results since the calibration process does not significantly impact unreliable models (Abbaspour et al., 2017). Therefore, I initially did one simulation with a dummy parameter that does not change anything, WDPQ (ranges from 0 to 0), to see the initial model results (Table 4.20). Moreover, I compared the graphs provided in APPENDIX B to understand better the difference between observed and simulated flow and the precipitation

effects. I ran the dummy simulation only for the calibration period, while the graphs included the entire simulation period.

All gauge stations for flow gave good results for R^2 . Results show that sub-basins 1, 6, and 7 already have satisfactory R^2 and NS results. While the model overestimates the flow at six outlets, sub-basins 1, 6, 7, 9, 10, 71 and sub-basins 8, 89, 92, and 99 show underestimations. Since sub-basin 99 is downstream of the watershed and is affected by different uncalibrated sub-basins, it can be considered as usual.

Table 4.20. Initial objective function values before calibration.

Variable	R^2	NS	PBIAS	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
FLOW_OUT_1	0.74	0.74	-5.8	0.36(0.34)	0.46(0.53)
FLOW_OUT_6	0.64	0.51	-26.8	0.36(0.28)	0.46(0.42)
FLOW_OUT_7	0.7	0.66	-14	0.50(0.43)	0.64(0.64)
FLOW_OUT_8	0.7	0.63	30.5	0.80(1.14)	1.04(1.49)
FLOW_OUT_9	0.71	0	-72.9	0.46(0.26)	0.59(0.39)
FLOW_OUT_10	0.64	0.31	-32.2	0.53(0.40)	0.69(0.53)
FLOW_OUT_71	0.62	-0.42	-68.7	2.50(1.47)	3.31(1.99)
FLOW_OUT_89	0.78	0.49	49.4	0.33(0.62)	0.43(1.04)
FLOW_OUT_92	0.76	0.36	58.9	0.16(0.37)	0.20(0.56)
FLOW_OUT_99	0.7	-7.07	-298.5	16.54(4.11)	24.21(7.76)
SED_OUT_4	0.15	-184916	-78566.5	2716.09(3.41)	1458.39(7.16)
SED_OUT_13	0.02	-1.42	-114.7	204.47(94.11)	124.89(127.72)
SED_OUT_95	0.46	-5.51	-375.7	1719.93(355.22)	3061.30(1098.85)
SED_OUT_99	0.42	0.41	18.6	4925.23(5969.29)	8867.68(16351.28)
NO_3^- _OUT_4	0.03	-0.66	82.9	434.95(2558.72)	233.52(2573.73)
NO_3^- _OUT_13	0.17	-0.64	88.3	122.92(1053.78)	29.96(1144.17)
NO_3^- _OUT_91	0.18	-0.16	96.8	185.54(5818.27)	195.99(13456.84)
NO_3^- _OUT_95	0.06	-3.21	-133.54	16686.97(7186.88)	19953.01(10948.38)
NH_4^+ _OUT_4	0	-1.26	61.6	56.30(107.28)	84.10(86.61)
NH_4^+ _OUT_13	0.14	-0.35	91.2	31.37(284.00)	23.99(453.38)
NH_4^+ _OUT_91	0.84	-0.23	99.6	1.98(651.67)	3.57(1340.77)
NH_4^+ _OUT_95	0.06	-7.08	-21.3	26827.80(22576.08)	39442.89(16389.19)
NO_2^- _OUT_4	0.02	-0.95	99	0.08(5.54)	0.09(5.62)
NO_2^- _OUT_13	0.95	-1.82	100	0.01(68.91)	0.01(51.02)
NO_2^- _OUT_91	0.01	-0.44	100	0.00(110.60)	0.00(167.03)
NO_2^- _OUT_95	0.01	-0.22	72.9	504.24(1833.66)	499.17(2878.87)
TOT_N_4	1	-6314598	-6243	27478.88(482.00)	27431.13(15.32)
TOT_N_95	0.42	-24.67	-451.92	135347.50(28204.47)	129008.16(30529.43)

The remaining three sub-basins were checked, and it was seen that these sub-basins are located in the mountainous part of the basin, and the elevation difference is more remarkable in these sub-

basins than in other parts of the watershed. Besides this, all climate stations are located below 120 m elevation; therefore, prediction at the higher altitudes of the sub-basins was not well represented. Although elevation bands were not added when the model was being constructed, I created five elevation bands (Fontaine et al., 2002) using the utility program called elevation bands provided by SWAT-CUP. The sub-basins with less than a 1000 m difference in elevation were not included in the program, and only 64 sub-basins were used (see APPENDIX C).

After the flow results were checked, I determined the sediment and quality stations which can be used for the calibration. While the sub-basin 4 gave a better result for R^2 , it significantly failed for NS. I obtained acceptable results from Sub-basin 95 and 99 to start calibration of sediment with 0.46 and 0.42 R^2 , respectively. Sub-basin 13, on the other hand, was not good but enough to try an iteration. When I consider the other quality gauge stations' result, only total nitrogen in sub-basin 4 gave an unacceptably bad result for NS. This station had only two observed data for total nitrogen, so the result was not unexpected, therefore, I eliminated it. I kept other stations besides these two, sediment and total nitrogen in sub-basin 4.

I also used the other utility program, Upstream Basins, which is mentioned in the previous section 4.3. (Calibration), to determine the nested sub-basin in the watershed (see APPENDIX D). According to the observation outlets of our data, I eliminate this list as can be seen in Table 4.21. Because all other sub-basins related with sub-basin 99, I integrated the calibration process. However, I chose different parameter sets for the sub-basins which are unnested, sub-basin 1, 6, 7, 8, 9, 10, 89, 92, then added parameters for the sub-basin 71, and added parameters for the sub-basin 99. When I added the parameters for 71 and 99, I excluded the other sub-basins from the rest of them. Parameters discussed in detail in section 4.3.3. (Streamflow Calibration).

Table 4.21. Upstream sub-basin numbers of observation streamflow stations.

Sub-basin Number	Number of Related Sub-basins
1	1
6	1
7	1
8	1
9	1
10	1
71	10
89	1
92	1
99	99

As mentioned in the SWAT-CUP manual, it has more accuracy therefore, I chose all-at-a-time sensitivity analysis (global sensitivity analysis) for this study. However, to do global sensitivity analysis, one iteration should be done, therefore, at the beginning of the calibration, parameters were decided with literature review. Abbaspour et al. (2015) determined parameter sets for special situations according to the initial model result, to calibrate the model without wasting time. For instance, if the initial model gives the peak flow too low, the recommendations are to increase CN2 and decrease SOL_AWC and ESCO parameters. From this perspective, I determined our initial model results, which can be seen in APPENDIX B, and confirmed that I generally have these patterns. Therefore, I decided to use these parameters to initialize calibration process (see Figure 4.22).



Figure 4.22. Mostly used parameters that are collected from literature review.

Because the fitting of the parameters can conclude uncertain results, as I mentioned before, I did the calibration, adding the parameters for each iteration. On the other hand, iterations must be done with the same number of simulations as in the last calibration iteration due to the SWAT-CUP algorithm. Also, 500-1000 runs should be used according to the number of parameters (Abbaspour et

al., 2017). Considering this information, I chose to do 1500 runs to calibrate the model because I had many gauge stations, and for this reason, at the end of the calibration, I would have used more parameters.

4.3.3. Streamflow Calibration

As I mentioned in the previous section, I analyzed the graphical results and the statistical results of our initial model with the meaningless run. According to the results, the model overestimated the flow in sub-basins 1, 6, 7, 9, 10, and 71 and underestimated the flow in sub-basins 8, 89, 92, and 99. However, R^2 results for all gauge stations were already greater than 0.6. Nash Sutcliffe's values were also not bad for an initial model. Sub-basins 1, 6, 7, and 8 already had results greater than 0.5, which is the boundary value for this statistic. Also, when I compared the results with graphs, I assessed the results were enough to start calibration.

The only thing was the underestimations of sub-basins 8, 89, and 92. I plumped the reason behind the results and found that these basins were located in the mountainous part of the basin. Because climate data give lower precipitation in regions with higher elevations, precipitation correction can be a solution for underestimation of flow. Therefore, elevation bands were added as I discussed in section 4.3.2. (Before Calibration). Before starting the calibration of flow parameters, I did 120 runs of iteration for the parameters PLAPS and TLAPS, which stands for precipitation lapse rate (mm/km) and temperature lapse rate ($^{\circ}\text{C}/\text{km}$), respectively. While the atmospheric temperature generally decreases with elevation, the actual rate of precipitation generally increases. The change in precipitation depends on the storm type and direction (Fontaine et al., 2002). Initial values for PLAPS and TLAPS were 0, and I selected minimum and maximum parameters as 0, 100 for PLAPS and -8, -4 for TLAPS.

Both parameters used are different for sub-basins. In our first iteration, I ran the calibration to include all the sub-basins without differentiating between the sub-basins, but I saw from the results that the results decreased in some points that were good at the beginning. On the other hand, a sufficient improvement was observed for sub-basin 8 with R^2 86, NSE 86, and PBIAS -2.3. For this reason, these parameter ranges have been fitted for sub-basin 8. For this reason, these parameter ranges have been fitted for sub-basin 8. For the other two stations, different trials, including 25 and 20 simulations, respectively, for sub-basin 89 and sub-basin 92, were made separately. While doing these iterations, the new parameters suggested in the previous iteration were also taken into account.

The goal type used in SWAT-CUP was chosen as R^2 for all values since it was observed that the results were better compared to NSE. Minimum and maximum values are shown in Table 4.22

Table 4.22. Parameters that are used to calibrate PLAPS and TLAPS.

Parameter Name	Min value	Max value
V__PLAPS.sub _____8	0.00	100.00
V__TLAPS.sub_____8	-8.00	-4.00
V__PLAPS.sub _____89	80.00	180.00
V__TLAPS.sub_____89	-8.00	-4.00
V__PLAPS.sub _____92	250.00	550.00
V__TLAPS.sub_____92	-8.00	0.00

I discussed the literature review for selecting the initial parameters in section 4.3.2. (Before Calibration). After fitting the PLAPS and TLAPS values, I started to flow calibration with nine parameters that I determined from the literature review (Table 4.23). Three are the parameters related with soil characteristics, SOL_AWC, SOL_BD, and SOL_K. Even though soil parameters are determined in the soil database, which is the FAO database in our study, their resolution is discourse and I have only three soil types (Malone et al., 2015). Therefore, I add these parameters to see the effects on hydrology. Abbaspour et al. (2015) recommended decreasing SOL_AWC if the base flow is too high and peaks too low. In our study, I have low peaks flow in sub-basins 8, 89, and 92, as I determined before. The other parameter is CN2 which is in the management file. CN2, SCS runoff curve number, is the parameter that is used to calibrate runoff in the watershed in average moisture conditions (Neitsch et al., 2011). CN is the parameter that is generally found the most sensitive parameter for simulated surface runoff in the literature (Malone et al., 2015). Decreasing the CN2 causes a decrease in runoff; therefore, if the model overestimates the streamflow, this parameter can be used to solve it. I am concerned about this, especially in the sub-basins 6, 9, 71, and 99. I also used four different groundwater parameters to calibrate streamflow; GWQMN, REVAPMN, ALPHA_BF, and GW_REVAP. Abbaspour et al. (2015) have recommendations for groundwater parameters too. If the baseflow is too low and evapotranspiration too high in the results, GWQMN and GW_REVAP should be decreased, and REVAPMN should be increased. Also, these parameters can be used with the other three parameters, CN2, SOL_AWC, and ESCO, if the base flow is too high and peaks too low. In our study, observing base flow was not clear because the flow is approximately 0 for many stations in dry months. However, I interpreted low baseflow for sub-basins 7, 9, and 10 from graphs. The last parameter I add for the initial calibration is ESCO, which represents the soil evaporation compensation factor and is located in the hru files. Decreasing the ESCO parameter helps to increase

the peak flow in SWAT simulation, and vice versa; increasing the parameter decreases the flow. In our study, the initial ESCO already has the maximum value.

I chose the relative change for the first six parameters and chose the replace method for the last three according to the order in the table. I considered the parameter thresholds and our initial parameter values when determining the parameter ranges, but I also benefited from the literature. Since I have nested sub-basins for gauge stations, I added parameters for all of them separately. As mentioned in section 4.3. (Calibration), fitting one parameter set has uncertainty because different parameter sets can give the same value for objective functions, so I chose to calibrate them simultaneously. I sorted the parameters according to sub-basins' numbers, and for nine parameters and ten stations, I had 90 parameters for the initial run. I used 1500 simulations with these initial parameters and chose NSE as an objective function for SWAT-CUP.

Table 4.23. Initial Parameters that are used to start flow calibration.

Method__Parameter.ext	Description	Min value	Max value
R__CN2.mgt	SCS runoff curve number for moisture condition II	-0.5	0.5
R__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur.	-0.8	0.8
R__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm).	-0.5	0.5
R__SOL_AWC(..).sol	Available water capacity of the soil layer.	-0.5	0.5
R__SOL_BD(..).sol	Moist bulk density.	-0.5	0.5
R__SOL_K(..).sol	Saturated hydraulic conductivity.	-0.75	0.75
V__ALPHA_BF.gw	Baseflow alpha factor (days).	0	1
V__ESCO.hru	Soil evaporation compensation factor	0.1	0.95
V__GW_REVAP.gw	Groundwater "revap" coefficient.	0.02	0.2

Generally, the recommendation is doing 4-5 iterations for the flow calibration; however, I have many parameters and many stations, so I did ten iterations, not only changing parameter ranges but also, I added extra parameters to calibration. At the end of the calibration, I had 105 parameters for flow. I provided the last calibration parameters and ranges in APPENDIX E.

4.3.4. Sediment Calibration

The sediment calibration was more challenging than the streamflow. The principal determinant is the uncertainty of the observed data. As explained in section 4.1.6. (Observed Flow, Sediment and Nutrient Data), I calculated values using the graph's equation which EİE provided on the same page of the sediment report in station 601 in the Küçük Menderes River Watershed. Even though this observed data set offered us an approximation, this is highly dependent on flow. The other station I used for the sediment calibration was in the outlet of sub-basin 95. In this gauge station, I used daily suspended solid measurements and spot samples of discharge and multiplied them to have monthly sediment data loads. For this dataset, the problem was whether the daily data represented that month or not. In addition, I had data points only for 21 months, including only the fourth, seventh, and tenth months.

After the flow calibration, I added the parameters related to the sediment to the SWAT-CUP parameter info page without any further changes in parameter ranges that I got from flow calibration or any change in the number of simulations. Also, I did not separate parameters according to sub-basins because I used the parameters that are included in the basin file. In the first iteration for sediment, I used 12 parameters with ranges of the minimum and maximum values available in the absolute SWAT values file, but after six iterations, I realized these parameters do not significantly affect sediment. However, these affected the total nitrogen worse; at the end of the calibration, I kept only PRF_BSN, SPEXP, and SPCON with the same range as the initial and deleted the others.

Table 4.24. Initial Parameters that are used to start sediment calibration.

Parameter	Description	Min value	Max value
v__PRF_BSN.bsn	Peak rate adjustment factor for sediment routing in the main channel.	0	2
v__SPEXP.bsn	Exponent parameter for calculating sediment re-entrained in channel sediment routing.	1	1.5
v__SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing.	0.0001	0.01
v__CH_ERODMO().rte	Jan. channel erodibility factor	0	1
v__CH_COV1.rte	Channel erodibility factor.	-0.05	0.6
v__CH_COV2.rte	Channel cover-factor.	-0.001	1
v__ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	0.5	2
v__USLE_P.mgt	USLE equation support practice factor.	0	1
v__USLE_C{20}.plant.dat	Min value of USLE C factor applicable to the land cover/plant.	0.001	0.5
v__USLE_K().sol	USLE equation soil erodibility (K) factor.	0	0.65
v__SOL_ROCK(1).sol	Rock fragment content.	0	25
v__SOL_ROCK(2).sol	Rock fragment content.	0	25

4.3.5. Nutrient Calibration

After six iterations in the sediment calibration, I decided to continue nutrient calibration since I could not get good results. I used 15 parameters for the initial calibration of nutrients, and as I did for sediment, I selected the ranges from the absolute values file—four variables and four gauges stations that I used for the initial calibration. NO_3^- , NH_4^+ , and NO_2^- were the variables available for the stations in the outlet of the sub-basins 4, 13, 91, and 95, and TOT N was only available for the sub-basin 4 and 95. However, I used only sub-basin 95 for TOT N because sub-basin 4 gave us significantly bad results from the initial run, and it had only two data points. I did not include phosphorus parameters since they had a small amount of data, and their initial results were unsatisfactory. I kept the flow and sediment parameters range as they did, added these 15 parameters to the list, and did 1500 simulations.

Table 4.25. Initial Parameters that are used to start nutrient calibration.

Parameter	Description	Min value	Max value
v__RCN.bsn	Concentration of nitrogen in rainfall.	0	15
r__N_UPDIS.bsn	Nitrogen uptake distribution parameter	0	0
v__SHALLST_N.gw	Concentration of nitrate in groundwater contribution to streamflow from subbasin (mg N/l).	0	1000
v__HLIFE_NGW.gw	Half-life of nitrate in the shallow aquifer (days)	0	200
v__ERORGN.hru	Organic N enrichment ratio.	0	5
v__NPERCO.bsn	Nitrogen percolation coefficient.	0	1
v__CMN.bsn	Rate factor for humus mineralization of active organic nitrogen.	0.001	0.003
v__CDN.bsn	Denitrification exponential rate coefficient.	0	3
v__SDNCO.bsn	Denitrification threshold water content	0	1
v__BC1.swq	Rate constant for biological oxidation of NH_3 (1/day)	0.1	1
v__BC2.swq	Rate constant for biological oxidation NO_2^- to NO_3^- (1/day)	0.2	2
v__BC3.swq	Rate constant for hydrolysis of organic nitrogen to ammonia (1/day)	0.2	0.4
v__FRT_SURFACE{[,3].mgt	Fraction of fertilizer applied to top 10mm of	0	1
v__SOL_NO3().chm	Initial NO_3 concentration in the soil layer. [mg/kg]	0	100
v__SOL_ORGN().chm	Initial organic N concentration in the soil layer. [mg/kg]	0	100

After one iteration, I did not get satisfactory results from nutrient calibration. For this reason, I checked the results after the flow calibration and after flow and sediment calibration, and I confirmed that the sediment calibration caused the deterioration of nutrient objective function values. I decided to reduce the number of sediment parameters from the calibration to at least obtain a good result from the nutrient calibration. I also reduced the number of nutrient parameters and did one more iteration

with these parameters set. Even though I did not obtain good results from some variables, I did not continue to calibrate after that due to the uncertainties in our data, which is discussed in section 5.1.

4.4. Sensitivity Analysis

As mentioned in the SWAT-CUP manual, it has more accuracy; therefore, I chose all-at-a-time sensitivity analysis (global sensitivity analysis) for this study. Global sensitivity analysis requires one iteration, so at the end of every iteration, one global sensitivity analysis can be done. However, every analysis gives different results according to parameter ranges. Therefore, I did the global sensitivity analysis at the end of every iteration to determine how to continue calibrating the model. Nevertheless, the last iteration's global sensitivity analysis is provided in section 5.1.

4.5. Validation

Validation was implemented for different time steps than the calibration I provided in section 4.3.2. (Before Calibration) with the same parameter range that I used for the final calibration. I used all flow outlets for validation, but due to lack of data I could only use station EIE601 at the outlet of subbasin 99 for sediment validation and could not use any dataset for nutrient validation. I did an iteration for the validation process without making any further changes. As calibration results, SWAT-CUP provides summary statistics for validation; however, the best simulation may vary. I discussed the results in section 5.1.

4.6. Management Scenarios

After the calibration and validation, management scenarios were applied to understand the effects of the management practices on water quantity and quality in the basin. I have determined three scenarios: reducing the irrigation amount by 30 %, reducing the amount of fertilizer by 30 %, and applying both together. I applied the changes via the SWAT-CUP program and used the output.rch file to compare the outputs.

Table 4.26. Management scenarios applied to the model.

Scenario-1	Irrigation application amounts were decreased by 30 %.
Scenario-2	Fertilizer application rates were decreased by 30 %.
Scenario-3	Combination of Scenario 1 and 2

5. RESULTS

5.1. Calibration, Validation, and Sensitivity Analysis Results

I analyzed the initial results of the model to calibrate it using the SWAT-CUP SUFI 2 algorithm. Although flow stations had good results to begin calibration, I identified a certain underestimation at downstream outlets 8, 89, and 92. When the characteristics of the sub-basins, such as DEM, land use, and soil types, were examined, I determined that the common problem was height differences. These three sub-basins were located in the mountainous regions of the basin, and the height differences were more significant than in other places. I did not add height bands when building the model. After initial results and examination and determination of the mountainous part of the basin, I added five height bands using the SWAT-CUP SUFI 2 algorithm extension, the Elevation Bands. After adding the altitude bands, I calibrated the PLAPS and TLAPS parameters to correct for precipitation and temperature due to altitude differences. I covered the detailed process in section 4.3.2. (Before Calibration). After the calibration, I found the values shown in Table 5.1 and fitted these parameters.

Table 5.1. Fitted values for PLAPS and TLAPS after calibration.

Parameter Name	Fitted Value
V__PLAPS.sub _____8	97.08
V__TLAPS.sub _____8	-6.15
V__PLAPS.sub _____89	134.00
V__TLAPS.sub _____89	-4.08
V__PLAPS.sub _____92	452.50
V__TLAPS.sub _____92	-1.40

After adding the elevation bands and calibrating the PLAPS and TLAPS parameters, it was observed that the objective functions increased in the 8, 89, and 92 sub-basins. However, since sub-basin number 8 is associated with sub-basin number 71, calibration caused a change in the modeled flow of this station, and a decrease in objective functions was observed in sub-basin number 71. In addition, due to the location of sub-basin 99, all three calibrated sub-basins are associated with sub-basin 99, so the calibration results for the station located at the outlet of this sub-basin also changed. I compared the results before and after calibration, as shown in Table 5.2. While it was observed that the NSE and PBIAS values of sub-basin 71 and 99 decreased, it was observed that these values increased in other sub-basins, and there was an improvement in R^2 values in all sub-basins. However,

I accepted the reductions here, as I predicted that sub-basins 71 and sub-basins 99 would need more calibration as they already have sub-basins associated with them.

Table 5.2. Alteration of objective functions after PLAPS and TLAPS fitted.

Variable	R ² (Before)	R ² (After)	Alteration	NSE (Before)	NSE (After)	Alteration	PBIAS (Before)	PBIAS (Before)	Alteration
FLOW_OUT_8	0.7	0.86	increased	0.62	0.85	increased	30.5	-3.9	increased
FLOW_OUT_71	0.62	0.68	increased	-0.37	-0.68	decreased	-68.7	-94.3	decreased
FLOW_OUT_89	0.79	0.79	increased	0.46	0.62	increased	49.4	29.9	increased
FLOW_OUT_92	0.76	0.78	increased	0.34	0.74	increased	58.9	-5.2	increased
FLOW_OUT_99	0.7	0.71	increased	-6.87	-7.39	decreased	-301.15	-317.52	decreased

After calibrating PLASP and TLAPS parameters, I calibrated the flow parameters. I had ten related flow monitoring stations, and after determining the parameters separately for each station, I calibrated all of them simultaneously since it is an application with a margin of error to continue the calibration by fixing each one. I evaluated our results using three objective functions: R², NSE, and PBIAS. However, I also used the p-factor and r-factor values, which are used in uncertainty analysis and give more reliable results because they evaluate the accuracy of the selected parameter range, not the value of a single parameter, and are recommended many times in the literature (Abbaspour et al., 2015). While the recommended values for the p-factor and r-factor for flow are specified as greater than 0.7 and less than 1.5, respectively, the threshold value for sediment and nutrient is not shared, it is only mentioned that it may be smaller or greater than these values. Therefore, I used threshold values of 0.4 for residue and 0.3 for nutrients for the p-factor, which I used when assessing R². While evaluating the results, I also checked the mean and standard deviation of the simulation and observation values. Graphs were another assessment tool I used. After trying several options, I chose NSE as the SWAT-CUP goal objective function. The overall performance of the flow calibration for all stations gave satisfactory results at 0.65 for the NSE.

Table 5.3. Calibration results for flow.

Station	Variable	p-factor	r-factor	R ²	NS	PBIAS	Mean_sim/(Mean_obs)	StdDev_sim/(StdDev_obs)
D06A011	FLOW_OUT_1	0.74	1	0.75	0.74	16.6	0.28(0.34)	0.44(0.53)
D06A027	FLOW_OUT_6	0.61	1.4	0.63	0.5	-15.9	0.32(0.28)	0.47(0.42)
D06A025	FLOW_OUT_7	0.73	1.22	0.71	0.62	-19.8	0.51(0.43)	0.71(0.64)
D06A033	FLOW_OUT_8	0.65	1.12	0.85	0.84	11.7	1.00(1.14)	1.40(1.49)
D06A012	FLOW_OUT_9	0.72	1.1	0.77	0.76	5.4	0.25(0.26)	0.39(0.39)
D06A013	FLOW_OUT_10	0.72	1.27	0.68	0.58	-13	0.45(0.40)	0.60(0.53)
D06A001	FLOW_OUT_71	0.82	1.46	0.78	0.76	18.6	1.19(1.47)	1.66(1.99)
D06A026	FLOW_OUT_89	0.61	0.49	0.46	0.45	7.1	0.58(0.62)	0.71(1.04)
D06A042	FLOW_OUT_92	0.72	0.83	0.8	0.59	40.4	0.22(0.37)	0.29(0.56)
EIE601	FLOW_OUT_99	0.41	1.09	0.79	0.63	-62.4	6.68(4.11)	8.64(7.76)

Although successful results were obtained from the calibration result, it was not possible to obtain the same results for sediment and nutrient variables. In addition, the evaluation of the results differed considerably according to the objective functions. Due to the uncertainty of the measurement values, an iteration was performed for the nutrient variables and then calibration was not continued. The results of the calibration are shown in Table 5.4.

Table 5.4. Calibration results for sediment and quality.

Station	Variable	p-factor	r-factor	R ²	NS	PBIAS	Mean_sim (Mean_obs)	StdDev_sim (StdDev_obs)
KGİ02	SED_OUT_95	0.29	0.93	0.16	0.16	15.1	301.54(355.22)	449.56(1098.85)
EİE601	SED_OUT_99	0.52	0.21	0.67	0.08	81.7	962.56(5269.59)	1630.83(14121.21)
KGİ02	NO ₃ ⁻ _OUT_95	0.45	8.41	0.22	0.19	20.8	5691.76(7186.88)	6372.71(10948.38)
KGİ02	NH ₄ ⁺ _OUT_95	0.26	1.37	0.02	-1.7	63.9	8140.29(22576.08)	13459.07(16389.19)
KGİ02	NO ₂ ⁻ _OUT_95	0.33	0.14	0.35	-0.13	83.3	305.52(1833.66)	417.54(2878.87)
KGİ02	TOT_N_95	0.75	4.42	0.85	0.74	26.3	20791.00(28204.47)	21468.01(30529.43)

For validation, 1500 simulations were performed again using a different simulation period than the calibration, keeping the parameter ranges determined in the calibration constant. However, something needs to be clarified for the validation processes of the SWAT-CUP SUFI 2 Algorithm. SWAT-CUP gives the best simulation value according to the best results of all values and calculates the objective functions according to the results of the parameters determined in this simulation. Therefore, the number of the best simulation determined for the calibration and validation process and, therefore, the parameter values may change. For our study, the best simulation for the calibration period was the 1134th simulation, while the 237th simulation for the validation period was calculated as the best simulation. Since it would be more accurate to evaluate the objective functions when they have the same parameter values as the calibration period, I performed another dummy simulation with the parameter values I found in the 1134th simulation using the validation observation stations after the validation. Since it was not possible to evaluate the p-factor and r-factor from this simulation, I performed the evaluations using the p-factor and r-factor values I found as a result of the validation and the objective function values I found after the dummy simulation. In Table 5.5 and Table 5.6, I provided both results.

Global sensitivity analysis results for the nested subbasins calibration are different from the calibration processes that is used separately for all stations because global sensitivity analysis gives one output for all parameters that effected to overall value of the calibration processes. In this study, I used ten stations to calibrate the simulated streamflow and give different parameter ranges for

different gauge stations. Since sub-basin 99 has 98 upstream sub-basins and also the worse initial results, it dominated the sensitivity analysis.

Table 5.5. Validation results.

Station	Variable	p-factor	r-factor	R ²	NS	PBIAS	Mean_sim (Mean_obs)	StdDev_sim (StdDev_obs)
D06A011	FLOW_OUT_1	0.89	1.27	0.77	0.66	-10.4	0.36(0.32)	0.57(0.48)
D06A027	FLOW_OUT_6	0.76	1.79	0.74	0.38	-13.2	0.35(0.31)	0.54(0.37)
D06A025	FLOW_OUT_7	0.73	1.11	0.5	0.43	-11.2	0.50(0.45)	0.58(0.61)
D06A033	FLOW_OUT_8	0.88	1.41	0.8	0.73	-12.4	1.16(1.03)	1.27(1.13)
D06A012	FLOW_OUT_9	0.79	1.52	0.68	0.57	11.9	0.23(0.26)	0.39(0.34)
D06A013	FLOW_OUT_10	0.73	1.58	0.6	0.52	15.6	0.38(0.45)	0.50(0.48)
D06A001	FLOW_OUT_71	0.64	1.32	0.78	0.43	-15.1	2.47(2.15)	3.59(2.47)
D06A026	FLOW_OUT_89	0.39	0.58	0.5	0.26	58.1	0.26(0.61)	0.38(0.90)
D06A042	FLOW_OUT_92	0.65	1.04	0.79	0.74	2.9	0.29(0.30)	0.28(0.40)
EiE601	FLOW_OUT_99	0.48	1.12	0.72	0.62	-54.7	8.93(5.77)	8.28(10.06)
EiE601	SED_OUT_99	0.52	0.18	0.58	0.02	81.7	1346.16(7368.68)	1595.81(20008.47)

Table 5.6. Validation results for fitted calibration parameters.

Variable	R ²	NS	PBIAS	Mean_sim (Mean_obs)	StdDev_sim (StdDev_obs)
FLOW_OUT_1	0.7	0.53	-14.4	0.37(0.32)	0.60(0.48)
FLOW_OUT_6	0.77	-0.05	-33.2	0.41(0.31)	0.64(0.37)
FLOW_OUT_7	0.49	0.43	12.9	0.39(0.45)	0.56(0.61)
FLOW_OUT_8	0.79	0.77	15.6	0.87(1.03)	1.07(1.13)
FLOW_OUT_9	0.69	-0.31	-40.3	0.37(0.26)	0.61(0.34)
FLOW_OUT_10	0.69	-0.22	-32.1	0.59(0.45)	0.84(0.48)
FLOW_OUT_71	0.84	0.8	22.4	1.67(2.15)	2.40(2.47)
FLOW_OUT_89	0.28	0.19	1.4	0.60(0.61)	0.75(0.90)
FLOW_OUT_92	0.63	0.39	50.4	0.15(0.30)	0.19(0.40)
FLOW_OUT_99	0.65	0.59	-17.1	6.76(5.77)	5.81(10.06)
SED_OUT_99	0.54	-0.04	89.2	793.12(7368.68)	890.33(20008.47)

I did global sensitivity analysis after the calibration of streamflow and determined the most sensitive parameters. The first seven sensitive parameters were found CN2 for subbasins 99, 8, 71, 6, 1, 7, and 10 respectively. Even though they are not in the first, for subbasins 92 and 9, CN2 also was found sensitive. It is not unexpected, because CN2 is reported as sensitive for streamflow many times in the literature (Guzman et al., 2015; Abbaspour et al., 2017; Li & Kim, 2019; Swain et al., 2020; Malik et al., 2022). Other sensitive parameters are mostly the soil parameters. SOL_BD are sensitive for subbasins 10, 8, 1, and 9, respectively. SOL_AWC is found sensitive for subbasins 71 and 99 while SOL_K was found sensitive for subbasins 8 and 10.

Table 5.7. The most sensitive 20 parameters after the flow calibration.

Parameter	Subbasin
R__CN2.mgt	subbasin 99
R__CN2.mgt	subbasin 8
R__CN2.mgt	subbasin 71
R__CN2.mgt	subbasin 6
R__CN2.mgt	subbasin 1
R__CN2.mgt	subbasin 7
R__CN2.mgt	subbasin 10
R__GWQMN.gw	subbasin 71
R__SOL_BD(..).sol	subbasin 10
R__SOL_AWC(..).sol	subbasin 71
R__CN2.mgt	subbasin 92
R__SOL_BD(..).sol	subbasin 8
R__SOL_AWC(..).sol	subbasin 99
R__SOL_K(..).sol	subbasin 8
R__SOL_K(..).sol	subbasin 10
R__REVAPMN.gw	subbasin 71
R__CN2.mgt	subbasin 9
V__ESCO.hru	subbasin 71
R__SOL_BD(..).sol	subbasin 1
R__SOL_BD(..).sol	subbasin 9

Table 5.8. The most sensitive 20 parameters after the last calibration.

Parameter	Subbasin
CN2.mgt	subbasin 99
NPERCO.bsn	all
FRT_SURFACE{..}.mgt	all
SOL_K(..).sol	subbasin 89
SOL_AWC(..).sol	subbasin 71
HRU_SLP.hru	subbasin 7
GW_REVAP.gw	subbasin 7
GW_REVAP.gw	subbasin 9
SOL_AWC(..).sol	subbasin 99
SOL_BD(..).sol	subbasin 92
SOL_AWC(..).sol	subbasin 89
GW_REVAP.gw	subbasin 71
SOL_K(..).sol	subbasin 8
ALPHA_BF.gw	subbasin 1
REVAPMN.gw	subbasin 9
SOL_K(..).sol	subbasin 92
SPCON.bsn	all
SOL_BD(..).sol	subbasin 10
GWQMN.gw	subbasin 99
GWQMN.gw	subbasin 8

After the last calibration, I did one more global sensitivity analysis. The results show that the most sensitive parameter is CN2 for subbasin99. It is not unexpected because, due to the overestimation of flow for the initial simulation, I had to calibrate CN2 to decrease flow. The second and third sensitive parameters are NPERCO and FRT_SURFACE, respectively. I observed large results when considering the r-factors of NO_3^- and Total Nitrogen. It is assessed due to the NPERCO and FRT_SURFACE sensitivity because since I did not further calibration for the nutrients, the NPERCO parameters range is fitted to its minimum and maximum value. When I compared to other results from the first sensitivity analysis, I observed that CN2 parameters were not found sensitive, and instead of them, many parameters were found sensitive to groundwater. Soil parameters SOL_AWC, SOL_BD, and SOL_K are also found sensitive in this analysis.

5.2. Evaluation Calibration and Validation Results at Each Stations

5.2.1. Station D06A011 - Subbasin 1 Results

For station D06A011 at the outlet of sub-basin 1, the p-factor and r-factor were calculated as 0.74 and 1, respectively. As I discussed earlier, these are good values for uncertainty analysis. The model also simulated flow as satisfactory, good, and unsatisfactory for R^2 , NSE, and PBIAS, respectively. Although it is found to be unsatisfactory according to the PBIAS evaluation criteria, the result is very close to the threshold value. In addition, I chose the threshold values with a study that suggests more stringent and narrow range values compared to other studies, so it is possible to say that I obtained satisfactory results for this station when all criteria values are considered. Sub-basin 1 is located at the northern boundary of the basin, is generally covered with forests, and there are no reservoirs in the basin; therefore, a satisfactory simulation was expected. After the calibration of the station, the R^2 value increased by 0.01, while the NSE value did not change, but the PBIAS value decreased. While the value obtained from the initial simulation for PBIAS was -5.8, this value changed in the opposite direction and became 16.6 after calibration. The minus or plus state of the PBIAS value is an indicator to understand whether there is underestimation or overestimation. As can be seen from the graph, the initial simulation overestimated the flow, but after calibration, the situation reversed, and some underestimation was observed for the calibration period except for the two peaks in late 2007 and early 2011. As can be seen in Figure 5.1, the overestimations for the 2007 and 2011 periods are thought to result from the precipitation data. Only one peak value was overestimated in 2013 for the validation period of station D06A011, with satisfactory results according to all evaluation criteria.

Table 5.9. Calibration and validation results for station D06A011 in subbasin 1.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.74	satisfactory	0.89	satisfactory
r-factor	1	satisfactory	1.27	satisfactory
R ²	0.75	satisfactory	0.7	satisfactory
NSE	0.74	good	0.53	satisfactory
PBIAS	16.6	unsatisfactory	-14.4	satisfactory

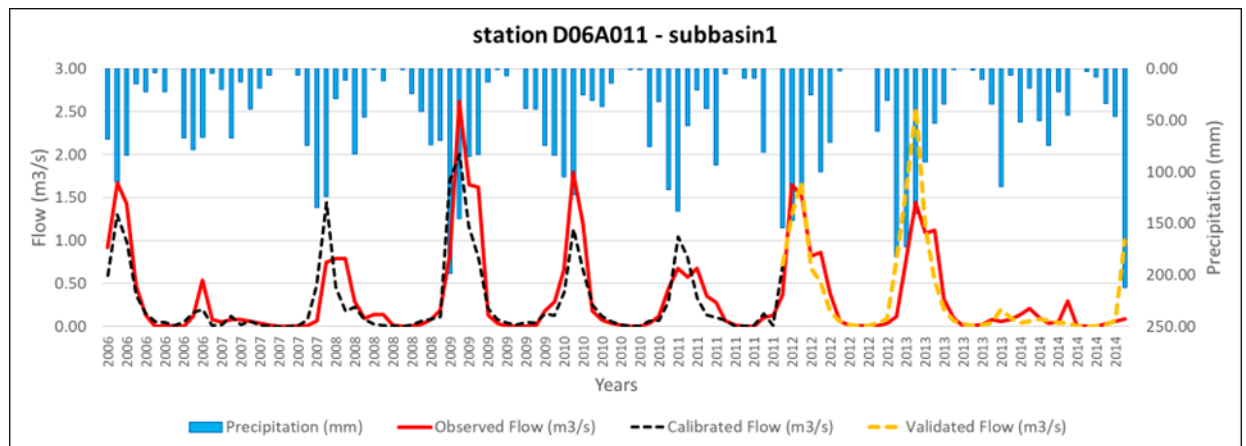


Figure 5.1. Calibrated flow result for station D06A011 in subbasin 1.

5.2.2. Station D06A027 - Subbasin 6 Results

The p-factor and r-factor values for the calibration period of station D06A027 at the outlet of sub-basin six were found to be 0.61 and 1.4, respectively. Although the p-factor is found to be unsatisfactory according to the rule of greater than 0.7, 0.61 is not a bad result. Also, the values for NSE and PBIAS were rated as unsatisfactory, but the results cannot be said to be too bad, as I observed that the values for both were within the threshold limits. I evaluated the calibration result for this station as satisfactory, with the R² value also being found to be satisfactory. When the graphs are examined, it is seen that two peaks are underestimated, and three peaks are overestimated.

Sub-basin 6, located on the northern border of the Küçük Menderes Basin, is generally covered with forests and olive groves, and there is a reservoir named Ergenli Dam at the outlet of the sub-basin. The construction of the reservoir started in 2014, and according to DSI, the reservoir is currently still under construction. Considering that the calibration period does not cover the year 2014, it is not thought that the reservoir will have an impact on the results of the calibration period.

It was observed that while the p-factor increased for the 2012-2014 validation period at the station, the r-factor also increased. This means that the uncertainty in the parameters is greater than over the calibration period, but there is also an increase in the data included in this parameter range relative to the calibration. Therefore, the validation results were evaluated as satisfactory and unsatisfactory, with the opposite of calibration for the p-factor and r-factor, respectively. The R^2 value also increased to 0.77 during the validation period and was evaluated as good; however, the NSE and PBIAS values were considerably reduced compared to the calibration period. The construction of the reservoir in the sub-basin was started at the end of the validation period, but when the flow values observed and simulated in 2014 are evaluated on the graph, it is seen that the problem may not be the reservoir construction. There appears to be an overestimation of two peaks in 2012 and 2013, so the problem is thought to be more likely to be associated with precipitation data.

Table 5.10. Calibration and validation results for station D06A027 in subbasin 6.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.61	unsatisfactory	0.76	satisfactory
r-factor	1.4	satisfactory	1.79	unsatisfactory
R^2	0.63	satisfactory	0.77	good
NSE	0.5	unsatisfactory	-0.05	unsatisfactory
PBIAS	-15.9	unsatisfactory	-33.2	unsatisfactory

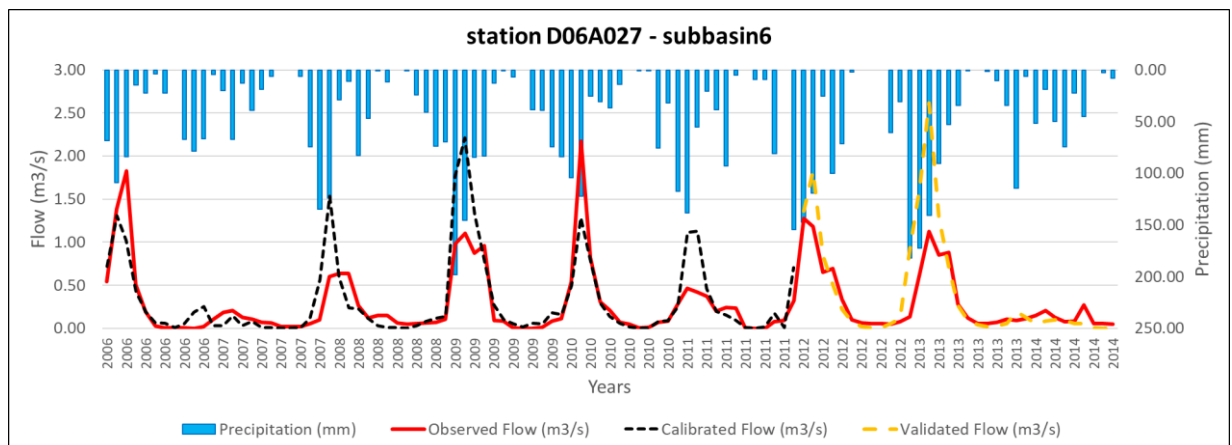


Figure 5.2. Calibrated flow result for station D06A027 in subbasin 6.

5.2.3. Station D06A025 - Subbasin 7 Results

The results of station D06A025 at the outlet of sub-basin 7 are quite reasonable compared to other indicator stations. Both the p-factor and r-factor calibration and validation times were found to be satisfactory. While R^2 and NSE were found to be satisfactory, with values of 0.71 and 0.62, respectively, for the calibration period, PBIAS was found to be unsatisfactory. However, this difference is not more extensive and can be considered satisfactory in the literature according to the ± 25 threshold (Moriassi et al., 2007). Results for the validation time vary inversely, with R^2 and NSE being found to be unsatisfactory, while PBIAS is rated as satisfactory. It is considered that increased precipitation data in the same time period may cause overestimation at the first peak in the validation period in 2015. Also, the underestimation in 2018 may be due to the same reason, the decrease in precipitation data. I can also see the irrigation effects at this station because there is AGRR land cover in the sub-basin, which contains the data I entered for corn silage.

Table 5.11. Calibration and validation results for station D06A025 in subbasin 7.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.73	satisfactory	0.73	satisfactory
r-factor	1.22	satisfactory	1.11	satisfactory
R^2	0.71	satisfactory	0.49	unsatisfactory
NSE	0.62	satisfactory	0.43	unsatisfactory
PBIAS	-19.8	unsatisfactory	12.9	satisfactory

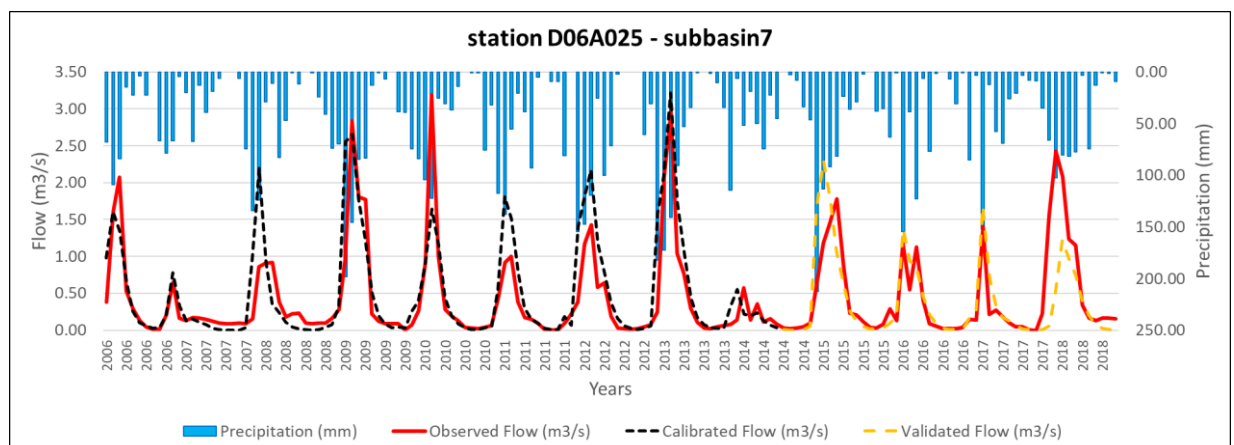


Figure 5.3. Calibrated flow result for station D06A025 in subbasin 7.

5.2.4. Station D06A033 - Subbasin 8 Results

Considering all the evaluation criteria, the D06A033 station can be considered very well simulated. Only the p-factor for the calibration period and the PBIAS for the validation period were evaluated as unsatisfactory, but they cannot be said to be bad as both are quite close to the threshold values. During the calibration period, the results were good for R^2 and NSE and very good for NSE. When I compare the calibration and validation results, I can see some decrease in the objective functions for the validation period.

Sub-basin 8 has an irrigation pond, Çatak (Kiraz) Reservoir, located close to the spring. The construction of the Çatak (Kiraz) Reservoir was started in 2012, and the reservoir was put into service in 2015 when the validation period started. After this period, the results are expected to worsen as reservoir operations control the flow (Abbaspour et al., 2015). While the decrease in the validation period can be explained in this way, the results obtained are still satisfactory (Abbaspour et al., 2015).

Table 5.12. Calibration and validation results for station D06A033 in subbasin 8.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.65	unsatisfactory	0.88	satisfactory
r-factor	1.12	satisfactory	1.41	satisfactory
R^2	0.85	good	0.79	good
NSE	0.84	very good	0.77	good
PBIAS	11.7	satisfactory	15.6	unsatisfactory

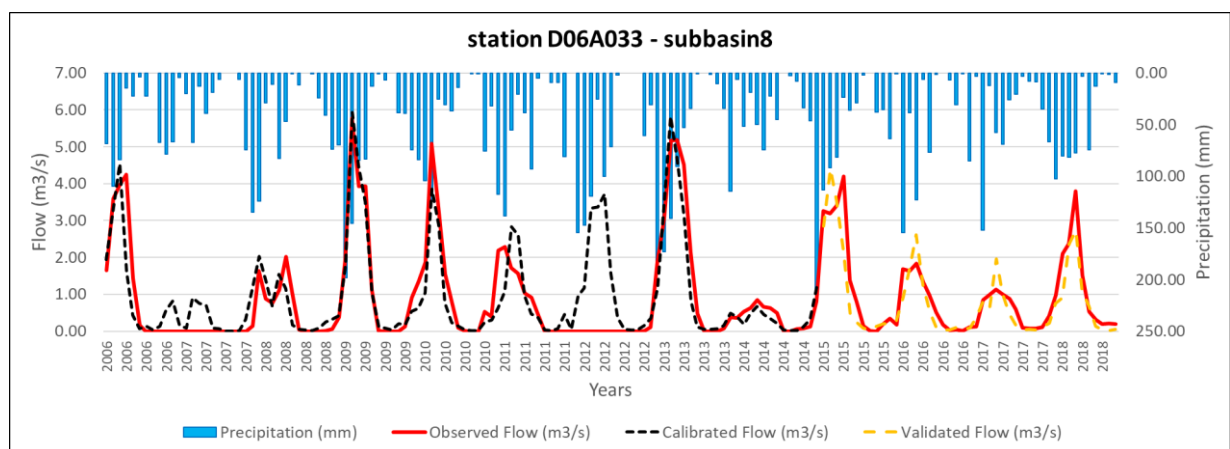


Figure 5.4. Calibrated flow result for station D06A033 in subbasin 8.

5.2.5. Station D06A012 - Subbasin 9 Results

In station D06A012, the flow is very well simulated by the model for the calibration time. The P-factor and r-factor for the calibration period are satisfactory; that is, the parameter ranges determined for the calibration represent the conditions in the 9th sub-basin located on the northern border of the Küçük Menderes Basin. R^2 was found to be good for the NSE and PBIAS calibration period. For the confirmation time, it can be seen that the r-factor increases and can be considered unsatisfactory, but the difference with the threshold is not significant and is an acceptable value. However, the NSE and PBIAS values were considered unsatisfactory, showing a tremendous decrease compared to the calibration period. Although the R^2 value was considered satisfactory, it also decreased.

There is a reservoir built in 2011-2017 in sub-basin 9, where station D06A012 is located. Therefore, as I mentioned, it is normal for the reservoir operation to affect the flow directly. On the other hand, when I evaluate the graph, it is seen that there is an overestimate for the peak in 2013, and the precipitation also increased in the same time period.

Table 5.13. Calibration and validation results for station D06A012 in subbasin 9.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.72	satisfactory	0.79	satisfactory
r-factor	1.1	satisfactory	1.52	unsatisfactory
R^2	0.77	good	0.69	satisfactory
NSE	0.76	good	-0.31	unsatisfactory
PBIAS	5.4	good	-40.3	unsatisfactory

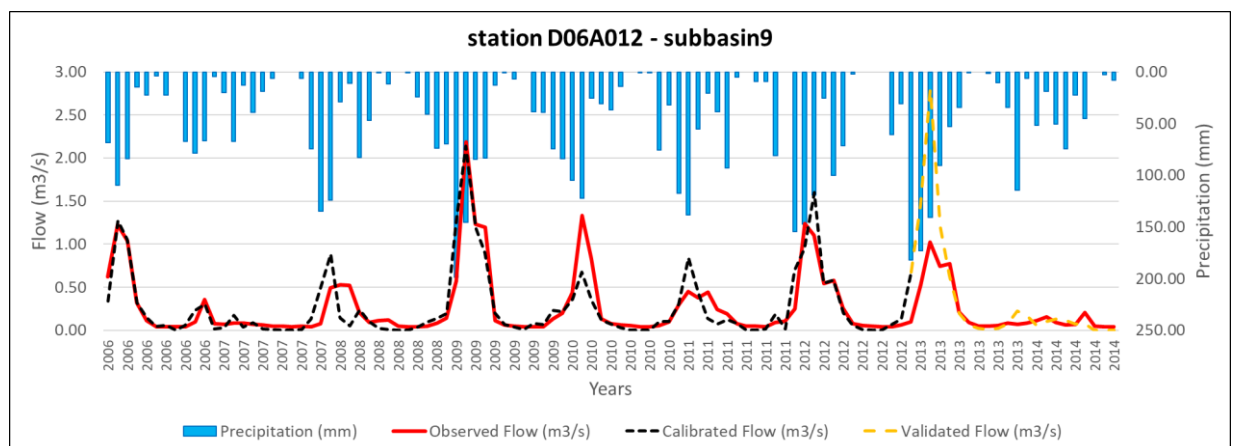


Figure 5.5. Calibrated flow result for station D06A012 in subbasin 9.

5.2.6. Station D06A013 - Subbasin 10 Results

It is seen that the calibration period is better simulated than the validation period according to the objective functions for station D06A013 located at the outlet of sub-basin 10. The P-factors for the calibration and validation period were found to be close to each other, 0.72 and 0.73, respectively, and were considered satisfactory. Although the r-factor for the validation period is considered unsatisfactory, the difference between the threshold value of 1.5 is not that great. For the calibration time, the r-factor is satisfactory. Like p-factors, R^2 values were found to be close and satisfactory for both periods. However, NSE and PBIAS values were found to be satisfactory for the calibration period but unsatisfactory for the validation period.

As a result of the evaluation of the results in the graph, I determined overestimated peaks during the validation period. Sub-basin 10, located at the northern border of the basin, is mainly covered with forests and olive groves, and there is no reservoir in the sub-basin. For this reason, it has been interpreted that the overestimated peaks may be due to the increase in precipitation data.

Table 5.14. Calibration and validation results for station D06A013 in subbasin 10.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.72	satisfactory	0.73	satisfactory
r-factor	1.27	satisfactory	1.58	unsatisfactory
R^2	0.68	satisfactory	0.69	satisfactory
NSE	0.58	satisfactory	-0.22	unsatisfactory
PBIAS	-13	satisfactory	-32.1	unsatisfactory

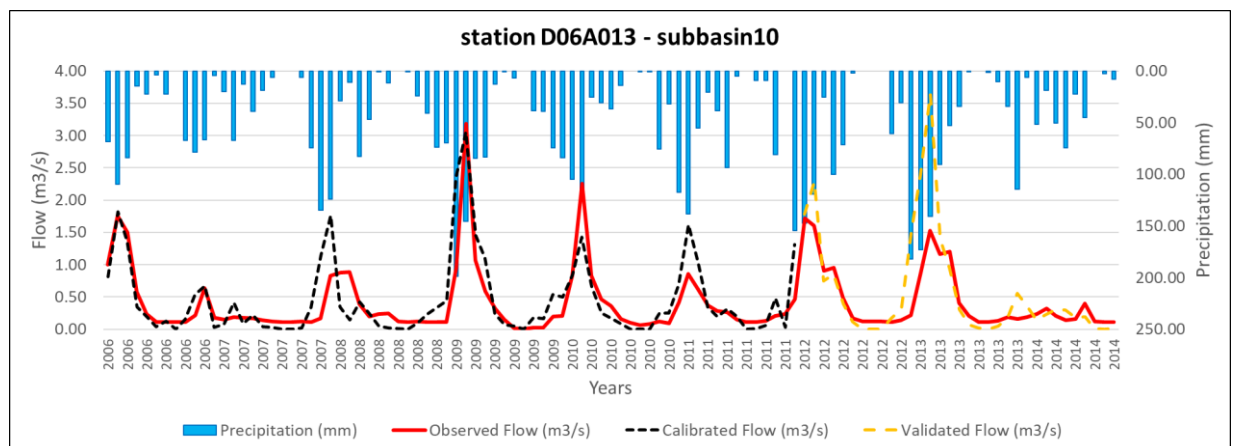


Figure 5.6. Calibrated flow result for station D06A013 in subbasin 10.

5.2.7. Station D06A001 - Subbasin 71 Results

Station D06A001 generally has good results for flow simulation calibration and validation periods. It is the station with the largest p-factor value for the calibration period, with a value of 0.82. Although the r-factor was very close to the threshold value, it was found sufficient for the calibration time. While R^2 and NSE values were evaluated as good, the PBIAS value was evaluated as unsatisfactory, but the result is not bad and can be considered satisfactory for different thresholds in the literature. Similar results can be observed during the validation period, except that the p-factor is 0.64. The p-factor does not have a bad value either. The same interpretation made for the PBIAS value during the calibration period can also be made for the validation period, i.e., the result is not bad even if it is evaluated as unsatisfactory and can be evaluated as satisfactory according to different studies. When compared with the calibration period, it is seen that the R^2 and NSE values for the validation period increase during the validation period, unlike the other stations.

Station D06A001 was more difficult to calibrate than other stations. The station is located at the outlet of sub-basin 71 and sub-basin 71 has nine upstream sub-basins. In addition, Beydağ Dam, which is the largest dam lake, is located in the sub-basin number 71. The reservoir was constructed between 1993-2009, and operation started in 2009. In addition, sub-basin 55 and sub-basin 71 of the upstream sub-basins are affected by agricultural land and, therefore, irrigation. Considering all these, it can be said that the model simulates the flow very well for this outlet.

Table 5.15. Calibration and validation results for station D06A001 in subbasin 71.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.82	satisfactory	0.64	unsatisfactory
r-factor	1.46	satisfactory	1.32	satisfactory
R^2	0.78	good	0.84	good
NSE	0.76	good	0.8	good
PBIAS	18.6	unsatisfactory	22.4	unsatisfactory

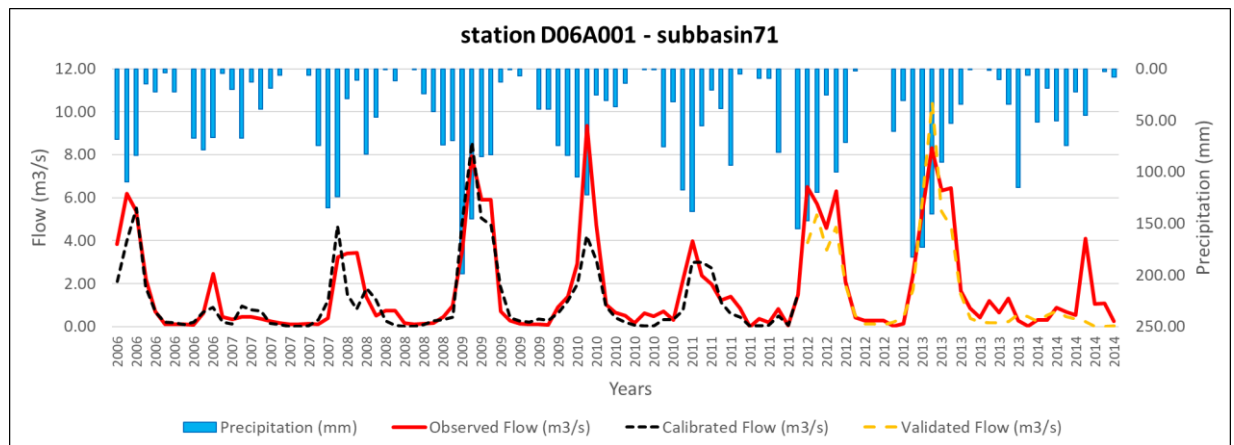


Figure 5.7. Calibrated flow result for station D06A001 in subbasin 71.

5.2.8. Station D06A026 - Subbasin 89 Results

Station D06A026 was the most problematic starting point for calibration. When I identified underestimation after the initial results, I added the height band and calibrated the PLAPS and TLAPS parameters for this station. After adjusting the calibrated parameters, I observed that the three objective functions increased (see Table 5.2) but decreased again for the R^2 and NSE objective functions after the flow calibration was completed, and the values were considered unsatisfactory. PBIAS was evaluated as good for the calibration period and very good for the validation period.

As can be seen in Table 5.16, the r-factors for both calibration and validation are very small. This means that the selected parameter ranges do not cause a significant change in the simulated flow. Although I selected nine initial parameters for each station for the first calibration, I added three more parameters, OV_N, SLSUBBSN, and HRU_SLP, for station D06A026 after I determined that the results did not change. Unfortunately, the results still did not change much, but I accepted the results both because I had good results for PBIAS, and the p-factor was not so bad.

Table 5.16. Calibration and validation results for station D06A026 in subbasin 89.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.61	unsatisfactory	0.39	unsatisfactory
r-factor	0.49	satisfactory	0.58	satisfactory
R^2	0.46	unsatisfactory	0.28	unsatisfactory
NSE	0.45	unsatisfactory	0.19	unsatisfactory
PBIAS	7.1	good	1.4	very good

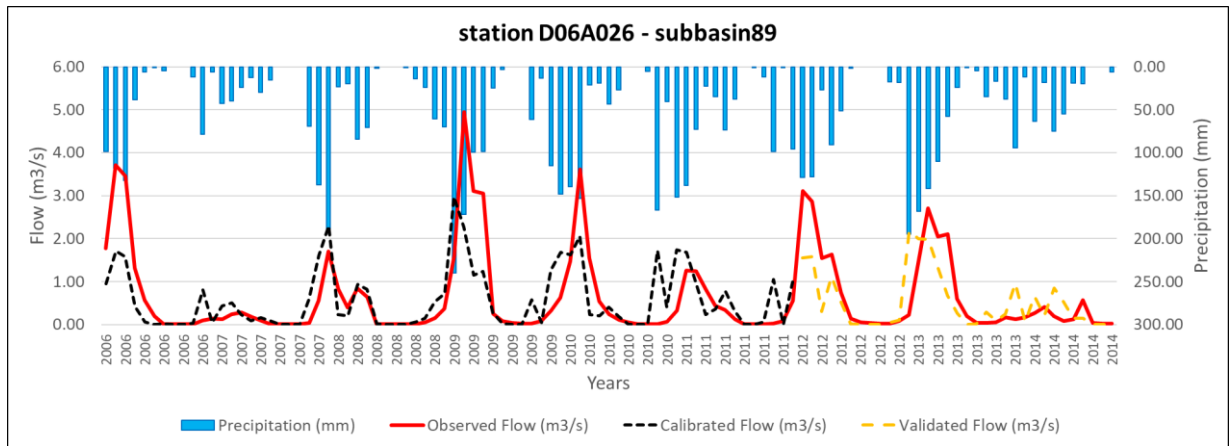


Figure 5.8. Calibrated flow result for station D06A026 in subbasin 89.

The main reason for the simulation difficulty observed here may be that station D06A026 is located at the outlet of sub-basin 89, and there is a reservoir there as well. The construction of Bademli Reservoir, located at the outlet, started in 2011 and was completed at the end of 2015. The dam was put into operation in 2015; that is, the calibration and validation periods do not cover this year but include the construction period. On the other hand, sub-catchment 89 includes generic farmland that I have not included in management practices due to its type. Therefore, if irrigated here, it may affect the downstream flow.

5.2.9. Station D06A042 - Subbasin 92 Results

Station D06A042 is located in sub-basin 92, one of the three sub-basins where I added the elevation bands and calibrated the PLAPS and TLAPS parameters. It was observed that R^2 , NSE, and PBIAS increased after PLAPS and TLAPS values were fitted. When I evaluated the results of the calibration period, the p-factor, r-factor, and NSE values were found to be satisfactory, the R^2 value was found to be good, but the PBIAS value was found to be unsatisfactory. For the validation time, the p-factor is less than 0.70 but not too bad. While r-factor and R^2 are satisfactory, NSE and PBIAS are not. In addition, when the calibration and validation periods are compared, a decrease is observed between the two periods. When I also evaluate the graph, I can see that the flow for the entire simulation period is approximately underestimated.

D06A042 station is located at the outlet of sub-basin number 92, located on the southern border of Küçük Menderes Basin. The sub-basin land cover is mainly forested but also includes generic agricultural lands such as sub-basin 89. Therefore, the problem may be due to irrigation programs I do not include on such farmland. On the other hand, I did not calibrate the snow parameters because

they were in the watershed file, and I observed by doing a calibration experiment that it affected most of the watershed worse. However, since this sub-basin is located in the mountainous part of the basin, it may be affected by snow parameters.

Table 5.17. Calibration and validation results for station D06A042 in subbasin 92.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.72	satisfactory	0.65	unsatisfactory
r-factor	0.83	satisfactory	1.04	satisfactory
R ²	0.8	good	0.63	satisfactory
NSE	0.59	satisfactory	0.39	unsatisfactory
PBIAS	40.4	unsatisfactory	50.4	unsatisfactory

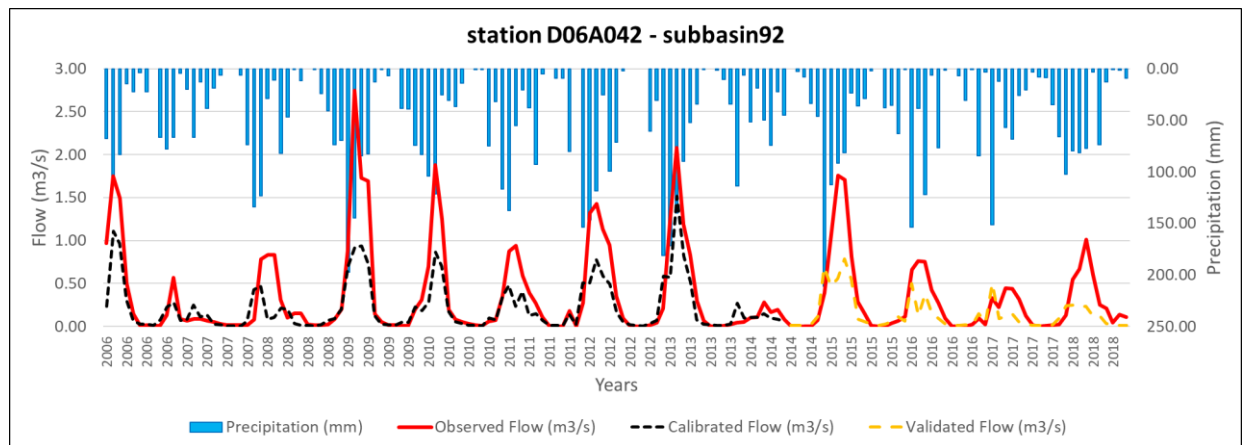


Figure 5.9. Calibrated flow result for station D06A042 in subbasin 92.

5.2.10. Station EIE601 - Subbasin 99 Results

The most challenging calibration process was for the EIE601 station located at the outlet of sub-basin number 99. Calibration data was only four years old, and validation data was only two years old. Additionally, the initial results were poor, and the model overestimated the flow for this station. Because the station has 98 upstream sub-basins, I had to calibrate them all within the same parameter ranges, but the actual situation may differ.

Although the initial results were not good, I achieved satisfactory results in the calibration and validation periods. Also, R² was rated as good for the calibration time. On the other hand, PBIAS was found unsatisfactory for both periods but indeed increased for the validation period and can be considered satisfactory for the different thresholds I discussed (see Table 4.16). I could not obtain

satisfactory results from the p-factors showing the percentage of data remaining within the 95 PPU band. Parameterization was not easy due to the number of upstream sub-basins, so I accept that.

Table 5.18. Calibration and validation results for flow for station EİE601 in subbasin 99.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.41	unsatisfactory	0.48	unsatisfactory
r-factor	1.09	satisfactory	1.12	satisfactory
R ²	0.79	good	0.65	satisfactory
NSE	0.63	satisfactory	0.59	satisfactory
PBIAS	-62.4	unsatisfactory	-17.1	unsatisfactory

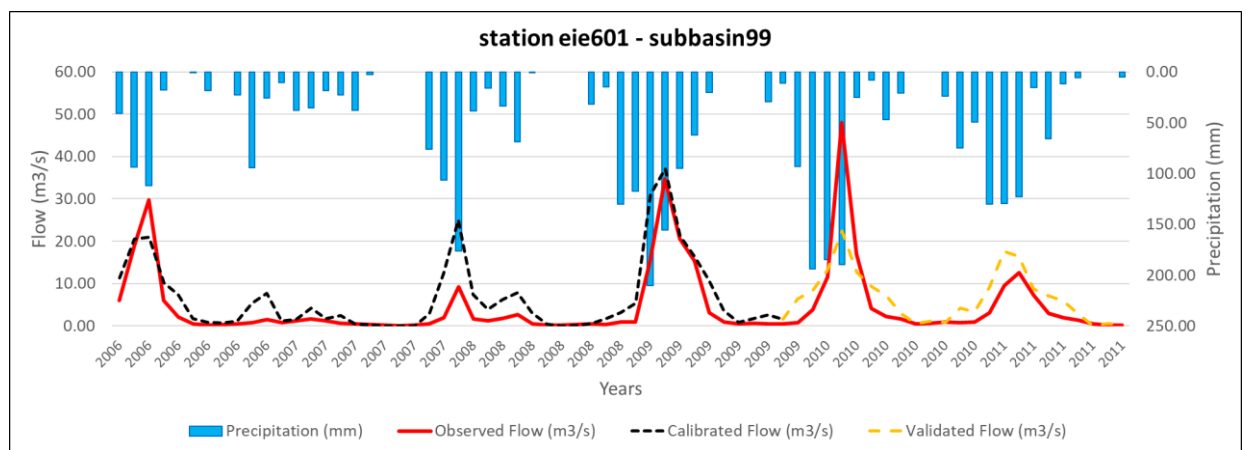


Figure 5.10. Calibrated flow result for station EİE601 in subbasin 99.

Sediment calibration and validation for station EİE601 were also challenging. Although the initial R², NSE, and PBIAS results were quite good, with values of 0.42, 0.41, and 18.6, respectively, they experienced a tremendous decrease after calibration. Since the sediment observation data were calculated based on the flow with the chart equation (see section 4.1.6.), and therefore, the sediment values were primarily flow dependent, I also saw a decrease in the sediment loads since I reduced the flow considerably after the calibration. However, since the difference between the observed values and the simulated values was due to this, it was accepted as usual, and no further calibration was attempted. R² was found to be good for the calibration period and satisfactory for the validation period. On the other hand, Abbaspour et al. (2017) mentioned that the p-factor for sediment and nutrient variables may be smaller than 0.7, as I said before, for this reason, I set the threshold value as 0.40 and therefore I evaluated the p-factor values as satisfactory for the calibration and validation period.

Table 5.19. Calibration and validation results for sediment for station EİE601 in subbasin 99.

	Calibration	Evaluation	Validation	Evaluation
p-factor	0.52	satisfactory	0.52	satisfactory
r-factor	0.21	satisfactory	0.18	satisfactory
R ²	0.67	good	0.54	satisfactory
NSE	0.08	unsatisfactory	-0.04	unsatisfactory
PBIAS	81.7	unsatisfactory	89.2	unsatisfactory

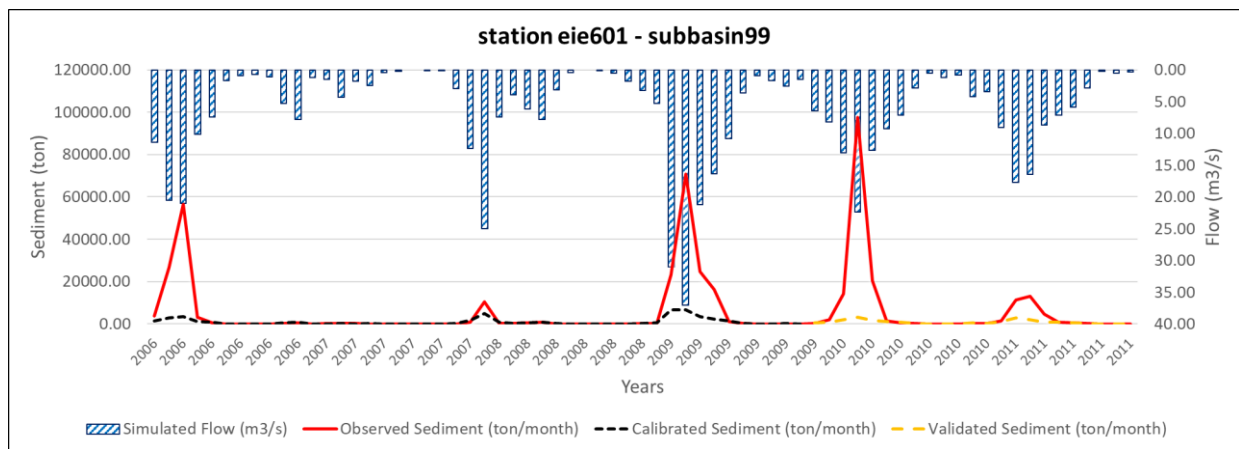


Figure 5.11. Calibration and validation results for sediment in subbasin 99.

5.2.11. Station KGİ02 - Subbasin 95 Results

Since our initial sediment and nutrient results were not very good, I only used the KGİ02 station for nutrient calibration. KGİ02 station is located at the outlet of sub-basin number 95, which is representative of the basin since it is closer downstream. Also, this station has a more acceptable number of data and results for the NO_2^- , NO_3^- , NH_4^+ and Total N variables.

Although the sediment calibration results are considered unsatisfactory for R² and NSE, they are better than the sediment results of the EİE601 station. In addition, the PBIAS result, and r-factor were found to be satisfactory. The difference between the two sediment stations was the observation data. While EİE601 station data were calculated with the equation from the graph created by the EİE, I used the suspended solids concentrations measured for the KGİ02 station and the monthly loads calculated from them. Therefore, due to the uncertainty within these data sets, the difference between the two cannot be interpreted.

Table 5.20. Calibration results for sediment for station KGI02 in subbasin 95.

	Calibration	Evaluation
p-factor	0.29	unsatisfactory
r-factor	0.93	satisfactory
R ²	0.16	unsatisfactory
NSE	0.16	unsatisfactory
PBIAS	15.1	satisfactory

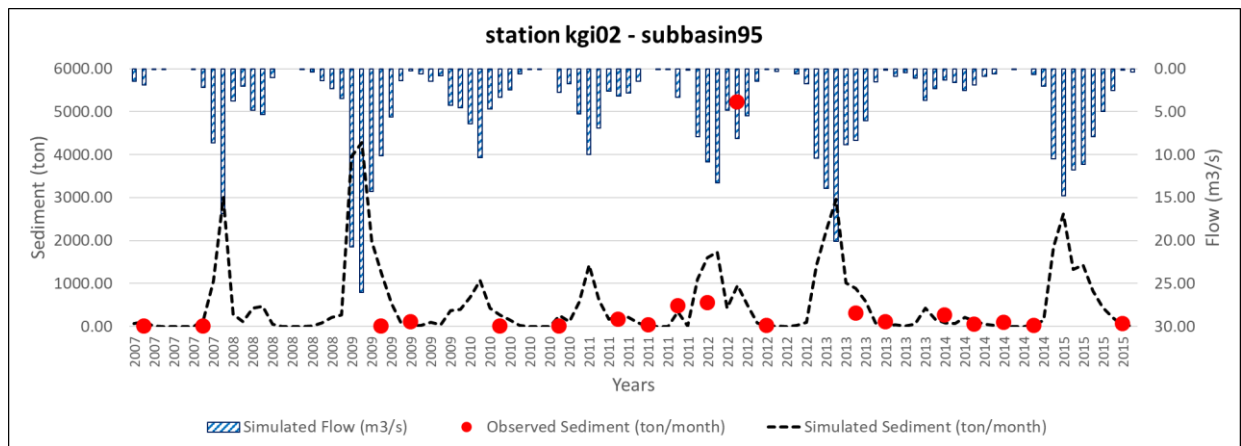


Figure 5.12. Calibration results for sediment for station KGI02 in subbasin 95.

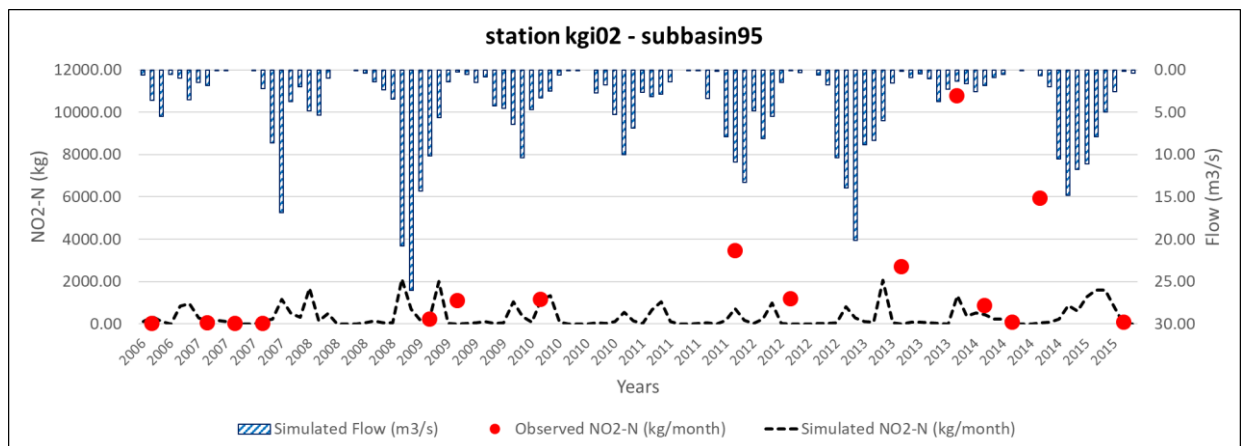
I only used six parameters for the nutrient calibration: SHALLST_N, RCN, NPERCO, CMN, SOL_NO3, and FRT_SURFACE. Due to the uncertainty of the data sets for the nutrient variables, calibration of the nutrient was really challenging, so I only did one iteration and did not go further. Also, I could validate them due to the amount of data.

Calibration results for NO_2^- were found satisfactory for p-factor and R²; on the other hand, NSE and PBIAS were unsatisfactory. Since the amount of data is not enough to evaluate outputs with only objective functions, the graph is also evaluated. It can be seen from Figure 5.12 that there is no pattern between simulated data and observed data. The model failed to simulate peak values for NO_2^- .

Even though the R² result of NO_3^- was worse than NO_2^- , satisfactory results obtained for p-factor and PBIAS, also the graph also looks better.

Table 5.21. Calibration results for NO_2^- for station KGI02 in subbasin 95.

	Calibration	Evaluation
p-factor	0.33	satisfactory
r-factor	0.14	satisfactory
R^2	0.35	satisfactory
NSE	-0.13	unsatisfactory
PBIAS	83.3	unsatisfactory

Figure 5.13. Calibration results for NO_2^- for station KGI02 in subbasin 95.Table 5.22. Calibration results for NO_3^- for station KGI02 in subbasin 95.

	Calibration	Evaluation
p-factor	0.45	satisfactory
r-factor	8.41	unsatisfactory
R^2	0.22	unsatisfactory
NSE	0.19	unsatisfactory
PBIAS	20.8	satisfactory

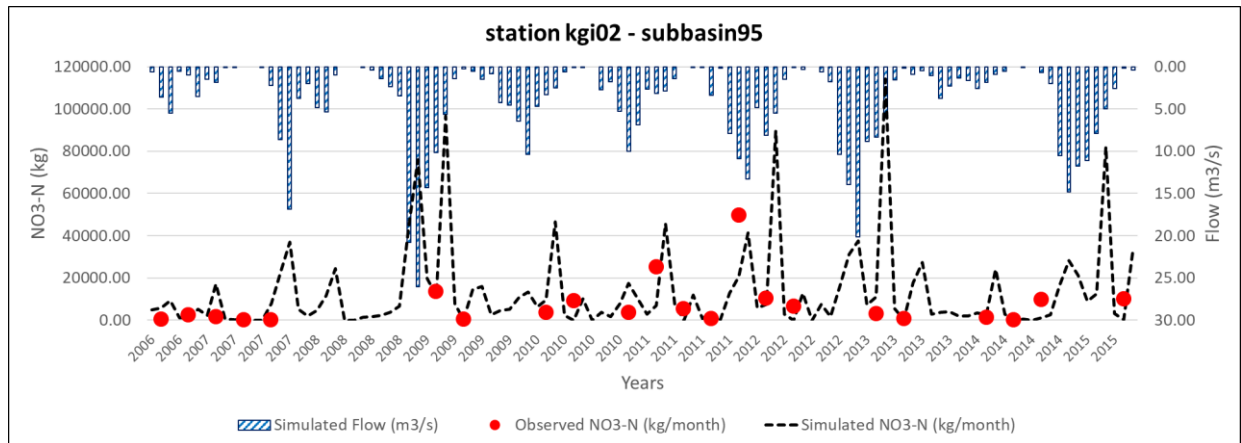


Figure 5.14. Calibration results for NO_3^- for station KGI02 in subbasin 95.

For NH_4^+ , all results are unsatisfactory. From the graphical assessment, I identified only a few data points that matched the observed data. Overall, the model failed to simulate NH_4^+ .

Table 5.23. Calibration results for NH_4^+ for station KGI02 in subbasin 95.

	Calibration	Evaluation
p-factor	0.26	unsatisfactory
r-factor	1.37	satisfactory
R^2	0.02	unsatisfactory
NSE	-1.7	unsatisfactory
PBIAS	63.9	unsatisfactory

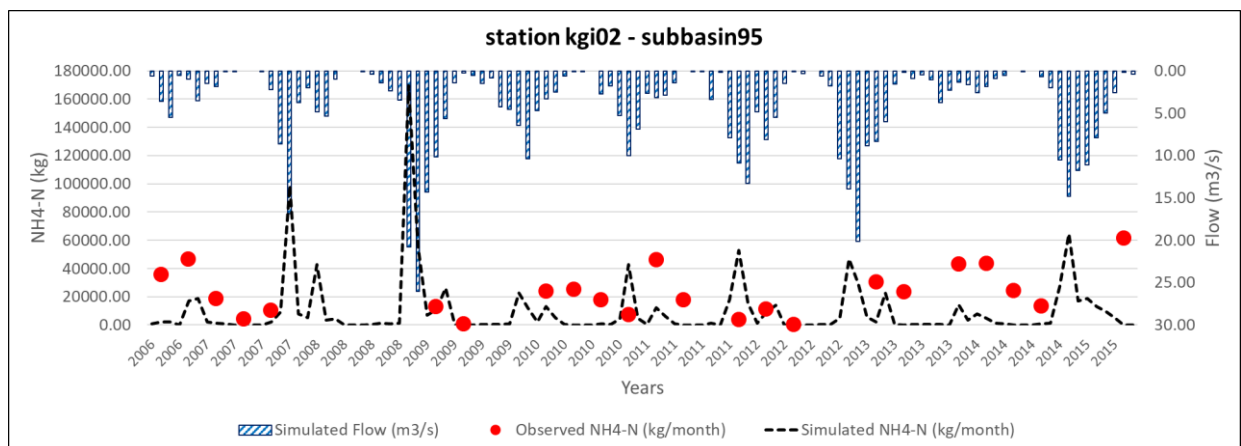


Figure 5.15. Calibration results for NH_4^+ for station KGI02 in subbasin 95.

Table 5.24. Calibration results for Total N for station KGI02 in subbasin 95.

	Calibration	Evaluation
p-factor	0.75	satisfactory
r-factor	4.42	unsatisfactory
R ²	0.85	very good
NSE	0.74	very good
PBIAS	26.3	satisfactory

Unlike other parameters, I obtained very good results from the total nitrogen calibration. The p-factor and PBIAS were found to be sufficient, while R² and NSE were evaluated as very good. The r-factor, on the other hand, was found to have an immense value for the Total nitrogen calibration and was rated as unsatisfactory. It is interpreted that this is due to the uncertainties I experience in nutrient calibration and the selection of the parameter range from minimum and maximum values. Although I got good results from the total nitrogen calibration, it is highly inaccurate to evaluate them with objective functions because I only have four data points for this variable. Also, from the graph in Figure 5.16, I see that the first observed data is not very close to the simulated data; on the other hand, the average simulation and average observation values are 20791.00 tons and 28204.47 tons, respectively. For this reason, these results also contain uncertainties in themselves.

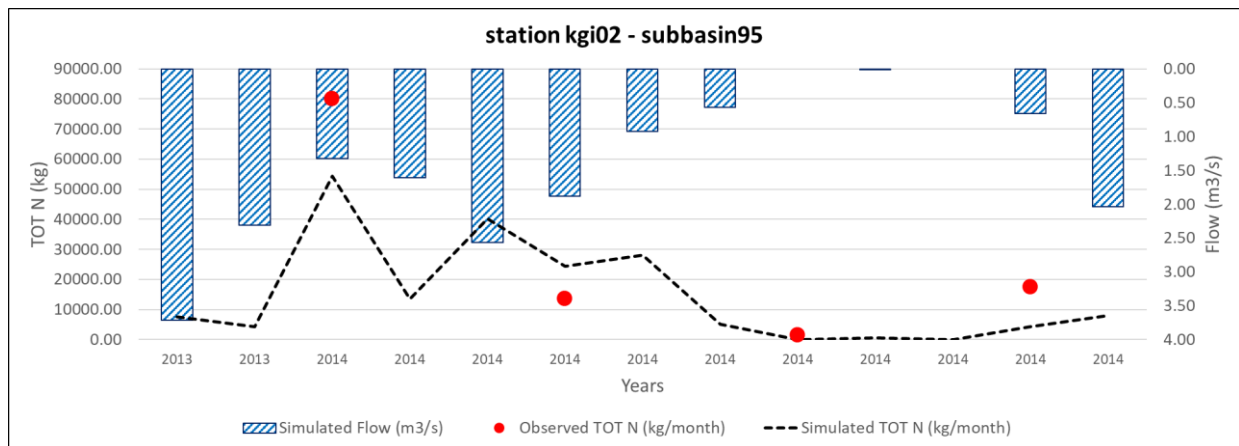


Figure 5.16. Calibration results for Total N for station KGI02 in subbasin 95.

5.3. Management Scenarios Results

I compared the values I obtained after the calibration and the annual total values obtained after the scenarios for the variables of flow, sediment, NO_2^- , NO_3^- , NH_4^+ , and TN. I evaluated the graphs and compared the percentage change of the average annual total loads. Since I have calibrated it, I

only evaluated the KGİ02 station at the outlet of sub-basin 95. Although no significant change was observed for most variables, the biggest change was in nitrate when scenario-2 was added, and the second also was in nitrate variable when scenario-3 was added. It was observed that the change for the sediment was in scenario-1 and scenario-3, and since the values were the same, it was interpreted that the decrease in the amount of fertilizer did not affect the sediment but only irrigation. While the total nitrogen was less affected by irrigation, it was slightly more affected by fertilization, but the situation was the opposite for NO_2^- and NH_4^+ . Flow is also a variable observed to be affected only by irrigation, and the expectation is already in this way.

Table 5.25. Management scenarios' results for station KGİ02 in subbasin 95.

	FLOW_OUT (cms)	NO_3^- _OUT (kg)	NO_2^- _OUT (kg)	TOT_N (kg)	NH_4^+ _OUT (kg)	SED_OUT (tons)
Scenario 1	-1.5 %	2.4 %	-0.6 %	-0.3 %	-0.9 %	-1.6 %
Scenario 2	0.0 %	-18.8 %	-0.2 %	-3.1 %	0.0 %	0.0 %
Scenario 3	-1.5 %	-17.2 %	-0.8 %	-3.6 %	-0.9 %	-1.6 %

For corn silage, I added 15.15.15 and urea fertilizer as stated by the authorities and farmers, so in the scenario where fertilization was reduced, the most significant change (-18.8 %) was likely to be in the nitrate variable.

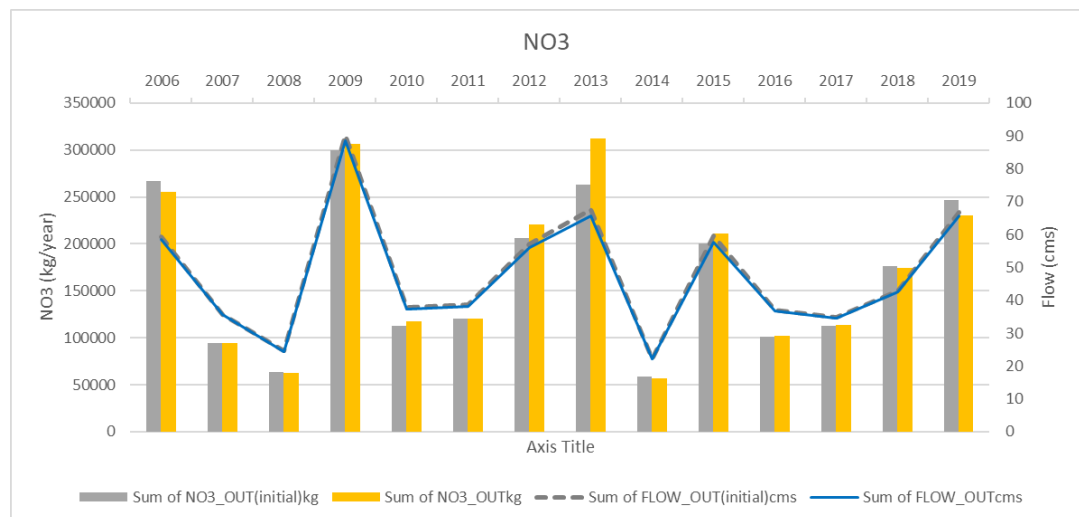


Figure 5.17. Scenario-1 for NO_3^- for station KGİ02 in subbasin 95.

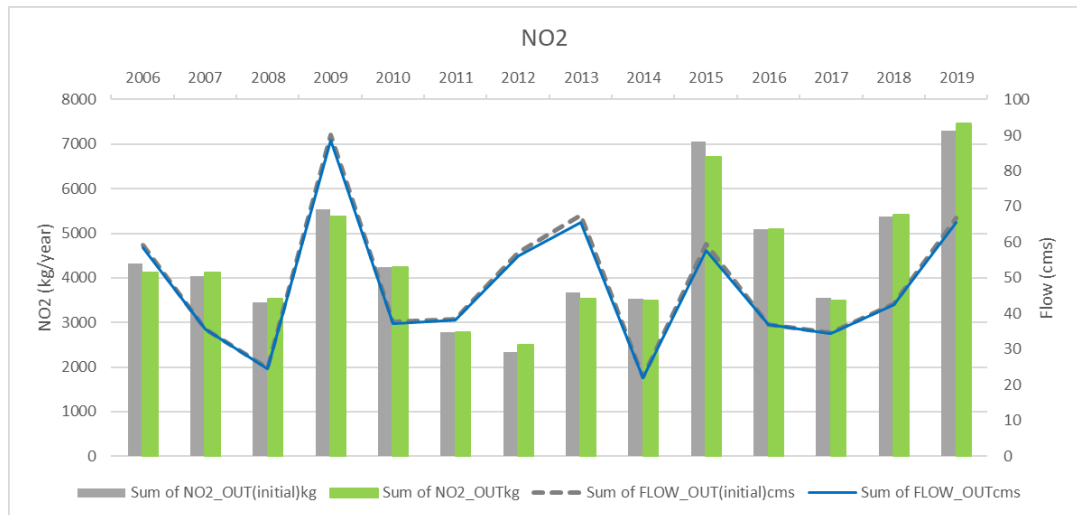


Figure 5.18. Scenario-1 for NO_2^- for station KGI02 in subbasin 95.

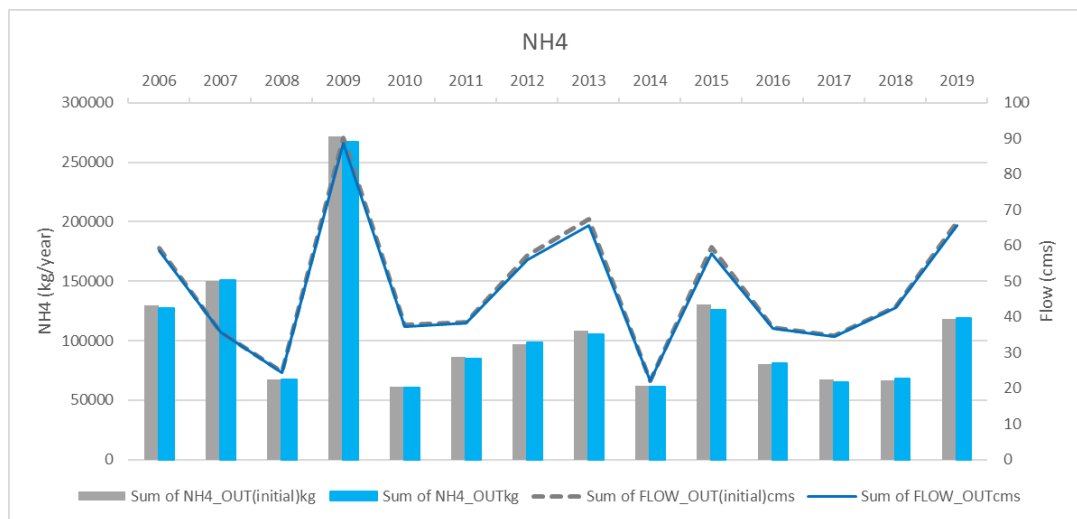


Figure 5.19. Scenario-1 for NH_4^+ for station KGI02 in subbasin 95.

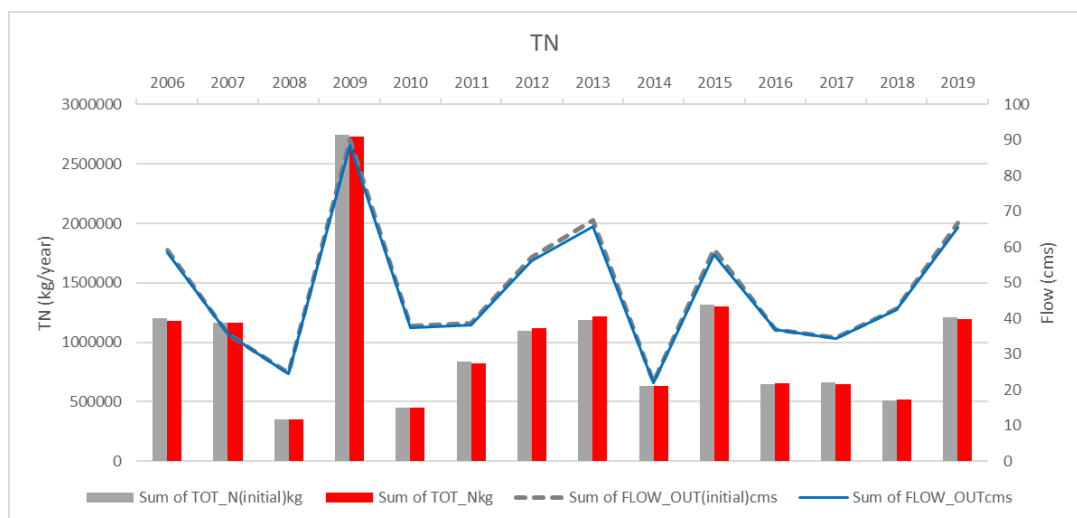


Figure 5.20. Scenario-1 for TN for station KGI02 in subbasin 95.

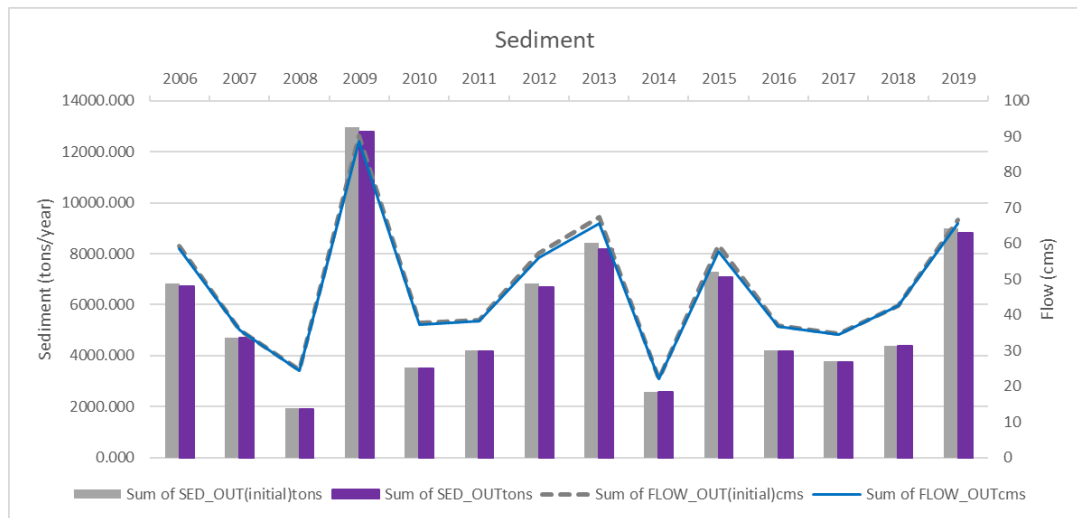


Figure 5.21. Scenario-1 for sediment for station KGI02 in subbasin 95.

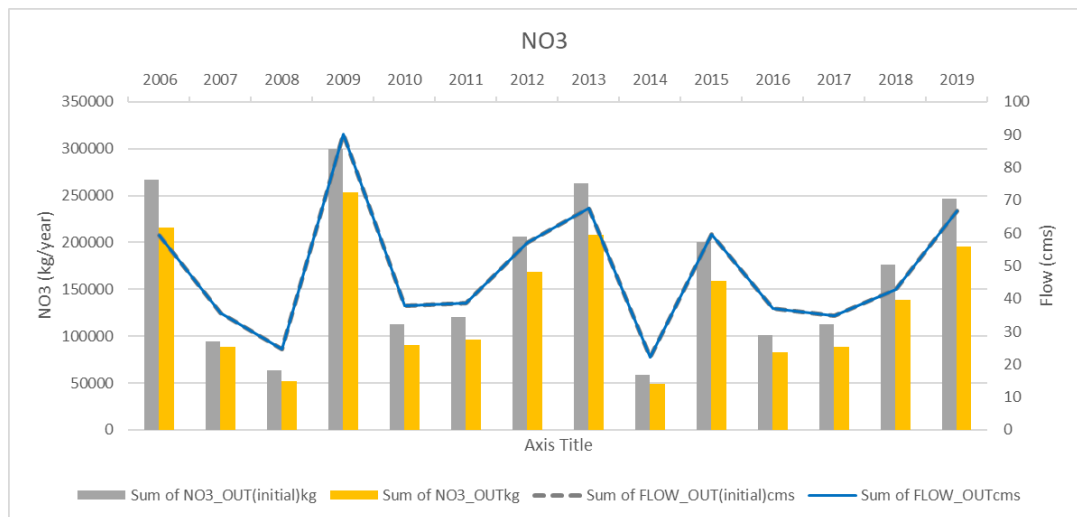


Figure 5.22. Scenario-2 for NO_3^- for station KGI02 in subbasin 95.

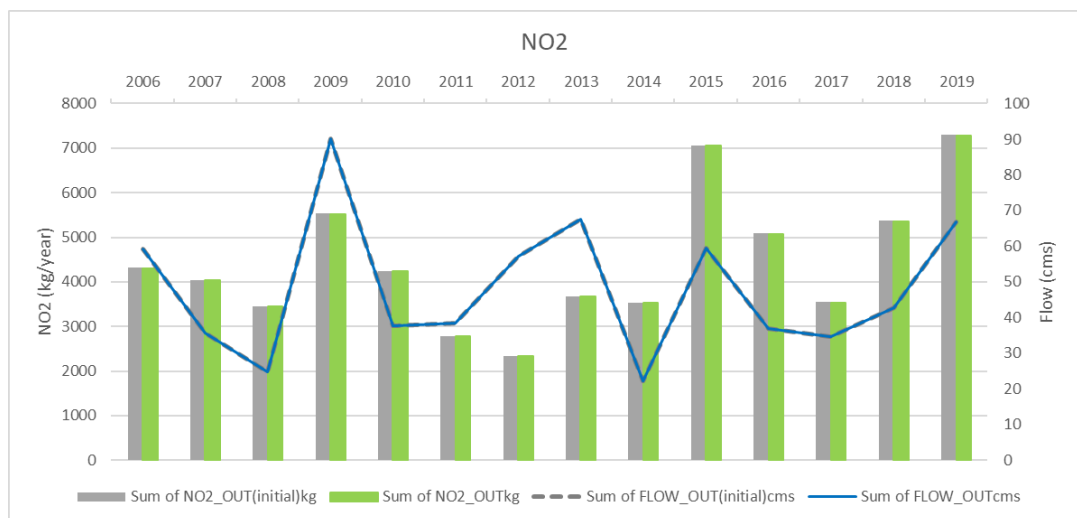


Figure 5.23. Scenario-2 for NO_2^- for station KGI02 in subbasin 95.

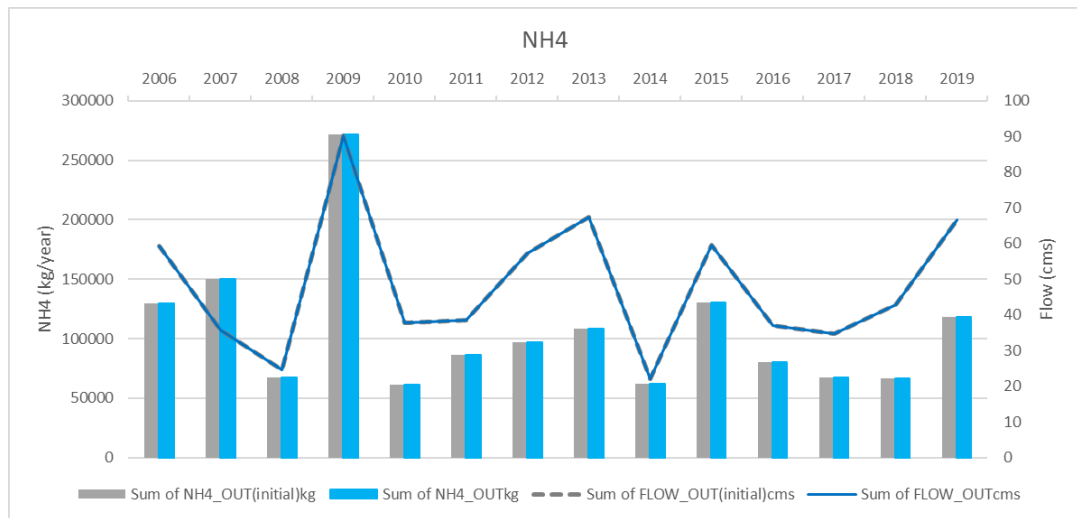


Figure 5.24. Scenario-2 for NH_4^+ for station KGI02 in subbasin 95.

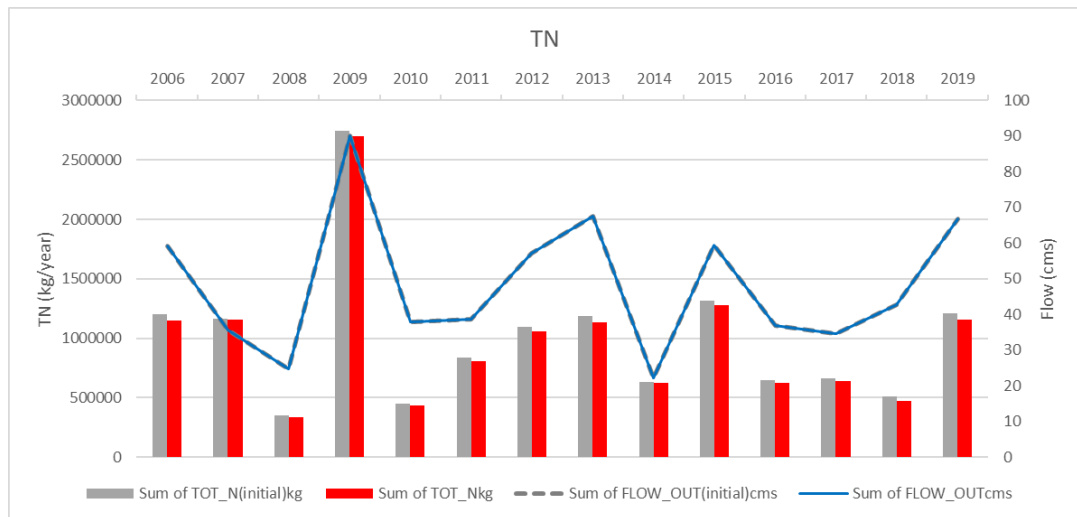


Figure 5.25. Scenario-2 for TN for station KGI02 in subbasin 95.

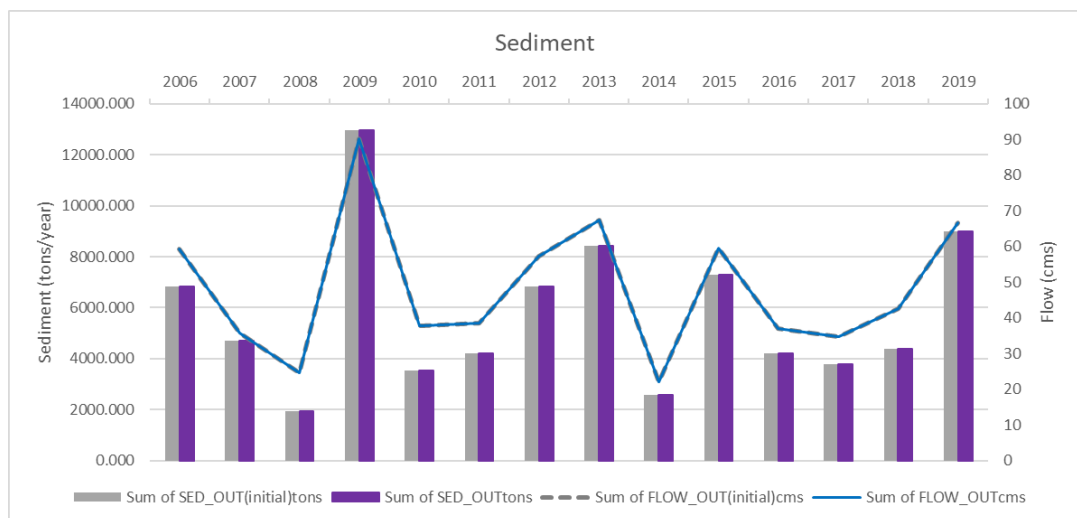


Figure 5.26. Scenario-2 for sediment for station KGI02 in subbasin 95.

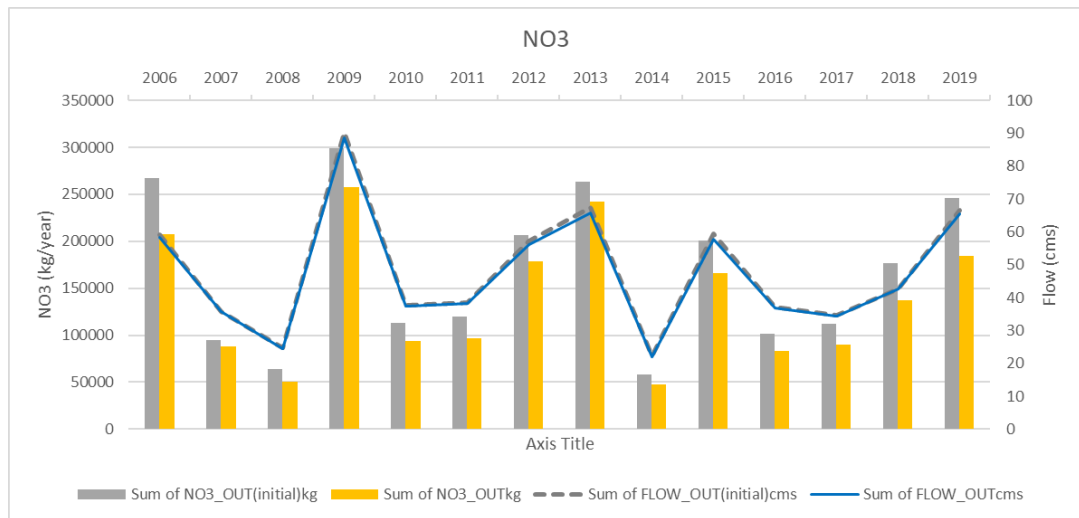


Figure 5.27. Scenario-3 for NO_3^- for station KGI02 in subbasin 95.

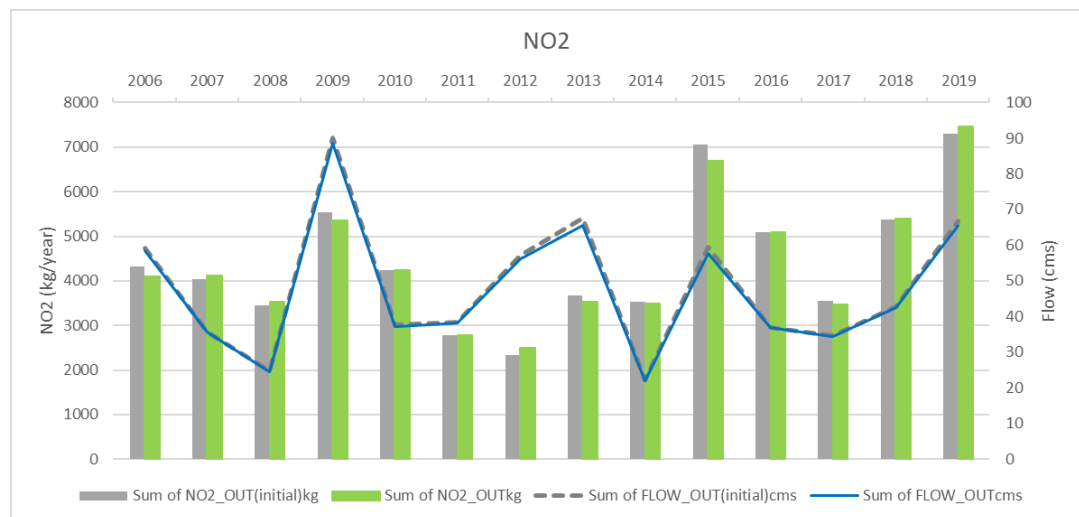


Figure 5.28. Scenario-3 for NO_2^- for station KGI02 in subbasin 95.

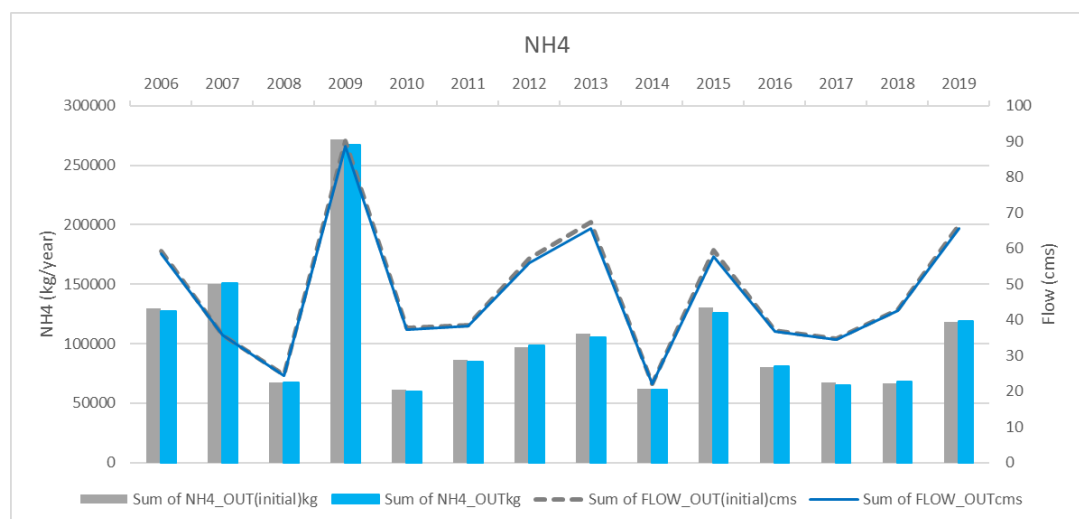


Figure 5.29. Scenario-3 for NH_4^+ for station KGI02 in subbasin 95.

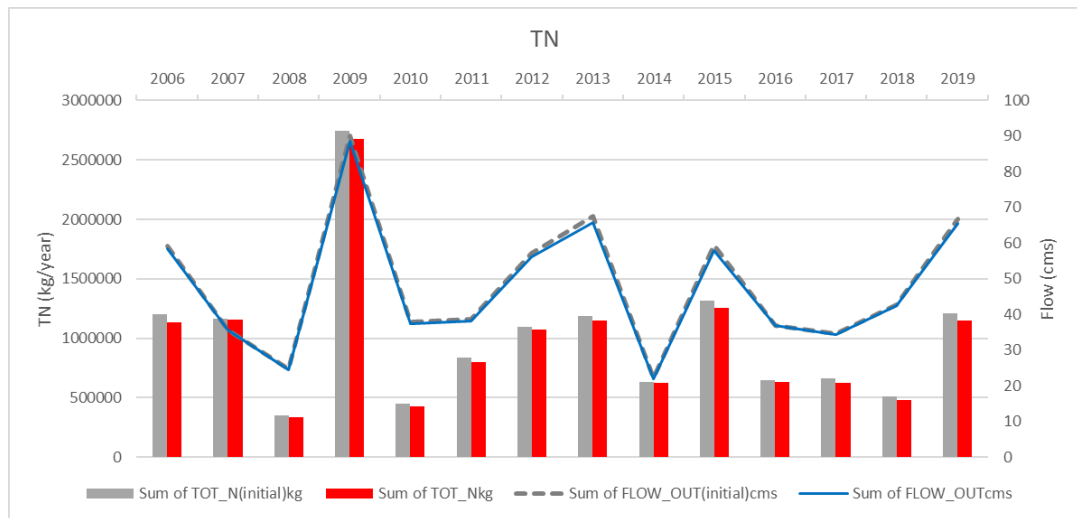


Figure 5.30. Scenario-3 for TN for station KGI02 in subbasin 95.

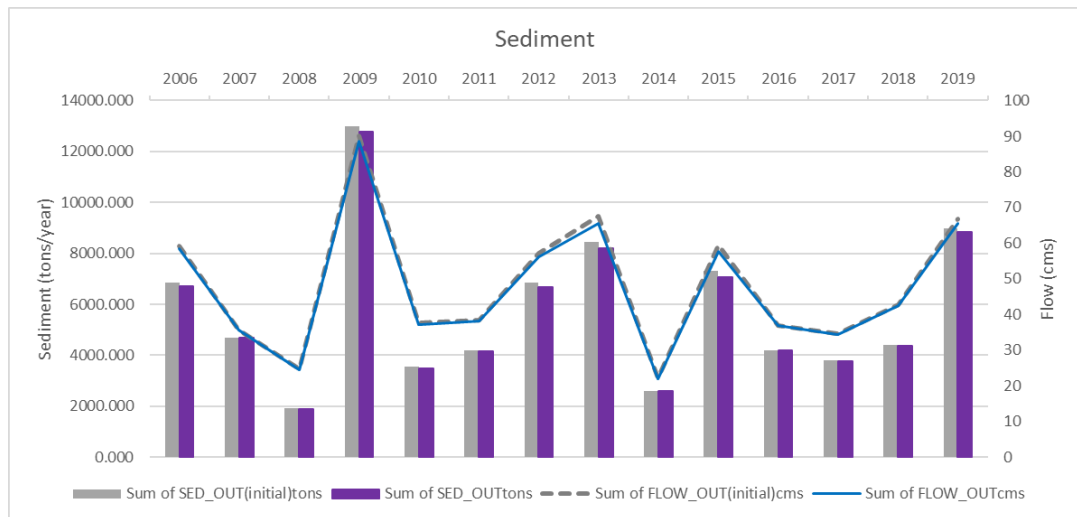


Figure 5.31. Scenario-3 for sediment for station KGI02 in subbasin 95.

6. DISCUSSION

6.1. Challenges in the Study

Simplifying the model was necessary due to the time and budget constraints of the study. In addition, the fact that the model has some limitations in terms of its own applicability is another factor that requires this simplification. For this purpose, as mentioned in Section 4.2, some assumptions were made during the model setup phase. However, while these assumptions facilitate model setup, they also reduce the closeness of the model to reality.

The most important and influential assumptions are in the Management section. Although detailed agricultural practices in the basin were formulated as a result of both literature review and fieldwork, it was impossible to include precise practices implemented in the basin to the model. Many different products are grown in the basin, with silage corn, wheat, olives, and potato cultivation coming to the fore. Although we have compiled data on the agricultural practices of these products, since it was not possible to detail which product would be added to which region during the model installation phase, silage corn was planted only in agricultural areas with AGRR codes in the basin. Here, the fact that the SWAT model does not allow adding more than one product to an HRU and no data on the exact spatial location of products is present, an assumption was inevitable. For this reason, I could not add a different product type in the AGRR area, assumed that silage corn would be planted consecutively twice a year. However, the reality is quite different from this. The authorities have informed that although there is almost no fallow in the basin, three crops can be planted yearly and wheat, potatoes, and some types of vegetables and fruits are grown predominantly. Although the olive trees and vineyards in the basin were entered into SWAT as land use, no operation information for them was included in the model. However, olive production is also carried out quite intensively in the basin.

Another assumption is that all irrigation in the basin is from groundwater and is supplied from the area where each sub-basin is located. Although field studies inform that the majority of the irrigation in the basin is provided by groundwater, there are also many irrigation reservoirs. Additionally, not every sub-basin may have groundwater resources. Therefore, although the assumption made here brings us closer to actual practice, it is not entirely correct. In addition, another the same amount of irrigation is applied in all agricultural areas at the same time. Unfortunately, this

is not possible in reality, but it has been arranged as a result of literature research and with the information obtained from farmers in a way that brings us as close to the truth as possible.

A similar situation applies to other agricultural practices. It was assumed that all agricultural practices, such as crop planting, fertilizer application, and harvest, were carried out simultaneously on the same day in all agricultural areas throughout the simulation years. However, in reality, the situation may be much different than this. Since I visited only three districts within the scope of the study and these practices may differ even within districts, much more time and budget are required to regionalize this study. Different techniques, such as remote sensing, are also being developed to regionalize crop types in the literature.

In addition to agricultural practices, point pollutant sources such as domestic wastewater and industrial wastewater treatment facilities are currently not added to the model. In addition, diffuse pollutant sources (livestock farming), are known to be applied intensively in the basin, however excluded in the model as an assumption. While the region contains intensive agricultural lands, it also includes some organized industrial facilities and olive factories, and there are also settlements and wastewater treatment facilities in the basin. Similarly, the model did not include pollutant loads from these point sources. Although animal husbandry is perhaps one of the most important sources of pollutants, sufficient field studies have not been conducted regarding animal husbandry.

As a result, all these applications that are not included in the model can be included in the model by other studies, of which this study will be a pioneer, and the model can be improved. However, as a result of evaluating the model as it is in this study, the reasons for the inadequate calibration results that cannot be obtained in terms of water quality can be based mainly on these assumptions. We see that when we compare the average simulation and average observation values. The model generally underestimated ammonium, nitrite, nitrate, and total nitrogen at the quality station located in the subbasin. When we evaluate especially for ammonium, we see that while the average simulation value is 8140, the average observation value is 22576. If we consider the ammonium concentration in animal waste, especially in animal urine, we can comment that it is possible to relate it to livestock activities.

After evaluating all these difficulties and unknowns, I examined different studies carried out for similar purposes. I investigated the similarities and differences between different studies dealing with scenarios of irrigation, fertilizer application, and agricultural practices.

As discussed before, irrigation time and amount were applied the same to the entire watershed for our study, which created uncertainty regarding agricultural practices. Githui et al. (2016) have established two separate SWAT models in which irrigation is fixed and changed and conducted a study to compare them with auto-irrigation. While the study emphasizes the importance of irrigation differences, it states that application differences affect the model, especially in dry and wet years. Similar to our study, this study, which used R^2 and NSE for evaluation, calculated the R^2 for fixed irrigation and varied irrigation systems as 0.51 and 0.80, respectively, when it evaluated the monthly results of the two scenarios. NSE values were found to be 0.74 and 0.91, respectively. Misaghi et al. (2020) who ran five different irrigation and three different fertilization scenarios, evaluated the model using p-factor, r-factor, R^2 and NSE, similar to our study. Focusing on nitrate and phosphate pollution, the study reported that the irrigation scenario results did not affect pollution much, but using fertilizers did make a difference. It seems that these results coincide with the results of our studies.

6.2. Uncertainties and Data Scarcity

Although modeling has a significant advantage for studies' budgets and deadlines, building a satisfactory model can be compelling. Every model can be considered wrong since I have a lot of uncertainties. There are four main uncertainties against constructing an adequate model: input data, simplification of the processes, missing processes, and unknown model parameters. There are many unknown parameters and processes during the model setup and calibration phase. On the other hand, modeler predictions can be inadequate because of the lack of experience and knowledge (Abbaspour et al., 2017).

Data scarcity is one of the biggest problems for hydrologic and water quality modeling. Further research is therefore required to understand the full context of problems and solutions. Data inadequacy can be related to various issues. For instance, the quality and quantity of gauging stations are the most significant problems, especially for developing countries, because establishing gauging stations can be pricey (Donmez et al., 2020). The issue is not only the establishment of a new station but also off-line gauging stations. So, monitoring historical data essential for modeling will get hard (Slaughter et al., 2017). Lack of budgets and poor laboratory conditions lead to observed data deficiencies and diminished data quality (Bui et al., 2019). With more variables to consider, the problem will exacerbate (Slaughter et al., 2017).

For the SWAT model, one crucial data is weather data; for instance, examining runoff needs rainfall data because rainfall acts as a driving force. Researchers can achieve the rainfall data via the weather radar or rainfall stations; however, every area may not have an adequate number of weather stations, or there are spatial and temporal gaps in the dataset of some gauge stations. On the other hand, weather radar can be used in place of weather gauges, but this time, low-resolution problems may arise (Slaughter et al., 2017). Besides meteorological data, historical observation of flow, sediment, and water quality data may be essential to calibrate and validate the model according to the study's focus. Similarly, with the previous, there are also missing data problems.

For instance, according to a study which is used to model in South Africa with Water Quality Systems Assessment Model (WQSAM), daily rainfall data are required, and these should be full of data which means there is no missing data. Although the importance of the full data to model, getting this data nearly impossible, therefore; the database called Lynch is used to get the full data. These datasets are fulfilled by the data of adjacent rainfall gauges instead of the missing data. Also, there is another problem is the data used for the fulfil only available to 2000. Calibration of the model simulated water quality done by 2000 (Slaughter et al., 2017).

Similar results are seen when the data availability for this study is examined. The inadequacy of both the input data and the calibration data creates difficulties in the setup phase of the model and increases the uncertainty in the results of the study. The effect of climate data on the SWAT model was frequently observed during the model setup and calibration phase in this study. It has been observed that the climate data obtained from the General Directorate of Meteorology contain gaps, and the solar radiation data is deficient. In this case, the Penman-Monteith method, which was initially intended to be used for evapotranspiration calculation, could not be used; instead, the Hargreaves method, which requires less data, was used as input. Although the Hargreaves method gave successful results, differences due to precipitation were observed in some sub-basins during the calibration phase.

Another lack of data is seen in the measurement data I used to calibrate the flow, sediment, and nutrient variables. Since the data is provided for a fee, the project budgets directly affect the data acquisition, and this is the first problem. Another problem is that there are gaps in the provided data. Especially in nutrient datasets, measurements made on only one day of the month may be far from being representative of that month. In addition, since the total loads were used in the SWAT calibration, the obtained concentration data had to be converted to monthly loads. Since there is very

little data for the station found separately for the sediment, a sediment calculation was made in the graphic equation created by the EİE, and these data were used in the sediment calibration. Since the sediment values are converted here by multiplying the daily flow rate, a highly flow-dependent data set is obtained. Researchers have addressed this issue and mentioned that they perform manual calibration instead of auto-calibration in case of insufficient sediment and nutrient data (Jiang et al., 2021). In addition, one study mentioned using sediment concentrations instead of sediment loads for sediment calibration and stated that this would reduce the uncertainty experienced in calibration (Malagó et al., 2017b).

The data I obtained from literature research and field research to integrate agricultural practices into the SWAT model is another problem. As a result of the fieldwork, I received different answers from the officials and farmers working in the institutions, even though they were close to each other. Due to the limitations of the project conditions for the fieldwork, I visited only three districts, I got information about the practices here, but I could only conduct literature research on the districts where fruit cultivation is intense, such as Selçuk, Kiraz, Menderes. I have obtained different answers according to the product and region regarding the use of fertilizers. Another problem was the amount of water used in irrigation. Farmers reported that they generally do flood irrigation in the basin and that irrigation is mostly done with water drawn from wells. However, no clear information could be obtained about irrigation amounts. For this reason, the data on irrigation amounts were used from the data obtained from the literature review. Irrigation days were reported as once every three days for corn silage, but since there are no exact start and end dates, I have obtained and used an approximate plan by integrating this information with the information obtained from the literature for the irrigation plan.

One of the most challenging areas of the study was time management. Even if the simulations performed with SWAT do not take much time, it is possible to encounter many software errors in the SWAT model. Although it is helpful to have mail groups that can solve these errors, finding answers for some problems was not easy. For example, within the scope of this study, I wanted to add the river network that I drew and digitized on google earth, using the SWAT burn-in option, instead of using the river network formed as a result of DEM data since the Küçük Menderes River was structurally changed with many irrigation channels. Unfortunately, I received many errors during this process, and I learned after wasting much time that the problem was caused by the ArcMap version I were using.

However, the time lost with these errors was negligible compared to the SWAT-CUP calibration process. The SWAT-CUP calibration time is dependent on both the modeler's experience and the computer performance required by the program. By being wise in choosing parameters and parameter ranges, the modeler can shorten this process considerably. On the other hand, if it does not have enough equipment to support this software, most of the time will be spent waiting for the simulation results. For this study, I performed 15 iterations consisting of 1500 simulations, and one iteration took approximately 15-20 hours. Of course, before that, there were also different simulations for trials. SWAT-CUP offers a plug-in called parallel processing as a suggestion for this problem, but this plug-in is free for only 20 simulations, and a license must be purchased to perform more than 20 simulations.

Considering all these problems, hydrology and water quality models still have their advantages and will continue to play a role in effectively using water resources. The development of this field, which has an essential place to be informed about the current and future status of water resources and to guide policymakers, is possible by improving the issues discussed. It is seen that these areas, which have been discussed for a long time in the literature, are still open to development. Although the existence and quality of the data still maintain its importance, it can still be said that the SWAT model achieves successful results even in areas with data scarcity.

7. CONCLUSION

I carried out this research in order to contribute to the determination of the amount of water and the state of water quality in the Küçük Menderes Basin, which was determined by different studies to be under pressure as a result of livestock and agricultural practices and to investigate possible methods that could affect the course positively. Within the scope of the study, I used the SWAT watershed model, which has been successfully used for a long time in the literature, to determine the water quantity and quality of the basin, and the SWAT-CUP program, the SUFI 2 algorithm, which is widely used in SWAT studies to calibrate the model with observation data. In the model setup, I used DEM for elevation data, FAO for soil data, and CORINE 2012 for land use data. I obtained the climate data from MGM and, after analyzing them, chose Hargreaves methods to calculate PET due to the lack of solar radiation data.

In addition, I conducted interviews with institutions and farmers in Ödemiş, Tire, and Bayındır districts in order to determine the agricultural practices carried out in the basin as closely as possible and to use them as model inputs. Considering the information, I obtained as a result of the studies; I determined that corn silage was the product that could represent the basin and integrated maize planting for the first crop and the second crop into the model. The model was run with a five-year warm-up period for 2001-2019, and I reported the monthly outputs. I used measurements of flow, sediment, and nutrient variables to evaluate the performance of the model outputs. In addition to the evaluation, I made using three objective functions, R^2 , NSE, and PBIAS; the p-factor and r-factor were used in uncertainty analysis, and the graphs I created by comparing the model outputs with the measurements were other performance evaluation tools.

At the end of the study, I added three scenarios in which I reduced the amount of irrigation and fertilizer by 30 % and applied these two simultaneously. These scenarios aimed to see how the changes in agricultural practices, carried out intensively in the basin, affect the flow, sediment, and nutrient in the basin. I observed a reduction of 18.8 % for the nitrate variable in the scenario where fertilization was reduced by 30 %. If fertilization and irrigation were reduced by 30 % together, this reduction in nitrate amount decreased slightly and became 17.2 %. The maximum reduction for total nitrogen was 3.6 % in the third scenario, where the two conditions were applied together. No significant changes were observed in other variables.

Küçük Menderes Basin is an essential agricultural basin in danger due to intensive irrigation and fertilizer use. The study has shown that regulations to be made in agricultural activities can effectively reduce pollution loads. This study, which can contribute to the successful management of the water management of the basin, which is located in an important area where the amount of water and water quality is likely to deteriorate with climate change, has a significant water potential and is also located in an important area where intensive industry is located; It also contributes to the literature that the SWAT model can be successfully applied in agricultural basins even in the absence of data. Although the SWAT model has been used lots of time for modeling basins in the literature, the number of studies in Turkey is insufficient, and this study will be the first study in Küçük Menderes River Basin done by SWAT that focuses on agricultural pollution. It will take place as an example of the SWAT model application in estimating pollution loads originating from diffuse sources.

Since this study focuses on nested subbasins, it contributes to the few similar studies in the existing literature focusing on Turkey. Since nested subbasins end at a point close to downstream, it helps to approach the entire basin from a holistic perspective instead of calibrating at different stations one by one. This study, which can be a guide in the literature in terms of the calibration of nested subbasins, also shows that it can be improved by including management such as point sources and livestock and forms the basis for obtaining realistic results in terms of water quantity and quality.

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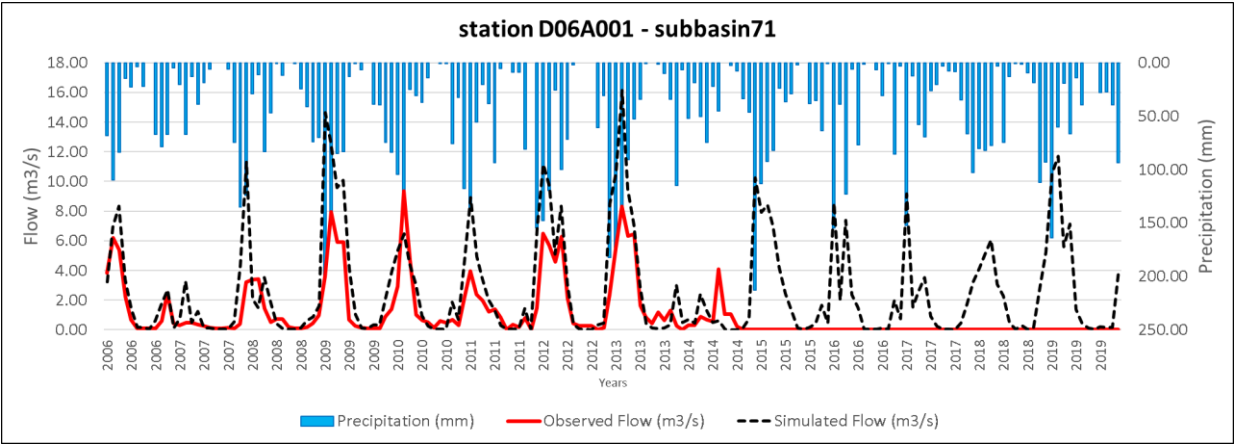
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APPENDIX A: MANAGEMENT DATABASE

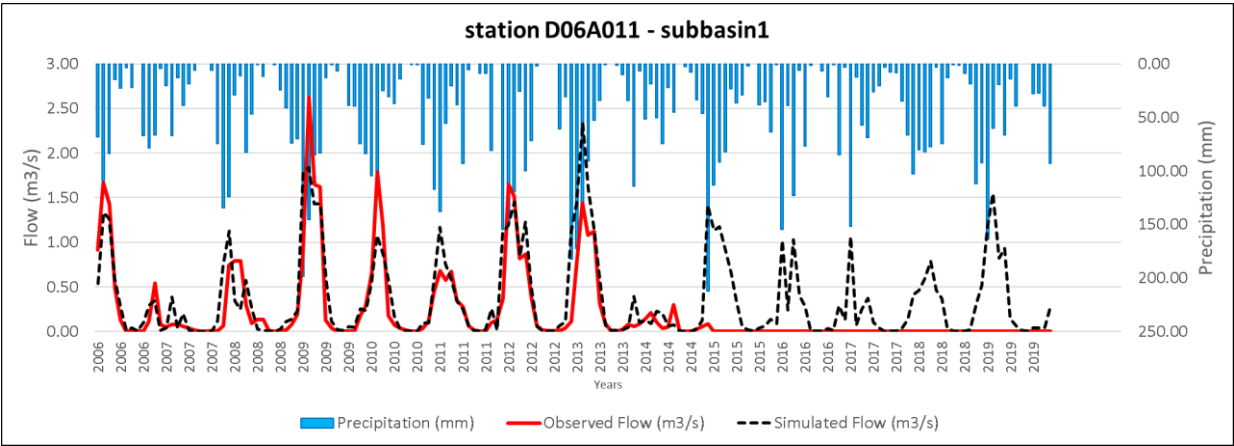
Management database for AGRR.

CRO P	YEA R	MONT H	DA Y	MGT_ OP	PLANT_ ID	IRR_A MT	FERT_ ID	FRT_ KG	FRT_SURF ACE	IRR_EF M	IRR_S Q	IRR_S C
	1	1	1	6	0	0	0	0	0	0	0	0
	1	4	14	3	0	0	21	600	0.1	0	0	0
CSIL	1	4	15	1	20	0	0	0	0	0	0	0
	1	4	18	2	0	30	0	0	0	0.6	0.1	3
	1	4	21	2	0	30	0	0	0	0.6	0.1	3
	1	4	24	2	0	30	0	0	0	0.6	0.1	3
	1	4	27	2	0	30	0	0	0	0.6	0.1	3
	1	5	1	2	0	30	0	0	0	0.6	0.1	3
	1	5	4	2	0	30	0	0	0	0.6	0.1	3
	1	5	7	2	0	30	0	0	0	0.6	0.1	3
	1	5	10	3	0	0	4	400	0.1	0	0	0
	1	5	10	2	0	30	0	0	0	0.6	0.1	3
	1	5	13	2	0	30	0	0	0	0.6	0.1	3
	1	5	16	2	0	30	0	0	0	0.6	0.1	3
	1	5	19	2	0	30	0	0	0	0.6	0.1	3
	1	5	22	2	0	30	0	0	0	0.6	0.1	3
	1	5	25	2	0	30	0	0	0	0.6	0.1	3
	1	5	28	2	0	30	0	0	0	0.6	0.1	3
	1	6	3	2	0	30	0	0	0	0.6	0.1	3
	1	6	6	2	0	30	0	0	0	0.6	0.1	3
	1	6	9	2	0	30	0	0	0	0.6	0.1	3
	1	6	12	2	0	30	0	0	0	0.6	0.1	3
	1	6	15	2	0	30	0	0	0	0.6	0.1	3
	1	6	30	5	0	0	0	0	0	0	0	0
	1	7	1	6	0	0	0	0	0	0	0	0
	1	7	30	3	0	0	21	600	0.1	0	0	0
CSIL	1	8	1	1	20	0	0	0	0	0	0	0
	1	8	4	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	7	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	10	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	13	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	16	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	19	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	22	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	25	2	0	15.3	0	0	0	0.6	0.1	3
	1	8	28	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	1	3	0	0	4	400	0.1	0	0	0
	1	9	1	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	4	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	7	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	10	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	13	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	16	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	19	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	22	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	25	2	0	15.3	0	0	0	0.6	0.1	3
	1	9	28	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	1	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	4	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	7	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	10	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	13	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	16	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	19	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	22	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	25	2	0	15.3	0	0	0	0.6	0.1	3
	1	10	30	5	0	0	0	0	0	0	0	0

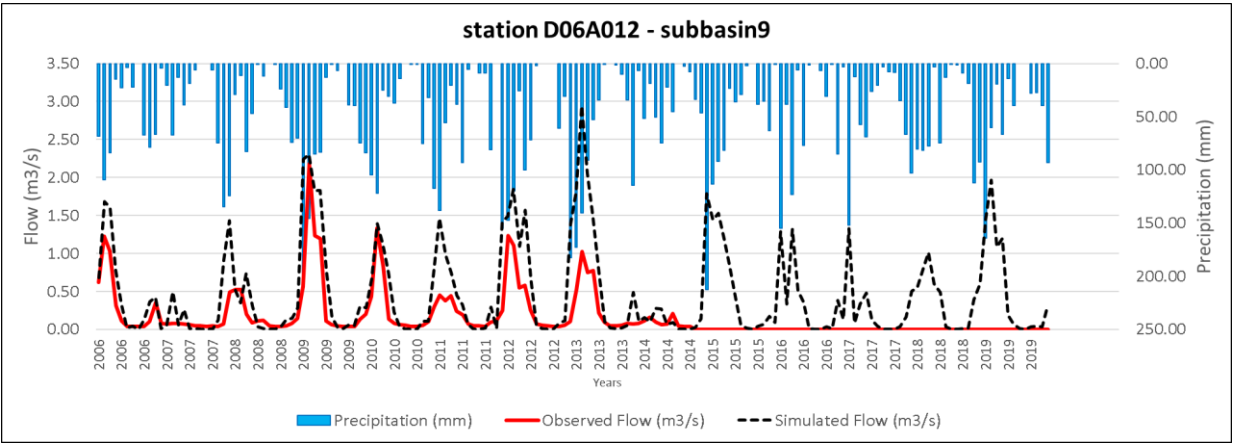
APPENDIX B: INITIAL MODEL RESULTS



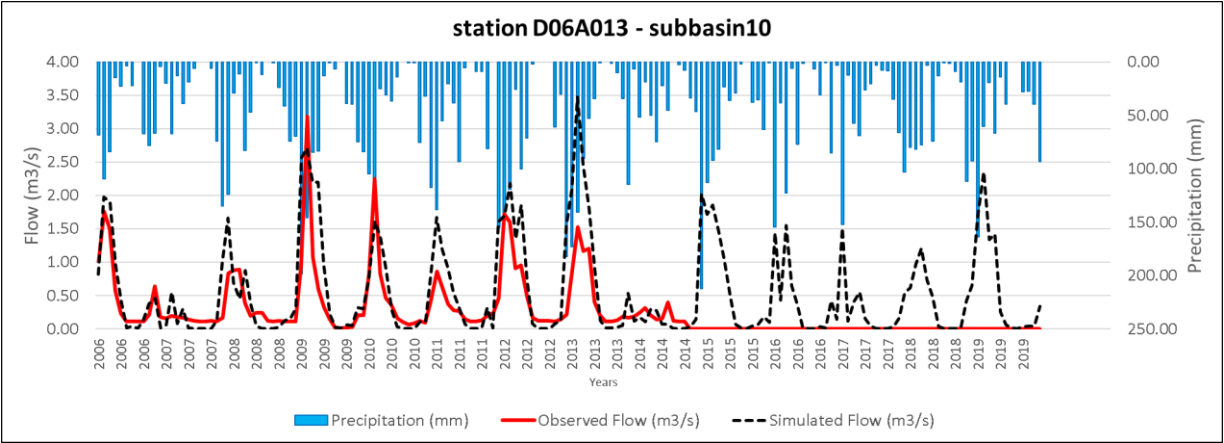
Initial flow result for station D06A001 in subbasin 71.



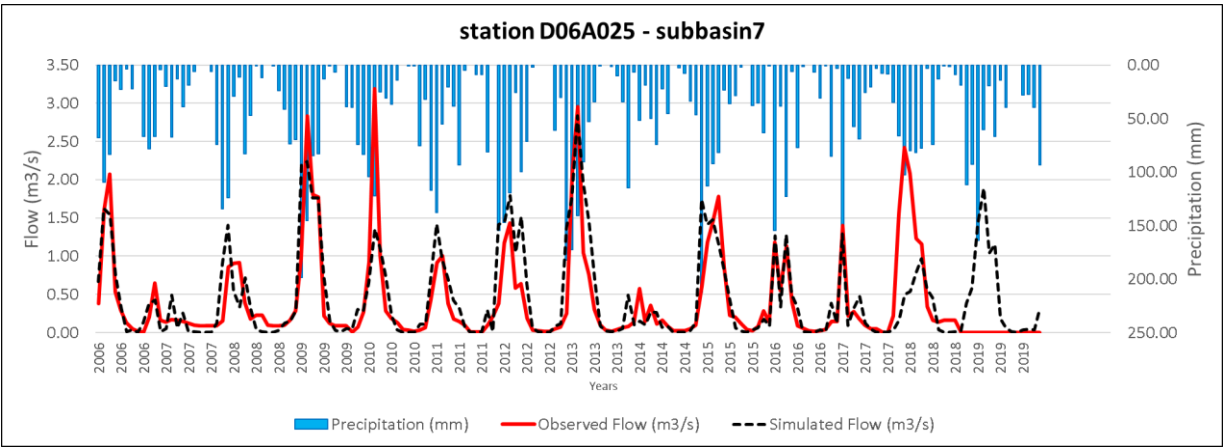
Initial flow result for station D06A011 in subbasin 1.



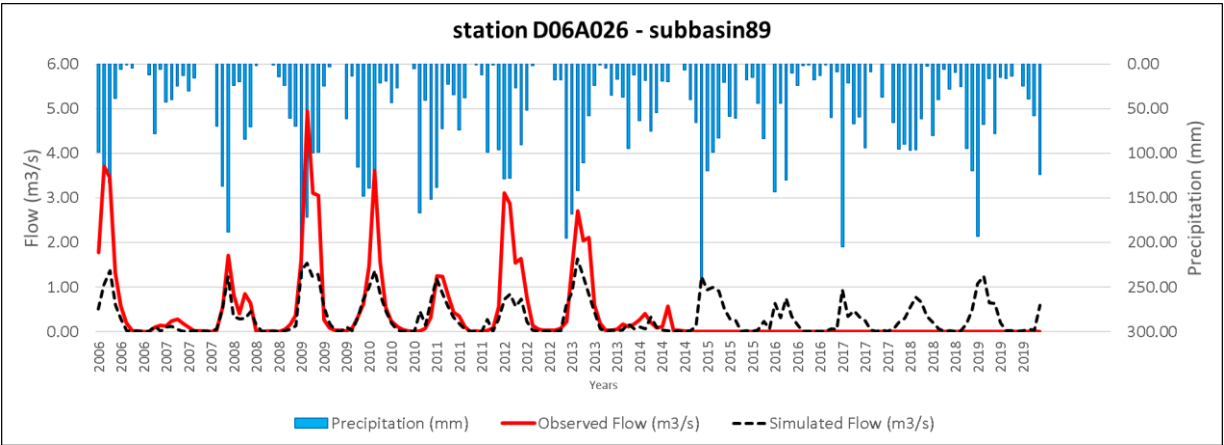
Initial flow result for station D06A012 in subbasin 9.



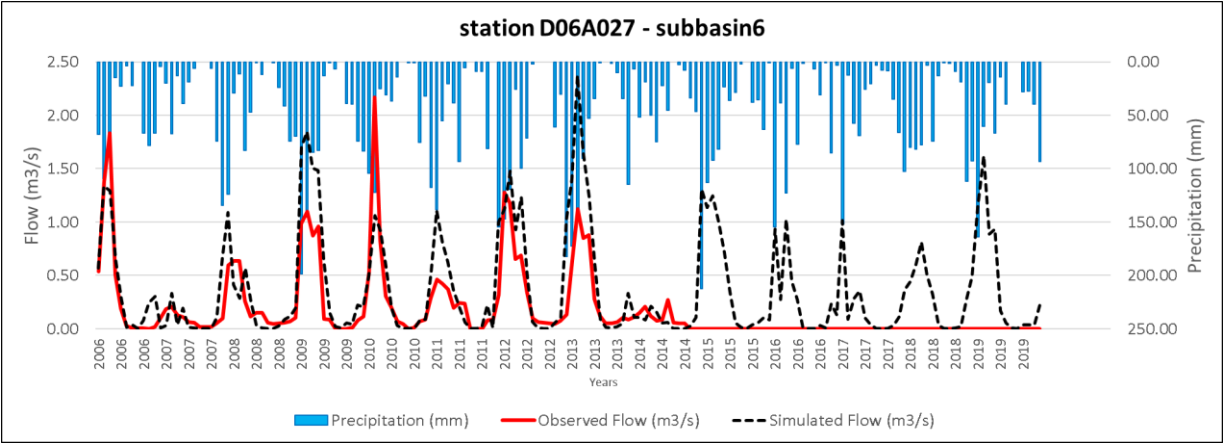
Initial flow result for station D06A013 in subbasin 10.



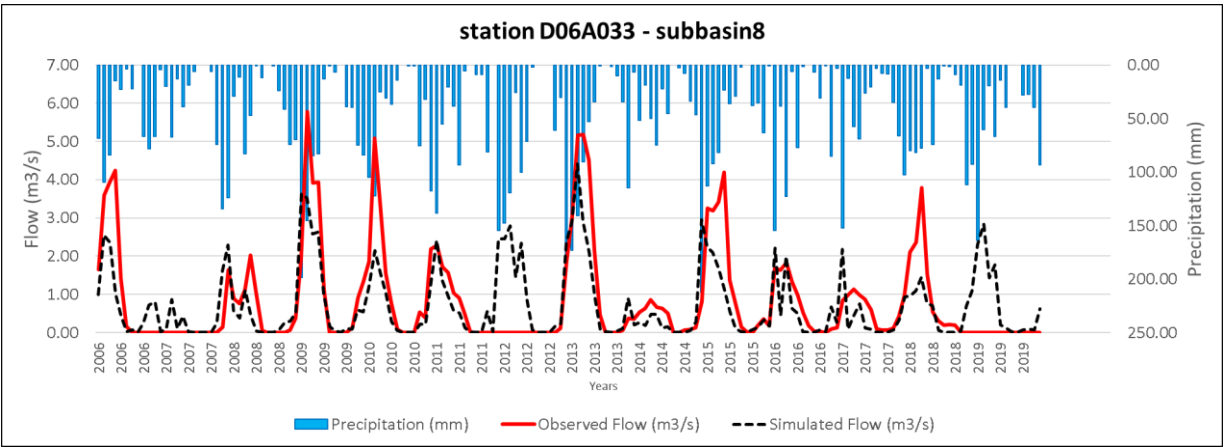
Initial flow result for station D06A025 in subbasin 7.



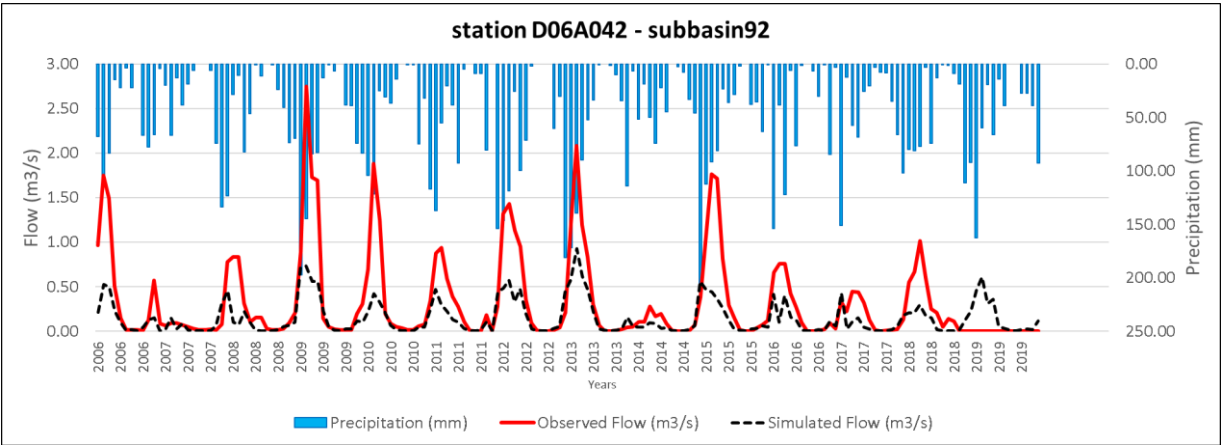
Initial flow result for station D06A026 in subbasin 89.



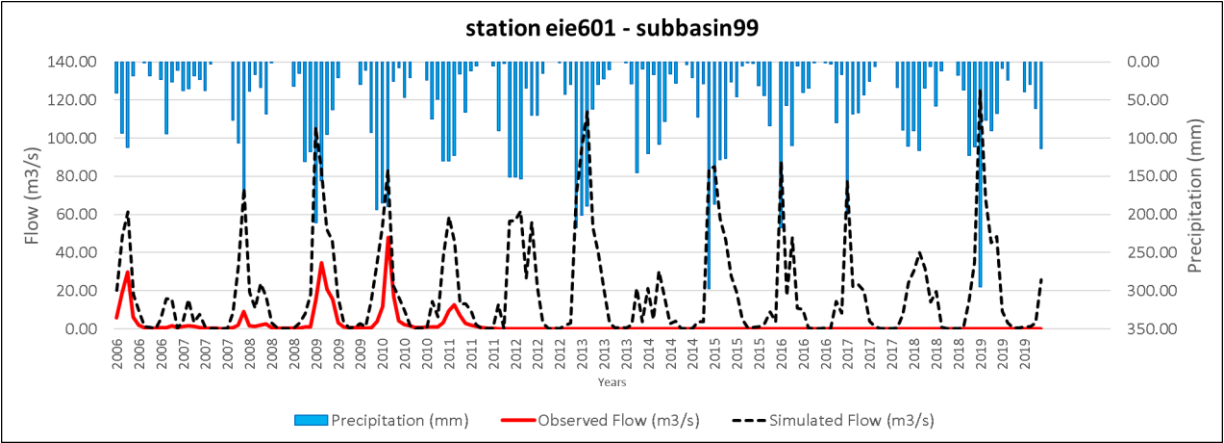
Initial flow result for station D06A027 in subbasin 6.



Initial flow result for station D06A033 in subbasin 8.



Initial flow result for station D06A042 in subbasin 92.



Initial flow result for station EIE601 in subbasin 99.

APPENDIX C: ELEVATION BANDS

Elevation bands and sub-basins.

Sub-basin	E1	E2	E3	E4	E5
1	334.4	561.2	788	1014.8	1241.6
2	261	527	793	1059	1325
3	209.1	373.3	537.5	701.7	865.9
5	261.6	504.8	748	991.2	1234.4
6	257.5	496.5	735.5	974.5	1213.5
7	210.9	392.7	574.5	756.3	938.1
8	494.9	856.7	1218.5	1580.3	1942.1
9	275.1	515.3	755.5	995.7	1235.9
10	256.7	496.1	735.5	974.9	1214.3
13	234.7	448.1	661.5	874.9	1088.3
14	379.1	665.3	951.5	1237.7	1523.9
15	349	575	801	1027	1253
19	380.6	633.8	887	1140.2	1393.4
20	344.8	580.4	816	1051.6	1287.2
23	89.9	215.7	341.5	467.3	593.1
24	167.3	335.9	504.5	673.1	841.7
25	205.3	451.9	698.5	945.1	1191.7
26	102.3	254.9	407.5	560.1	712.7
28	350.6	545.8	741	936.2	1131.4
31	150.1	306.3	462.5	618.7	774.9
33	289.2	695.6	1102	1508.4	1914.8
35	230.9	490.7	750.5	1010.3	1270.1
36	148.8	306.4	464	621.6	779.2
38	89.5	214.5	339.5	464.5	589.5
39	129.4	242.2	355	467.8	580.6
41	168	328	488	648	808
44	127	309	491	673	855
45	200.5	413.5	626.5	839.5	1052.5
47	115.3	229.9	344.5	459.1	573.7
49	173.9	289.7	405.5	521.3	637.1
53	79.4	220.2	361	501.8	642.6
54	82.1	220.3	358.5	496.7	634.9
55	252.8	368.4	484	599.6	715.2
56	142.7	320.1	497.5	674.9	852.3
58	189.1	337.3	485.5	633.7	781.9
59	199.2	345.6	492	638.4	784.8
67	293.1	489.3	685.5	881.7	1077.9
70	160.8	372.4	584	795.6	1007.2
72	133	351	569	787	1005
74	263.9	541.7	819.5	1097.3	1375.1
75	70.4	191.2	312	432.8	553.6
77	153.3	319.9	486.5	653.1	819.7
79	191.6	458.8	726	993.2	1260.4
82	275	497	719	941	1163
83	275	603	931	1259	1587
84	84.2	236.6	389	541.4	693.8
88	307.2	587.6	868	1148.4	1428.8
89	386	676	966	1256	1546
90	156.4	349.2	542	734.8	927.6
91	352	608	864	1120	1376
92	496.6	721.8	947	1172.2	1397.4
93	163.2	371.6	580	788.4	996.8
94	83.6	236.8	390	543.2	696.4
96	78.2	244.6	411	577.4	743.8
97	70.8	208.4	346	483.6	621.2
98	82	252	422	592	762
99	57.2	171.6	286	400.4	514.8
100	76.5	231.5	386.5	541.5	696.5
102	64.3	198.9	333.5	468.1	602.7
104	64.9	198.7	332.5	466.3	600.1
106	54.2	172.6	291	409.4	527.8
110	72.8	220.4	368	515.6	663.2
111	60.3	184.9	309.5	434.1	558.7
112	71.8	217.4	363	508.6	654.2

APPENDIX D: UPSTREAM SUBBASINS

Upstream sub-basins for outlet 1 to outlet 55.

Outlet Number	Number of Related Sub-basins	Related Sub-basins
1	1	1,
2	1	2,
3	1	3,
4	3	4,2,3,
5	1	5,
6	1	6,
7	1	7,
8	1	8,
9	1	9,
10	1	10,
11	4	11,2,3,4,
12	1	12,
13	1	13,
14	1	14,
15	3	15,19,28,
16	1	16,
17	3	17,16,29,
18	1	18,
19	1	19,
20	2	20,8,
21	5	21,14,15,19,28,
22	5	22,16,17,18,29,
23	1	23,
24	2	24,1,
25	1	25,
26	2	26,7,
27	5	27,5,6,23,38,
28	1	28,
29	1	29,
30	4	30,1,24,25,
31	1	31,
32	29	32,8,13,14,15,19,20,21,28,33,34,35,37,41,43,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
33	1	33,
34	23	34,8,13,14,15,19,20,21,28,35,48,49,50,55,58,59,67,71,73,74,83,88,89,
35	2	35,13,
36	2	36,9,
37	27	37,8,13,14,15,19,20,21,28,33,34,35,41,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
38	3	38,5,6,
39	34	39,1,8,13,14,15,19,20,21,24,25,28,30,32,33,34,35,37,41,43,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
40	39	40,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,41,42,43,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
41	25	41,8,13,14,15,19,20,21,28,34,35,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
42	36	42,1,8,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,37,39,41,43,45,48,49,50,55,58,59,67,71,73,74,83,88,89,
43	1	43,
44	2	44,10,
45	1	45,
46	45	46,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,45,48,49,50,55,58,59,67,71,73,74,77,82,83,85,88,89,91,92,
47	1	47,
48	20	48,8,14,15,19,20,21,28,49,50,55,58,59,67,71,73,74,83,88,89,
49	1	49,
50	17	50,8,14,15,19,20,21,28,49,55,58,59,67,71,73,74,88,
51	56	51,1,8,9,10,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,44,45,46,47,48,49,50,52,55,56,57,58,59,60,63,67,70,71,73,74,77,79,82,83,85,88,89,91,92,
52	47	52,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,45,46,47,48,49,50,55,58,59,67,71,73,74,77,82,83,85,88,89,91,92,
53	1	53,
54	1	54,
55	8	55,8,14,15,19,20,21,28,

Upstream sub-basins for outlet 56 to outlet 105.

Outlet Number	Number of Related Sub-basins	Related Sub-basins
56	49	56,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,45,46,47,48,49,50,52,55,58,59,67,71,73,74,77,79,82,83,85,88,89,91,92,
57	53	57,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,45,46,47,48,49,50,52,55,56,58,59,60,63,67,70,71,73,74,77,79,82,83,85,88,89,91,92,
58	15	58,8,14,15,19,20,21,28,55,59,67,71,73,74,88,
59	1	59,
60	51	60,1,8,9,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,45,46,47,48,49,50,52,55,56,58,59,67,70,71,73,74,77,79,82,83,85,88,89,91,92,
61	3	61,53,54,
62	8	62,5,6,7,23,26,27,38,
63	1	63,
64	1	64,
65	12	65,5,6,7,23,26,27,38,53,54,61,62,
66	58	66,1,8,9,10,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,44,45,46,47,48,49,50,51,52,55,56,57,58,59,60,63,67,70,71,72,73,74,77,79,82,83,85,88,89,91,92,
67	1	67,
68	1	68,
69	1	69,
70	1	70,
71	10	71,8,14,15,19,20,21,28,55,67,
72	1	72,
73	11	73,8,14,15,19,20,21,28,55,67,71,
74	13	74,8,14,15,19,20,21,28,55,67,71,73,88,
75	7	75,16,17,18,22,29,68,
76	1	76,
77	5	77,82,85,91,92,
78	9	78,16,17,18,22,29,68,75,76,
79	1	79,
80	6	80,2,3,4,11,12,
81	11	81,16,17,18,22,29,68,75,76,78,84,
82	1	82,
83	2	83,89,
84	1	84,
85	3	85,91,92,
86	18	86,2,3,4,11,12,16,17,18,22,29,68,75,76,78,80,81,84,
87	14	87,5,6,7,23,26,27,38,53,54,61,62,64,65,
88	1	88,
89	1	89,
90	1	90,
91	2	91,92,
92	1	92,
93	1	93,
94	33	94,2,3,4,5,6,7,11,12,16,17,18,22,23,26,27,29,38,53,54,61,62,64,65,68,75,76,78,80,81,84,86,87,
95	60	95,1,8,9,10,13,14,15,19,20,21,24,25,28,30,31,32,33,34,35,36,37,39,40,41,42,43,44,45,46,47,48,49,50,51,52,55,56,57,58,59,60,63,66,67,69,70,71,72,73,74,77,79,82,83,85,88,89,91,92,
96	3	96,90,93,
97	94	97,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,91,92,94,95,
98	4	98,90,93,96,
99	99	99,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,
100	1	100,
101	100	101,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,
102	1	102,
103	102	103,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,
104	1	104,
105	112	105,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,106,107,108,109,110,111,112,

Upstream sub-basins for outlet 106 to outlet 112.

Outlet Number	Number of Related Sub-basins	Related Sub-basins
106	104	106,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,
107	110	107,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,106,108,109,110,111,112,
108	5	108,109,110,111,112,
109	3	109,110,112,
110	1	110,
111	1	111,
112	1	112,

APPENDIX E: CALIBRATION RANGES AND FITTED VALUES

Calibration parameters ranges and their fitted values (First 65).

Parameter	Fitted Value	Min value	Max value
r_CN2.mgt_1	-0.07884	-0.22	0.31
r_GWQMN.gw_1	-0.02175	-1	0.05
r_REVAPMN.gw_1	0.720528	-0.09219	0.723519
r_SOL_AWC().sol_1	0.118735	-0.15019	0.549519
r_SOL_BD().sol_1	-0.11272	-0.13985	0.580519
r_SOL_K().sol_1	-0.07384	-0.64428	0.285279
v_ALPHA_BF.gw_1	0.6657	0	0.7
v_ESCO.hru_1	0.134167	0	0.7
v_GW_REVAP.gw_1	0.122365	0.079907	0.199733
r_CN2.mgt_6	-0.26738	-0.5	0.35
r_GWQMN.gw_6	-0.47148	-0.8	0.35
r_REVAPMN.gw_6	-0.08	-0.5	0.3
r_SOL_AWC().sol_6	-0.13185	-0.25	0.6
r_SOL_BD().sol_6	-0.04498	-0.3	0.35
r_SOL_K().sol_6	0.18655	-0.7	0.35
v_ALPHA_BF.gw_6	0.727	0	1
v_ESCO.hru_6	0.32275	0.3	0.95
v_GW_REVAP.gw_6	0.17474	0.02	0.2
r_OV_N.hru_6	-0.05293	-0.2	0.2
r_SLSUBBSN.hru_6	-0.01187	-0.2	0.2
r_HRU_SLP.hru_6	0.095867	-0.2	0.2
r_CN2.mgt_7	-0.17013	-0.5	0.3
r_GWQMN.gw_7	-0.23985	-0.25	0.8
r_REVAPMN.gw_7	0.195	-0.5	0.5
r_SOL_AWC().sol_7	-0.49233	-0.5	0.5
r_SOL_BD().sol_7	0.006183	-0.25	0.7
r_SOL_K().sol_7	-0.58463	-0.75	0.35
v_ALPHA_BF.gw_7	0.730333	0	1
v_ESCO.hru_7	0.570617	0.1	0.95
v_GW_REVAP.gw_7	0.17234	0.02	0.2
r_OV_N.hru_7	-0.04387	-0.2	0.2
r_SLSUBBSN.hru_7	0.009467	-0.2	0.2
r_HRU_SLP.hru_7	0.178267	-0.2	0.2
r_CN2.mgt_8	-0.35167	-0.5	0.5
r_GWQMN.gw_8	0.1936	-0.8	0.8
r_REVAPMN.gw_8	-0.7181	-0.8	0.5
r_SOL_AWC().sol_8	-0.17033	-0.7	0.3
r_SOL_BD().sol_8	0.1508	-0.3	0.9
r_SOL_K().sol_8	-0.0835	-0.75	0.75
v_ALPHA_BF.gw_8	0.301	0	1
v_ESCO.hru_8	0.832417	0.1	0.95
v_GW_REVAP.gw_8	0.07742	0.02	0.2
r_OV_N.hru_8	0.131067	-0.2	0.2
r_SLSUBBSN.hru_8	-0.01293	-0.2	0.2
r_HRU_SLP.hru_8	0.191867	-0.2	0.2
r_CN2.mgt_9	-0.04742	-0.32	0.1
r_GWQMN.gw_9	-0.6184	-0.8	0
r_REVAPMN.gw_9	-0.1312	-0.35	0.05
r_SOL_AWC().sol_9	0.8568	0.2	1
r_SOL_BD().sol_9	0.111	-0.2	0.4
r_SOL_K().sol_9	0.128333	-0.35	0.65
v_ALPHA_BF.gw_9	0.5862	0.2	0.8
v_ESCO.hru_9	0.49515	0.4	0.95
v_GW_REVAP.gw_9	0.146567	0.06	0.16
r_CN2.mgt_10	-0.0466	-0.4	0.2
r_GWQMN.gw_10	-0.14846	-0.72	0.3
r_REVAPMN.gw_10	0.47975	-0.25	0.5
r_SOL_AWC().sol_10	0.39675	-0.15	0.6
r_SOL_BD().sol_10	0.398277	-0.13	0.6
r_SOL_K().sol_10	0.220093	-0.16	1
v_ALPHA_BF.gw_10	0.484167	0	0.7
v_ESCO.hru_10	0.5745	0.2	0.9
v_GW_REVAP.gw_10	0.089567	0.02	0.12
r_CN2.mgt_89	0.366162	-0.14319	0.570519
r_GWQMN.gw_89	2.148002	0.185154	2.355646

Calibration parameters ranges and their fitted values (Last 49).

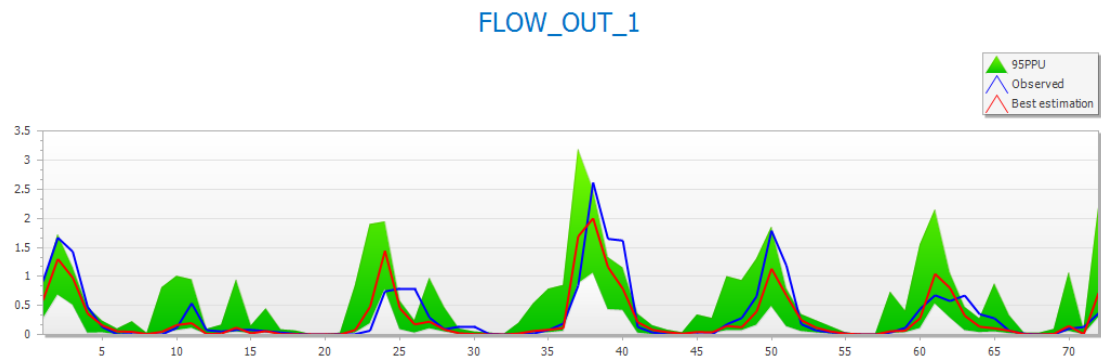
Parameter	Fitted Value	Min value	Max value
r_REVAPMN.gw_____89	-0.74854	-0.84252	0.052519
r_SOL_AWC().sol_____89	-0.5115	-0.67952	0.106852
r_SOL_BD().sol_____89	0.20313	-0.18752	0.437519
r_SOL_K().sol_____89	-0.95945	-0.97552	0.008185
v_ALPHA_BF.gw_____89	0.510549	0.253481	0.760519
v_ESCO.hru_____89	0.824817	0.400743	1
v_GW_REVAP.gw_____89	0.284777	0.108947	0.286853
r_OV_N.hru_____89	0.024851	-0.09194	0.124207
r_SLSUBBSN.hru_____89	-0.24647	-0.30141	0.032874
r_HRU_SLP.hru_____89	0.018985	-0.09381	0.118607
r_CN2.mgt_____92	-0.10033	-0.5	0.5
r_GWQMN.gw_____92	0.357867	-0.8	0.8
r_REVAPMN.gw_____92	0.366333	-0.5	0.5
r_SOL_AWC().sol_____92	-0.38233	-0.5	0.5
r_SOL_BD().sol_____92	-0.213	-0.5	0.5
r_SOL_K().sol_____92	-0.3435	-0.75	0.75
v_ALPHA_BF.gw_____92	0.992333	0	1
v_ESCO.hru_____92	0.727583	0.1	0.95
v_GW_REVAP.gw_____92	0.18158	0.02	0.2
r_CN2.mgt_____71,14,15,19,20,21,28,55,67	-0.2694	-0.5	0.1
r_GWQMN.gw_____71,14,15,19,20,21,28,55,67	-0.18176	-0.36	0.6
r_REVAPMN.gw_____71,14,15,19,20,21,28,55,67	-0.08775	-0.2	0.55
r_SOL_AWC().sol_____71,14,15,19,20,21,28,55,67	0.33825	-0.25	0.5
r_SOL_BD().sol_____71,14,15,19,20,21,28,55,67	-0.2922	-0.35	0.25
r_SOL_K().sol_____71,14,15,19,20,21,28,55,67	-0.94884	-1	0.03
v_ALPHA_BF.gw_____71,14,15,19,20,21,28,55,67	0.490183	0.35	1
v_ESCO.hru_____71,14,15,19,20,21,28,55,67	0.8205	0.45	0.95
v_GW_REVAP.gw_____71,14,15,19,20,21,28,55,67	0.0922	0.02	0.14
r_CN2.mgt_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	-0.4905	-0.5	0
r_GWQMN.gw_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	0.73723	-0.1	0.77
r_REVAPMN.gw_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	-0.26853	-0.46	-0.05
r_SOL_AWC().sol_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	-0.04545	-0.2	0.35
v_ESCO.hru_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	0.666617	0.6	0.95
v_GW_REVAP.gw_____2,3,4,5,11,12,13,16,17,18,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,56,57,58,59,60,61,62,63,64,65,66,68,69,70,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,90,91,93,94,95,96,97,98,99	0.157633	0.1	0.2
r_OV_N.hru_____9	0.1988	-0.2	0.2
r_SLSUBBSN.hru_____9	0.1396	-0.2	0.2
r_HRU_SLP.hru_____9	-0.02707	-0.2	0.2
r_OV_N.hru_____10	0.016933	-0.2	0.2
r_SLSUBBSN.hru_____10	-0.17693	-0.2	0.2
r_HRU_SLP.hru_____10	-0.08147	-0.2	0.2
v_PRF_BSN.bsn	1.675333	0	2
v_SPEXP.bsn	1.377167	1	1.5
v_SPCON.bsn	0.006565	0.0001	0.01
"v_SHALLST_N.gw	59.5	0	100
v_RCN.bsn	9.495	0	15
v_NPERCO.bsn	0.194333	0	1
v_CMN.bsn	0.001357	0.001	0.003
v_SOL_NO3().chm	75.50001	0	100
v_FRT_SURFACE{[,3].mgt	0.864333	0	1

APPENDIX F: SENSITIVITY ANALYSIS RESULTS

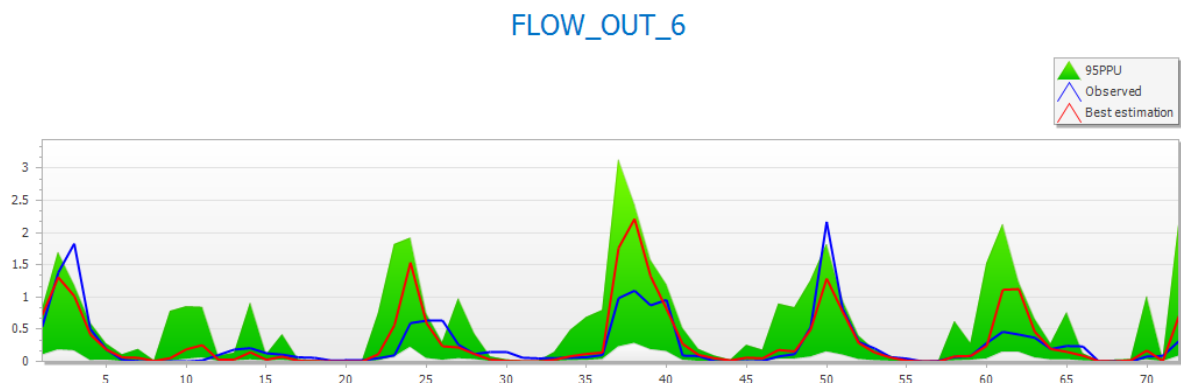
The last sensitivity analysis results.

Parameter Name	t-Stat	P-Value	Parameter Name	t-Stat	P-Value
94:R_CN2.mgt	-19.190464864	0.000000000	105:R_HRU_SLP.hru	0.868376863	0.385338499
111:V_NPERCO.bsn	-11.683223438	0.000000000	44:R_SLSUBBSN.hru	0.868222984	0.385422688
114:V_FRT_SURFACE{...}.mgt	-10.849567633	0.000000000	6:R_SOL_K(..).sol	0.864756130	0.387322403
69:R_SOL_K(..).sol	2.996207148	0.002782210	102:R_HRU_SLP.hru	0.852314509	0.394186911
88:R_SOL_AWC(..).sol	-2.711738508	0.006775923	1:R_CN2.mgt	-0.851113881	0.394853220
33:R_HRU_SLP.hru	-2.674079644	0.007581603	57:R_REVAPMN.gw	0.847700400	0.396751309
30:V_GW_REVAP.gw	-2.393785316	0.016807889	65:R_GWQMN.gw	-0.842504335	0.399651176
54:V_GW_REVAP.gw	-2.271204926	0.023287488	86:R_GWQMN.gw	-0.823753142	0.410221662
97:R_SOL_AWC(..).sol	2.037123689	0.041827445	12:R_REVAPMN.gw	-0.800945920	0.423300330
80:R_SOL_BD(..).sol	2.012320424	0.044379459	90:R_SOL_K(..).sol	0.737896357	0.460702434
67:R_SOL_AWC(..).sol	1.952317665	0.051101741	15:R_SOL_K(..).sol	-0.723083089	0.469750928
93:V_GW_REVAP.gw	1.929481472	0.053875180	58:R_SOL_AWC(..).sol	-0.715627355	0.474342103
39:R_SOL_K(..).sol	-1.915975576	0.055573878	49:R_SOL_AWC(..).sol	-0.682430565	0.495080852
7:V_ALPHA_BF.gw	-1.834594480	0.066780191	8:V_ESCO.hru	0.661400363	0.508465605
48:R_REVAPMN.gw	1.714133521	0.086727944	79:R_SOL_AWC(..).sol	-0.652565348	0.514144824
81:R_SOL_K(..).sol	1.697074544	0.089907246	29:V_ESCO.hru	0.644427977	0.519404660
108:V_SPCON.bsn	1.694502021	0.090394738	28:V_ALPHA_BF.gw	-0.631233794	0.527991826
59:R_SOL_BD(..).sol	-1.684383679	0.092332855	78:R_REVAPMN.gw	0.630291639	0.528607767
95:R_GWQMN.gw	1.636018897	0.102062839	87:R_REVAPMN.gw	-0.623413846	0.533115250
35:R_GWQMN.gw	-1.600711021	0.109668993	52:V_ALPHA_BF.gw	-0.611345733	0.541071046
45:R_HRU_SLP.hru	1.550990678	0.121132380	5:R_SOL_BD(..).sol	0.585825418	0.558088288
46:R_CN2.mgt	-1.535607714	0.124863020	3:R_REVAPMN.gw	0.583244874	0.559823422
37:R_SOL_AWC(..).sol	1.508338285	0.131696036	103:R_OV_N.hru	0.556344683	0.578065119
98:V_ESCO.hru	-1.502400641	0.133221628	10:R_CN2.mgt	0.549775992	0.582561667
2:R_GWQMN.gw	1.463860495	0.143458987	38:R_SOL_BD(..).sol	-0.545493784	0.585501792
82:V_ALPHA_BF.gw	-1.410703060	0.158556749	11:R_GWQMN.gw	0.398784540	0.690113442
20:R_SLSUBBSN.hru	1.410201340	0.158704774	4:R_SOL_AWC(..).sol	0.394959574	0.692933539
62:V_ESCO.hru	-1.384802624	0.166335857	18:V_GW_REVAP.gw	-0.385846402	0.699669685
40:V_ALPHA_BF.gw	-1.311374635	0.189948578	63:V_GW_REVAP.gw	0.353612139	0.723683394
53:V_ESCO.hru	-1.304412292	0.192309763	89:R_SOL_BD(..).sol	0.346853971	0.728753720
16:V_ALPHA_BF.gw	1.261519264	0.207334249	36:R_REVAPMN.gw	-0.341384486	0.732865937
112:V_CMN.bsn	1.225192244	0.220711112	91:V_ALPHA_BF.gw	-0.335544361	0.737265306
109:V_SHALLST_N.gw	1.224971952	0.220794078	17:V_ESCO.hru	-0.317554545	0.750870725
23:R_GWQMN.gw	1.213671004	0.225080306	66:R_REVAPMN.gw	0.314873708	0.752904975
41:V_ESCO.hru	-1.199188331	0.230659843	99:V_GW_REVAP.gw	-0.303412648	0.761620978
68:R_SOL_BD(..).sol	-1.152673396	0.249243369	47:R_GWQMN.gw	-0.285314867	0.775445585
31:R_OV_N.hru	-1.127130491	0.259882549	24:R_REVAPMN.gw	-0.284803913	0.775836953
22:R_CN2.mgt	-1.087189889	0.277142063	25:R_SOL_AWC(..).sol	-0.266302979	0.790045518
72:V_GW_REVAP.gw	-1.077662239	0.281372176	70:V_ALPHA_BF.gw	-0.261195075	0.793980909
104:R_SLSUBBSN.hru	-1.058640342	0.289948202	77:R_GWQMN.gw	-0.258566346	0.796008271
61:V_ALPHA_BF.gw	-1.023454310	0.306271816	27:R_SOL_K(..).sol	0.254113714	0.799445429
55:R_CN2.mgt	-1.022485694	0.306729638	84:V_GW_REVAP.gw	0.248955205	0.803432344
42:V_GW_REVAP.gw	-1.013667729	0.310918375	85:R_CN2.mgt	0.239618340	0.810661602
83:V_ESCO.hru	-0.966595294	0.333915137	13:R_SOL_AWC(..).sol	0.233929170	0.815074540
34:R_CN2.mgt	-0.951405215	0.341564711	19:R_OV_N.hru	-0.224480787	0.822416327
96:R_REVAPMN.gw	-0.911618105	0.362128427	21:R_HRU_SLP.hru	-0.196593035	0.844174864
14:R_SOL_BD(..).sol	-0.881731638	0.378074941	43:R_OV_N.hru	0.168734835	0.866029855

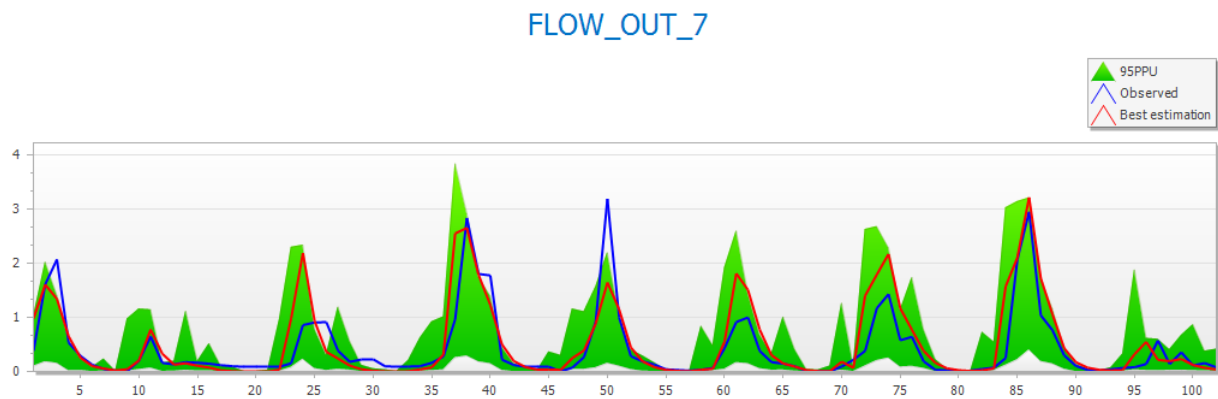
APPENDIX G: SWAT-CUP CALIBRATION RESULTS



Calibrated flow in subbasin 71.

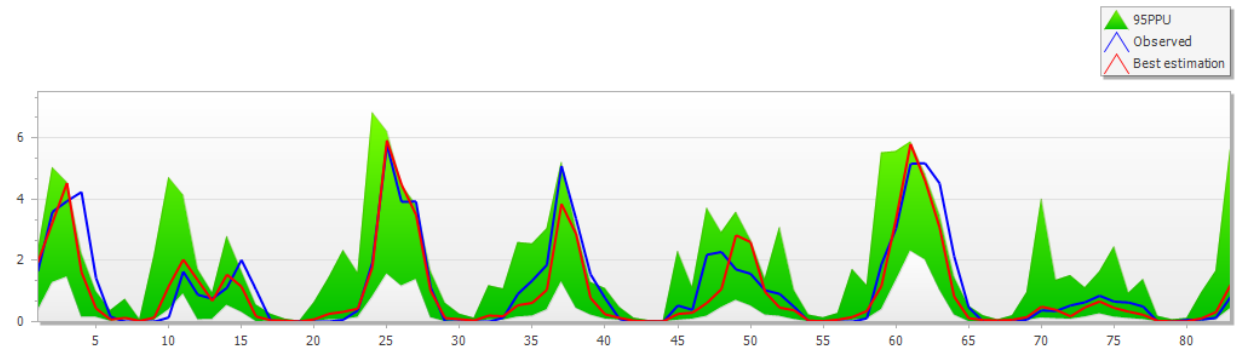


Calibrated flow in subbasin 6.



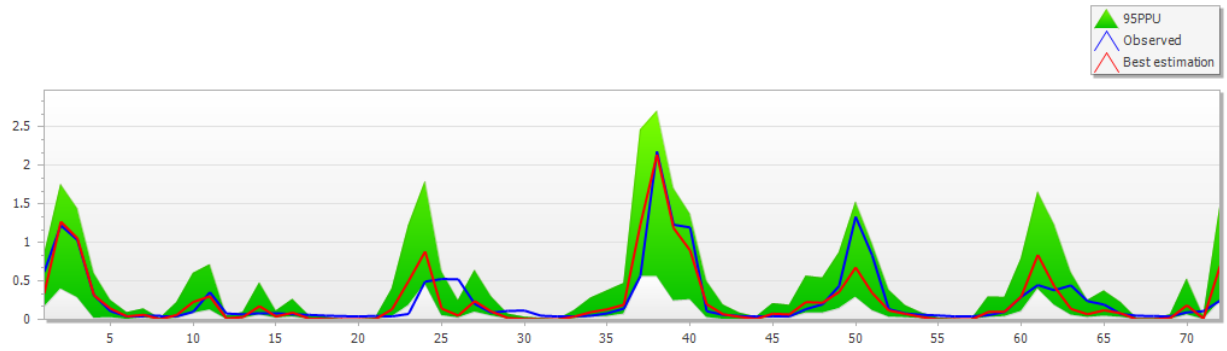
Calibrated flow in subbasin 7.

FLOW_OUT_8



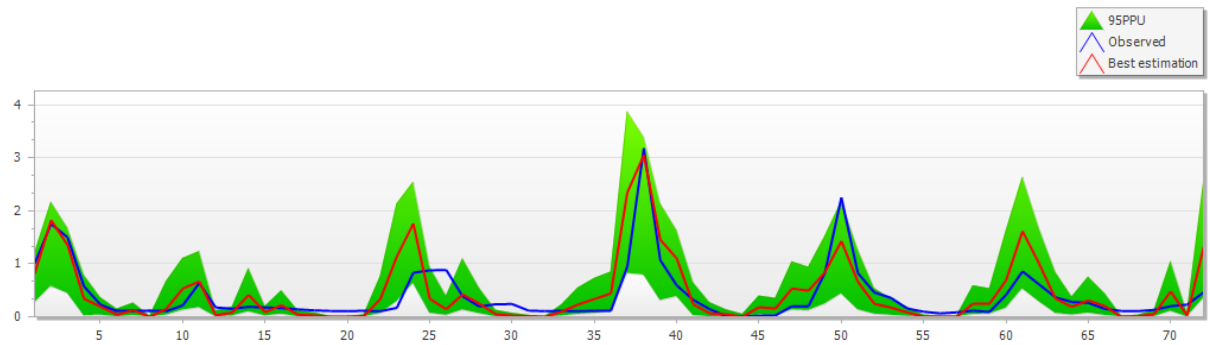
Calibrated flow in subbasin 8.

FLOW_OUT_9



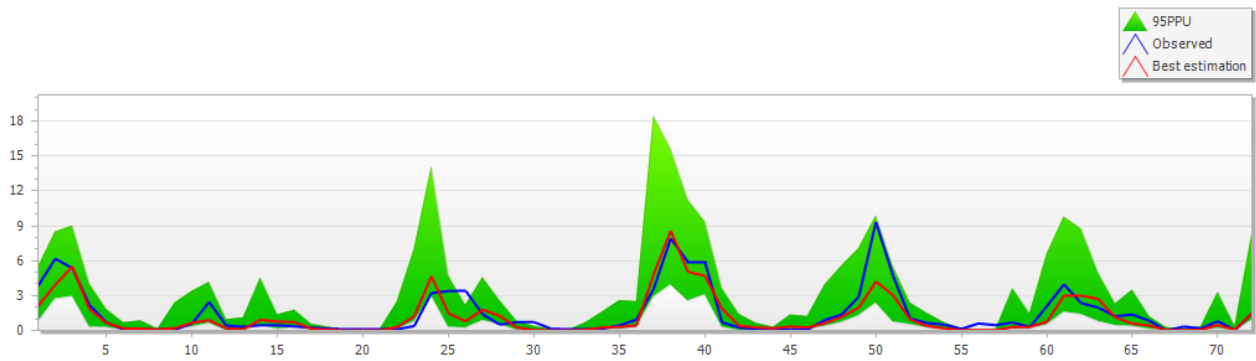
Calibrated flow in subbasin 9.

FLOW_OUT_10



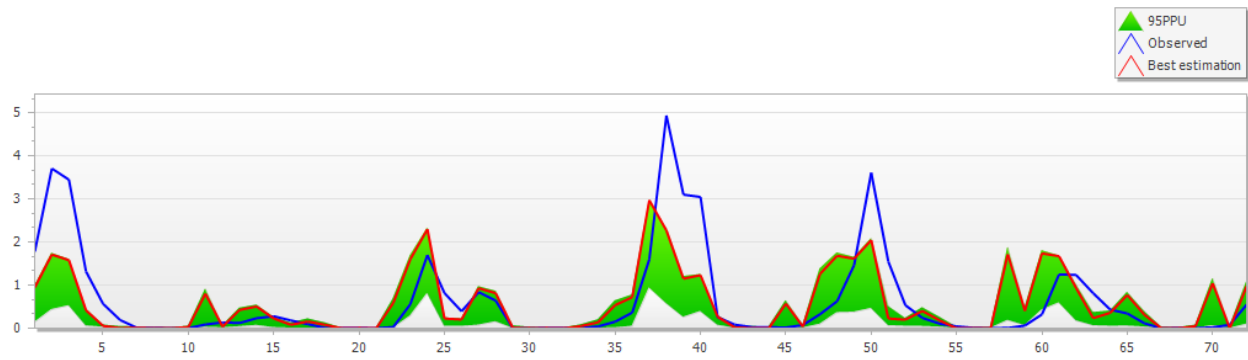
Calibrated flow in subbasin 10.

FLOW_OUT_71



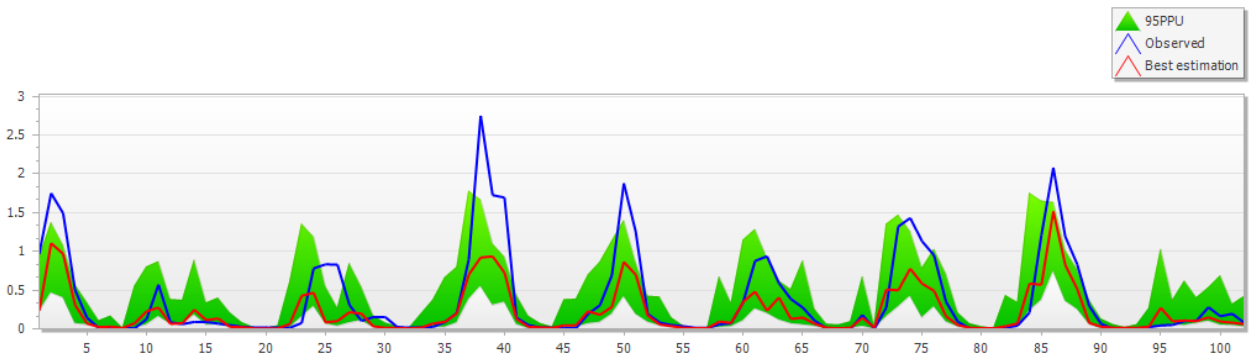
Calibrated flow in subbasin 71.

FLOW_OUT_89



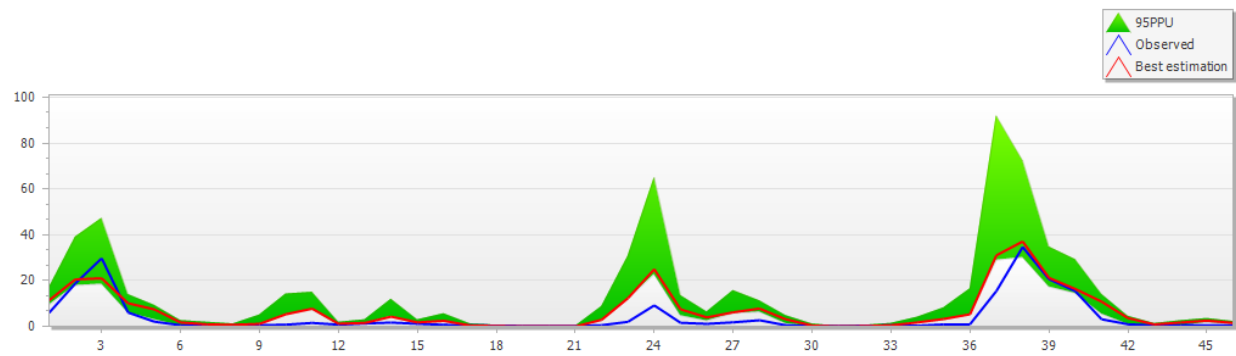
Calibrated flow in subbasin 89.

FLOW_OUT_92



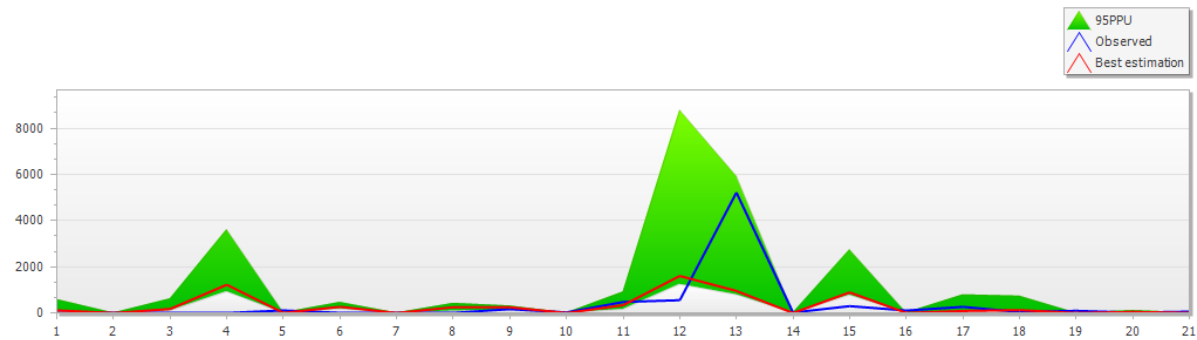
Calibrated flow in subbasin 92.

FLOW_OUT_99



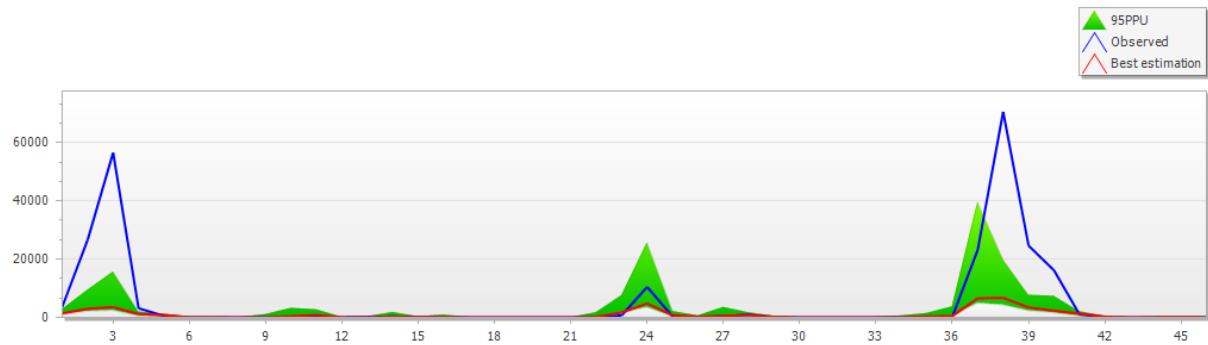
Calibrated flow in subbasin 99.

SED_OUT_95



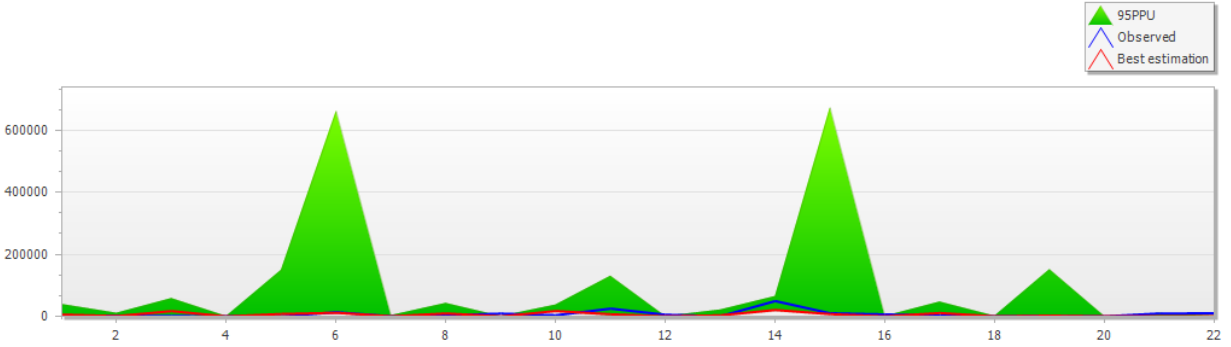
Calibrated sediment in subbasin 95.

SED_OUT_99



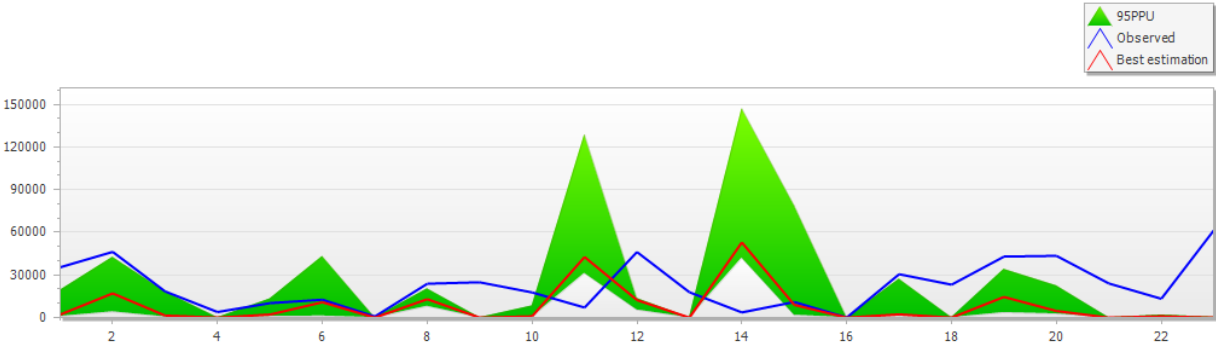
Calibrated sediment in subbasin 99.

NO3_OUT_95



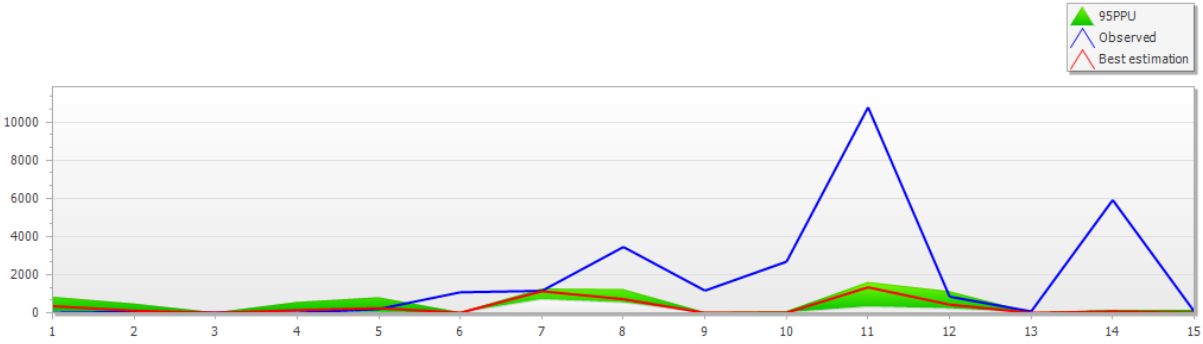
Calibrated NO_3^- in subbasin 95.

NH4_OUT_95

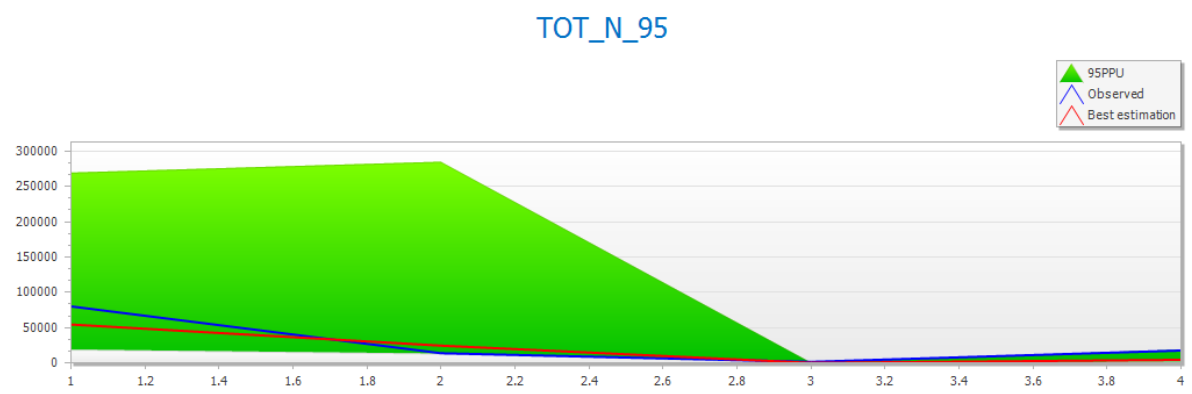


Calibrated NH_4^+ in subbasin 95.

NO2_OUT_95



Calibrated NO_2^- in subbasin 95.



Calibrated TN in subbasin 95.