**DOKUZ EYLÜL UNIVERSITY**
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

# APPLICATION OF CONTINUOUS HYDROLOGIC MODELING IN KÜÇÜK MENDERES RIVER BASIN

**by**
**Yosife A.M. Allahwani**

**November, 2016**
**İZMİR**

# APPLICATION OF CONTINUOUS HYDROLOGIC MODELING IN KÜÇÜK MENDERES RIVER BASIN

**A Thesis Submitted to the**
**Graduate School of Natural and Applied Sciences of Dokuz Eylül University in**
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**Civil Engineering, Hydraulics, Hydrology and Water Resources Program**

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**İZMİR**

## THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"APPLICATION OF CONTINUOUS HYDROLOGIC MODELING IN KÜÇÜK MENDERES RIVER BASIN"** completed by **YOSİFE A.M. ALLAHWANİ** under the supervision of **ASSOC.PROF. GÜLAY ONUŞLUEL GÜL** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Yosife A.M. Allahwani

# APPLICATION OF CONTINUOUS HYDROLOGIC MODELING IN KÜÇÜK MENDERES RIVER BASIN

## ABSTRACT

In this study, a lumped continuous hydrologic model was carried out by using HEC-HMS modeling system and Geographic Information Systems (GIS), as an application for continuous hydrologic modeling in Küçük Menderes river basin. Küçük Menderes river basin is located in the city of Izmir on the western side of Turkey. Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) was used throughout the study for preparing the required basin data in HEC-HMS model based on ASTER digital elevation model. Meteorological data for Ödemiş and Selçuk Meteorologic stations were used for calculating the basin meteorological data, while the flow measurements data for Selçuk station (Station 601) was considered the observed outflow for the basin. Basin land use distribution was prepared based on Corine (1990), and basin soil distribution was obtained according to soil maps from FAO (2005). One-layer Deficit and Constant method in HEC-HMS was used for simulating the loss method. Also, Priestly and Taylor's method was selected to simulate evapotranspiration losses. Leaf Area Index (LAI) was needed for calculating maximum canopy storage over the basin. The aim of this study is to calibrate the lumped continuous hydrologic model in Küçük Menderes river basin. Both manual calibration and automated calibration were used throughout the calibration process from 1965 to 1998 for average daily flow and average monthly flow modeling. In HEC-HMS Nash-Sutcliffe objective function was used for calibration. Calibration of the model was executed according to some statistical parameters. Throughout the calibration process, the simulated streamflow almost meet the observed stream flow. As a result, The calibrated parameters and validated model of the basin with the extended data set can be used as an effective tool for basin planning and management studies in Küçük Menderes river basin.

**Keywords:** Continuous hydrologic model, Küçük Menderes river basin, GIS, HEC-HMS, HEC-GeoHMS, calibration.

# KÜÇÜK MENDERES AKARSU HAVZASI'NDA SÜREKLİ HİDROLOJİK MODELLEMENİN UYGULANMASI

## ÖZ

Bu çalışmada, sürekli hidrolojik modellemenin bir uygulaması, Küçük Menderes Nehri Havzası içinde HEC-HMS modelleme sistemi ve coğrafi bilgi sistemleri (CBS) kullanılarak gerçekleştirilmiştir. Küçük Menderes Havzası, Türkiye'nin batısında yer almaktadır. Çalışmada, HEC-HMS modeli için gerekli olan verilerin hazırlanmasında HEC-GeoHMS ArcGIS eklentisi kullanılmıştır. Ödemiş ve Selçuk istasyonları için meterolojik veriler Meteoroloji Genel Müdürlüğü'nden alınmış, akım ölçümleri ise havza çıkışında bulunan 601 numaralı Selçuk istasyonu için akım gözlem yıllıklarından elde edilmiştir. Corine haritası kullanarak havza'nın arazi kullanım haritası hazırlanmış ve FAO (Gıda ve Tarım Örgütü ) tarafından oluşturulan toprak haritaları kullanılarak havzanın toprak haritası hazırlanmıştır. Priestly ve Taylor yöntemi evapotranspirasyon kayıplarını hesaplanmak üzere seçilmiştir. Bitkiler tarafından tutulan miktarın hesaplanmasında LAI (leaf area index) kullanılmıştır. Bu çalışmada, Küçük Menderes havzası için sürekli hidrolojik model oluşturulmuş ve modelin parametreleri tahmin edilerek doğrulaması gerçekleştirilmiştir. 1965 - 1998 yılları arası dikkate alınarak hem ortalama günlük akış modeli hem de ortalama aylık akış modelinin kalibrasyon ve doğrulama çalışmaları yapılmıştır. Amaç fonksiyonu olarak Nash-Sutcliffe kullanılmıştır. Çalışma sonucunda, Küçük Menderes Havzası için elde edilen kalibre edilmiş parametreler ve doğrulaması gerçekleştirilen havzanın sürekli hidrolojik modeli, yeni verilerin eklenmesi ile tekrar gözden geçirilerek havza ile ilgili su yönetimi ve planlaması çalışmalarında kullanılabilecektir.

**Anahtar kelimeler:** Sürekli hidrolojik model, Küçük Menderes nehri havzası, CBS, HEC-HMS, HEC-GeoHMS, kalibrasyon.

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# CHAPTER ONE
# INTRODUCTION

## 1.1 Problem Statement

Water greatly impacts on food security, health, education, energy production, public health, gender equity and livelihood, so water is considered the prime component of the life. Moreover, water is very important for economic and social development process, so water studies are needed to reduce the poverty levels (García, Rodríguez, Wijnen, & Pakulski, 2016). That means water management is very important to maintain the demand for energy and food requirements at safe limits. It is important to note that human civilizations were constructed in the places which had rich sources of fresh water such as rivers, wells, and springs (Gowda et al., 2008).

The concept of hydrologic cycle illustrates that water sources are continuously recharged by precipitation (Barron, Hay, & Thompson, 1989). Precipitation takes all forms of water that reach the earth from the atmosphere. The usual forms of precipitation are rainfall, snowfall, hail, frost, and dew (Subramanya, 2008).

Precipitation process is negatively affected by some factors such as a change in global climate, which sometimes leads to natural disasters, for example, discharges, and droughts (Alexander et al., 2008). Because of these natural disasters, the science of water resources management plays an important role in ensuring the wellbeing of people's life (Loucks, Van Beek, Stedinger, Dijkman, & Villars, 2005).

Tools of water resources management are required to help countries to understand their water challenges and risks of unexpected changes in the hydrological regimes, for example, the severe changes on stream flows which support aquatic ecosystem, navigation, hydropower, irrigation system, etc. (Shaka, 2008).

Hydrologic modeling is one of the water resources management tools which can be used for preparing good future scenarios about the changes in the hydrological

regimes, such as climate change or changes in the properties of the basin (Dooge, 1992). Because of the difference between the observed streamflow values and the simulated streamflow values, hydrologic models should be calibrated to obtain the optimum values for the basin parameters (Refsgaard & Storm, 1990).

Küçük Menderes river basin is one of the basins which has low flow rates (Sayit & Yazicigil, 2012). In another hand, the basin is considered an important source for the agricultural requirements for the people in the city of Izmir on the western side of Turkey. Therefore it is very important to develop the hydrologic models for this basin to take some decisions about the water safety of the basin requirements.

## 1.2 Objectives and Scope of the Study

The main objective of this study is to develop the continuous hydrologic model in Küçük Menderes river basin. Thus, the outcomes of the study will be able to use for climate change, irrigation planning, irrigation management and any other hydrologic and hydraulic studies.

The U.S Army Corps of Engineers Hydrologic Modeling System (HEC-HMS) was used for developing the continuous hydrologic model for Küçük Menderes river basin by considering the following specific objectives:-

- Preparing the HEC-HMS model based on the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS).

- Developing the continuous hydrologic model both daily and monthly base.

- Comparing the simulated and observed hydrographs based on statistical efficiency tests.

## 1.3 Research Outline

The study consists of eight chapters. Chapter one introduces the problem statement and identifies the objectives of the research. Chapter two investigates literature related to hydrologic models. Chapter three provides an overview of the case study area. Chapters four, and five give detailed information about the tools used in this research, including HEC-HMS and HEC-GeoHMS. Running of the model is presented in Chapter six. Chapter seven describes calibration and validation of the model. Finally, conclusions are given in Chapter eight.

# CHAPTER TWO
# LITERATURE REVIEW ON HYDROLOGICAL MODELS

Water is the prime requirement for the existence of life (Swyngedouw, 2004). Since the study of hydrologic cycle includes mainly the quantity and quality of water studies, hydrologists have been working on projects to build many hydrologic models. Hydrologic models are very important and needed for making sensitive hydrologic simulations for the complex hydrologic phenomena.

## 2.1 Definition of Hydrologic Models

Hydrologic models are defined as the simulation of the watershed systems (Salas, 1980). Both physical approaches and mathematical approaches are used to make a simplification for the complex hydrological phenomena (Singh & Frevert, 2005). Physical approaches depend on the nature of the watershed, but mathematical approaches depend on the sequence of mathematical equations (Chow, Maidment, & Mays, 1988). More generally, watershed models can be classified into three mainly groups: parametric models, stochastic models, and physically-based mathematical models (Masson, 2000). A sample of a hydrological model is presented in Figure 2.1.

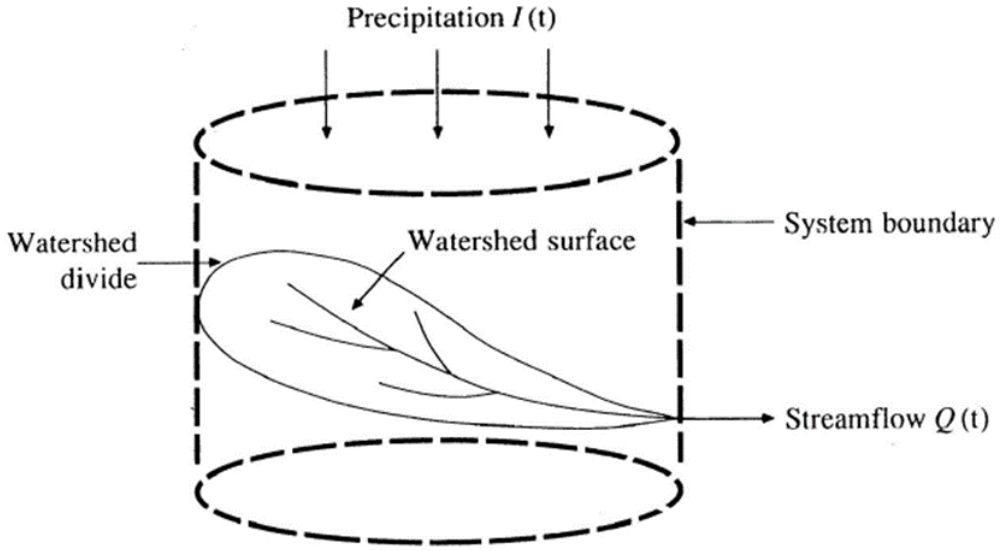


Figure 2.1 Hydrologic system (Chow et al., 1988).

## 2.2 Importance of Hydrologic Models

Defining the operation system for the hydrological phenomena in the watersheds is not an easy task for most of the cases. Therefore, hydrologic models are really required to understand the full detailed data for the watershed systems, and to control the watershed processes easily. Also, hydrological models are used for forecasting watershed responses due to changes in properties of watershed such as climate change. (Baird & Wilby, 1999).

## 2.3 History of Hydrologic Models

According to Chow (1964) hydrology has main eight periods along its history as follows:

- Period of speculation (from prior to AD 1400)
- Period of observation (from 1400 to 1600)
- Period of measurement (from 1600 to 1700)
- Period of experimentation (from 1700 to 1800)
- Period of modernization (from 1800 to 1900)
- Period of empiricism (from 1900 to 1930)
- Period of rationalization (from 1930 to 1950)
- Period of theorization (from 1950 to date)

## 2.4 Developments of Hydrologic Models

Many developments and applications of hydrological models have been achieved by hydrologists. Xu, (2003) introduced some of the most important developments as the following:

### *2.4.1 Period of Modernization*

Period of modernization (from 1800 to 1900) has many important developments in rainfall-runoff models, which have very important uses such as the urban sewer design, land reclamation drainage systems design, and reservoir spillway design in hydrological models applications. In this period, the concept of the rational method was proposed by Mulvaney in1850. The rational method is used for calculating the discharge peak discharge in the watersheds by using intensity of the rainfall, runoff coefficient, and area of the watershed (Rahman, Haddad, Zaman, Kuczera, & Weinmann, 2011).

### *2.4.2 Period of Empiricism*

The period of empiricism (from 1900 to 1930) includes many modifications in rational method to be applicable for non-uniform distributed catchments and large size watersheds. The modification was based on transfer function which used Manning formula for calculating the different time of concentration due to the topography of the watersheds (Guo, 2001).

### *2.4.3 Period of Rationalization*

During the period of rationalization (from 1930 to 1950), hydrologists introduced new rainfall-runoff models. Sherman in 1932 introduced the concept of the unit hydrograph model which depends basically on the superposition principles (Figure 2.2). Unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth of rainfall excess occurring uniformly over the watershed and at a uniform rate for a specified duration. Hydrologists have been able to calculate the runoff volume as a function of time by using the concept of unit hydrograph based on the linear theory (Beven, 2011).

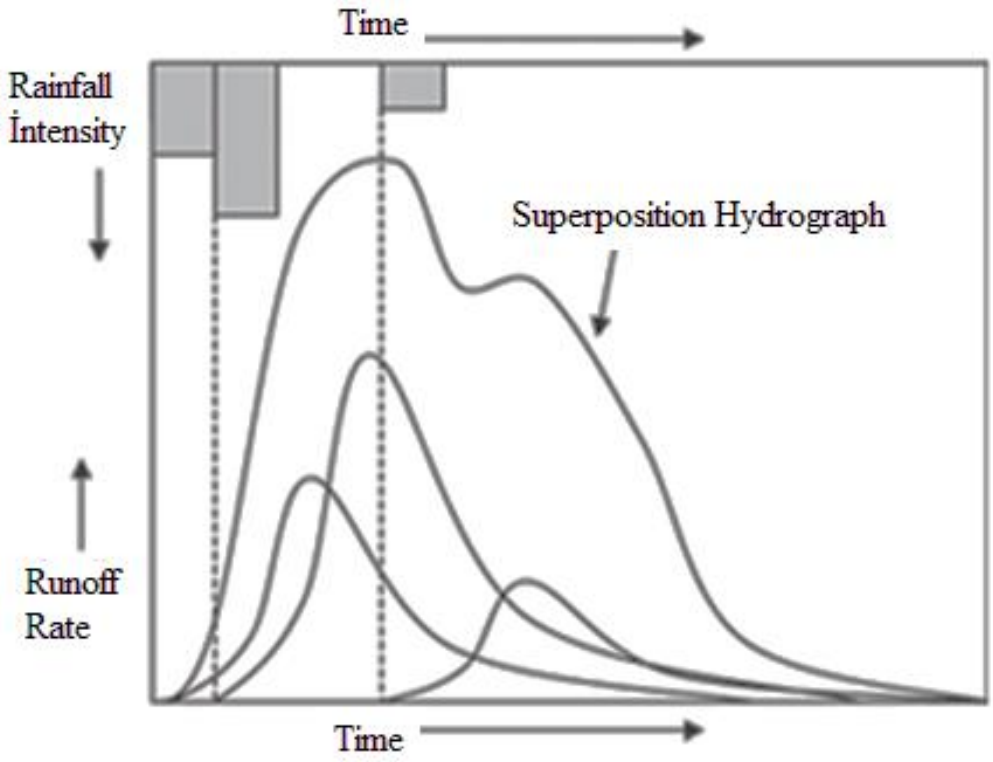


Figure 2.2 Concept of runoff hydrograph.

### *2.4.4 Period of Theorization*

The period of theorization (from 1950 to date) is the period when conceptual rainfall-runoff models formed by computing the runoff from excess precipitation throughout a simplified representation of the hydrologic system such as SCS dimensionless synthetic hydrograph method. After that, runoff is routed to the outlet of the watershed to calculate the runoff hydrograph (Krause, Boyle, & Bäse, 2005).

Throughout period of theorization many of popular rainfall-runoff models were constructed such as:

- Dawdy and O'Donnell: which was one of the first single event rainfall-runoff models which were developed in 1965 to predict discharge volume and peak rates of runoff for small drainage areas.

- Stanford Model IV: is a continuous, dynamic event or steady-state simulator of hydrologic, hydraulic and water quality processes.

- Sacramento Model: is a continuous rainfall-runoff model used for generating daily stream flow from daily rainfall and potential evapotranspiration data. It uses soil moisture accounting to simulate the water balance within the catchment.

- Hydrologiska byråns vattenbalansavdelning model- HBV: is initially intended in Sweden for runoff simulation and hydrological forecasting.

- Tank model: is a process-oriented, semi-distributed or lumped continuous simulation model.

- TOPMODEL model: is a physically based, distributed and continuous hydrologic simulation model.

In 1970, Box and Jenkins introduced one of the time series stochastic model by creating the autoregressive moving average (ARMA) model. In 1980, the Systéme Hydrologique Européen (SHE) model was developed for forecasting purpose. Forecasting hydrologic models were constructed as warning tools for flood discharge dangers. Therefore these models are used for studying the effects of many parameters in the watershed management studies such as land-use change, climate change, diffusion of pollutants and sediments, and hydrologic modeling of ungauged watersheds. Variable Infiltration Capacity (VIC) model (1992) and Macro-scale Probability Distributed Moisture (Macro-PDM) model (1999) were developed as macro-scale hydrological models and supported by GIS extensions (Al-Sabhan, Mulligan, & Blackburn, 2003).

## 2.5 Types of Hydrologic Models

Hydrologic models have many types such as descriptive (simulation), prescriptive (optimization), deterministic, probabilistic or stochastic, static, dynamic, discrete, continuous and deductive, inductive, or floating (Grayson, & Blöschl, 2001).

### *2.5.1 Statistical Models*

Statistical models consider uncertainties in parameters and input data. The simple statistical analysis could include techniques such as double mass curve analysis, regression, and discharge frequency analysis (McCuen, 2016).

### *2.5.2 Deterministic Models*

Deterministic models use mathematical equations to simulate the hydrological phenomena in several stages in the hydrologic cycle (Huber, 1986). Examples of this kind of models are HEC-HMS, Hydrological Simulation Program – FORTRAN (HSPF), Precipitation-Runoff Modeling System (PRMS), EPA Storm Water Management Model (SWMM), DRAINMOD, and Agricultural Nonpoint Source Model (AGNPS).

### *2.5.3 Lumped Models*

Lumped hydrologic models such as HSPF and PRMS models do not consider spatial variability in watershed parameters (Carpenter & Georgakakos, 2006).

### *2.5.4 Distributed Models*

Distributed hydrologic models consider spatial variability in watershed parameters, hydrologic processes, input data, and boundary conditions by dividing the basin into uniformly sized cells (Vieux, 2001). The hydrologic processes are modeled in each

cell, and runoff is routed to neighboring cells based on the direction of cell slope until it reaches the basin outlet.

### *2.5.5 Event-Based Models*

Event-based models are used for simulating a single precipitation-runoff event during a short time interval (Talei, Chua, & Quek, 2010). Because of the short time duration of the simulation, some of the watershed processes are not considered such as evaporation, transpiration and soil moisture. Event-based models are mainly used for studying the peak discharge events.

### *2.5.6 Continuous Models*

Continuous models are used for simulating a long time series of precipitation runoff events. HSPF, PRMS, and SWMM models are the examples of the continuous models (Fleming & Neary, 2004). In a long time of the continuous simulation, all watershed process should be considered such as evaporation, and transpiration. Continuous models are used for many hydrologic applications (Akan, & Houghtalen, 2003). For example:

- Extending streamflow records,
- Flow forecasting,
- Evaluating the effect of land-use practices on catchment response,
- Design urban drainage, highway culverts, reservoirs, and the water quality modeling, and
- Irrigation planning and management.

## 2.6 Hydrologic Model Steps

A hydrologic model is carried out through the following steps (Refsgaard, 1997).

1. Selection of the most suitable hydrologic model type

Hydrologists select the type of hydrologic model considering for the research purposes, properties of the basin, data availability, and financial constraints.

2. Handling the required data

Nowadays, required data for modeling are available by using remote sensing methods and other new technologies. Therefore, obtaining necessary input data such as rainfall, infiltration, physiography, land use, channel characteristics, flow rates, and reservoir data are not difficult tasks.

3. Selection of Methodology

Methodology selection depends on the data and the purpose of the study.

4. Calibration & Verification of Model

Calibration is the process of modifying model parameters to reduce the error between the simulated streamflow and some portion of the observed flow record. Model validation tests the ability of the model to estimate runoff for periods. Selected period should be different from the one that is used for the calibration process. The validation process should be used to test a model's divergence over a wide range of hydrologic conditions.

5. Creating Scenarios

In order to predict the situation for the future periods, the model simulations are run under historical or design rainfall, various conditions of land use, and various control schemes for reservoirs and channels.

## 2.7 Some Applications of HEC-HMS Model for Continuous Simulation

Koch, Bene, and Hajnal (2013) developed a continuous hydrologic modeling with HMS in the Aggtelek Karst region. The Aggtelek-mountain region is located in the NE part of Hungary, directly neighboring Slovakia, with an area of about 202 $km^2$. Water recharged into karst aquifers moves downgradient through a combination of highly anisotropic pathways. The linear–reservoir model was typically used with the SMA model in base flow calculations. Rainfall data from one gage in the watershed was assumed to be uniformly distributed over the watershed. The monthly evapotranspiration was estimated based on the Thorn-Thwaite method. Canopy storage was assumed to be 10 mm and surface storage 20mm. The topsoil was assumed to be sandy loam, 100 cm deep, with 0.3 porosity, 0.2 air entry value, and 0.1 wilting points. Soil storage was 0.2mm/mm, and tension storage 0.1 mm/mm of soil depth. The model was calibrated using an eight-year span of data, from 1975 to 1982 was selected for calibration. During validation, only the initial conditions were changed in order to model the 1983-1992 observational periods. In 1990, it appeared that no spring flow measurements, but the simulation continued and extended one more year. The result of the validation procedure shows a reasonably good fit to the measured data. During the winter season, the program predicted some flow when no significant spring flow was measured. During summer, the peaks were again un-depredated for wet periods.

Wallner, Haberlandt, and Dietrich (2012) made the evaluation of different calibration strategies for large scale continuous hydrological modeling by using HEC-HMS model. The study investigates the impact of different calibration strategies and different optimization algorithms on the performance and robustness of a semi-

distributed model. The different calibration strategies were (a) Lumped, (b) 1-Factor, (c) Distributed and (d) Regionalization. The study was carried out for five sub-catchments of the Aller-Leine River Basin in Northern Germany. The model was run in a continuous mode on an hourly time step. Runoff concentration of the surface runoff is calculated with Clark's Unit Hydrograph, the interflow and base flow are calculated with linear reservoirs. All flows in the channel are routed with the Muskingum method. Calculation of the potential evapotranspiration is carried out with the Priestley-Taylor method and snow melt with the Temperature-Index method. All meteorological input data were interpolated using Ordinary-Kriging for precipitation, External-Drift-Kriging for temperature and Inverse-Distance for net radiation.

Neary, Habib, and Fleming (2004) carried out a lumped continuous hydrologic modeling with NEXRAD precipitation in two sub-basins of the Cumberland River basin in Middle Tennessee. The HEC-HMS model, with its soil-moisture-accounting SMA algorithm for continuous simulation, was used in order to carry out the continuous hydrologic model. Excess rainfall was transformed to direct runoff at each sub-basin outlet using the Clark unit hydrograph method, in the other hand channel routing was not performed. A monthly average method was used for simulating evapotranspiration in HMS. The automatic calibration option in HMS was used minimally due to parameter interactions between the tension zone depth and the initial soil storage. When manually calibrating the model, limits were placed on all three adjusted parameters to prevent unreasonable parameter values. Radar-driven HEC-HMS simulations were generally less accurate in prediction of streamflow volume as compared to gauge-driven simulations.

# CHAPTER THREE
# STUDY AREA

Küçük Menderes river basin (27.9642˚E, 38.2157˚N) is one of the open basins in the western side of Turkey in the city of İzmir as shown in Figure 3.1 (Saf, 2009). As a hydrological study, the most important and critical stage is the collection of the required data such as the basin data.




Figure 3.1 Küçük Menderes river basin (Google earth, 2016).

## 3.1 Importance of Watershed

Küçük Menderes river watershed is considered as the main source for vegetable products in Turkey. Since population in the watershed are nearly 500,000, the population density in the watershed is not so high, but most of the watershed area is for agricultural uses (Alçiçek, & Johan, 2008). There is a possibility that in future, the basin may be used as a good source for generating energy.

### 3.2 Hydrology of the Watershed

Küçük Menderes River (Figure 3.2) is one the water bodies which is located on the western side of Turkey in the city of İzmir in Aegean region. The river springs from the mountain of Bozdağ. The river flows to the south and it becomes large and large by a collection of the small flows which come from the lateral channels along the 175 km distance. The basin of the river starts from the mountain of Aydın and mountain of Boz. It flows into the Aegean Sea at Selçuk town (Ben-Zvi, 2010).

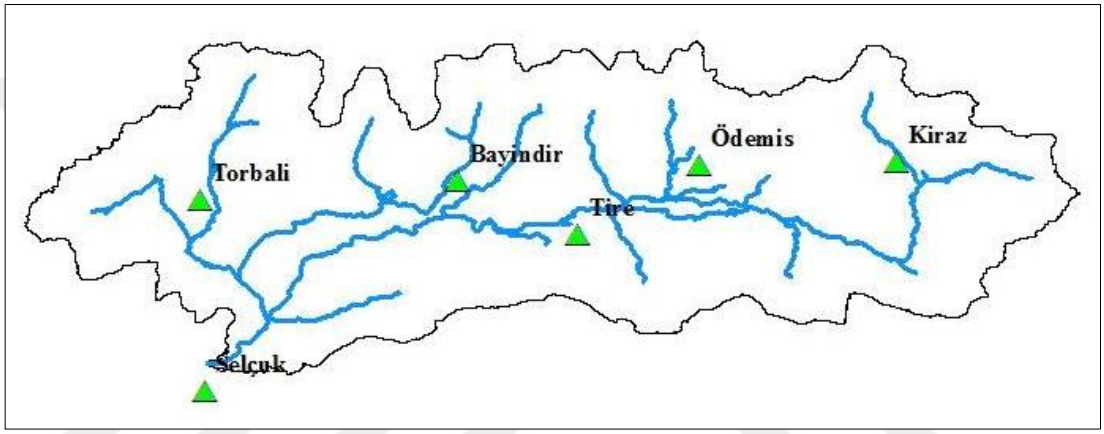


Figure 3.2 Küçük Menderes River.

### 3.3 Climate and Weather Description for the Watershed

The climate of the Küçük Menderes basin is the same as of Mediterranean Sea climates. Summer seasons are very hot and dry, winter seasons are mild and rainy and a little cold. Precipitation occurs mainly in winters, while during summer there is very little rain. The regional average annual precipitation of the basin is 730.2 mm/year according to long-term data. The average air temperature of the basin is 16.6 ºC. The average monthly air temperature varies from 7.1 ºC in January to 27.5 ºC in July (Durdu, 2010).

### 3.4 Land Use Data of the Watershed

The main land use for Küçük Menderes river basin (Figure 3.4) is agricultural uses with a ratio of 62.11%. Therefore, the study of the hydrological situation of the watershed has importance to maintain the safety of water resources for the basin. The summer season is generally dry and the irrigation process depends on surface water and groundwater resources. Artificial use have a ratio of 2.24%, and natural areas have a ratio of 35.65%.

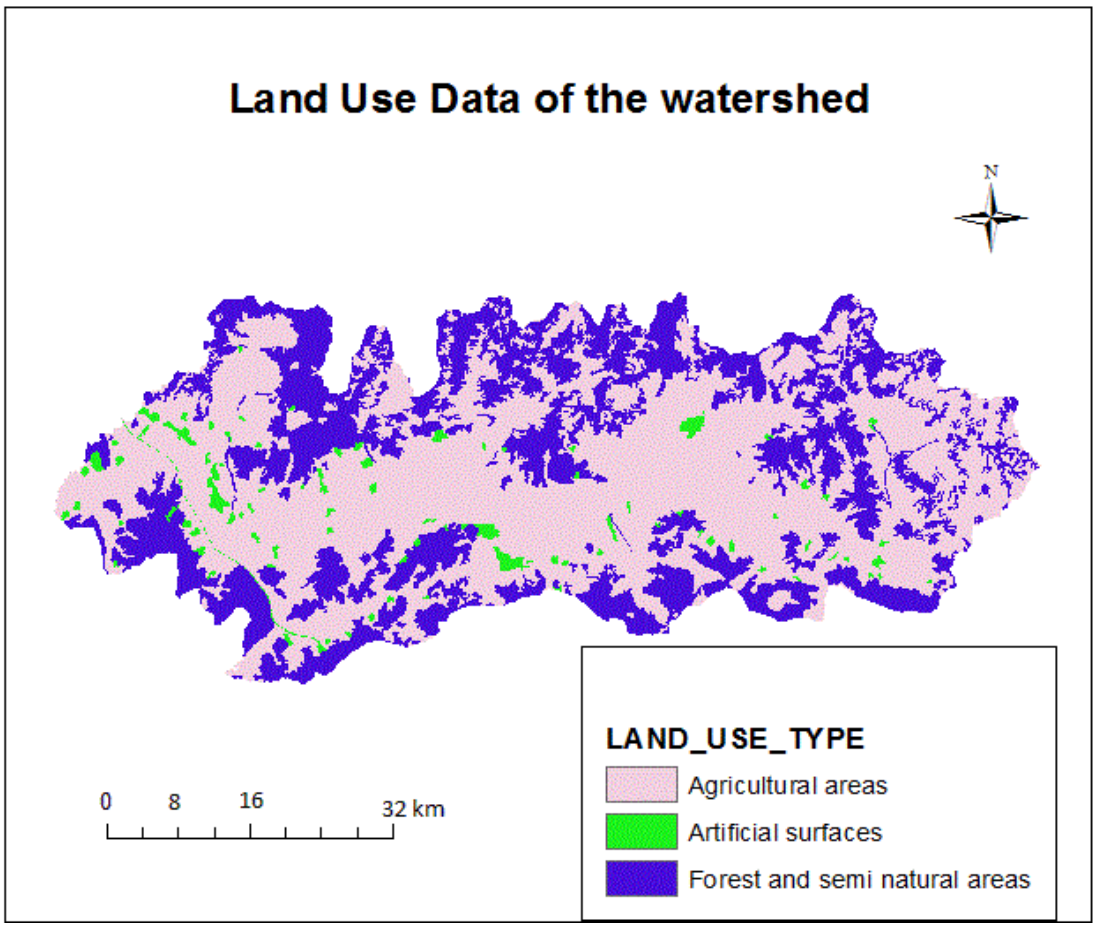


Figure 3.3 Land use raster for Küçük Menderes river basin (EEA, 2006).

### 3.5 Soil Classification of the Watershed

FAO is one of the international organizations which has soil classifications. Generally, FAO's soil classification is used for agricultural uses. According to FAO's

soil classification, Figure 3.5 below shows that the basin has a high content of clay soil.

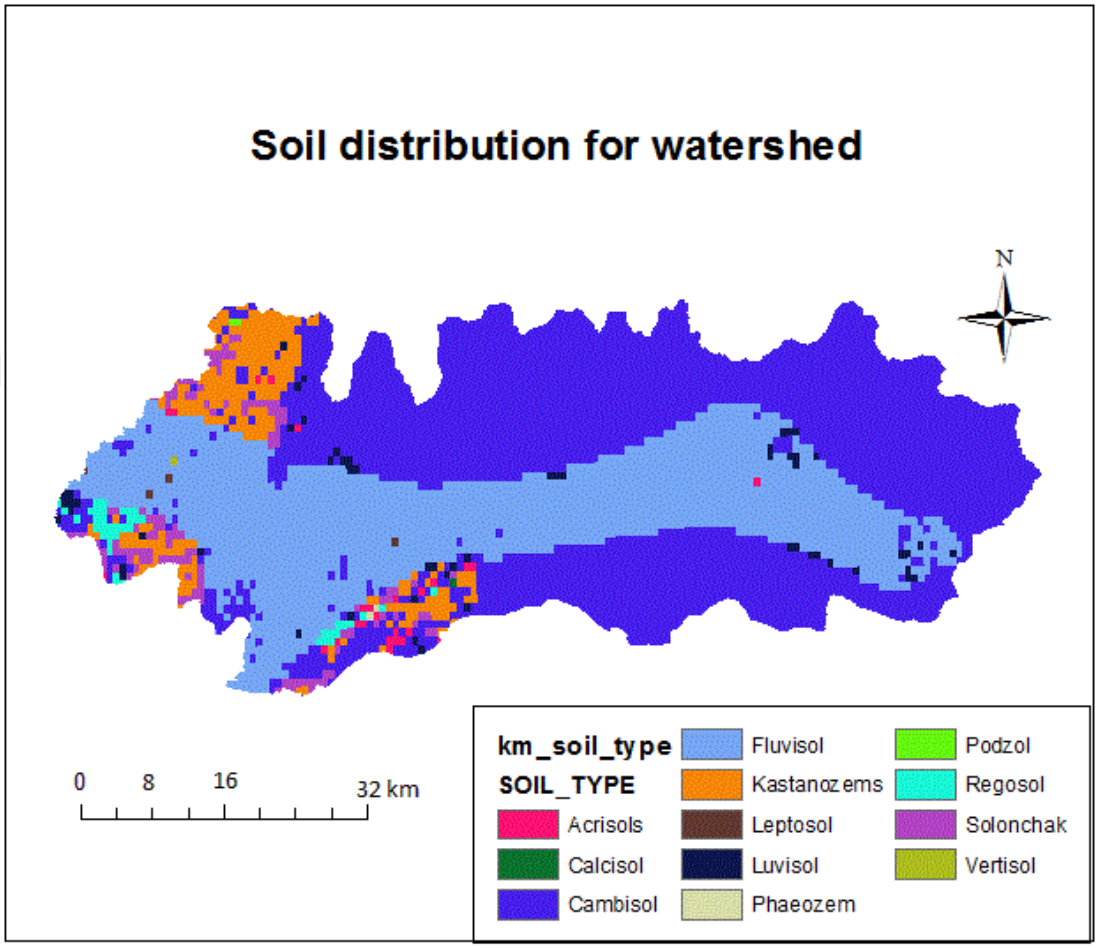


Figure 3.4 Soil distribution raster for Küçük Menderes river basin.

### 3.6 Topography of the Watershed

Küçük Menderes river basin includes towns of Bayındır, Beydağ, Kiraz, Ödemiş, Tire, Torbalı, Dağkızılca, Selçuk, and Ovakent. The drainage area of the basin is about 3502 $km^2$, and the basin extends in the direction from east to west. Many mountains are located around the basin as shown in Figure 3.1. The height of these mountains is between 600m and 2159m above sea level. The flat region is located in the middle of the basin. This flat area is the lowest elevations in the basin. Meanwhile, the elevations in the basin increase from the west to east (Peksezer & Yazıcıgil, 2010).

# CHAPTER FOUR
# HYDROLOGIC MODEL DESCRIPTION

A hydrologic model is defined as a simulation of basin response for hydrologic phenomena over a time such as rainfall-runoff hydrologic models as shown in Figure 4.1. In this chapter, general descriptions for HEC-HMS and HEC-GeoHMS models were introduced.

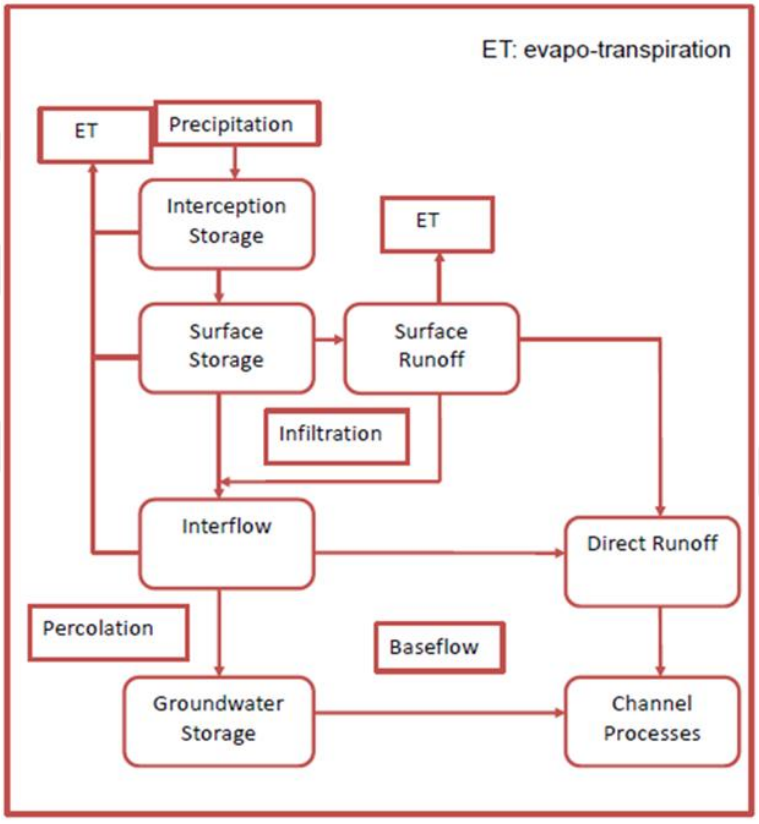


Figure 4.1 Flow chart of hydrologic models. (McCuen, 1989)

## 4.1 Hydrologic Modeling System (HEC-HMS)

In 1968, U.S Army Corps of Engineers Hydrologic Engineering Center (HEC) developed HEC-1 to be used for simulating a rainfall-runoff hydrologic model (HEC, 2001). HEC improved the HEC-1 model and developed HEC-HMS hydrologic model. HEC-HMS is physically based hydrologic model can be simulated response of watershed for hydrologic phenomena over a time.

### *4.1.1 HEC-HMS Simulation Steps*

Simulation of a rainfall-runoff model in HEC-HMS is carried out through the following steps:

- Start a new project,
- Create gage data,
- Enter basin model data,
- Enter precipitation model data,
- Enter control specifications,
- Create and execute a "run" (an application of the program.),
- View the results, and
- Exit the program.

### *4.1.2 Components of HEC-HMS Model*

HEC-HMS model consists of three main components, which are Basin Model, Meteorologic Model, and Control Specifications. Other components included into the HEC-HMS project such as Time-Series Data, Paired Data and Grid Data as shown in Figure 4.2. Basin Model consists of two elements; watershed schematic, and watershed data.

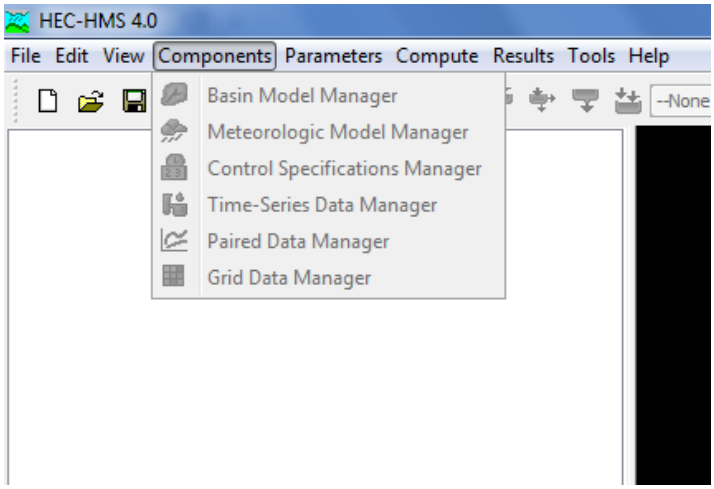


Figure 4.2 Components of HEC-HMS model.

Basin schematic is used for mapping watersheds. It includes sub-basins, river reaches, reservoirs, confluences, and junctions. Table 4.1 below describes the uses of basin schematic elements.

Table 4.1 Basin hydrologic schematic elements for HEC-HMS.

| Symbol | Element Name | Description |
|---|---|---|
|  | Subbasin | Used for rainfall-runoff computation on a watershed. |
|  | Reach | Used to convey (route) streamflow downstream in the basin model. |
|  | Reservoir | Used to model the detection and attenuation of a- hydrograph caused by a reservoir or detention pond. |
|  | Junction | Used to combine flows from upstream reaches and sub-basins. |
|  | Diversion | Used to model abstraction of flow from the main channel. |
|  | Source | Used to introduce flow into the basin model from a stream crossing the boundary of the modeled region. A source has no inflow. |
|  | Sink | Used to represent the outlet of the physical watershed. Sink has no outflow. |

Basin data section in the model (Figure 4.3) includes the part of the required model data which are used for the calculations of discharge hydrograph. It includes loss method, transform method, routing method, and baseflow method.

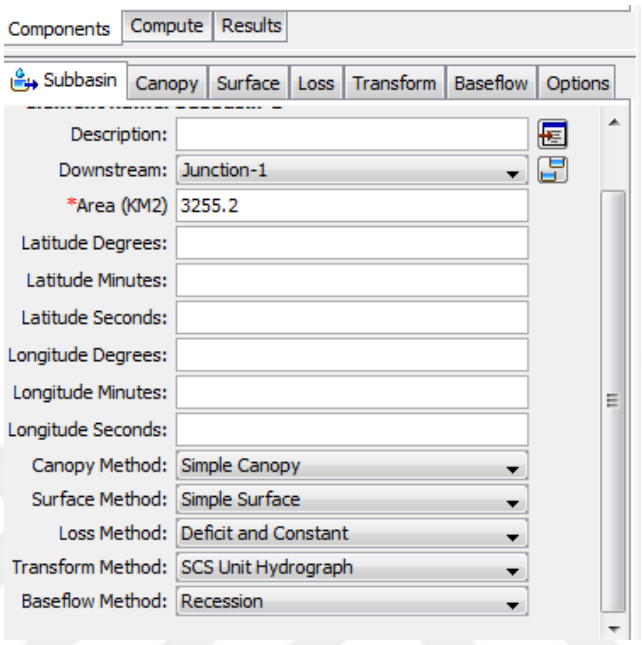


Figure 4.3 Data process elements of basin model in HEC-HMS.

- Baseflow method is used for calculating the contributed flow over a stream flow by groundwater. Table 4.2 below shows the available baseflow methods in HEC-HMS.

Table 4.2 Baseflow methods in HEC-HMS.

| Model | Categorization |
|---|---|
| Recession | event, lumped, empirical, fitted parameter |
| Bounded Recession | continuous, lumped, empirical, fitted parameter |
| Constant Monthly | continuous, lumped, empirical, fitted parameter |
| Linear Reservoir | event, lumped, empirical, fitted parameter |

- Loss method computes the losses that occur during a rainfall. Hydrologists developed many approaches for calculating the value of the losses due to infiltration process. Table 4.3 below shows the available loss methods in HEC-HMS.

Table 4.3 Loss methods in HEC-HMS.

| Model | Categorization |
|---|---|
| Initial and Constant | event-based, lumped, empirical, fitted parameter |
| SCS Curve Number (CN) | event-based, lumped, empirical, fitted parameter |
| Gridded SCS CN | event-based, distributed, empirical, fitted parameter |
| Green and Ampt | event-based, distributed, empirical, fitted parameter |
| Deficit and Constant | continuous, lumped, empirical, fitted parameter |
| Soil Moisture Accounting (SMA) | continuous, lumped, empirical, fitted parameter |
| Gridded SMA | continuous, lumped, empirical, fitted parameter |

Simple continuous modeling is developed by using the one-layer deficit and constant method. While five-layer soil moisture accounting model is used for the complex continuous models.

- Transform method converts the excessive rainfall over a basin into a discharge hydrograph at the outlet of the basin. Table 4.3 below shows the available transform methods in HEC-HMS.

Table 4.4 Transform methods in HEC-HMS.

| Model | Categorization |
|---|---|
| User-specified UH | event, lumped, empirical, fitted parameter |
| Clark UH | event, lumped, empirical, fitted parameter |
| Snyder UH | event, lumped, empirical, fitted parameter |
| SCS UH | event, lumped, empirical, fitted parameter |
| ModClark | event, distributed, empirical, fitted parameter |
| Kinematic Wave | event, lumped, conceptual, measured parameter |
| User-specified S-Graph | event, lumped, empirical, fitted parameter |

- Routing method is used for divided basins. The flow from the upstream should be routed over the channel flow to obtain the discharge hydrograph in the downstream. Table 4.5 below shows the available routing methods in HEC-HMS.

Table 4.5 Routing methods in HEC-HMS.

| Model | Categorization |
|---|---|
| Kinematic Wave | event, lumped, conceptual, measured parameter |
| Lag | event, lumped, empirical, fitted parameter |
| Modified Puls | event, lumped, empirical, fitted parameter |
| Muskingum | event, lumped, empirical, fitted parameter |
| Muskingum-Grunge Standard Section | event, lumped, quasi-conceptual, the measured parameter |
| Muskingum-Cung 8-point Section | event, lumped, quasi-conceptual, the measured parameter |
| Confluence | continuous, conceptual, measured parameter |
| Bifurcation | continuous, conceptual, measured parameter |

Meteorologic model (Figure 4.4) includes a measured metrological data such as precipitation, temperature and radiation.

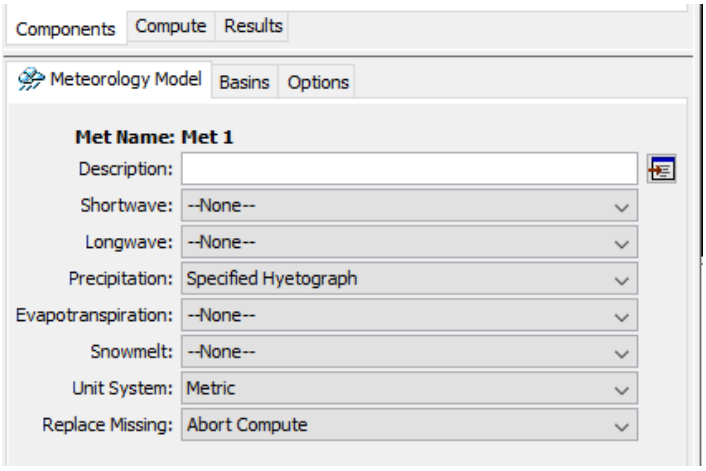


Figure 4.4 Meteorology model window in HEC-HMS.

Control specifications (Figure 4.5) includes start and end dates/times, and the computational time steps for the simulation.

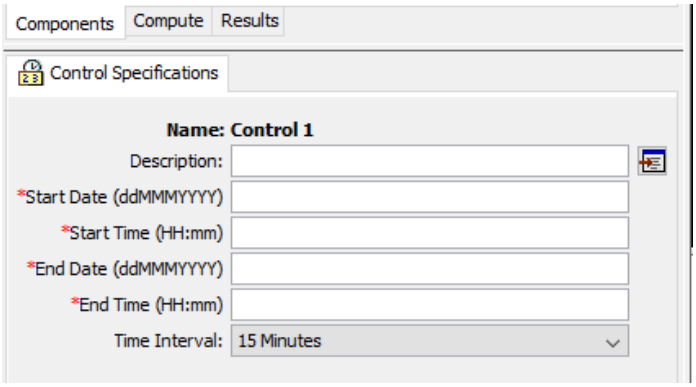


Figure 4.5 Control specifications window in HEC-HMS.

## 4.2 Geospatial Hydrologic Modeling Extension (HEC-GeoHMS)

HEC designed the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) to be compatible with GIS's applications and abilities (HEC, 2000). Moreover, HEC-GeoHMS is used for preparing a consistent model input file for HEC-HMS. HEC-GeoHMS model includes the steps of Preprocessing, Project Setup, Characteristics, Parameters, and HMS.

# CHAPTER FIVE
# HYDROLOGIC MODEL INPUT DATA

Preparing of required data is the time consuming and the most important step of hydrologic modeling studies. A hydrologic model is selected according to available data, and the purpose of the study. In this chapter the required data such as DEM, land use, hydro metrological data and basin related data, for the continuous hydrologic model of Küçük Menderes River watershed was prepared.

## 5.1 Digital elevation model of the basin

ASTER is one of the sources which provides DEM with a high accuracy. The accuracy of the provided DEM is from 7 to 14 m (NASA, 2016). Küçük Menderes river watershed is located in the city of Izmir on the western side of Turkey, so the required area was selected as shown in Figure 5.1. Digital elevation model (DEM) is required to develop the HEC-GeoHMS model for the basin as shown in Figure 5.2.

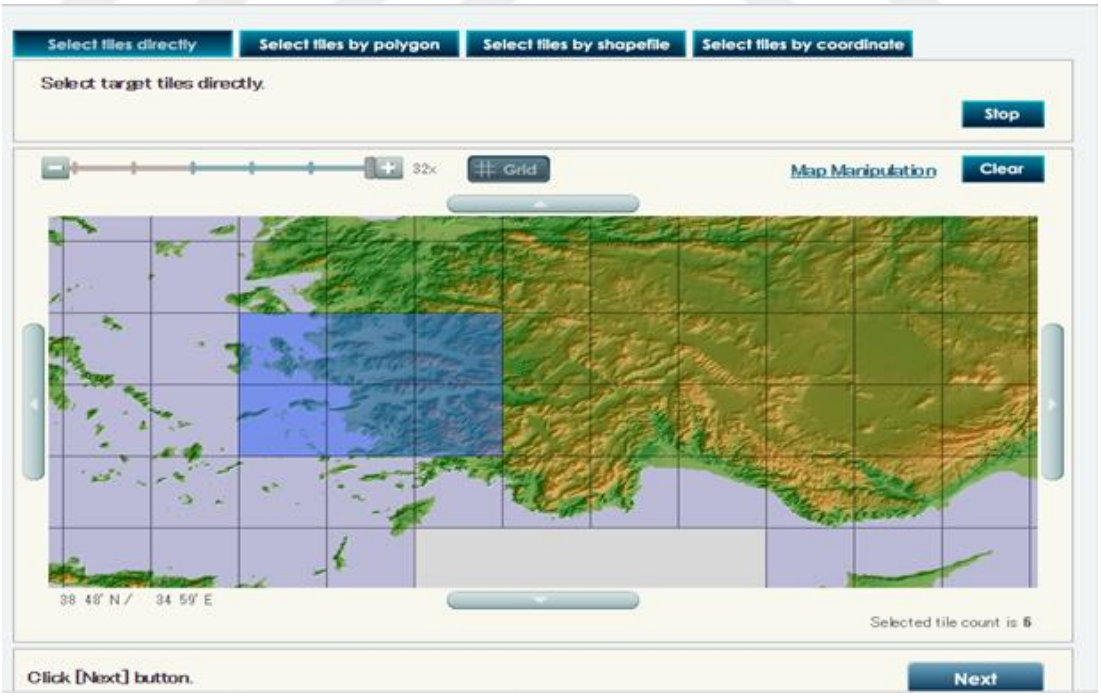


Figure 5.1 ASTER digital elevation model interface.

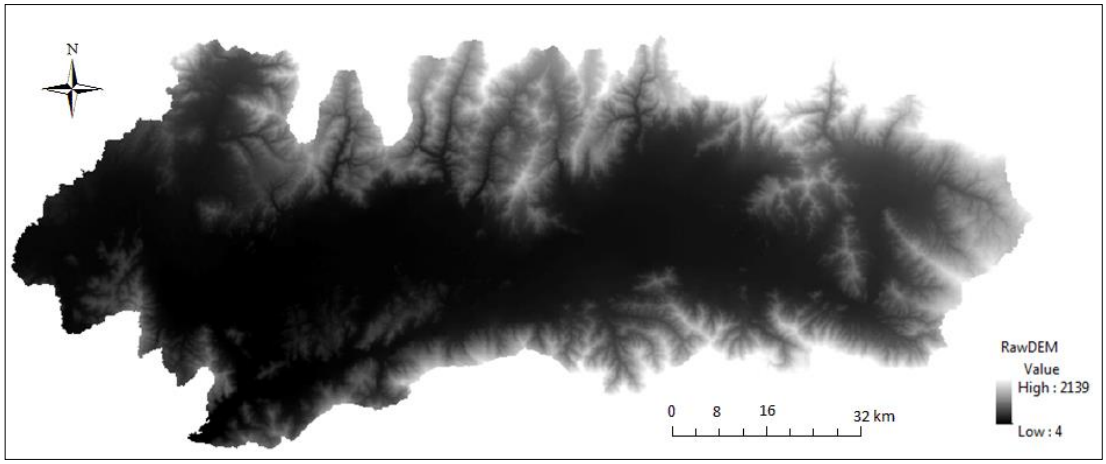


Figure 5.2 DEM for Küçük Menderes river basin.

## 5.2 Land use distribution of the basin

European Environment Agency developed European land use classification (EEA, 1990). The land use raster has the pixel size of 100m, which means a high special accuracy of land use data for the watershed (Figure 5.3). Land use raster is required to develop some of the basin related data such as leaf index area raster, maximum canopy storage raster, crop factor raster and impervious ratio raster.

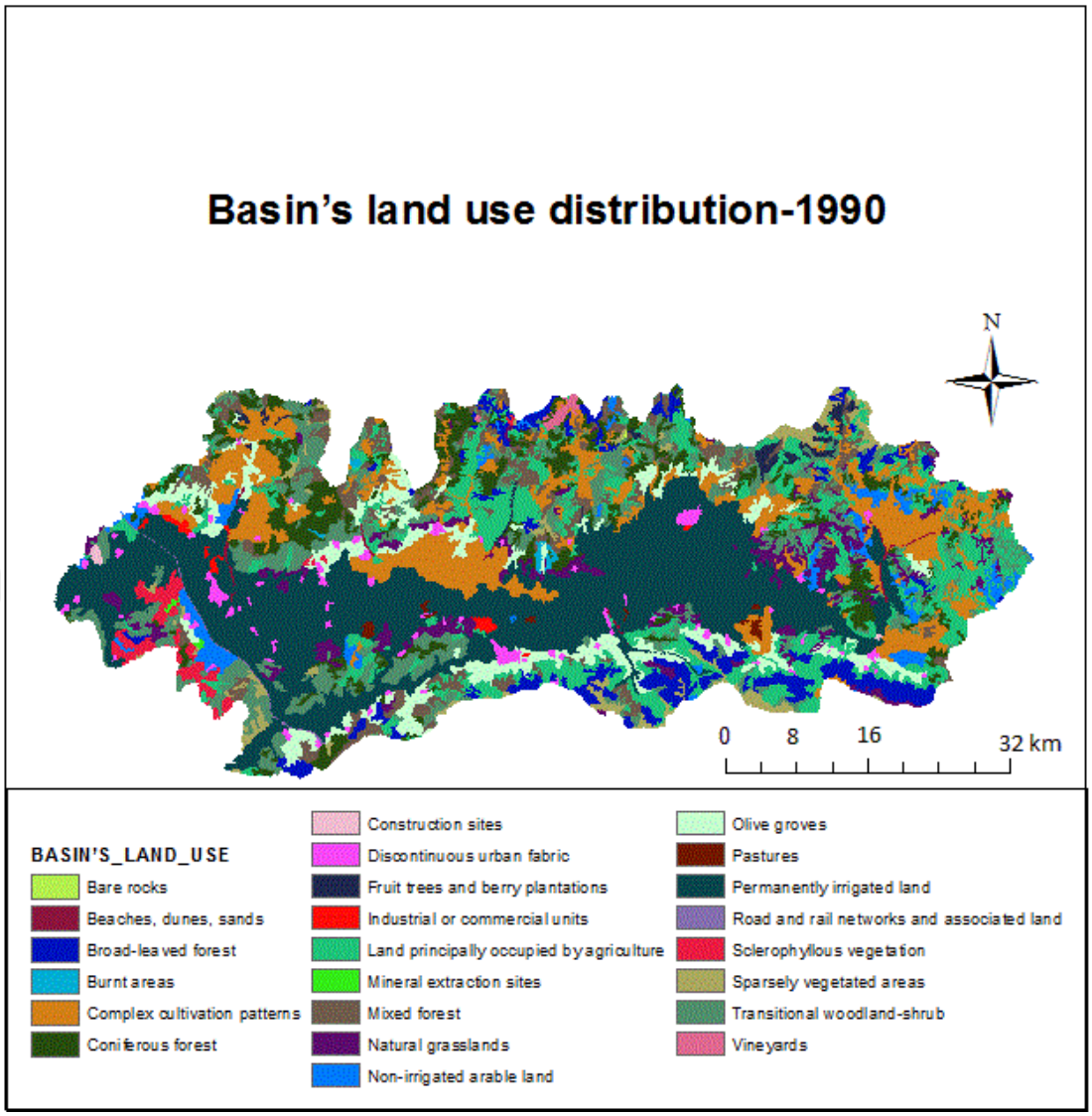


Figure 5.3 Land use raster for Küçük Menderes river basin (Corine, 1990).

## 5.3 Soil distribution of the basin

As mentioned in chapter 3, FAO has developed one of soil classifications. Soil classification is required to develop some of the basin related data such as maximum surface storage raster, infiltration rate raster, initial deficit raster and maximum deficit raster. Table 5.1 below explains the properties of the available soil types in the watershed.

Table 5.1 Soil classifications table (FAO, 2005)

| Soil type | Description |
|---|---|
| Acrisols | Red, brown or yellow colored soil, which has a high ratio of clay. |
| Calcisol | Soil with a high ratio of lime. |
| Cambisol | Mostly brownish colored soil. |
| Fluvisol | Soil developed above discharge plain sediments. |
| Kastanozems | The soil has a high ratio of humus. |
| Leptosol | Shallow soil over bedrock, calcareous material or a deeper soil, common in mountains. |
| Luvisol | This soil has a deposited clay. |
| Phaeozem | Sod organic-accumulative. |
| Podzol | Soil commonly in coniferous forests. |
| Regosol | Soils in arid, semi-arid areas and in mountain regions. |
| Solonchak | The soil is in gray type found in arid to subhumid, poorly drained conditions. |
| Vertisol | The soil has a high content of expansive clay. |

SCS-CN loss method is one of rainfall-runoff modeling methods which can simulate the infiltration loss. SCS-CN loss method classified soil infiltration conditions into four hydrologic soil groups, A, B, C, and D as shown in Table 5.3. Comparing the available soil infiltration conditions at Küçük Menderes river watershed with SCS-CN conditions, the available soil types in Küçük Menderes river basin is under C group. These soils have slow infiltration rates, and its infiltration rates were estimated from 0.05 in/h to 0.15 in/h (Chow et al., 1988).

Table 5.2 Hydrologic soil groups (Chow et al., 1988)

| Hydrologic Soil Group | Properties of Group |
|---|---|
| Group A | It is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates |
| Group B | It is silt loam or loam. It has a moderate infiltration rate |
| Group C | Soils are sandy clay loam. They have low infiltration rates |
| Group D | Soils are clay loam, silty clay loam, sandy clay, silty clay or clay. It has the highest runoff potential. They have very low infiltration rates |

## 5.4 Hydro-Meteorological Data

Hence the simulation is a continuous hydrologic model, evapotranspiration losses should be considered to obtain accurate results. HEC-HMS have developed a built-in model for calculating evapotranspiration losses by using Priestly and Taylor's method. The required input data in HEC-HMS model to calculate the evapotranspiration losses are mean temperatures and net shortwave radiations. Precipitation data is used to calculate the simulated runoff values over the watershed, while the observed runoff values are used for the calibration and the validation of the model (HEC, 2001).

### *5.4.1 Discharge Measurements for Station 601*

601 flow measurement station (27.31° E, 37.92°· N) is located at Selçuk in the city of Izmir (Figure 5.4). This station was constructed in 1952 to measure the runoff value over Küçük Menderes river basin. Time series file for the daily runoff measurements over the basin (Figure 5.5) was developed manually as an excel file during the period from 1964 to 1998. Maximum peak discharge occurred in 11/01/1981 with a value of 693 $m^3/s$.

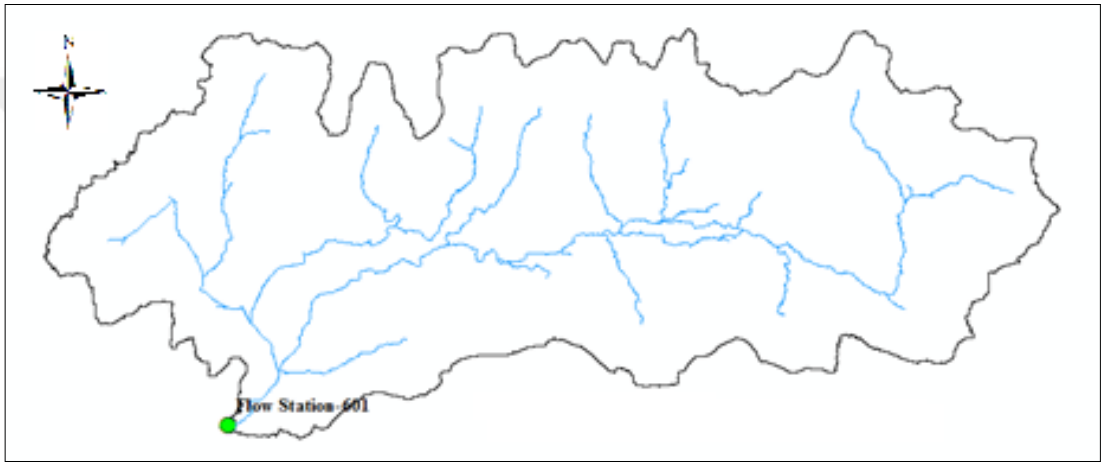


Figure 5.4 Position of station 601.

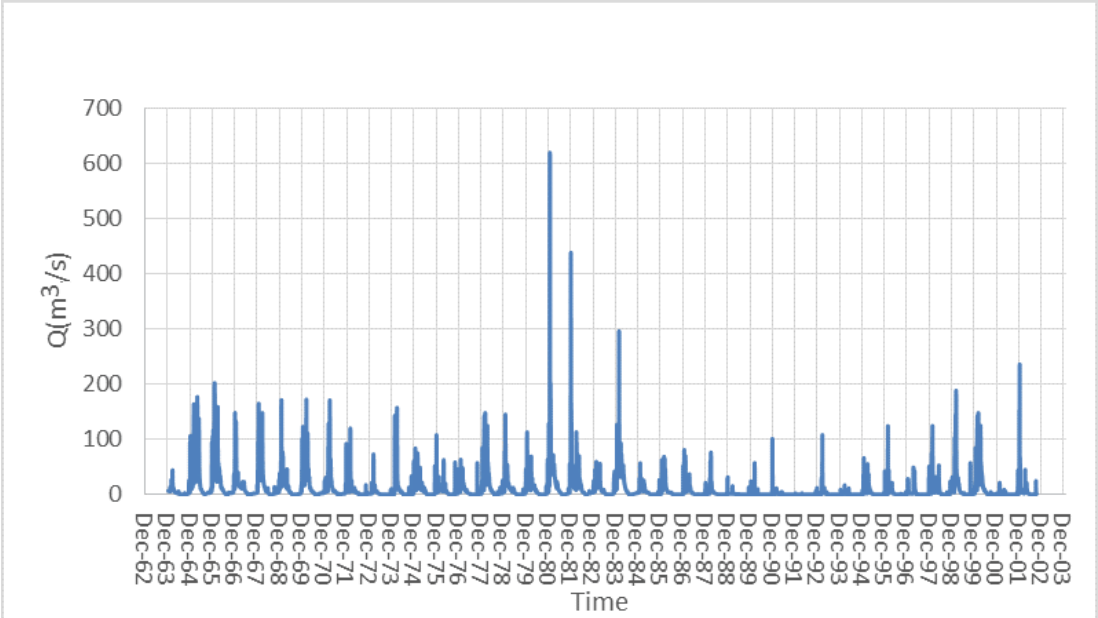


Figure 5.5 Flow measurements over station 601 (01/08/1964-01/08/1998).

### *5.4.2 Temperature and Rainfall data for Selçuk and Ödemiş Stations*

Mean temperatures are required to calculate evapotranspiration losses, while precipitation is required to calculate the simulated runoff values. Long time series daily measurements of mean temperature and precipitation for the basin are available only for Selçuk (37,945°· N, 27,367°· E) and Ödemiş (38,216°· N, 27,964° E) stations (Figure 5.6) during the period from 1964 to 2006. Temperatures (Figure 5.9) and precipitations (Figure 5.8) data were obtained from T.C Orman ve Su İşleri Bakanlığı_Meteoroloji Genel Müdürlüğü. As a result of Thiessen polygons, Ödemiş station represents a ratio of 65.5% from the basin area, while Selçuk station has a ratio of 34.5% (Figure 5.7).

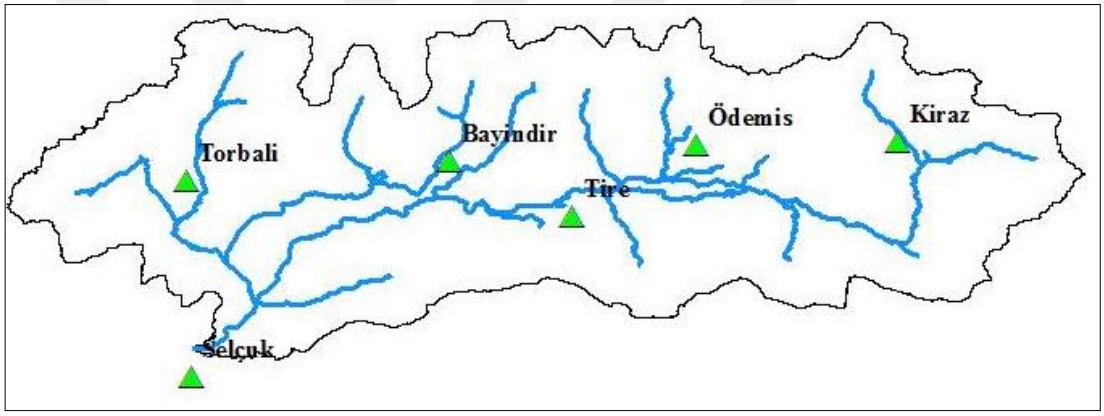


Figure 5.6 Meteorological stations in Küçük Menderes river basin.

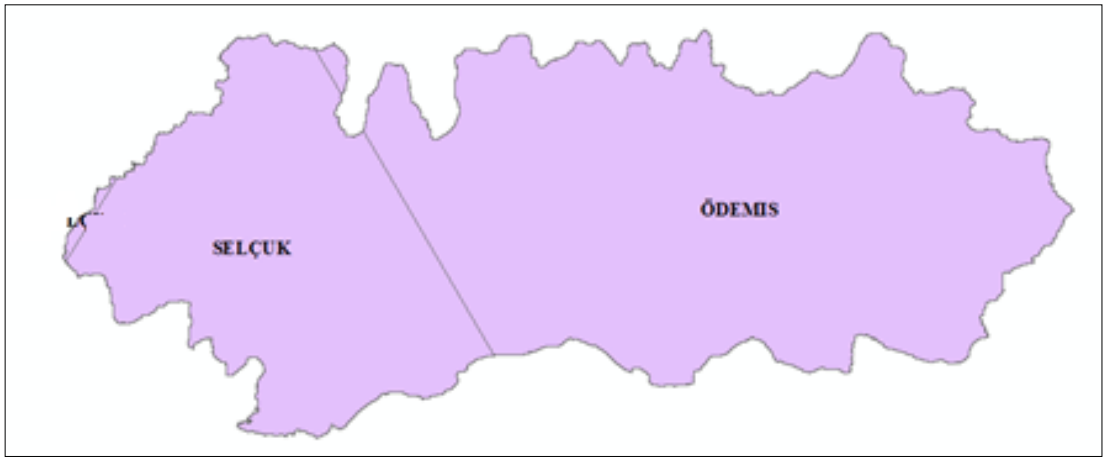


Figure 5.7 Thiessen polygons for the Ödemiş station and Selçuk station.

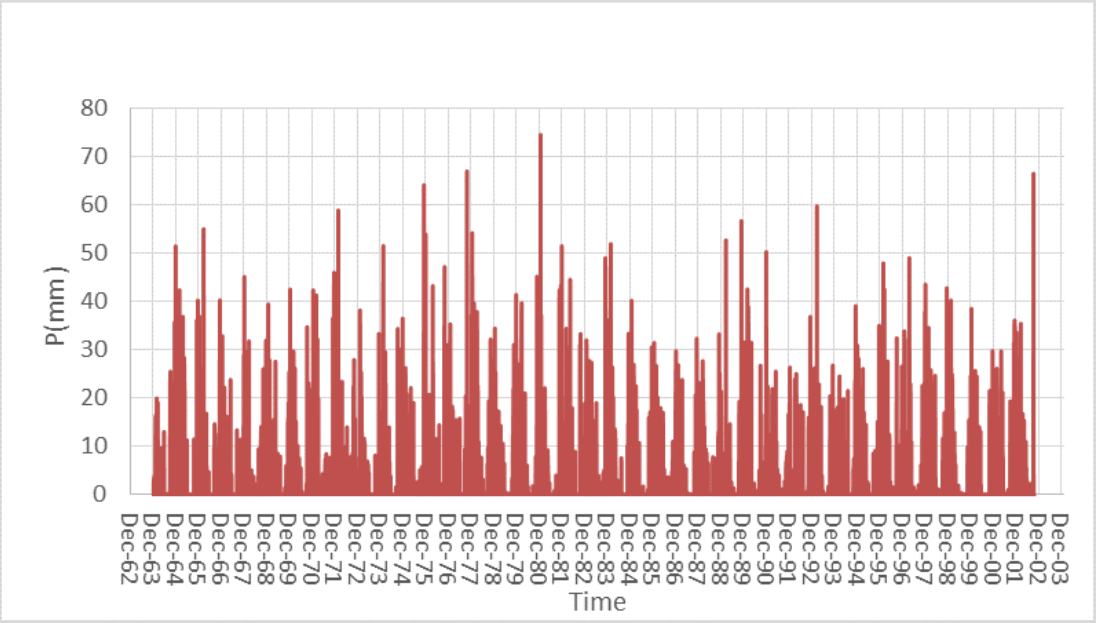


Figure 5.8 Rainfall measurements for Küçük Menderes river basin (01/08/1964-01/08/1998).

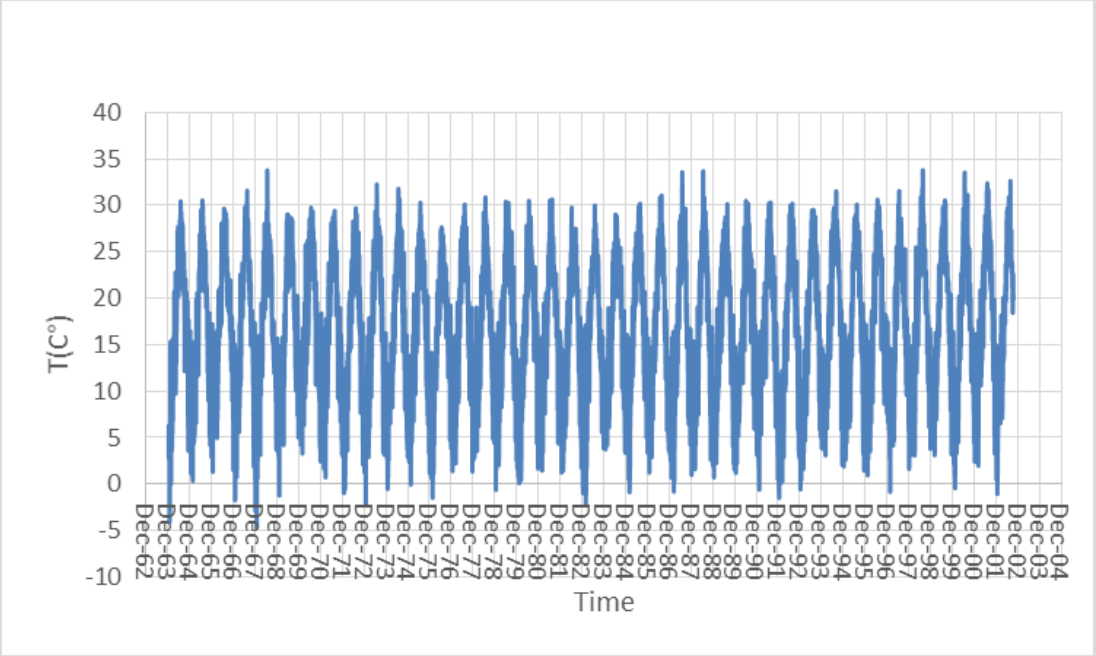


Figure 5.9 Temp. measurements for Küçük Menderes river basin (01/08/1964-01/08/1998).

### *5.4.3 Calculation of Net Shortwave Radiation for Selçuk and Ödemiş Stations*

Net shortwave radiation (Figure 5.10) is one of the required data to calculate the evapotranspiration losses by using Priestly and Tylor's method. Hargreaves formula (FAO, 2005) is used for calculating short wave radiation in the case of the daily actual

sunlight hours is not available, Eq. 5.1 below shows Hargreaves formula. Table 5.3 below shows the average monthly value of extraterrestrial radiation values for Ödemiş, and Selçuk (FAO, 2005).

$$Rs = kRs\sqrt{Tmax - Tmin}\, Ra \quad (5.1)$$

where:-

Ra = extraterrestrial radiation [MJ/m$^2$/day] (Table 5.3),
$T_{max}$ = maximum air temperature [°C],
$T_{min}$ = minimum air temperature [°C],
KRs = adjustment coefficient (between 0.16 and 0.19) [°C-0.5].

Table 5.3 Extraterrestrial radiation [MJ/m$^2$/day]

| **Month** | **Ödemiş** | **Selçuk** |
|---|---|---|
| January | 16.07 | 16.24 |
| February | 21.38 | 21.53 |
| March | 28.00 | 28.12 |
| April | 35.15 | 35.21 |
| May | 39.88 | 39.90 |
| Jun | 41.81 | 41.80 |
| July | 40.8 | 40.8 |
| August | 36.97 | 37.01 |
| September | 30.62 | 30.72 |
| October | 23.48 | 23.63 |
| November | 17.37 | 17.53 |
| December | 14.67 | 14.84 |

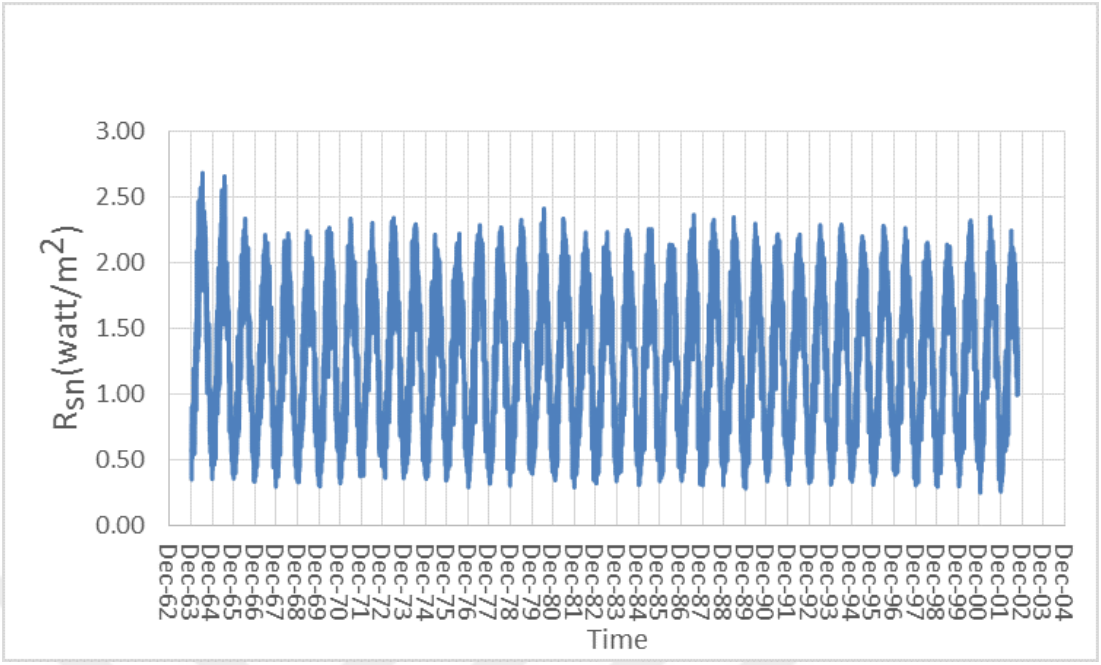


Figure 5.10 Rsn measurments for Küçük Menderes river basin (01/08/1964-01/08/1998).

## 5.5 Basin Related Data

Basin related data include canopy storage data, surface storage data, baseflow data, infiltration data, and transform data. Since the watershed does not have any sub-basins, so no need for the routing during the simulation.

### *5.5.1 Canopy Storage Capacity*

Canopy storage refers to the abstractions from precipitation, which were caused by a vegetation cover over a watershed surface. Due to the sun heat canopy storage goes as evapotranspiration losses. Canopy storage depends on properties of vegetation cover such as leaf area index (LAI), and crop factor ($K_c$). LAI [$m^2/m^2$] is defined as the total one-sided area of photosynthetic tissue per unit ground surface area. Table 5.4 below shows the values of the LAI according to a biome types (Asner, Scurlock & Hicke, 2003). Crop factor ($K_c$) is the ratio of the consumptive use of water to the pan evaporation. LAI and $K_c$ were calculated based on basin land use distribution.

Table 5.4 LAI table (FAO, 2005)

| Biome types | land cover | LAI[$m^2/m^2$] |
|---|---|---|
| Crops | Crops (temperate and tropical) | 3.6 |
| Desert | Deserts | 1.3 |
| Forest/BoDBL | Forest, boreal deciduous broadleaf | 2.6 |
| Forest/BoENL | Forest, boreal evergreen needle leaf | 2.7 |
| Forest/BoTeDNL | Forest, boreal/temperate deciduous needle leaf | 4.6 |
| Forest/TeDBL | Forest, temperate deciduous broadleaf | 5.1 |
| Forest/TeEBL | Forest, temperate evergreen broadleaf | 5.7 |
| Forest/TeENL | Forest, temperate evergreen needle leaf | 5.5 |
| Forest/TrDBL | Forest, tropical deciduous broadleaf | 3.9 |
| Forest/TrEBL | Forest, tropical evergreen broadleaf | 4.8 |
| Grasslands | Grasslands (temperate and tropical) | 1.7 |
| Plantations | Plantations (managed forests of temperate deciduous broadleaf, temperate evergreen needle leaf and tropical deciduous broadleaf lifeforms and species) | 8.7 |
| Shrublands | Shrublands (Mediterranean) | 2.1 |
| Tundra | Tundra (circumpolar and alpine) | 1.9 |
| Wetlands | Wetlands, temperate and tropical | 6.3 |

### *5.5.2 Surface Storage Capacity*

Amounts of collected precipitations during storms by depression in a watershed surface do not go to streams as a direct runoff, but it is lost by a process of infiltration and evaporation. Surface storage capacity depends on many factors such as the type of soil, the condition of the surface reflecting the amount and nature of depression, the slope of the watershed, and the antecedent precipitation as a measure of the soil moisture. Hence the calculations of a surface storage capacity are not easy, hydrologists gave estimated values for the surface storage capacity based on the soil type, so the value of 0.50 cm in sand, 0.40 cm in loam and 0.25 in clay can be taken as representatives for depression-storage loss during a storm (Subramanian, 2008).

### *5.5.3 Baseflow Method*

Baseflow method is used for calculating the amounts of a contributed flow over a stream flow by groundwater. HEC-HMS includes two baseflow methods for continuous hydrologic simulation as shown in Table (4.2), which are Bounded Recession method and Constant Monthly method. In this study, baseflow was separated by using Web-based Hydrograph Analysis TOOL (WHAT) as shown in Figure 5.11.

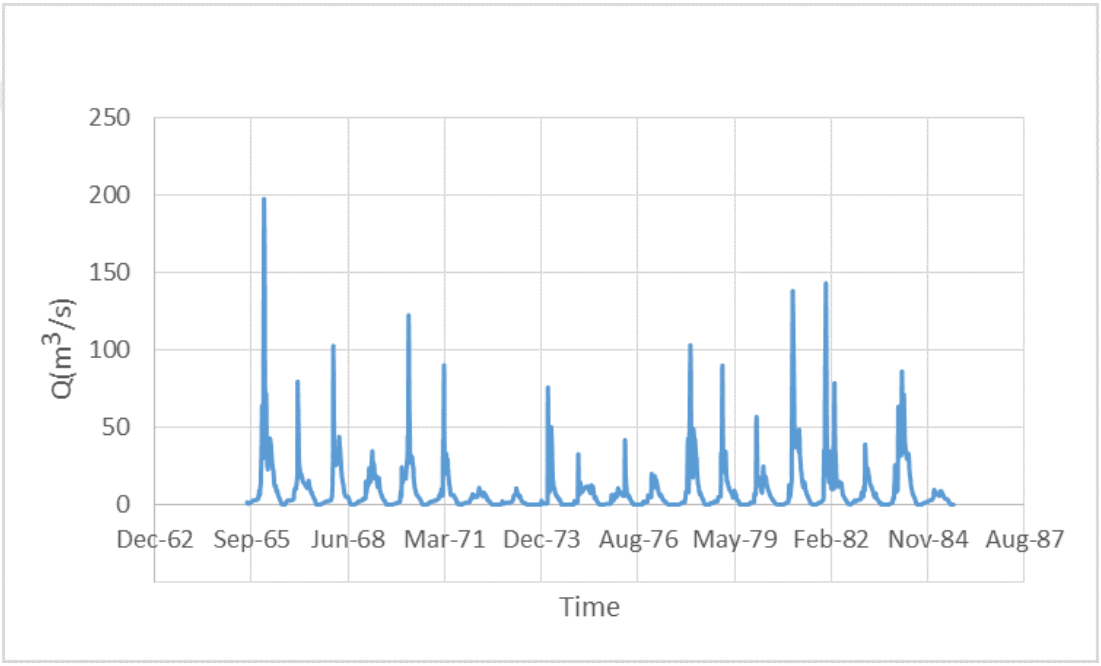


Figure 5.11 Baseflow measurements for Küçük Menderes River (01/08/1965-01/08/1985).

### *5.5.4 Loss Method*

Loss method computes the losses that occur during a rainfall which was caused by infiltration process, to find the amounts of effective rainfall. HEC-HMS include Initial and Constant, SCS Curve Number (CN), Gridded SCS CN, Green and Ampt, Deficit and Constant, Soil Moisture Accounting (SMA), and Gridded SMA to simulate infiltration losses during a storm as shown in Table (4.3). Simple continuous modeling is developed by using the one-layer deficit and constant method model, while for the complex continuous modeling the five-layer soil moisture accounting model is used

for this porous. The recommended thickness of earth top layer to develop a hydrologic infiltration model is from 10cm to 15 cm (FAO, 2005). Soil properties are one of the factors which are used for calculating the infiltration rate over a time. Table 5.5 below shows the properties of the available soil at Küçük Menderes river basin, which is sandy clay loam soil (FAO, 2005).

Table 5.5 Properties of the sand, loam and silty clay loam soils.

| **Properties** | **Inches of water/foot of soil** | | |
|---|---|---|---|
| | **Sand** | **Loam** | **Silty clay loam** |
| Saturation | 5.2 | 5.8 | 6.1 |
| Field Capacity | 2.1 | 3.8 | 4.4 |
| Permanent wilting point | 1.1 | 1.8 | 2.6 |
| Oven dry | 0 | 0 | 0 |
| Gravitational | 3.1 | 2 | 1.7 |
| Water holding capacity | 1 | 2 | 1.8 |
| Plant available | 0.5 | 1 | 0.9 |
| Unavailable | 1.1 | 1.8 | 2.6 |

### *5.5.5 Transform Method*

Transform method converts the excessive rainfall over a basin into a discharge hydrograph at the outlet of the basin. User-specified UH, Clark UH, Snyder UH, SCS UH, ModClark, kinematic wave, and user-specified S-Graph were used as a transform methods in HEC-HMS as shown in Table (4.4). Geometry properties of the watershed are considered as one of the input data for transform model such as basin slope, basin area, main channel slope, and main channel length. Table 5.6 below illustrates the geometrical properties for the watershed, while Figure 5.12 below shows basin slope raster.

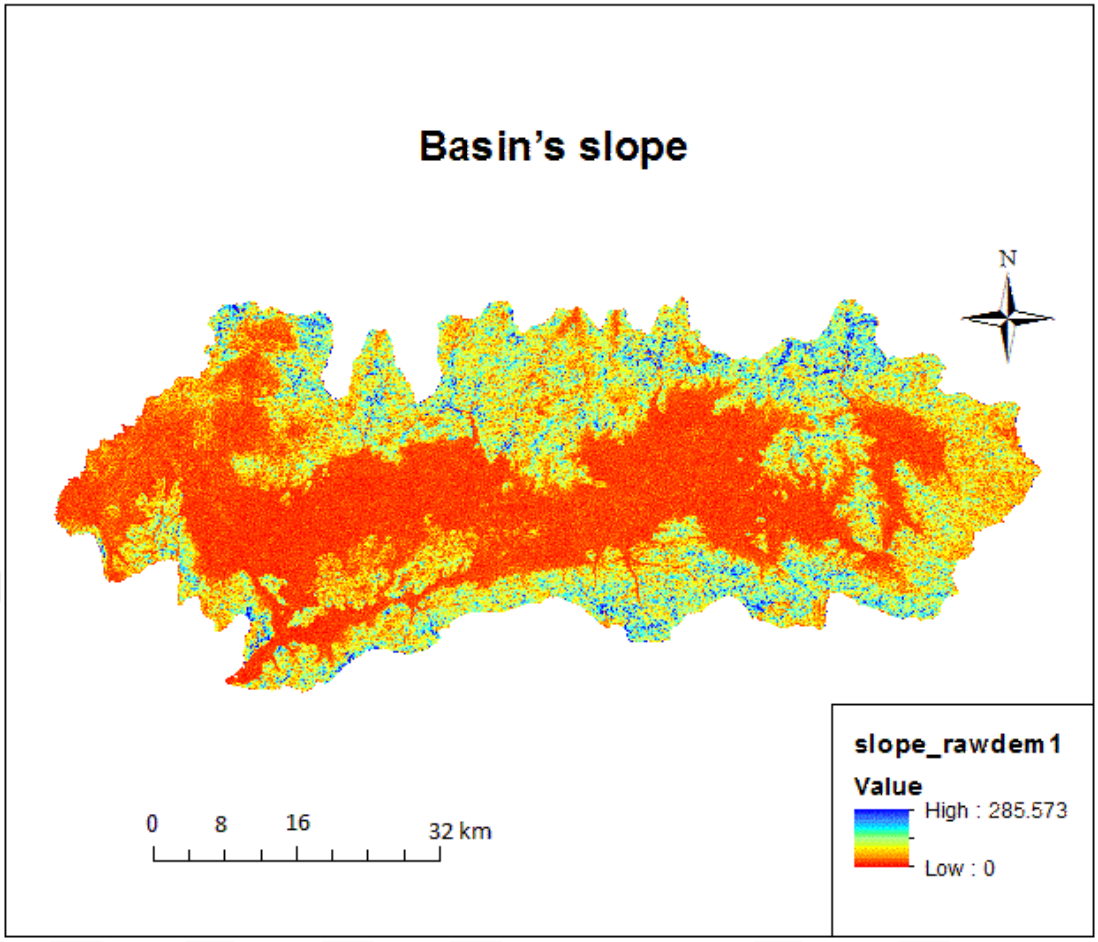


Figure 5.12 Basin slope raster.

Table 5.6 Basin geometrical properties.

| **Channel** | | **Watershed** | |
|---|---|---|---|
| length(m) | 146493.6 | length(m) | 146493.6 |
| length(mile) | 91.02671 | length(mile) | 91.02671 |
| Average slope(%) | 0.013407 | Average slope(%) | 21.491819 |
| slope(ft/mile) | 70.78911 | slope(ft/mile) | 113477.045 |
| | | Area(miles$^2$) | 1240.852 |

# CHAPTER SIX
# DEVELOPING OF HEC-GEOHMS AND HEC-HMS MODELS

After collecting the required data for the continuous hydrologic model in Küçük Menderes river basin, HEC- GeoHMS and HEC- HMS models were developed to prepare the continuous hydrologic simulation, to use it for the basin calibration and validation processes.

## 6.1 Development of HEC-GeoHMS Model

Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is used to prepare a consistent model input file for HEC-HMS by using the abilities of GIS based on basin DEM and main channel shape file. HEC-GeoHMS (Figure 6.1) model includes the processes of Preprocessing, Project Setup, Basin Processes, Characteristics, Parameters, and HMS (HEC, 2000).

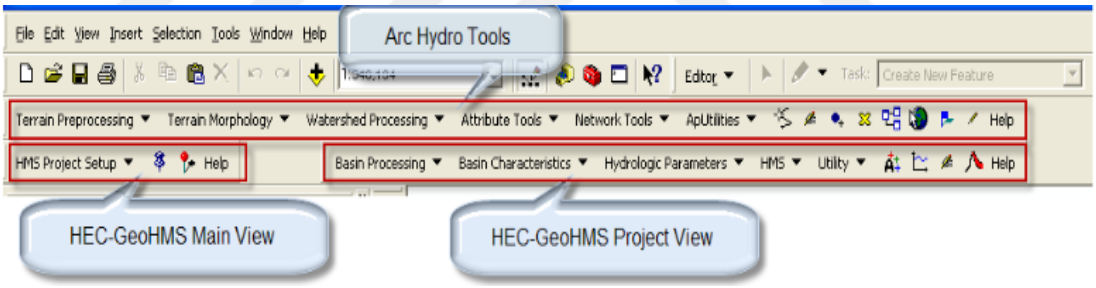


Figure 6.1 HEC-GeoHMS interface.

### *6.1.1 Preprocessing*

Preprocessing involves using of DEM and main channel shapefile to create stream network data and catchments data. The prepared data through Preprocessing are raster data, and vector data as shown in Table (6.1).

Table 6.1 HEC-GeoHMS preprocessing.

| Raster Data | Vector Data |
|---|---|
| 1-Raw DEM | 1-Catchment Polygons |
| 2-HydroDEM | |
| 3-Flow Direction Grid | 2-Drainage Line Polygons |
| 4-Flow Accumulation Grid | |
| 5-Stream Definition Grid | 3-Adjoint Catchment Polygons |
| 6- Stream Segmentation Grid | |
| 7-Catchment Grid Delineation | |

- HydroDEM

HydroDEM is a DEM after reconditioning and filling sinks (Figure 6.2) for the Raw DEM .

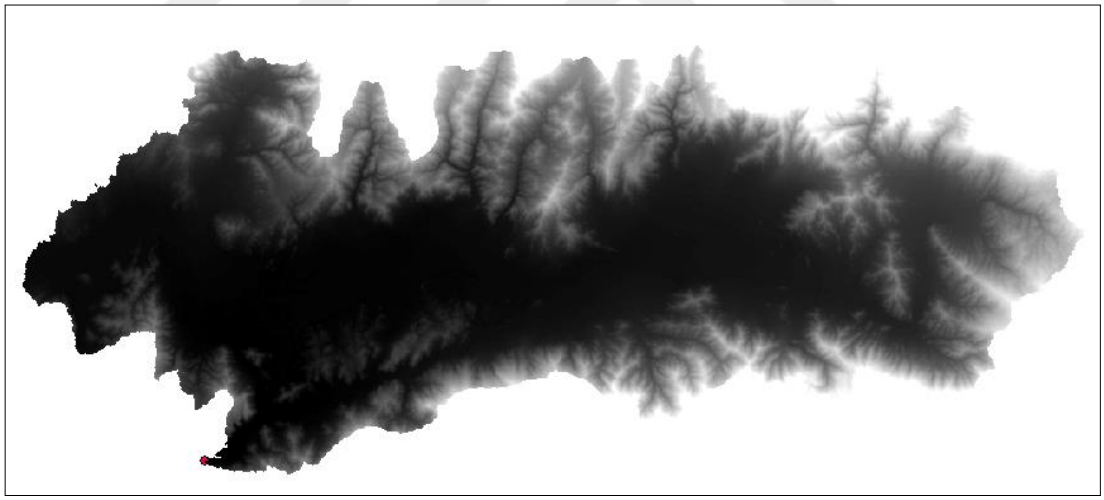

Figure 6.2 Filled DEM for Küçük Menderes River Basin.

- Flow Direction “Fdirgrid”

Flow directions raster (Figure 6.3) represents the directions of the water flows over the basin surface according to gravitational forces.

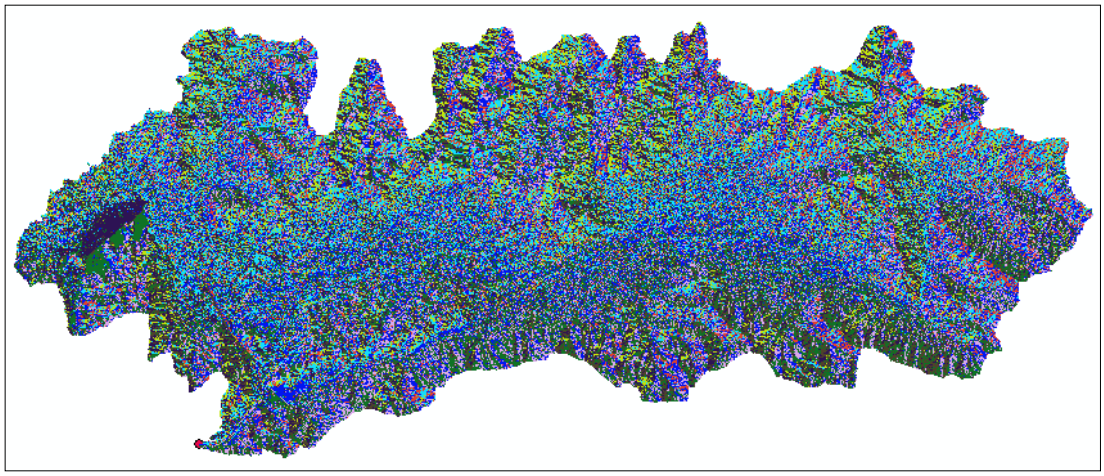

Figure 6.3 Flow direction raster.

- Flow Accumulation “Faccgrid”

Flow Accumulation raster (Figure 6.4) represents the accumulation of the flows based on flow directions “Fdirgrid”.

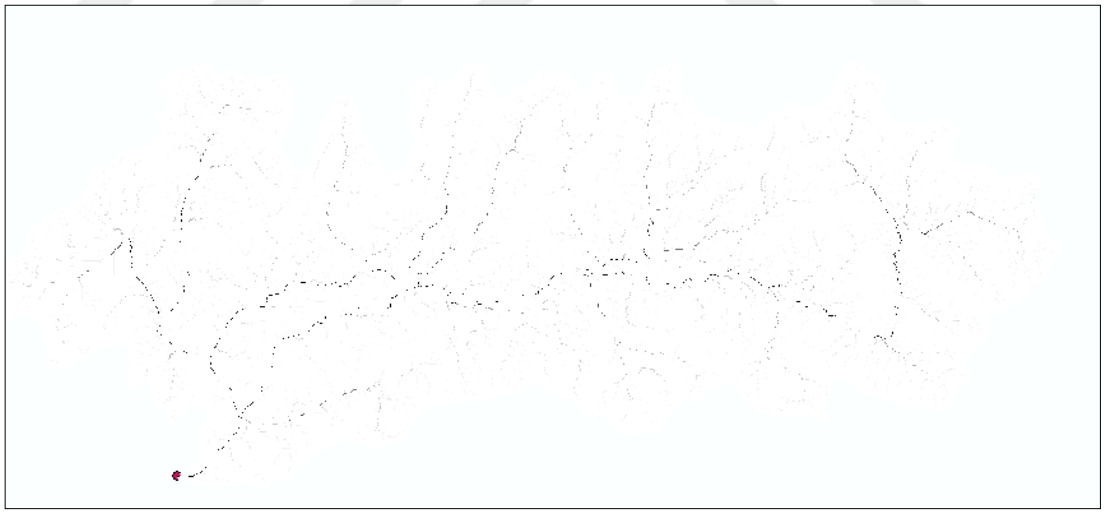

Figure 6.4 Flow Accumulation raster.

- Stream Definition “StrGrid”

Streams are defined (Figure 6.5) according to the minimum number of cells sufficient to create channeling along the way of water motion based on flow directions.

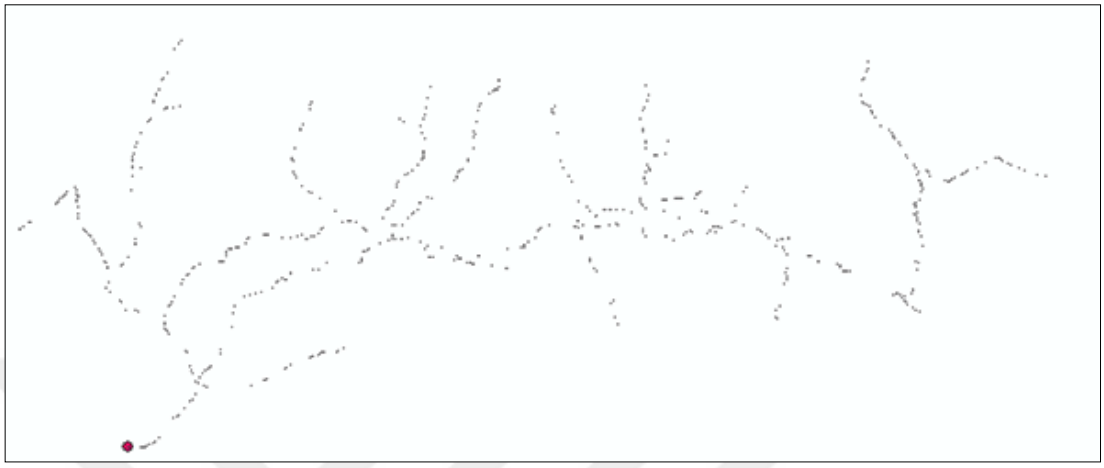

Figure 6.5 Stream definition raster.

- Stream Segmentation “StrLnkGrid”

Stream Segmentation raster (Figure 6.6) includes the channel segments which represent a link between two successive junctions, a junction and the outlet, or a junction and the drainage divide.

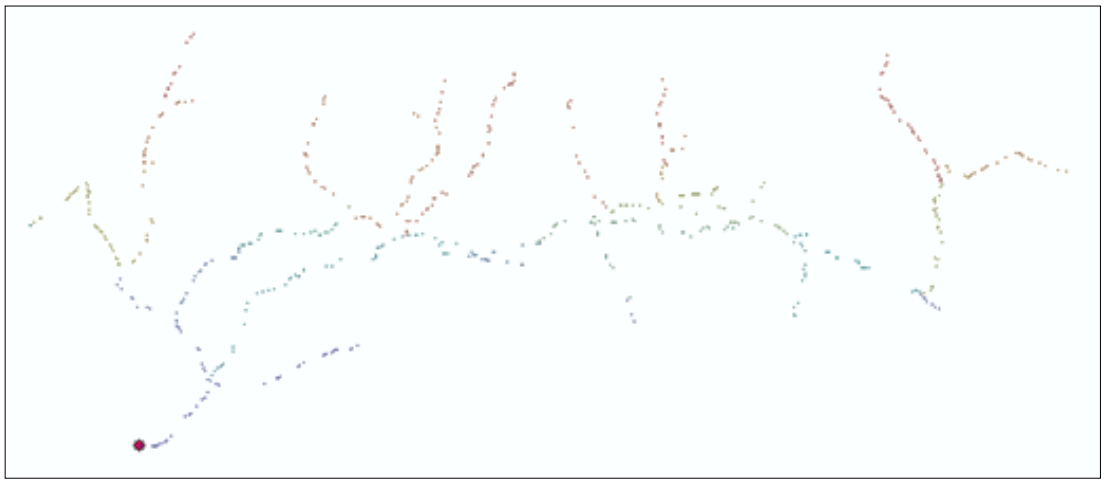

Figure 6.6 Stream segmentation raster.

- Catchment Grid Delineation “Catgrid”

Catchment Grid Delineation (Figure 6.7) includes delineated subbasins for every stream segment.

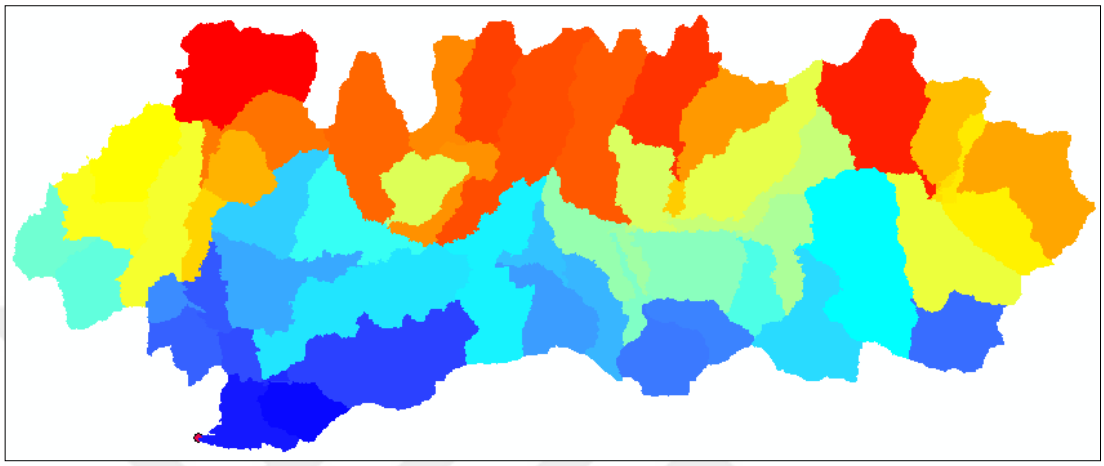

Figure 6.7 Catchment grid delineation.

- Catchment Polygons Processing “Catchment”

Catchment Polygons shapefile (Figure 6.8) is constructed by converting a-Catchment Grid into polygonal vector areas.

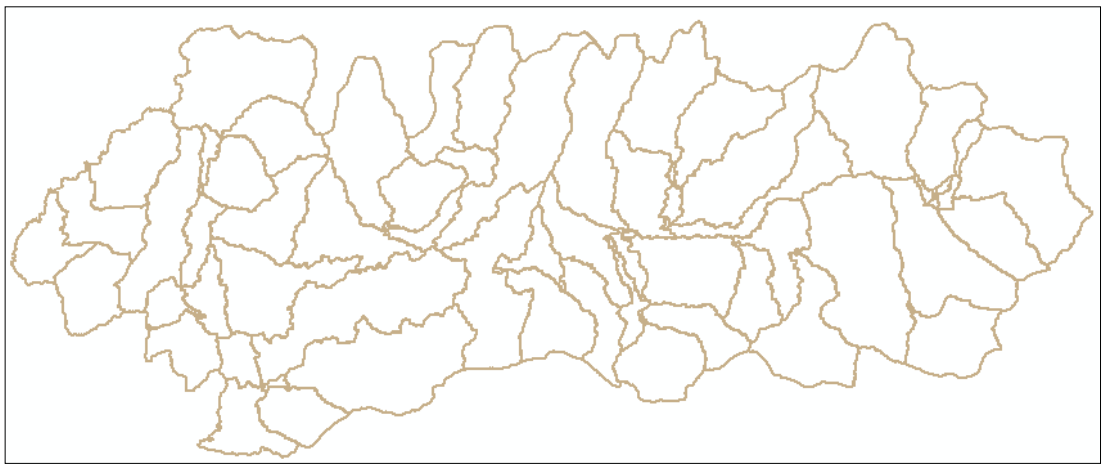

Figure 6.8 Catchment polygons shapefile.

- Drainage Line Polygons “Dranigeline”.

Drainage Line Polygons shapefile (Figure 6.9) represents the process of converting the grid-based streams into linear vector objects.

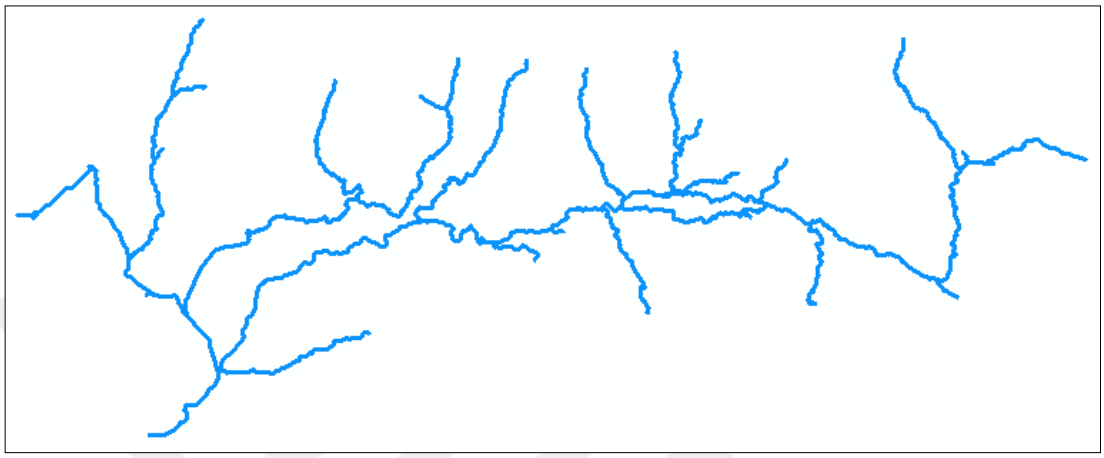

Figure 6.9 Drainage line polygons shapefile.

- Adjoint Catchment Processing “AdjointCatchment”.

Adjoint Catchment shapefile (Figure 6.10) constructs the aggregated catchment polygons shapefile.

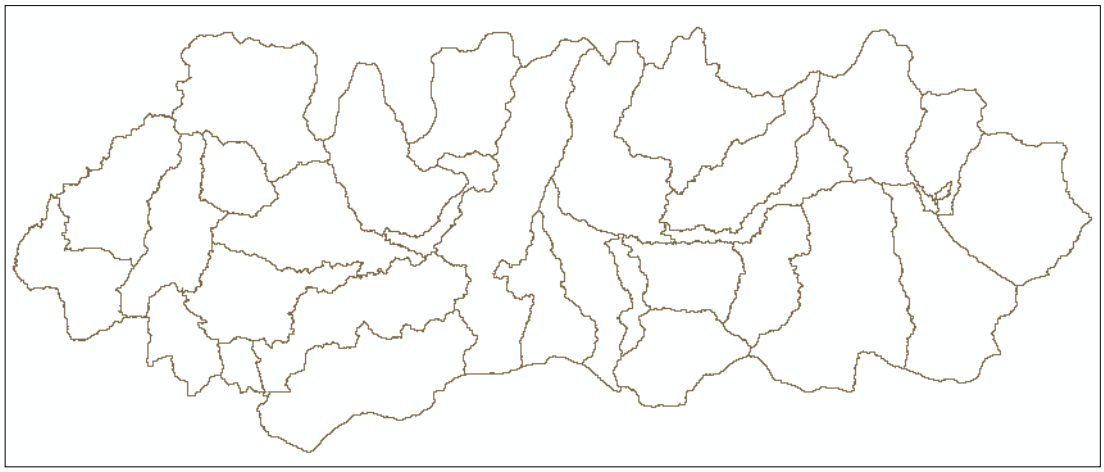

Figure 6.10 Adjoint catchment shapefile.

### *6.1.2 Project Setup*

After preparing all required preprocessing data, HEC-GeoHMS project is developed through the following steps:-

1- Start a new project as shown in Figure 6.11.

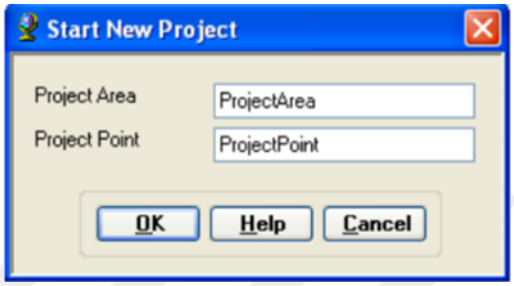


Figure 6.11 Start a new project (HEC-GeoHMS).

2- Define the project point, it is considered as the outlet of the basin.

3- Generate the project by approving about the selected area which flows to the project point (Figure 6.12).

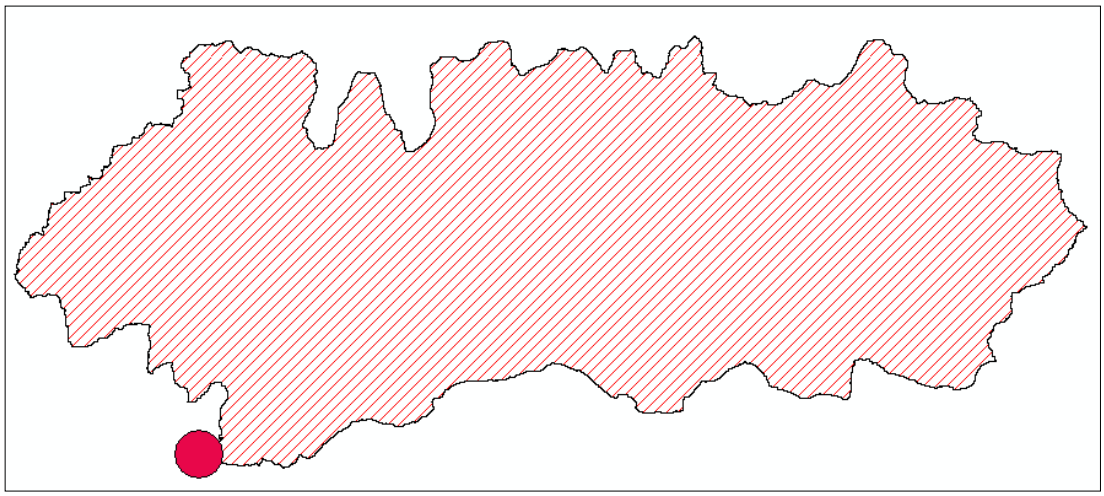

Figure 6.12 Project point and project area (HEC-GeoHMS).

4- Data management and confirm that all the inputs are correct (Figure 6.13).

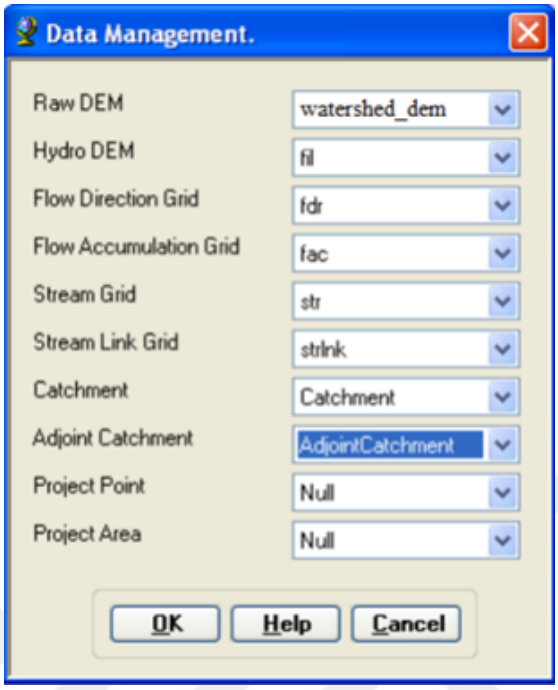


Figure 6.13 Data management (HEC-GeoHMS).

### *6.1.3 Basin Processes*

Since the model was developed over an undivided basin, during basin processes step, all the subbasins were merged into one basin as shown in Figure 6.14.

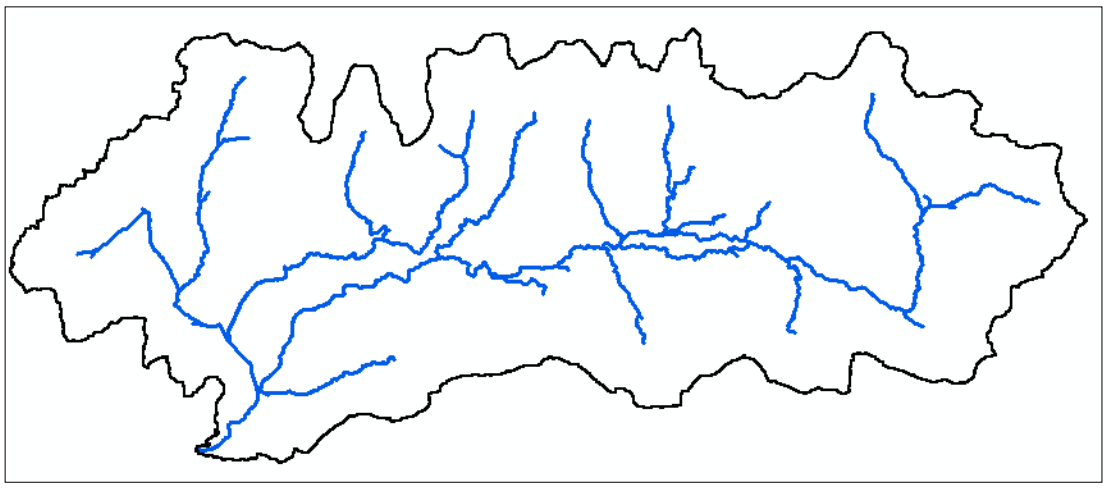

Figure 6.14 Drainage area for Küçük Menderes river basin.

### *6.1.4 Characteristics*

Basin geometrical characteristics were constructed to prepare the required data for Basin Model in HEC-HMS model (Figure 6.15). Basin geometrical characteristics include the following shapefiles:-

- River Length
- River Slope
- Basin Slope
- Longest Flow Path
- Basin Centroid
- Basin Centroid Elevation
- Centroidal Longest Flow Path

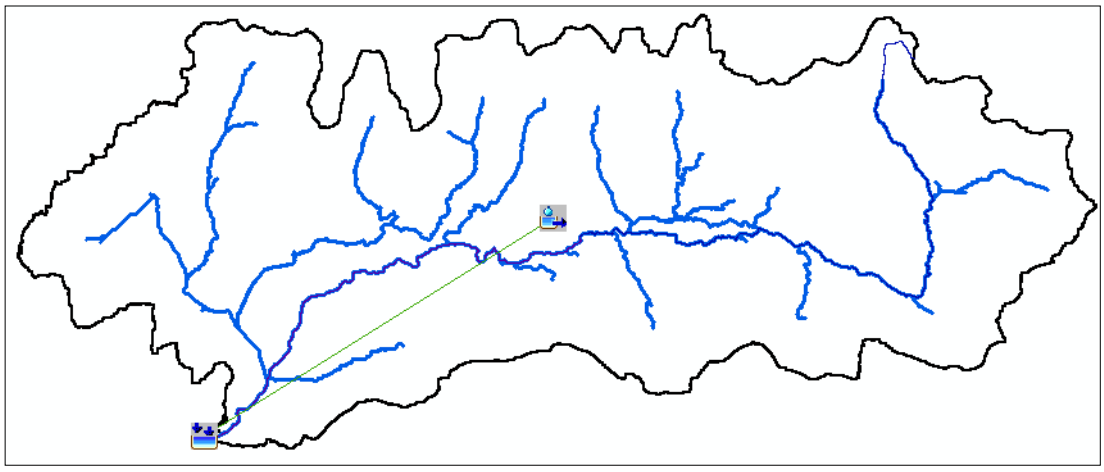

Figure 6.15 Basin HEC-GeoHMS model.

### *6.1.5 Parameters*

In these step, model parameters were defined such as:

- Select HMS Processes step which includes the determination of the HEC-HMS methods.
- River Auto Name step which defined the names of the streams automatically.
- Basin Auto Name steps which defined the names of the subbasins automatically.

### *6.1.6 HMS*

This stage is the last stage for preparing the consistent model input file for HEC-HMS by using HEC-GeoHMS , and it includes the following steps:

- Map to HMS Units (SI Unite).
- Check Data.
- HMS Schematic.
- HMS Legend (Figure 6.14).
- Add Coordinates.
- Prepare Data for Model Export.
- Background Shape File.
- Basin Model.
- Meteorologic Model.
- Creat HMS Project.

## 6.2 Development of HEC-HMS Model

HEC-HMS model needs the basin data and the Metrologic data (Figure 6.16) to run the continuous hydrologic simulation (HEC, 2001a). Basin geometrical data was imported from HEC-GeoHMS to HEC-HMS model. These part of the chapter includes the explanations for developing the last required parts of HEC-HMS components.

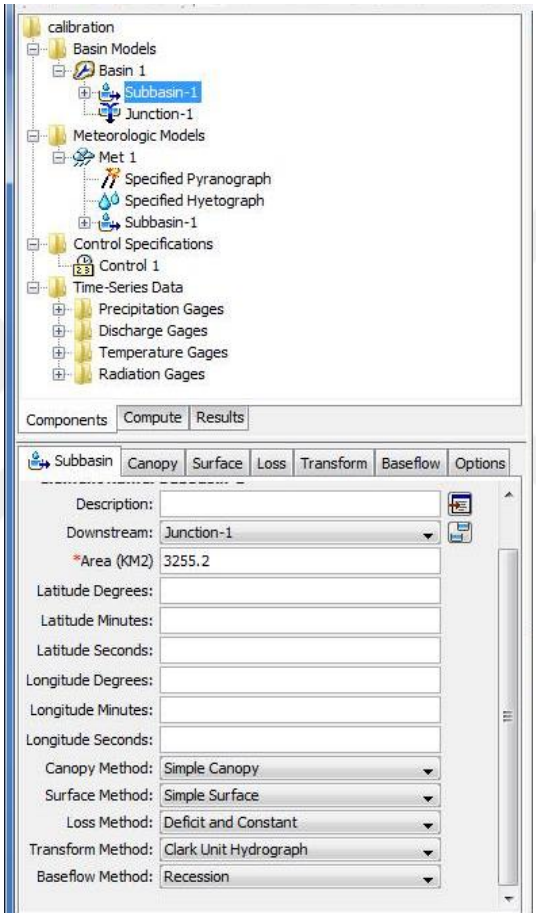


Figure 6.16 Basin's HEC-HMS model methods.

### *6.2.1 Basin-Related Data*

As mentioned in Section 5.5**,** that canopy storage, surface storage, and baseflow have been considered during the continuous hydrologic simulation. Moreover, data of loss method is required to calculate the abstractions from the rainfall, and data of the transform method is used in order to convert the effective rainfall into direct runoff.

- Canopy method

In order to calculate canopy storage capacity, HEC-HMS includes three methods, which are dynamic canopy method, gridded simple canopy method, and simple canopy method. Simple canopy method was selected in order to develop the continuous hydrologic model over Küçük Menderes river watershed. Simple canopy method requires the values of initial storage (%), maximum storage (mm), crop coefficient, and uptake method (Figure 6.17). Since the beginning of the simulation was in summer, initial storage (%) was considered 0%. Von Hoynigen Huene (1981) developed a mathematical expression to calculate the value of the maximum canopy storage (mm) for different plant types based on the leaf area index (LAI). Maximum canopy storage (mm) (Figure 6.18) for the basin were calculated by using Eq. (6.1). LAI were estimated based on Table 5.4 and Table 5.1 as shown in Table 6.2. Values of crop factor ($K_c$) for the basin was estimated based on the basin land uses as shown in Figure 6.19.

$$S_{max} = 0.935 + 0.498LAI - 0.00575LAI^2 \quad (6.1)$$

Where:-

$S_{max}$: Maximum canopy storage (mm).

LAI: Leaf area index [$m^2/m^2$].

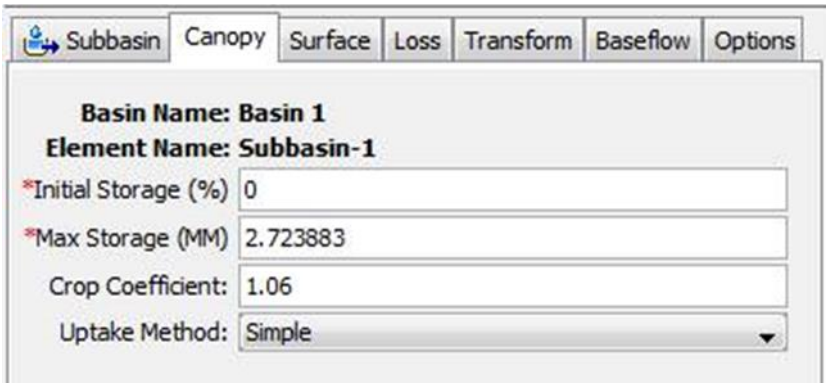


Figure 6.17 Simple canopy method in HEC-HMS.

Table 6.2 Kc, LAI, and $S_{max}$ for the basin.

| Land use | Kc | Biome | LAI | $S_{max}$ (mm) |
|---|---|---|---|---|
| Discontinuous urban fabric | 0.8 | Desert | 1.31 | 1.6 |
| Industrial /commercial units | 0.8 | Desert | 1.31 | 1.6 |
| Road/rail networks | 0.8 | Desert | 1.31 | 1.6 |
| Mineral extraction sites | 0.8 | Desert | 1.31 | 1.6 |
| Construction sites | 0.8 | Desert | 1.31 | 1.6 |
| Non-irrigated arable land | 0.8 | Crops | 3.62 | 2.7 |
| Permanently irrigated land | 1 | Crops | 3.62 | 2.7 |
| Vineyards | 0.53 | Plantation | 8.72 | 4.8 |
| Fruit / berry plantations | 0.62 | Plantation | 8.72 | 4.8 |
| Olive groves | 0.7 | Plantation | 8.72 | 4.8 |
| Pastures | 1 | Shrub | 2.08 | 1.9 |
| Complex cultivation | 1.2 | Crops | 3.62 | 2.7 |
| natural vegetation | 1.2 | Shrub | 2.08 | 1.9 |
| Broad-leaved forest | 1.3 | Forest/TeEBL | 5.7 | 3.6 |
| Coniferous forest | 1.3 | Forest/TeENL | 5.47 | 3.5 |
| Mixed forest | 1.3 | Forest/( TeEBL+ TeENL) | 5.585 | 3.5 |
| Natural grasslands | 1 | Grassland | 1.71 | 1.8 |
| Sclerophyllous vegetation | 1 | Forest/BoTeDNL | 4.63 | 3.1 |
| woodland-shrub | 1 | Shrub | 2.08 | 1.9 |
| Beaches, dunes, sands | 0.8 | Desert | 1.31 | 1.6 |
| Bare rocks | 0.8 | Desert | 1.31 | 1.6 |
| Sparsely vegetated areas | 0.8 | Desert | 1.31 | 1.6 |
| Burnt areas | 0.8 | Desert | 1.31 | 1.6 |
| **AVAREGE** | **1.06** | | **3.8** | **2.724** |

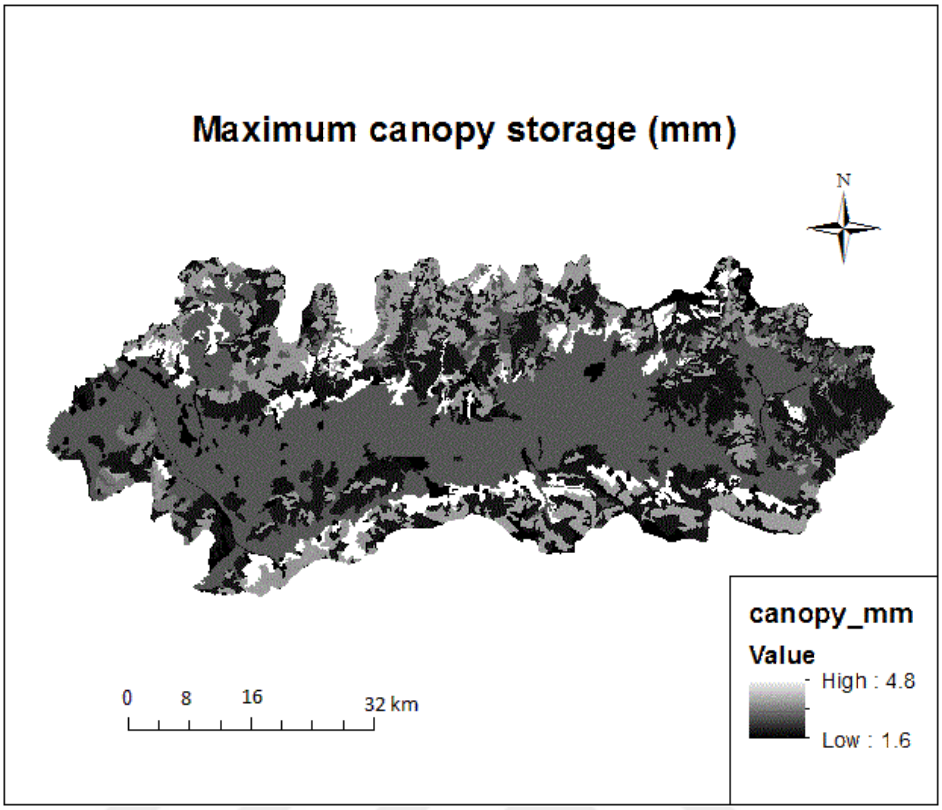


Figure 6.18 Maximum canopy storage (mm) raster for Küçük Menderes river basin.

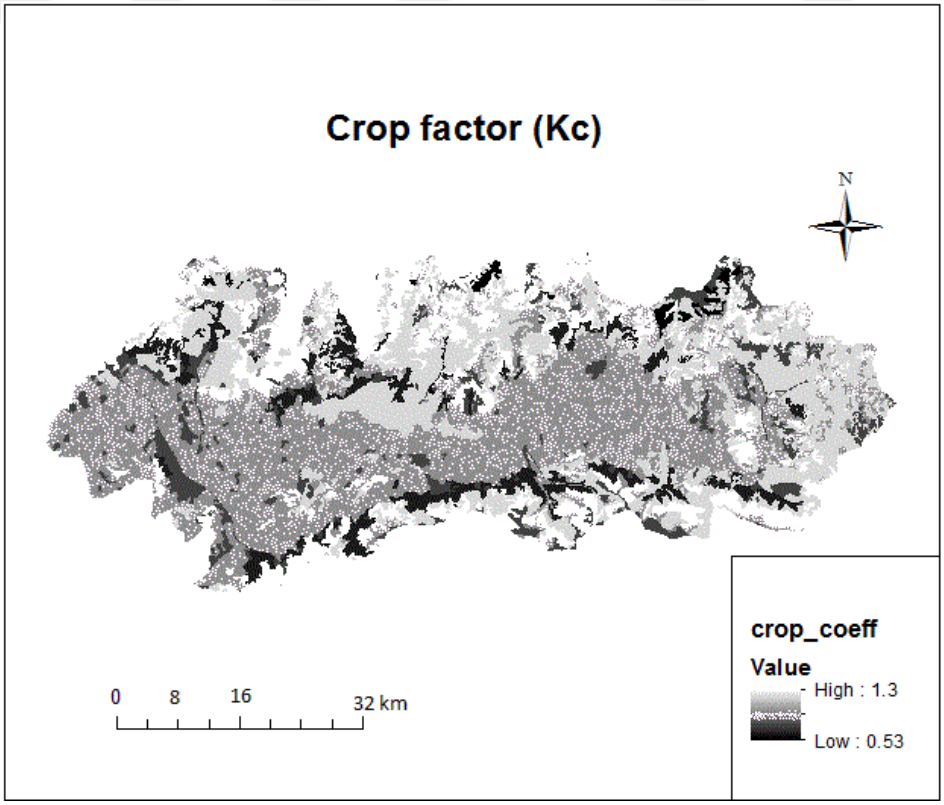


Figure 6.19 Crop factor (Kc) raster for Küçük Menderes river basin.

- Maximum surface storage capacity

The simple surface method was used for calculating the surface storage capacity in the continuous hydrologic model by using HEC-HMS. Initial Storage (%) and Max Storage are required as input data for the model. Since the beginning of the simulation is in summer, initial storage (%) was considered 0%. As motioned in Section 5.5.2, max storage was estimated based on the available soil type in the basin with a value of 33 mm.

- Baseflow method.

For the continuous hydrologic simulation, bounded recession method was selected as shown in Figure 6.20. Values of initial discharge and recession constant were estimated based on the river properties.

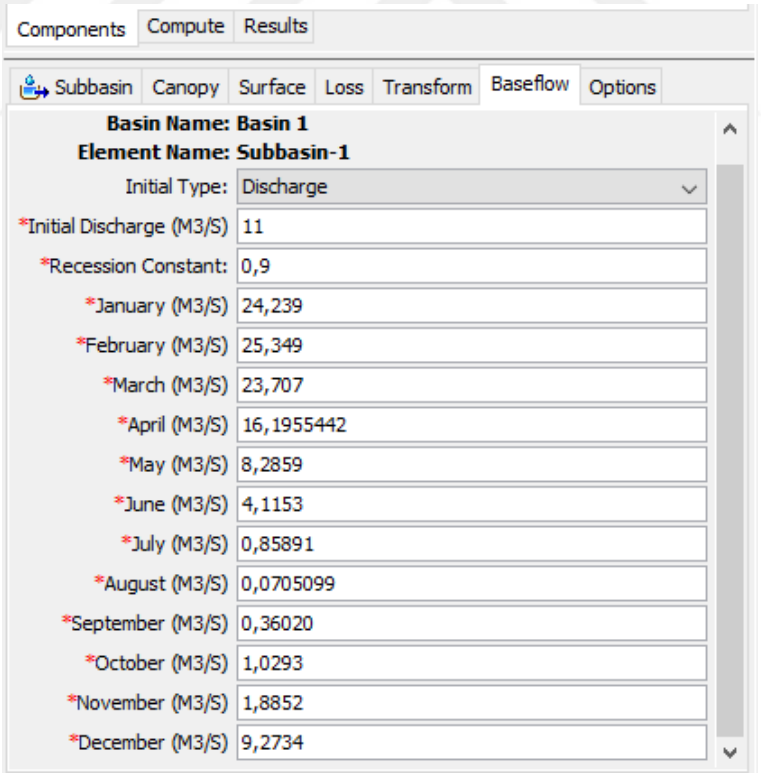


Figure 6.20 Bounded recession method in HEC-HMS.

- Losses method

The continuous hydrologic model over Küçük Menderes river watershed was developed by using the one-layer deficit and constant method (Figure 6.21), with a thickness of 125 mm for the earth top layer. Initial deficit (Figure 6.22) represents the required water to make the soil layer saturated as shown in Eq. (6.3).

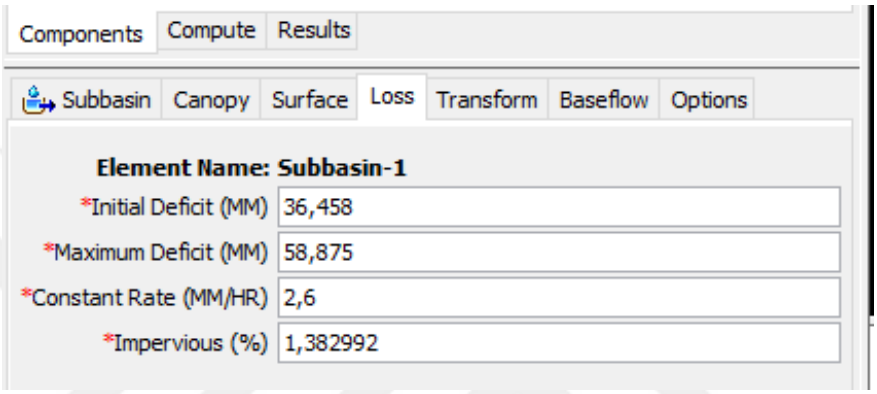


Figure 6.21 Deficit and constant losses method in HEC-HMS.

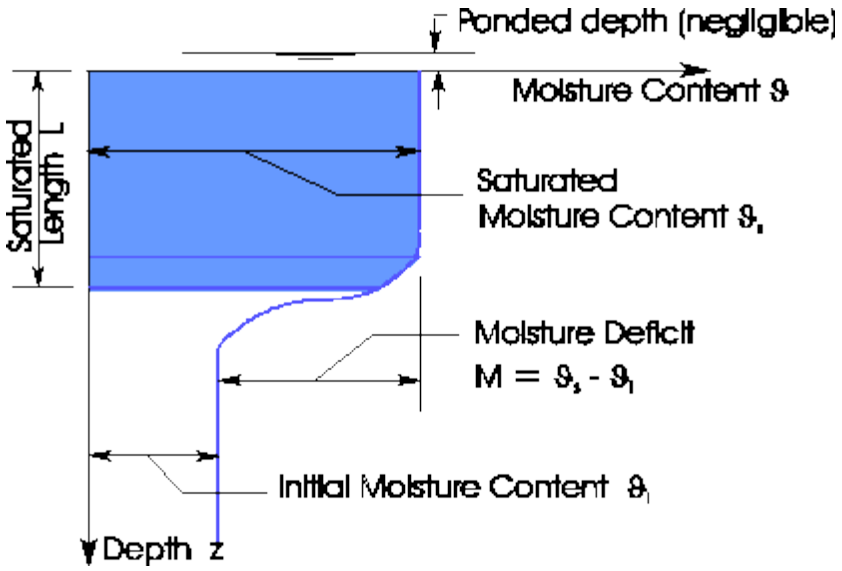


Figure 6.22 Schematic of moisture deficit.

Initial deficit = (saturation – wilting point)* thickness (6.2)

where the thickness equal to 125mm. Saturation and wilting point were calculated from table 5.5 based on the basin soil type (group C). By applying Eq. (6.2) initial deficit equals 36.458 mm, while Max. Deficit equals to the multiple of the porosity (0,471 for C group) with the thickness of the layer with a value of 58.875 mm. Figure 6.23 below shows the ratio of the impervious area over the basin, the average impervious area is 1.383%.

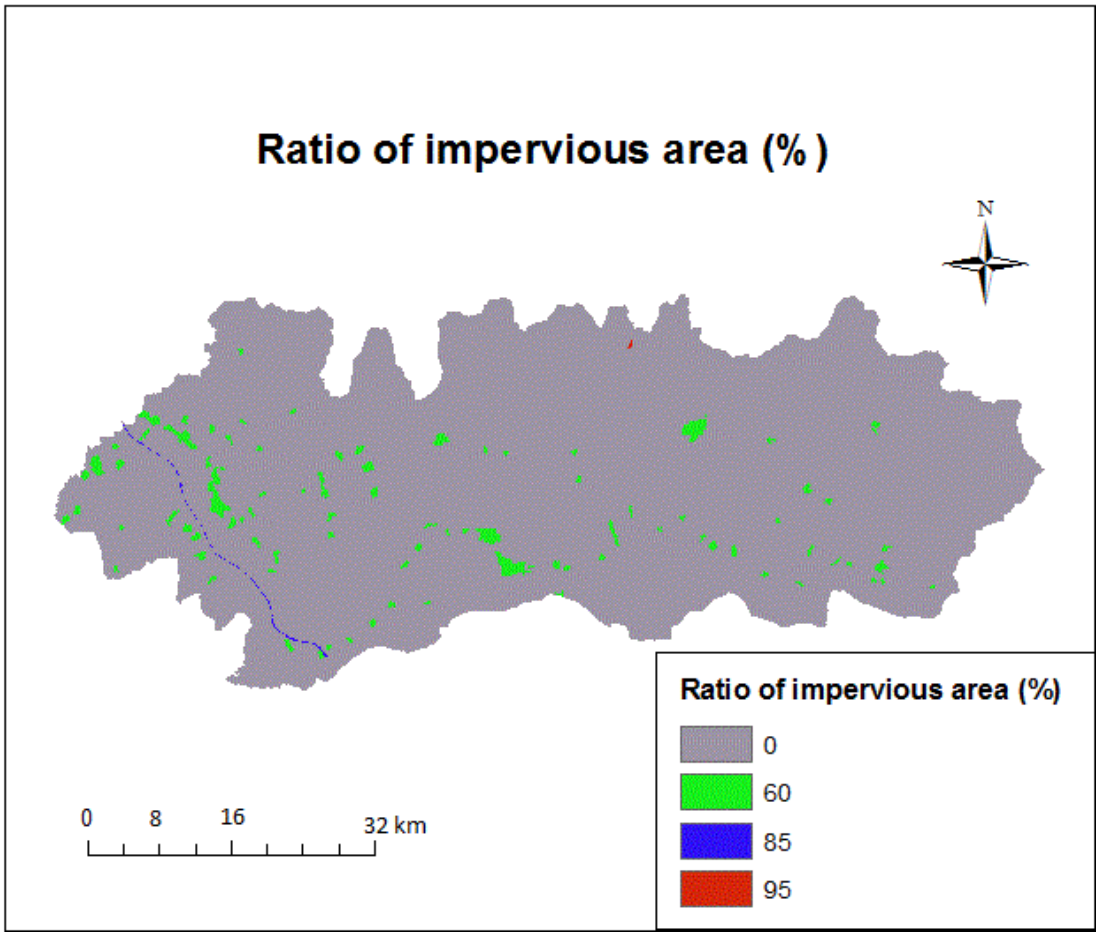


Figure 6.23 Ratio of impervious area (%).

- Transform method

Transform method converts the excessive rainfall over a basin into a discharge hydrograph at the outlet of the basin. Clark UH was used as a transform method to develop the model. Both time of concentration (Tc) and storage coefficient (k) are required as input data for the transform model as seen in Figure 6.24, and they were calculated by Johnstone formula based on basin geometrical properties.

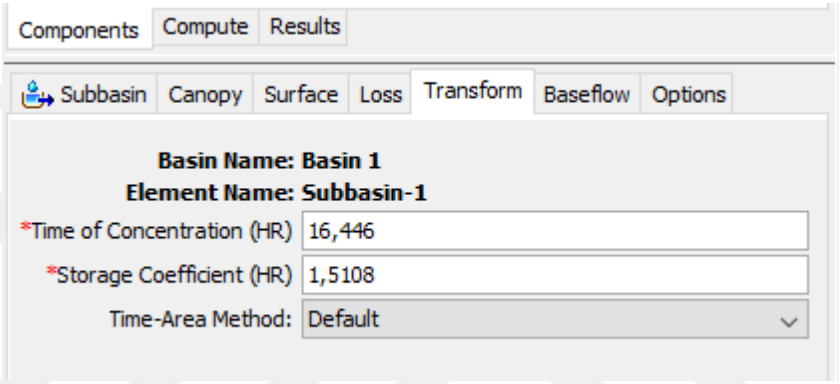


Figure 6.24 Clark transform method in HEC-HMS.

### *6.2.2* Construction of time series data and Control Specifications

Time series data for precipitation (Figure 6.25), mean temperature (Figure 6.26), shortwave radiation (Figure 6.27) (1 MJ/m$^2$/day = 11.6 Watt/m$^2$), and observed flow (Figure 6.28) over station 601 were constructed based on the prepared data in chapter five, while Control Specifications (Figure 6.29) determined the simulation start date (01/08/1965, 12:00) and the simulation end date (01/08/1985, 12:00). Both time series data and Control Specifications have the time step of one day.

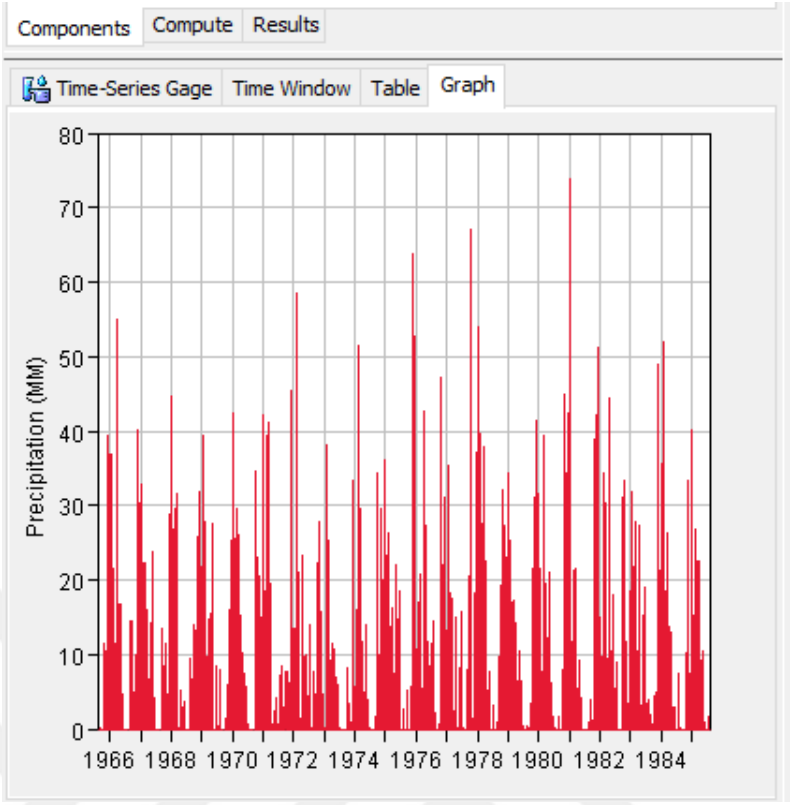


Figure 6.25 Time series data for precipitation in HEC-HMS.

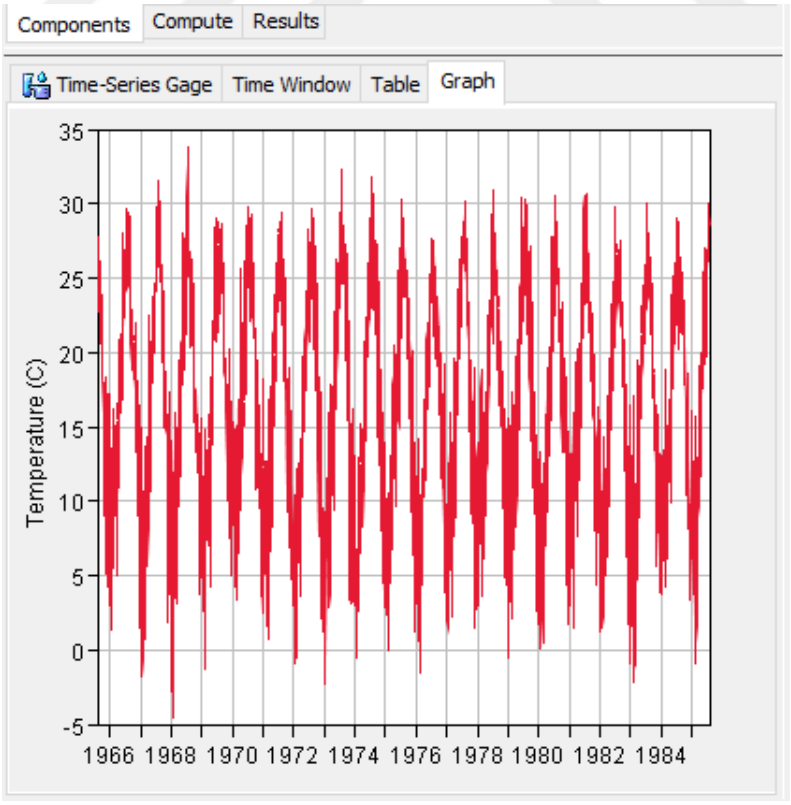


Figure 6.26 Time series data for mean temperature.

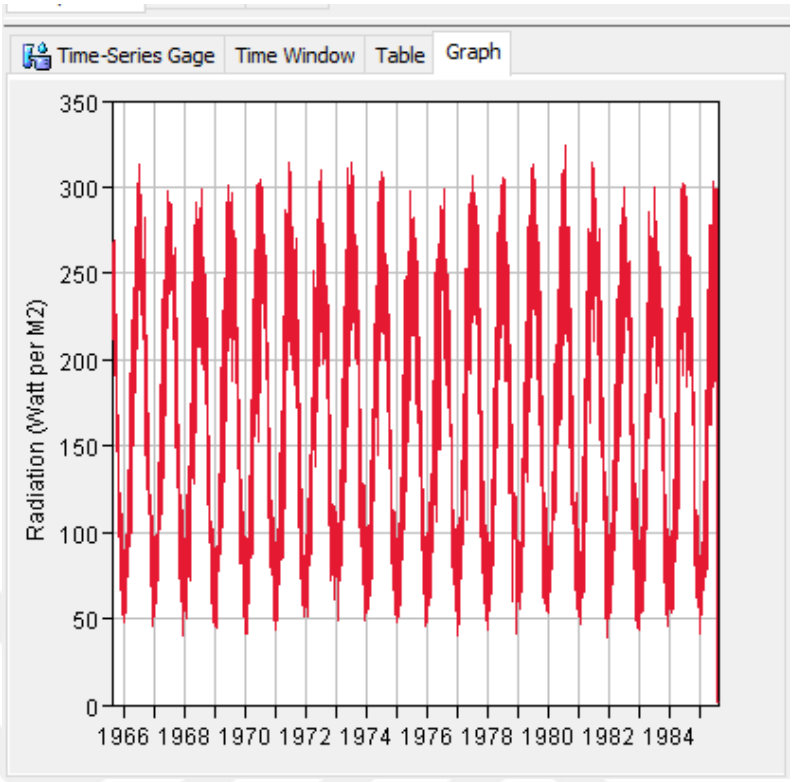


Figure 6.27 Time series data for shortwave radiation in HEC-HMS.

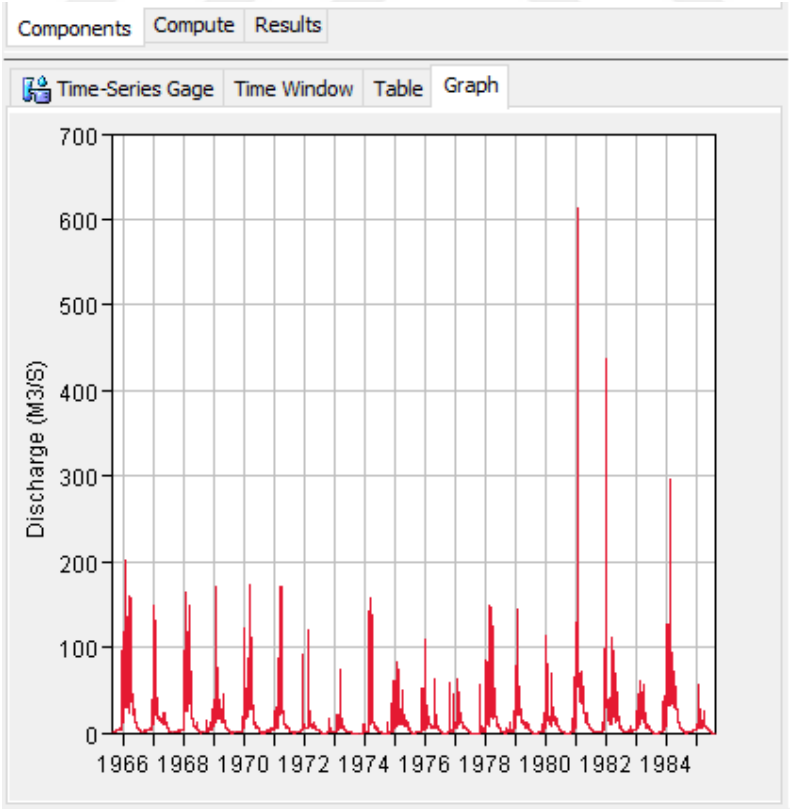


Figure 6.28 Time series data for observed flow in HEC-HMS.

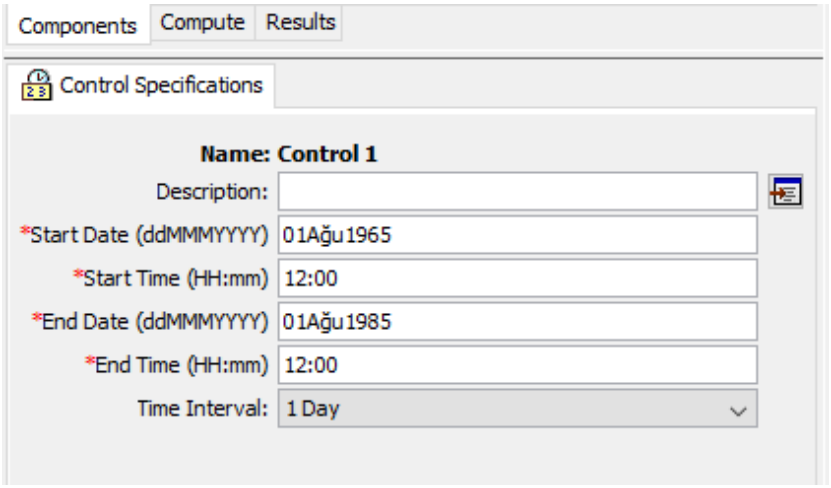


Figure 6.29 Control Specifications in HEC-HMS.

### *6.2.3 Runing the Model*

The simulation was carried out. After that the program gives a message. This message indicates that every thing is ok. Simulated flow can be obtained as shown in Figure 6.30. The processes of model calibration an model validition can be carried out.

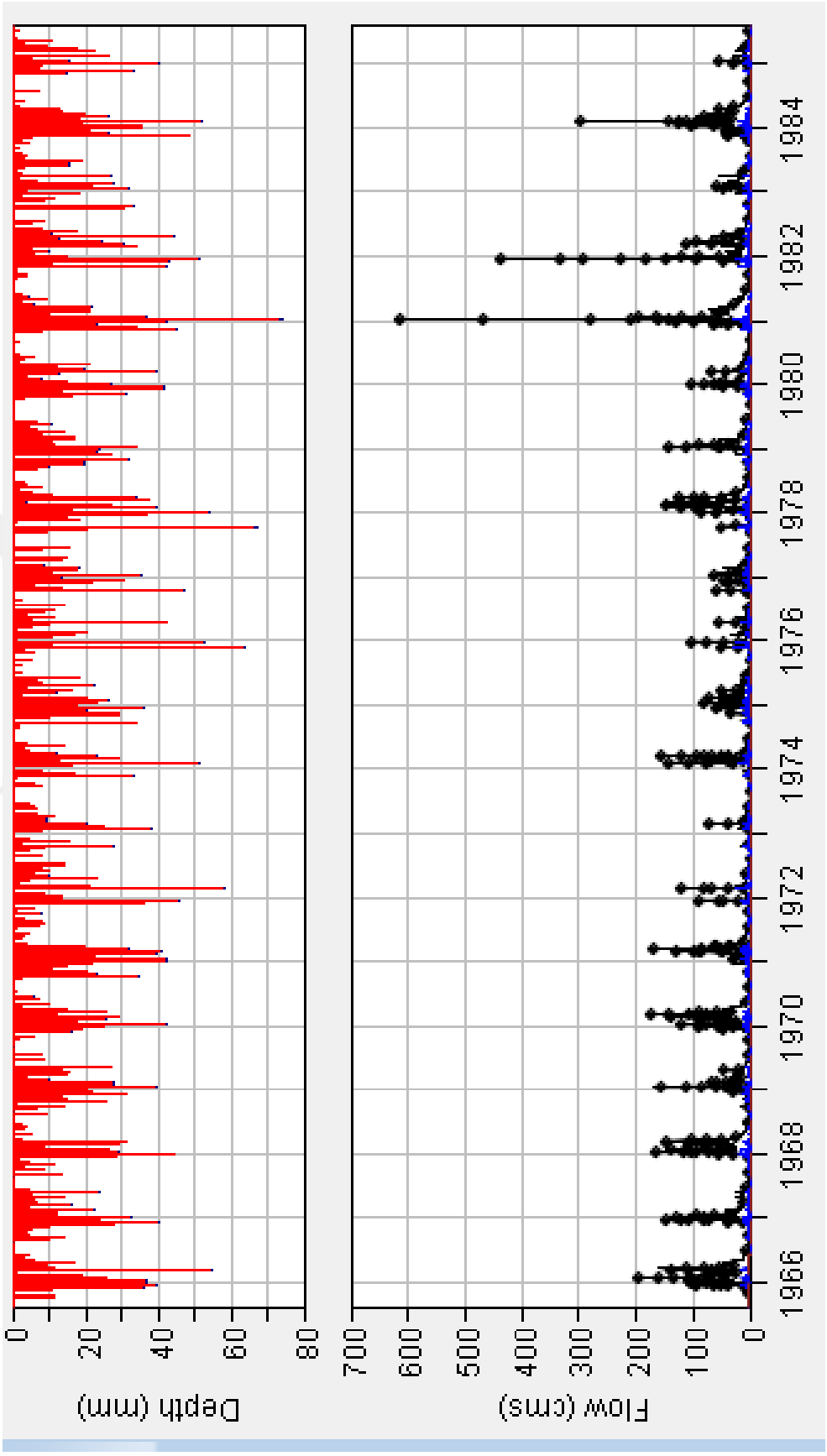


Figure 6.30 HEC-HMS simulation outputs.

# CHAPTER SEVEN
# RESULTS

Because of the difference between values of the simulated runoff and values of the observed one, calibration process is required to minimize the difference between them based on some statistical parameters such as Nash-Sutcliffe efficiency (**NSE**), Root Mean Square Error (**RMS**), Mean Absolute Error (**MAE**) and Coefficient of Determination ($\mathbf{R^2}$). Sequentially, the validation process is used in order to ensure that the calibrated parameters are still the accepted parameters, which satisfy the best fit for the continuous hydrological model. At these chapter calibration process, and validation process were explained for the continuous hydrological model in Küçük Menderes river basin from 1965 to 1998.

## 7.1 Calibration of the Model

Calibration of the hydrological model (Figure 7.1) is defined as an adjusting process for the values of the watershed parameters such as the parameters that cannot be obtained by measurement or have no direct physical meaning (HEC, 2001), to minimize the difference between the simulated streamflow and the measured streamflow values by using an objective function. Calibration of the hydrological model could be manually (by hand) or automatically (model optimization) operated. Manual calibration depends on the user experiences about the physical properties of the basin, while in the automated calibration an iterative adjusting for the model parameters is carried out according to the selected objective function.

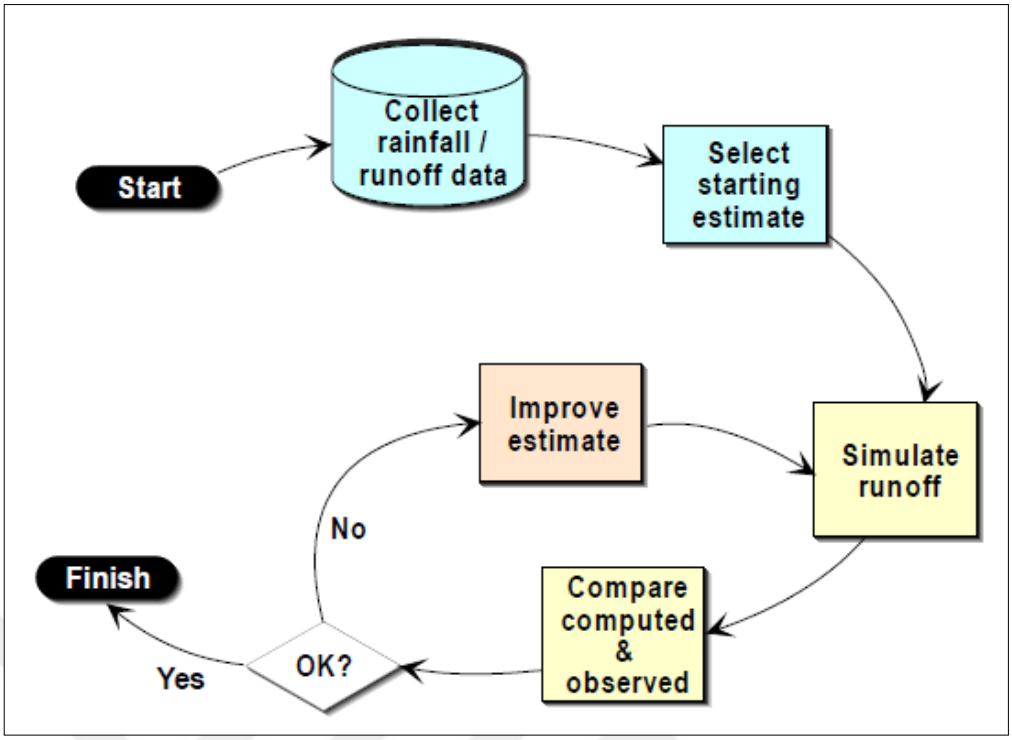


Figure 7. 1 Schematic of calibration procedure (HEC, 2001).

### *7.1.1 Optimization of the Hydrological Model by HEC-HMS*

HEC-HMS model can automatically optimize the watershed parameters (HEC, 2001). Optimization process in HEC-HMS model is carried out by using iterative adjusting for the parameters according to the recommended maximum value and minimum value for the watershed parameters as shown in Table 7.1. HEC-HMS has two different methods for parameter optimization, which are:-

1- Univariate Gradient method

In the Univariate Gradient Method, only the selected parameter is adjusted at a time, leaving the rest parameters constant.

2- Nelder & Mead method

In the Nelder & Mead Method method, every parameter is adjusted throw an iterative process according to the selected objective function.

Table 7.1Calibration parameter constraints.

| Parameter | Min. value | Max. value |
|---|---|---|
| Canopy initial storage (%) | 0 | 100 |
| Canopy Max. storage (mm) | 0 | 1500 |
| Surface initial storage (%) | 0 | 100 |
| Surface Max. storage (mm) | 0 | 1500 |
| Initial deficit (mm) | 0 | 500 |
| Max. deficit (mm) | 0 | 500 |
| Infiltration rate (mm/hr.) | 0 | 300 |
| Time of concentration (hr.) | 0.1 | 500 |
| Storage coefficient (hr.) | 0 | 150 |

### *7.1.2 Quantitative Statistics for the Calibration Process*

To decide that the calibrated parameters are the accepted ones, which can satisfy the best fit for the hydrological model, some of the quantitative statistics should be investigated such as Mean Absolute Error (**MAE**), Root Mean Square Error (**RMSE**), Coefficient of Determination ($\mathbf{R^2}$) and Nash-Sutcliffe efficiency (**NSE**) as shown in Table 7.2. The coefficient of determination ($R^2$) measures the proportion of total variation in the response variable that is explained by the least-squares regression line, and it is a number between 0 and 1. If $R^2$ equals 0, the line has no explanatory value, but if $R^2$ equals 1, that means the line variable explains 100% of the variation in the response variable (Di Bucchianico, 2008). Nash-Sutcliffe coefficient, also called the coefficient of efficiency (E) is a method to investigate the fit between the simulated runoff and actual observed runoff values (Jain, & Sudheer, 2008). In the case of Nash-Sutcliffe coefficient is 1, that is mean the observed value is the same as all simulated,

but if the E is between 0 and 1, it indicates deviations between observed and simulated values. While if E is negative, optimization is not good, and the average value of output is a better estimate than the model.

Table 7.2 Mathematical formulas for the MAE, RMSE, and NSE.

| Quantitative statistics | Mathematical formula | Where:- |
|---|---|---|
| Mean Absolute Error (**MAE**). | $MAE = \frac{1}{n}\sum_{i=1}^{n}\left\|Q_i - \hat{Q}_i\right\|$ | Qi: - observed flow. $\hat{Q}$ı: - simulated flow. Qavg: - average observed flow. n:- number of the observations |
| Root Mean Square Error (**RMSE**). | $RMAE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}$ | |
| Nash-Sutcliffe efficiency (**NSE**), | $E = \frac{\sum_{i=1}^{n}\left(Q_i - Q_{avg}\right)^2 - \sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}{\sum_{i=1}^{n}\left(Q_i - Q_{avg}\right)^2}$ | |

### *7.1.3 Results of Calibration Processes (1965-1975)*

During 6 months very hard efforts were made during the calibration process (Calibration duration is from 1965 to 1975) in order to obtain the best fit for the hydrological model in Küçük Menderes river watershed, so the model was calibrated as an average daily flow measurements model, while the average monthly flow measurements model was considered because of the high uncertainty ratio in some watershed parameters such as the value of baseflow.

Furthermore, statistical analysis was carried out for the results of the best calibrated two years measurements. According to the model results, which were obtained after running the model by using the estimated/calculated watershed parameters, baseflow method was changed as a constant monthly method. After the manual calibration, HEC-HMS was used in order to carry out the optimization of the hydrological model by using Nelder & Mead Method, while the method of the objective function was

selected as Nash-Sutcliffe method. The calibrated parameters are presented in Table 7.3.

Table 7.3 Values of calibrated parameters.

| **Parameter** | **Estimated /Calculated** | **Calibrated -By hand** | **Calibrated-Automatically** |
|---|---|---|---|
| Canopy initial storage (%) | 0 | 0 | 0,0849423 |
| Canopy Max. storage (mm) | 2.7 | 2.7 | 3,0385 |
| Crop coefficient $K_c$ | 1.06 | 1.06 | 1.06 |
| Surface initial storage (%) | 0 | 0 | 0,0849423 |
| Surface Max. storage (mm) | 33 | 1 | 1,0849 |
| Initial deficit (mm) | 36.5 | 30 | 30,085 |
| Max. deficit (mm) | 58.87 | 60 | 60,085 |
| Infiltration rate (mm/hr.) | 2.6 | 2.4 | 2,4849 |
| Impervious (%) | 1.4 | 7.5 | 7.5 |
| Time of concentration (hr.) | 16.44 | 80 | 80,085 |
| Storage coefficient (hr.) | 1.5 | 30 | 30,085 |
| Baseflow 1. (m3/s) | 24.24 | 30 | 30 |
| Baseflow 2. (m3/s) | 25.35 | 25 | 25 |
| Baseflow 3. (m3/s) | 23.71 | 26.5 | 26.5 |
| Baseflow 4. (m3/s) | 16.20 | 13.1 | 13.1 |
| Baseflow 5. (m3/s) | 8.29 | 4.9 | 4.9 |
| Baseflow 6. (m3/s) | 4.12 | 1.6 | 1.6 |
| Baseflow 7. (m3/s) | 0.86 | 0.52 | 0.52 |
| Baseflow 8. (m3/s) | 0.07 | 0 | 0 |
| Baseflow 9. (m3/s) | 0.36 | 0 | 0 |
| Baseflow 10. (m3/s) | 1.03 | 0 | 0 |
| Baseflow 11. (m3/s) | 1.89 | 0 | 0 |
| Baseflow 12. (m3/s) | 9.27 | 2.28 | 2.28 |

Table 7.4 below illustrates the values of MAE, RMSE, NSE, and $R^2$ for the model for all of the duration (from 1965 to 1975) and for the best calibrated two years (from 1967 to 1969).

Table 7.4 Values of MAE, RMSE, NSE and $R^2$ for the calibrated model.

| **Parameters** | **Cal. Daily** | **Cal. Monthly** | **Cal. Daily. (1967-1969)** | **Cal. Monthly. (1967-1969)** |
|---|---|---|---|---|
| MAE | 8.03 | 6.17 | 5.52 | 2.88 |
| RMSE | 16 | 10.72 | 12.91 | 5.55 |
| NSE | 0.53 | 0.65 | 0.68 | 0.91 |
| $R^2$ | 0.53 | 0.65 | 0.7 | 0.93 |

Since R is larger than 0.70, it indicates that the calibrated parameter are accepted. Furthermore, both of average daily model and average monthly model have a well-calibrated discharge hydrograph (Figure 7.2 & Figure 7.3).

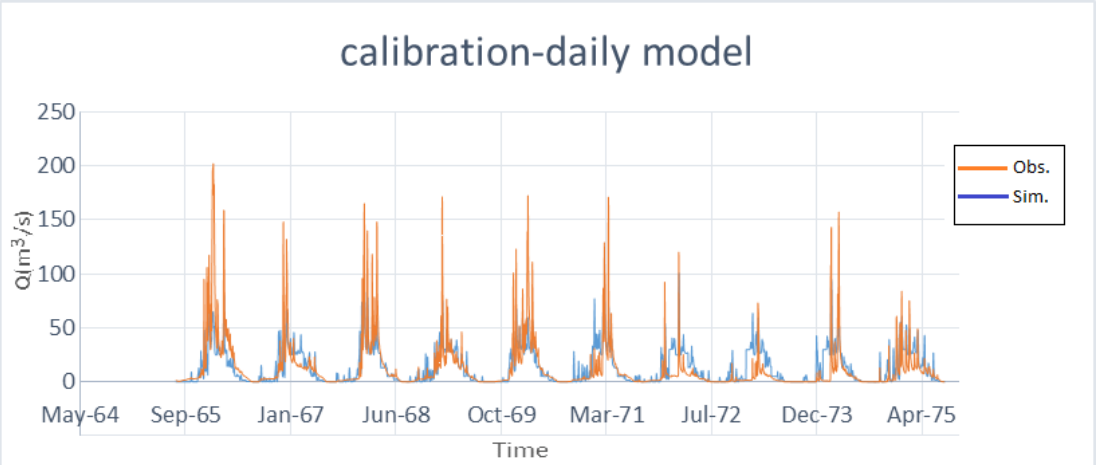


Figure 7. 2 Calibrated discharge hydrograph for the daily model.

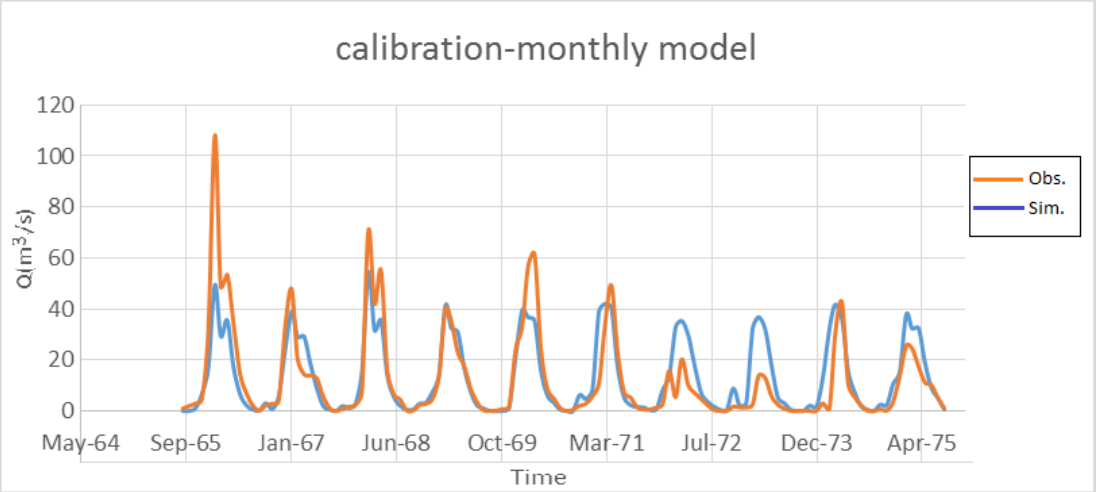


Figure 7. 3 Calibrated discharge hydrograph for the monthly model.

The coefficient of Determination ($\mathbf{R^2}$) is one of the most important statistical parameters, which was mentioned previously. Figure 7.4 shows the regression between the observed and the simulated values in the average daily model, while Figure 7.5 shows the regression between the observed and the simulated values in the average daily model.

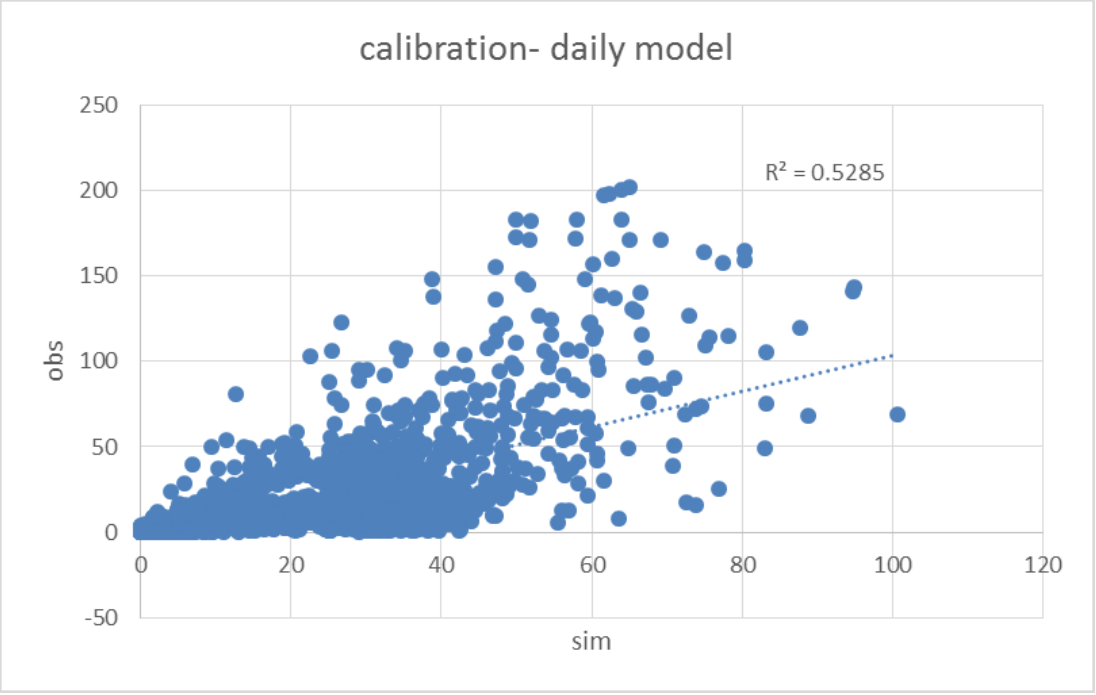


Figure 7. 4 Regression of calibrated daily model (1965-1975).

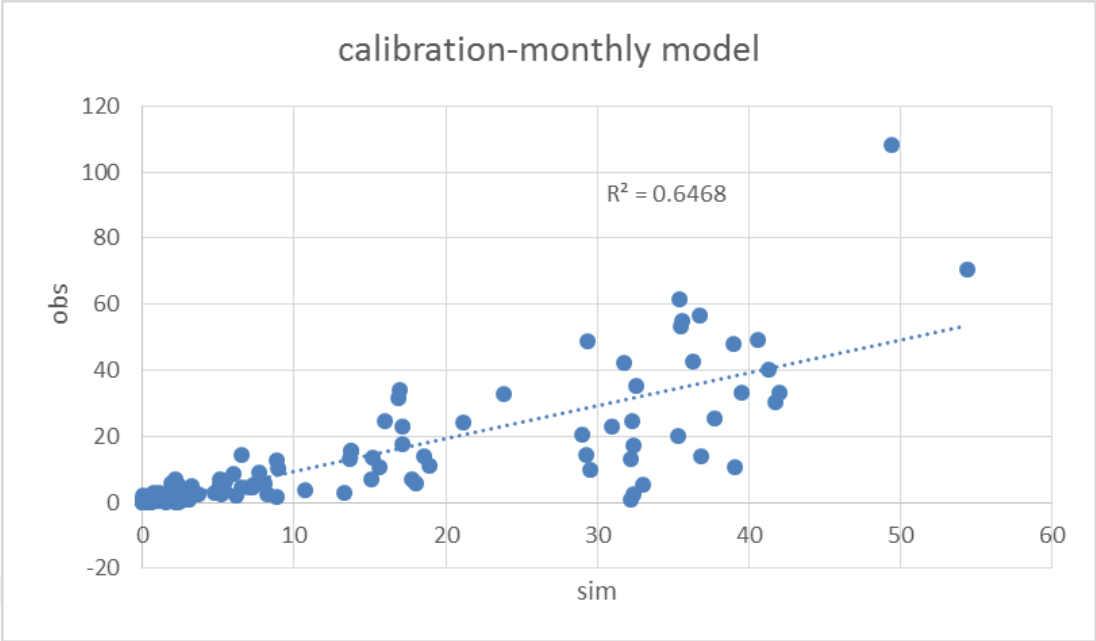


Figure 7. 5 Regression of calibrated monthly model (1965-1975).

Figure 7.6 and Figure 7.7 illustrate the regression between the observed and the simulated for the best two years for both of average daily model and average monthly model.

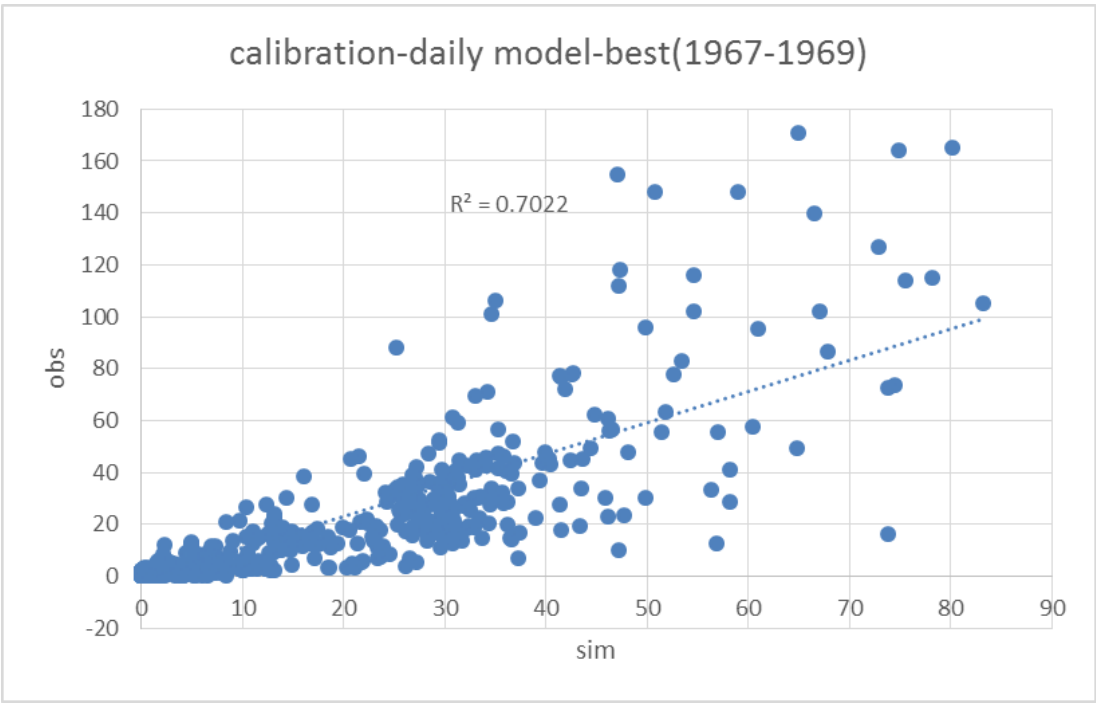


Figure 7. 6 Regression of calibrated daily model (1967-1969).

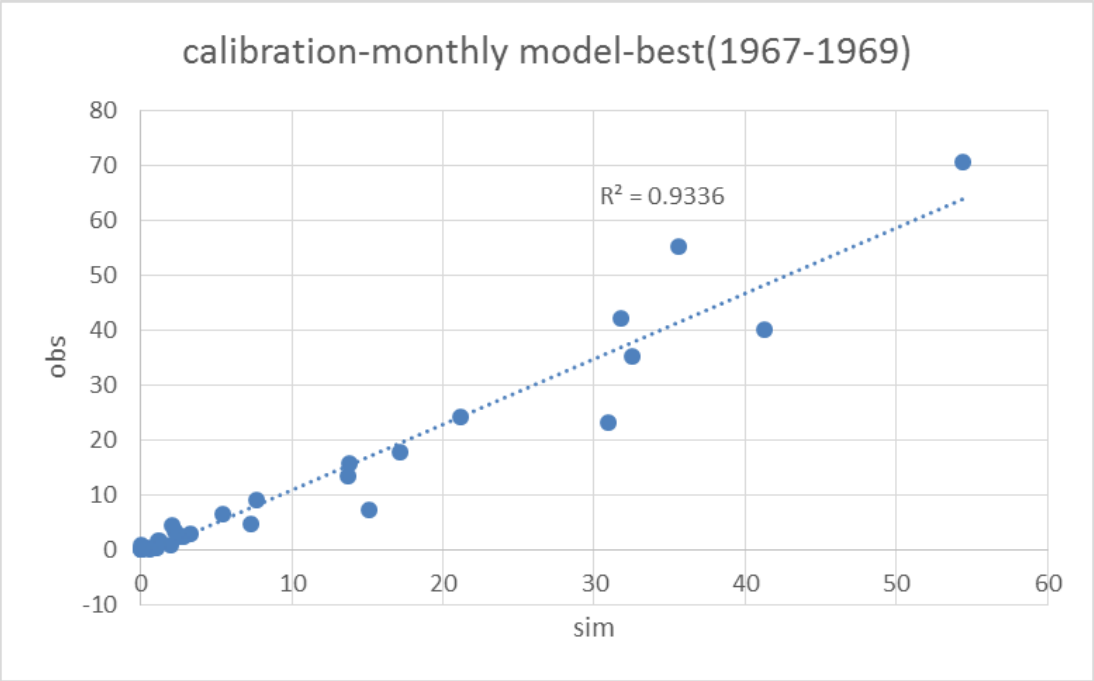


Figure 7. 7 Regression of calibrated monthly model (1967-1969).

## 7.2 Validation of the Model

As mentioned previously, validation process should be carried out to ensure that the calibrated watershed parameters are the adequate parameters, which satisfy the best fit for the hydrological model. Because of a high ratio of uncertainty in some watershed parameters such as baseflow, validation of the model was investigated during three durations (1976-1985), (1976-1989) and (1976-1998). From 1978 to 1980 is the best duration of the validation process as shown in Table 7.5 and Table 7.6.

Table 7.5 Values of MAE, RMSE, NSE and $R^2$ for the validation process (Part1).

| **Parameters** | **Val. Daily (1976-1985)** | **Val. Monthly (1976-1985)** | **Val. Daily (1976-1989)** | **Val. Monthly (1976-1989)** |
|---|---|---|---|---|
| **MAE** | 8.76 | 7.65 | 8.71 | 7.75 |
| **RMSE** | 20.58 | 14.93 | 18.97 | 14.29 |
| **NSE** | 0.5 | 0.57 | 0.44 | 0.49 |
| **$R^2$** | 0.51 | 0.58 | 0.45 | 0.5 |

Table 7.6 Values of MAE, RMSE, NSE and $R^2$ for the validation process(Part2).

| parameters | Val. daily (1976-1998) | Val. Monthly (1976-1998) | Val. daily. best (1978-1980) | Val. monthly. best (1978-1980) |
|---|---|---|---|---|
| **MAE** | 9.34 | 8.68 | 5.55 | 3.9 |
| **RMSE** | 17.89 | 14.56 | 10.4 | 5.96 |
| **NSE** | 0.27 | 0.22 | 0.64 | 0.8 |
| **$R^2$** | 0.36 | 0.38 | 0.66 | 0.84 |

Both average daily model and average monthly model have a good validation of discharge hydrograph as shown in Figure 7.8 and in Figure 7.9.

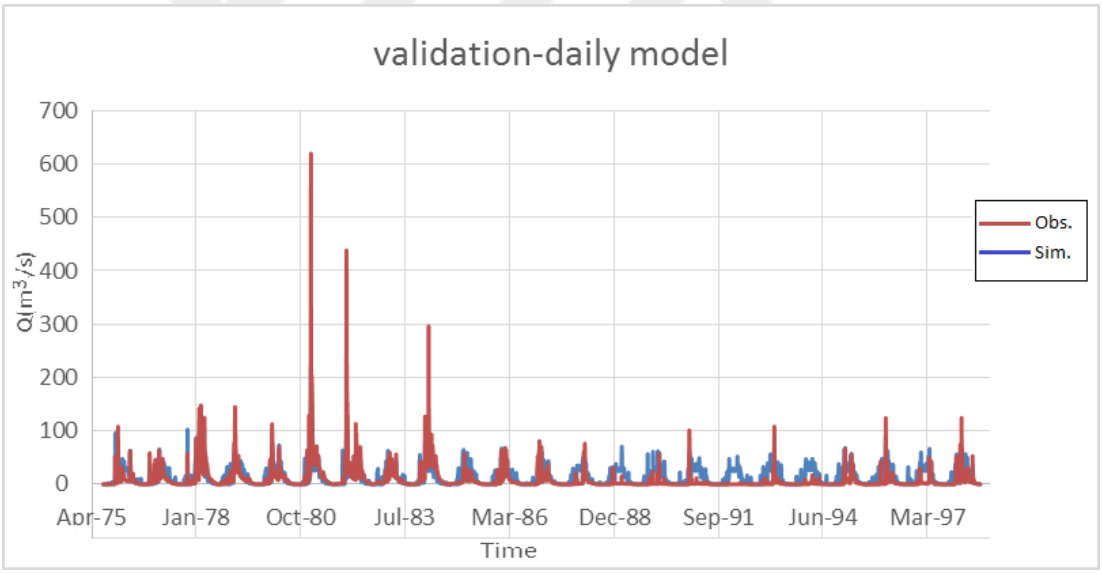


Figure 7. 8 Validation of discharge hydrograph for the daily model.

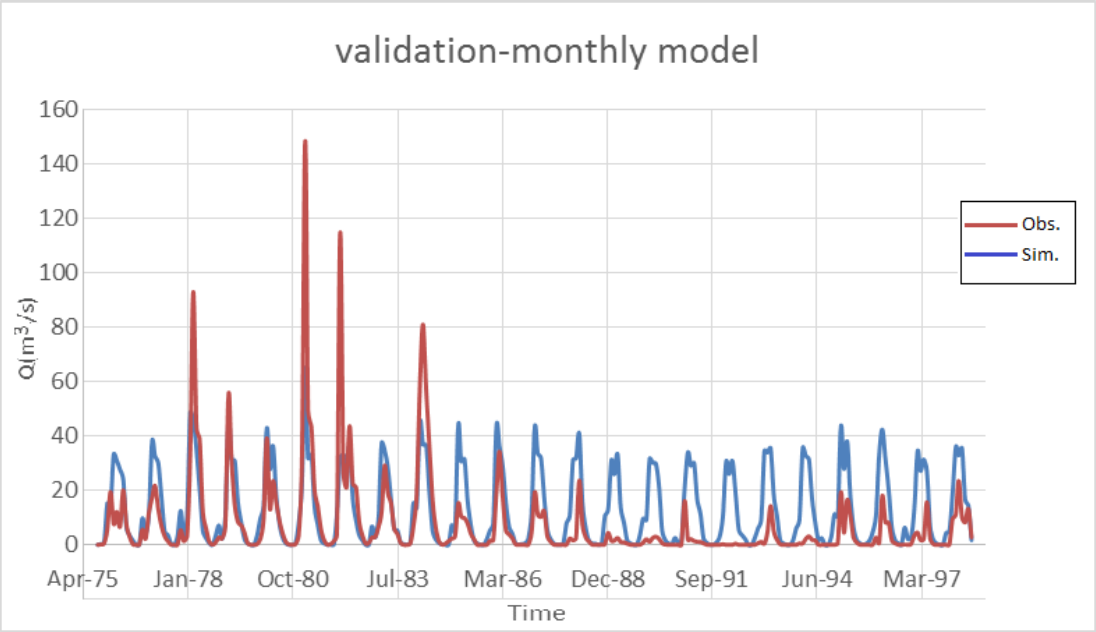


Figure 7. 9 Validation of discharge hydrograph for the monthly model.

The coefficient of Determination ($\mathbf{R^2}$) was investigated for the validation process through the regression between the observed and the simulated values. Figures 7.10 (1976-1985), Figures 7.11 (1976-1989), Figures 7.12 (1976-1998) and Figures 7.13 (1978-1970) illustrate the regression between the observed and the simulated values in the average monthly model.

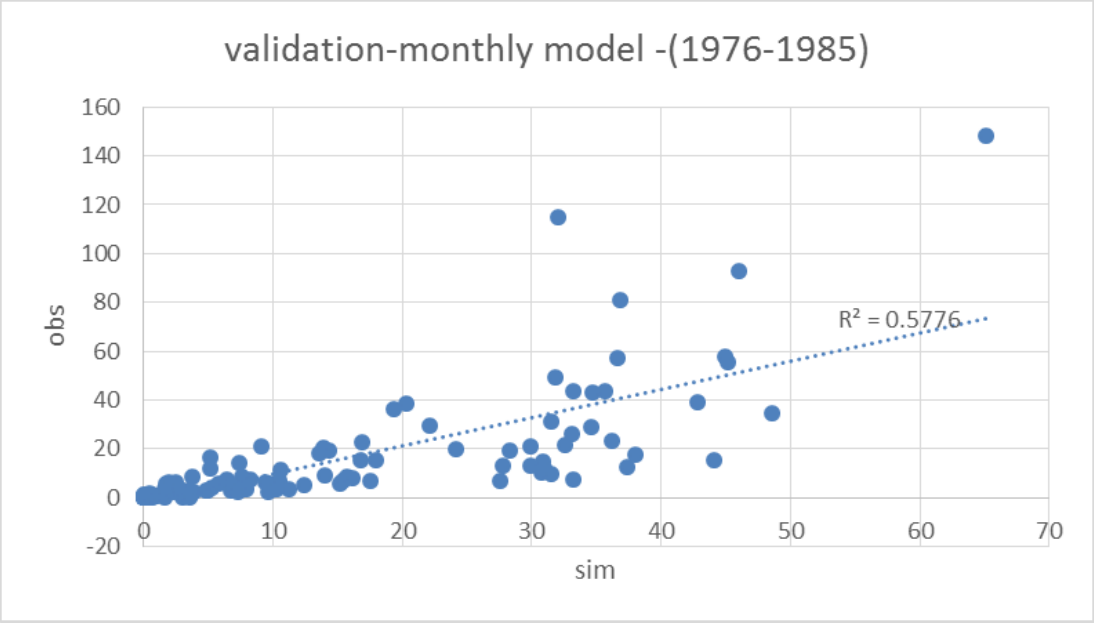


Figure 7. 10 Regression of validated monthly model (1976-1985).

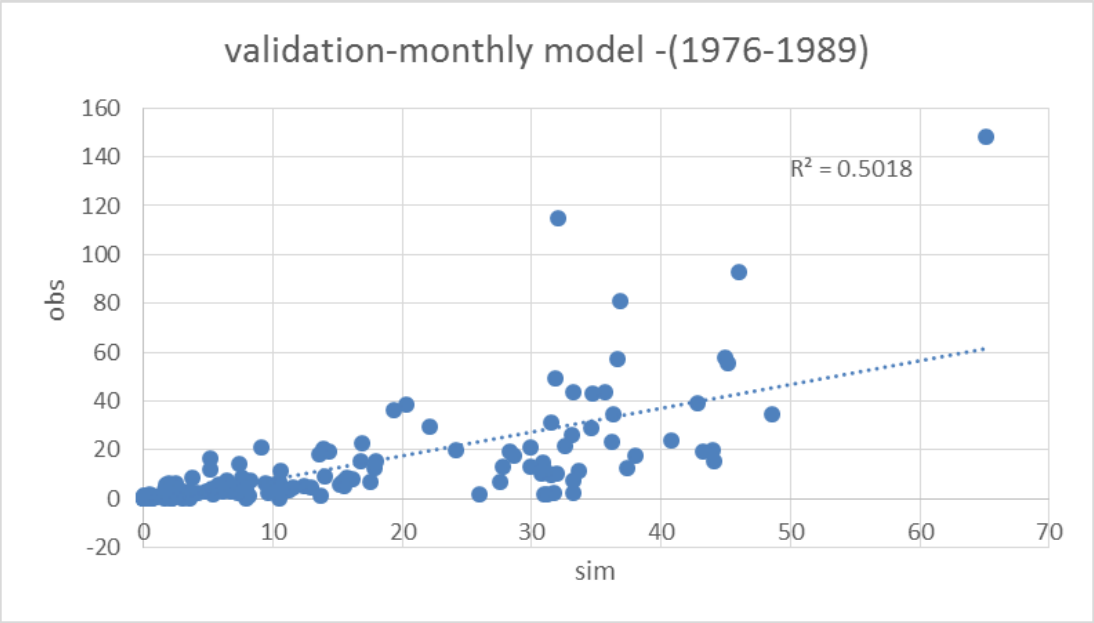


Figure 7. 11 Regression of validated monthly model (1976-1989).

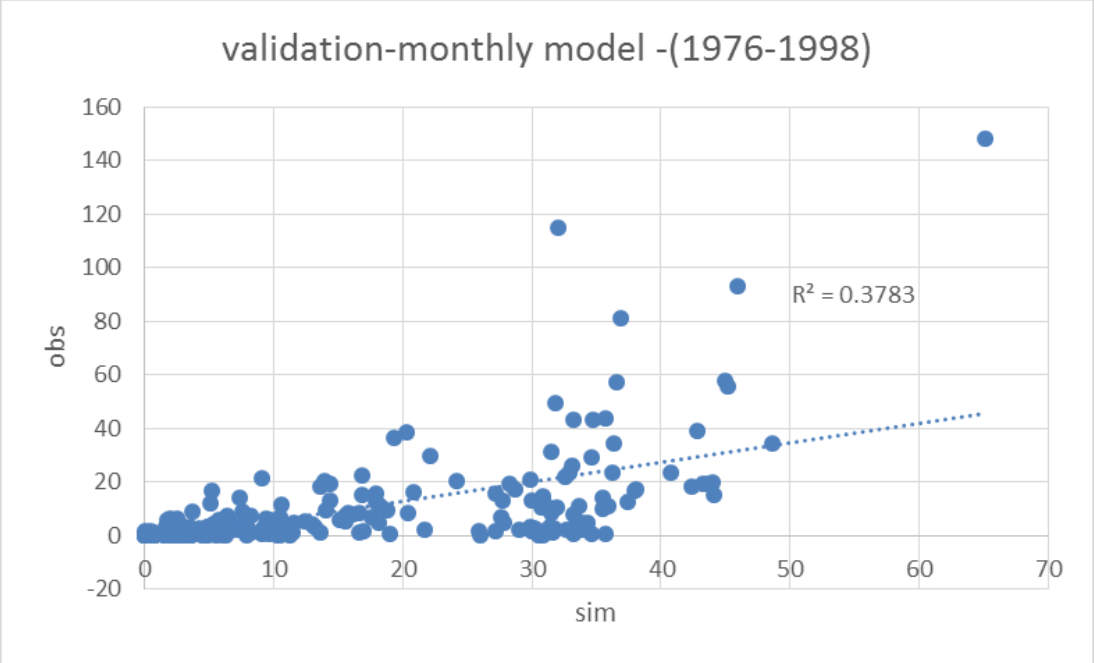


Figure 7. 12 Regression of validated monthly model (1976-1998).

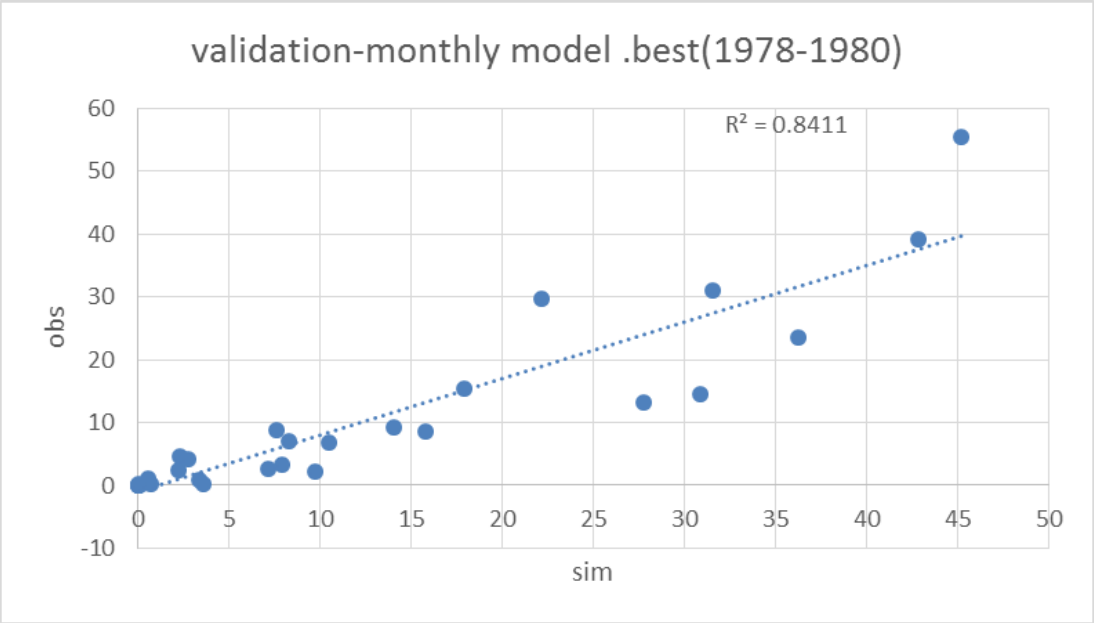


Figure 7. 13 Regression of validated monthly model (1978-1980).

Figures 7.14 (1976-1985), Figures 7.15 (1976-1989), Figures 7.16 (1976-1998) and Figures 7.17 (1978-1970) illustrate the regression between the observed and the simulated values in the average monthly model.

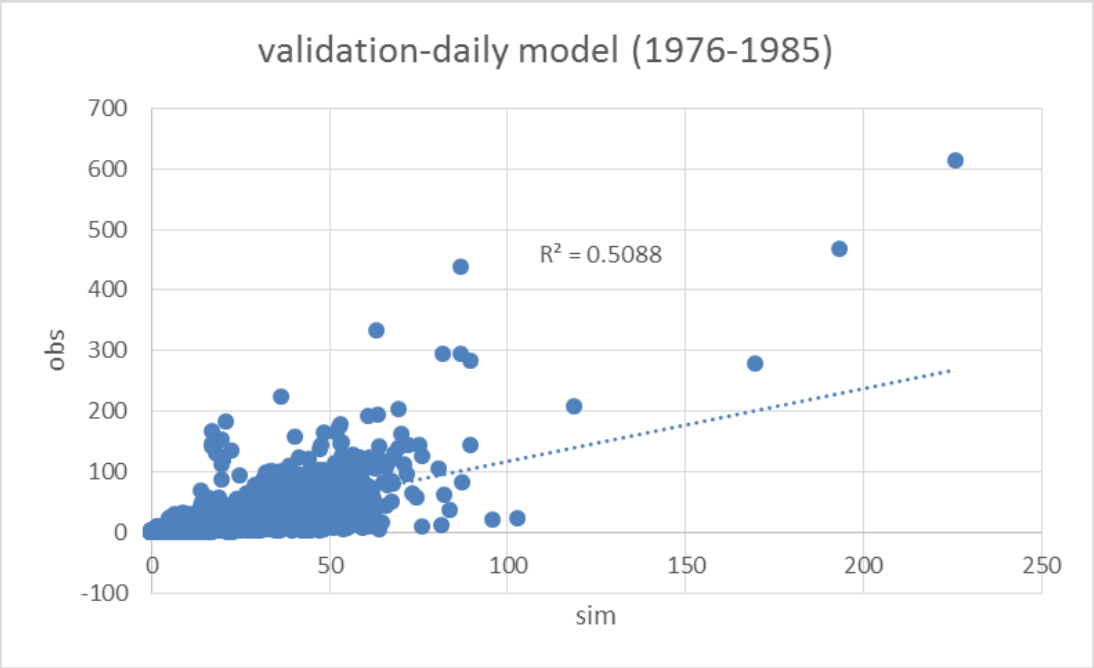


Figure 7. 14 Regression of validated daily model (1976-1985).

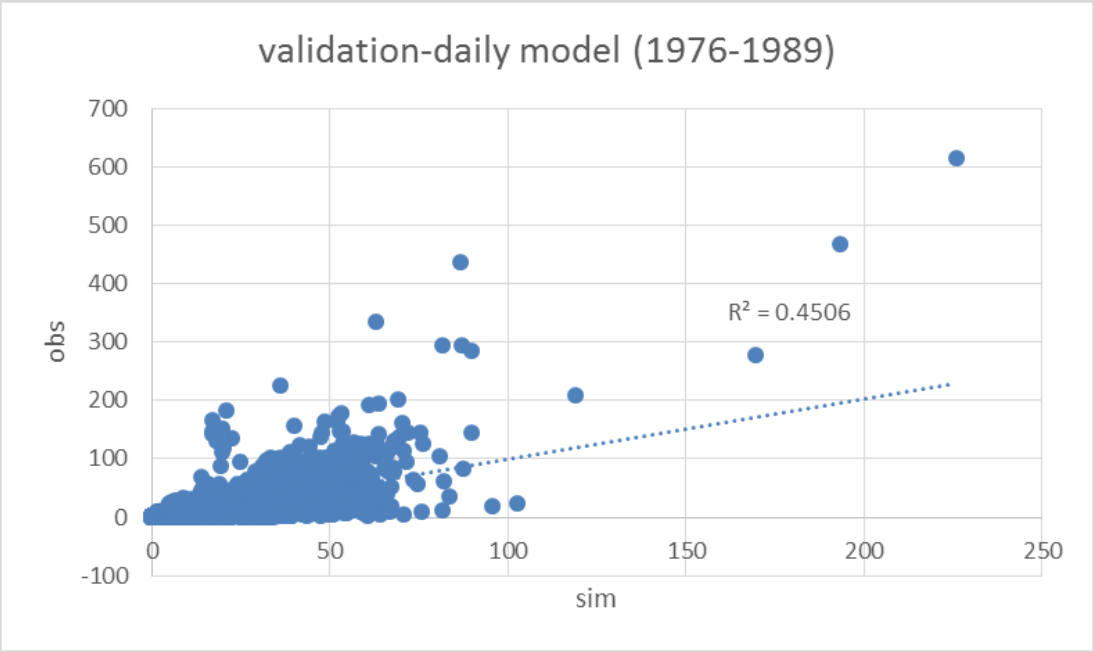


Figure 7. 15 Regression of validated daily model (1976-1989).

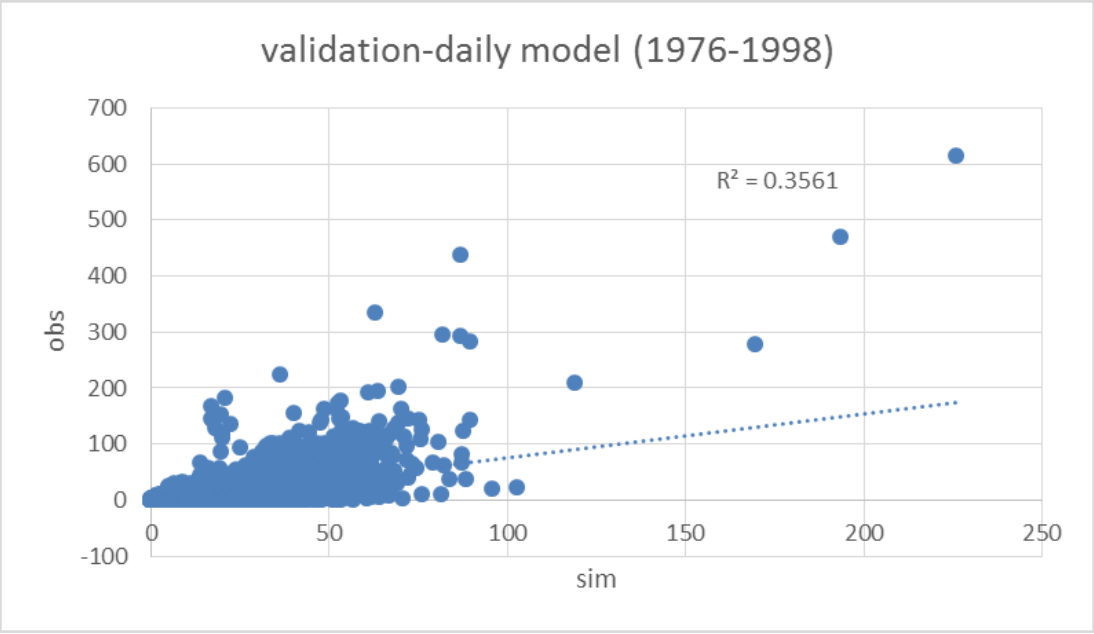


Figure 7. 16 Regression of validated daily model (1976-1998).

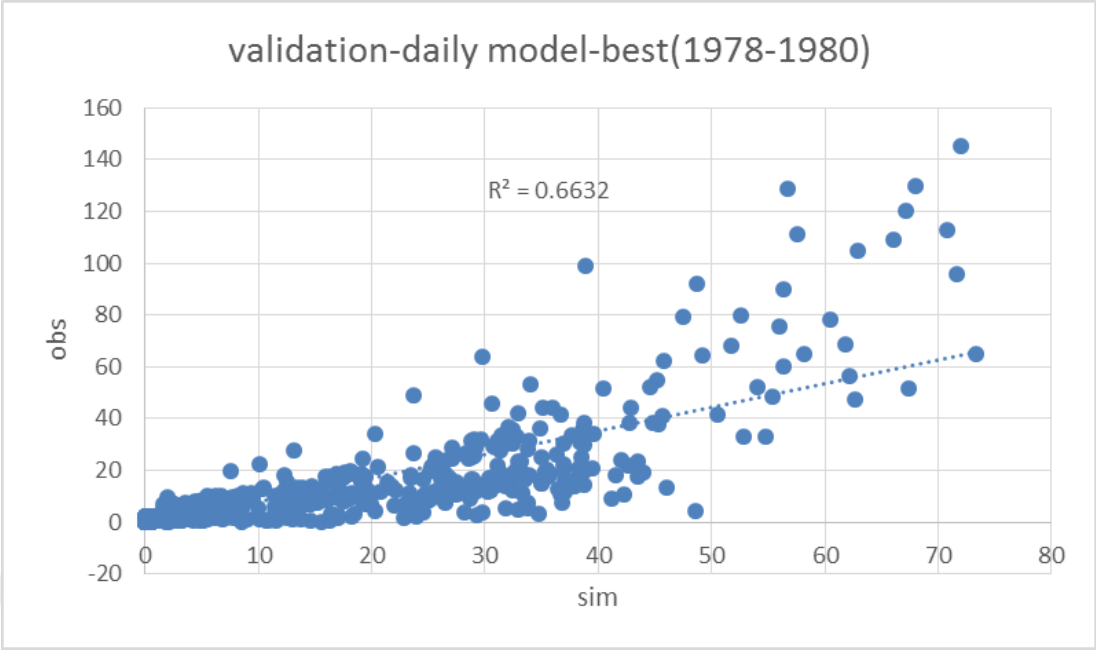


Figure 7. 17 Regression of validated daily model (1978-1980).

# CHAPTER EIGHT
# CONCLUSIONS

In this study, the continuous hydrological model was constructed for the period of 1965- 1998 in Küçük Menderes river watershed in the city of Izmir on the western side of Turkey. The model was divided into two parts; the first part is calibration and the second part is a validation of the model. The duration of the simulation is very long, so many problems happened, namely calculation of canopy losses value, calculation of surface losses value, calculation of net shortwave values and estimation of the river average monthly baseflow.

Firstly, canopy losses were calculated by using Von Hoynigen Huene (1981) formula, which depends on LAI factor. After that, calculation of evapotranspiration was calculated by using Priestly and Tylor's method. Net shortwave radiation is required in order to calculate the evapotranspiration by using Priestly and Tylor's method. Unfortunately, actual daily sunlight hours are not available for the metrological stations. An empirical formula was carried out which was Hargreaves formula. Hargreaves formula can calculate the values of the net shortwave radiation without any need for the values of actual daily sunlight hours.

River average monthly baseflow was estimated by separating baseflow by using Web-based Hydrograph Analysis Tool (WHAT) and calculating the average monthly values for the separated baseflow by using Excel program.

Finally, model calibration was carried out in order to meet the accepted values for the required quantitative statistics parameter. Due to high uncertainty ratio in some watershed parameters average daily flow model could not meet the accepted limit of the required quantitative statistics parameter. For example, the Nash-Sutcliffe efficiency (**NSE**) parameter was less than 0.5. Because of that, average monthly flow model was considered.

The calibrated parameters and validated model of the basin with the extended data set can be used as an effective tool for basin planning and management studies in Küçük Menderes.

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