İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

APPLICATION OF SWAT MODEL IN A WATERSHED IN TURKEY

M.Sc. Thesis by
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Department : Environmental Engineering

Programme : Environmental Sciences and Engineering

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<u>İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ</u>

SWAT MODELİNİN TÜRKİYE'DEKİ BİR HAVZADA UYGULANMASI

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FOREWORD

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ABBREVIATIONS

AGNPS	**:**	AGricultural Non-Point Source
ANSWERS	**:**	Areal Nonpoint Source Watershed Environment Response Simulation
CREAMS	**:**	Chemicals, Run off, and Erosion from Agricultural Management
DAP	**:**	Di Ammonium Phosphate
DEM	**:**	Digital Elevation Model
ET	**:**	Evapotranspiration
GIS	**:**	Geographical Information System
HRU	**:**	Hydrological Response Unit
HSPF	**:**	Hydrological Simulation Program-Fortran
NRCS	**:**	U.S. Natural Resources Conservation Service
OM	**:**	Organic Matter
ORGN	**:**	Organic Nitrogen
SWAT	**:**	Soil and Water Assessment Tool
SWRRB	**:**	Simulator for Water Resources in Rural Basins
TN	**:**	Total Nitrogen
TP	**:**	Total Phosphorus
TSP	**:**	Triple Super Phosphate
USEPA	**:**	United States Environmental Protection Agency

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APPLICATION OF SWAT MODEL IN TURKEY

SUMMARY

Nonpoint source pollution from agricultural watersheds has been recognized as a significant contributor to the degradation of quality of surface waters in the world. Non point source pollution modeling systems are significantly supportive to sustainable management and conservation of natural resources in watersheds. The aim of the study is application of SWAT model for a watershed in Turkey.

SWAT model has proven to be an effective tool for assessing water resource and nonpoint source pollution problems for a wide range of scales and environmental conditions across the globe. As a worldwide commonly used model, SWAT has advantages on agricultural management practices of the watersheds. As Turkey is considered an agricultural country, application of the SWAT model in a watershed in Turkey is important.

Within this scope Köyceğiz Dalyan Watershed is selected as the case study area which has available data and has previous watershed model applications. In this manner, required data is obtained, gathered, and derived for SWAT model. In next step necessary input files are prepared with respect to model requirements. Finally, SWAT model applied in Köyceğiz Dalyan Watershed. This study provides guidance on setting up SWAT model in Turkey's circumstances, by introducing this approach to a case study on Köyceğiz-Dalyan Watershed.

In the second section nonpoint source watershed models are explained briefly and SWAT model is introduced in detail with its modeling approach, inputs, and outputs. In the third section, the case study area, Köyceğiz Dalyan Watershed, is described. In the fourth section of the thesis, application of SWAT model in the case study area is explained in order to provide a framework how the SWAT model applied in developing countries in which data sources might be scarce, have shorter history, questionably reliable, distributed, or not well-publicized, and how the model is run.

According to SWAT simulation results, it was calculated that surface runoff was decreasing in summer months. On the other hand, groundwater contribution to the reaches continued in this period. Lateral flow existed in summer months as well. It might be said that irrigation contributes to lateral flow. Amount of groundwater flow is higher in the lower elevations around Köyceğiz Lake. It is seen that precipitation increases the transport of the nitrate. It should be underlined that a significant part of the nitrate that moves from basin to reaches was contributed by groundwater flow. Namnam Stream is important for the system in terms of its flow and nutrient loads.

SWAT MODELİNİN TÜRKİYE'DEKİ BİR HAVZADA UYGULANMASI

ÖZET

Tüm dünyada tarım yapılan havzalardan kaynaklanan, yayılı kirliliğin yüzeysel suların kalitesinin bozulmasında önemli bir etken olduğunun farkına varılmıştır. Yayılı kirletici kaynakların modellenmesi, doğal kaynakların korunmasını ve sürdürülebilir yönetimini önemli ölçüde desteklemektedir. Çalışmanın amacı SWAT modelinin Türkiye'de bir havzada uygulanmasıdır.

SWAT modelinin değişik ölçeklerde ve çevresel koşullardaki uygulamalarıyla su kaynaklarının ve yayılı kaynaklı kirliliğin değerlendirilmesinde etkili bir araç olduğu tüm dünyada kanıtlanmıştır. Dünyada yaygın olarak kullanılan SWAT modelinin havzalardaki tarımsal yönetiminin uygulanabilirliği açısından avantajları mevcuttur. Türkiye bir tarım ülkesi olarak düşünüldüğünde, modelin Türkiye'de bir havzada uygulanması önemlidir.

Tez kapsamında, elde edilebilir verisi bulunan ve mevcut modelleme uygulamalarına sahip olan Köyceğiz Dalyan Havzası çalışma alanı olarak seçilmiştir. Öncelikle ihtiyaç duyulan veri toplanmış, birleştirilmiş ve türetilmiştir. Bir sonraki adımda gerekli olan model girdi dosyaları SWAT'ın ihtiyaçlarına göre hazırlanmıştır. Tüm bunların sonucunda SWAT modeli Köyceğiz Dalyan Havzası için çalıştırılmıştır. Bu çalışma SWAT modelinin Köyceğiz Dalyan Havzası'nda uygulanmasıyla Türkiye koşullarında modelin çalıştırılmasında kılavuzluk görevi görecektir.

İkinci bölümde, yayılı kaynak havza modelleri kısaca anlatılırken SWAT modelleme yaklaşımı, ihtiyaç duyulan girdi dosyaları ve model çıktılarıyla birlikte detaylı olarak anlatılmıştır. Üçüncü bölümde çalışma alanı olarak seçilen Köyceğiz Dalyan Havzası tanıtılmaktadır. Tezin dördüncü bölümünde SWAT modelinin çalışma alanında uygulanması anlatılarak SWAT modelinin verilerin az bulunur, kısa süreli, güvenilirliğinin kesin olmadığı, dağınık ve halkla yaygın olarak paylaşılmadığı gelişmekte olan bir ülkede uygulanabilirliği ve modelin çalıştırılması anlatılmıştır.

SWAT modelleme sonuçlarına göre, yaz aylarında yüzeysel akışın azaldığı görülmektedir. Diğer taraftan aynı dönemde yeraltı suyu nehirler beslemeye devam etmektedir. Yüzey altı akışı da yaz aylarında nehirleri beslemeye devam etmektedir. Tarım alanlarında kullanılan sulama suyunun yüzey altı akışı beslediği düşünülebilir. Köyceğiz Gölü'nün çevresindeki düşük kotlu bölgelerde yeraltı suyu akışının yüksek olduğu görülmektedir. Yağışın ile birlikte nitratın havzadan nehirlere taşınımı artmaktadır. Havzadan nehirlere gelen nitrat yükünün büyük bir kısmı yeraltı suyu ile taşınmaktadır. Namnam akarsuyu debisi ve taşıdığı nütrient yükü açısından Köyceğiz Dalyan sistemi için önemlidir.

1. INTRODUCTION

1.1 Aim and Scope

One of the most valuable resources of the world is water. As a result of increasing awareness of the value of water, water conservation and preservation improve considerable. Over the past 20 years, substantial reductions have been achieved in the discharge of pollutants into the lakes, rivers, wetlands, estuaries, coastal waters, and groundwater.

Nonpoint source pollution from agricultural watershed has been recognized as a significant source of surface water problems last 30 years. Also, nonpoint source pollution in water sources has become one of the biggest environmental issues for a sustainable management of water resources. It is known that nonpoint source pollution is an essential contributor to the degradation of water resources in the world. These pollutants may be transported in solution with run off, stay suspended in water, or may be adsorbed on eroded soil particles. Nutrient loading from agricultural activities may lead to eutrophication of water resources in the watershed.

Watershed models have been used as a major tool to understand and control water pollution from nonpoint sources. Furthermore, to better understand the relationship between land use activities and water quality processes occurring within a watershed, models are widely used in all over the world. Also, models are applied for decision making and improve understanding of the system in terms of water resource management. In this scope, numerous hydrological and water quality models of different scales are available.

Existing watershed modeling applications should be increased in order to sustainably manage the water resources in Turkey. SWAT model is one of the most applied watershed models in all over the world. If it is considered that Turkey is an agricultural country, SWAT becomes an important tool in terms of its capabilities on agricultural operations, and elimination of some uncertainties. On the other hand, adaptation of the model is possible for the conditions of Turkey where detailed results are required. Consequently, in the scope of the study, application of the SWAT model in a watershed in Turkey is intended. Köyceğiz Dalyan Watershed is selected as the case study area which has available data and has previous watershed model applications.

Aim of the study is application of SWAT model in Köyceğiz Dalyan Watershed. The main objectives of the study are:

- Using ArcSWAT interface to realize the aimed study
- Obtaining, gathering, and deriving the required data for SWAT model
- Preparation of required input files
- Using additional programs to generate management input files
- Application of SWAT model in the case study area
- Implementing a pioneer study which will be useful for calculation of the nutrient loads, application of future management scenarios and other modeling studies
- Providing an opportunity to compare application of different watershed models in the case study area in future studies

Within the context of the study; in the second section of the thesis, nonpoint source watershed models are explained briefly and SWAT model is introduced in detail with its modeling approach, inputs, and outputs. In the third section, Köyceğiz Dalyan Watershed is described with its climate, land use, soil structure, agricultural activities, and other properties. In the fourth section of the study, application of SWAT model in the case study area is explained in order to answer the questions including how data is obtained, organized, how inputs are prepared, and how the model is run. In fifth section, result and discussions, in the last section conclusion and recommendations are provided.

1.2 Significance

Nonpoint source models are used as a decision making tool for sustainable management of resources. They require a wide range of data such as hydrology, soils, land use and land cover, meteorology. In Turkey, these data can be gathered from a variety of governmental and non-governmental organizations through their central, provincial or regional authorities. Thus, gathering and deriving the required data for nonpoint source models is a challenge in Turkey. Despite the challenges, recently application of nonpoint source models has increased in Turkey. However they are not adequate and their application should be widespread.

With this thesis, application of SWAT model as a nonpoint source model for whole Köyceğiz Dalyan Watershed is firstly implemented in detail. In this study, crop management operations are applied specifically for each crop which was not an available option in the previous modeling studies in the watershed.

In addition this study will be a guiding tool to answer following questions; how SWAT model is applied a medium scale watershed in Turkey, how and where required data is gathered from, and how the inputs are generated.

2. NONPOINT SOURCE MODELING

Increasing human activities pose threat to the ecosystems and natural capital of the watersheds. For more than 20 years, nonpoint source pollution is recognized as an essential contributor to the deterioration of water resources in the world (USEPA, 1985). Yet, there is an increasing requirement for better identification and evaluation of the nonpoint pollution sources. Successful management of nonpoint sources requires an understanding of the pollutant transport and transformation mechanisms. These mechanisms are very complex, and a variety of factors such as hydrological, topographical, chemical transport, soil-type and land use conditions are involved. Thus, computer modeling has gained widespread acceptance and models have been used as a major tool to understand and control pollution from nonpoint sources (Singh, 1995; Srinivasan et al., 1998; Beven 2001; Diplas, 2002).

2.1 Overview of Nonpoint Source Models

For addressing research questions and guiding watershed managers, nonpoint pollution models have been widely used in all over the world and many models can be found in the literature. Chemicals, Run off, and Erosion from Agricultural Management (CREAMS), AGricultural Non-Point Source (AGNPS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), Hydrological Simulation Program-Fortran (HSPF), Simulator for Water Resources in Rural Basins (SWRRB), and Soil and Water Assessment Tool (SWAT) are the well known models that simulate nonpoint source pollution. Some of them can be differs from the others according to their abilities such as simulation of single storm events (ANSWERS), simulation of storm and non-storm conditions (SWAT, HSPF, SWRRB).

After the development of Geographic Information System (GIS) in 1990s, application of GIS based models have begun to improve. With the development of decision support systems, GIS, models, and databases are required to solve the complex science and engineering problems (Martin et. al., 2005). GIS has been a popular spatial analysis, interpretation, and display method for different science and engineering disciplines. Also it is identified as an emerging and beneficial technology for water resource professional. The most important benefit of GIS is the ability to readily produce high quality maps incorporating both model output and geographic entities, further enabling visual support during decision making processes (Martin et. al., 2005). Models that have GIS interface are summarized as follows; QUAL2E, water quality model (Yang et al., 1999), ANSWERS, watershed erosion and deposition (Srinivasan and Engel, 1991), MIKE SHE, watershed hydrology and water quality (Borah and Bera, 2004), MIKE BASINS, Watershed hydrology, and water quality (Jha and Das Gupta, 2003), AGNPS, Water quality (Tim and Jolly, 1994), Non-point source pollution control (Liao and Tim, 1997), HSPF, QUAL2E, USEPA BASINS modelling system (Whittemore and Beebe, 2000), IDOR2D, water quality and pollutant transport (Tsanis and Boyle, 2001), SWAT, Watershed hydrology and water quality (Srinivasan and Arnold, 1994).

The Soil and Water Assessment Tool (SWAT) was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch et al., 2005a). The model is basin scaled and physically based. SWAT model has proven to be an effective tool for assessing water resource and nonpoint source pollution problems for a wide range of scales and environmental conditions across the globe. The ArcSWAT ArcGIS extension is a graphical user interface for the SWAT model. By using ArcSWAT, estimation of the nutrient loads is performed easily in basin scale.

Annualized AGricultural Non-Point Source (AnnAGNPS) model has been developed to determine the agricultural management practices' effects on watersheds (Yuan et. al., 2008).

Parajuli et al. (2008) compared simulation results of AnnAGNPS and SWAT models in USDA-CEAP agricultural watersheds in south-central Kansas. By using the hydrology, sediment, and total phosphorus simulation results from AnnAGNPS and SWAT, they separately calibrated and validated the watersheds. It is reported that total phosphorus predictions from calibration and validation of SWAT had indicated good correlation and model efficiency while total phosphorus predictions from validation of AnnAGNPS had been from unsatisfactory to very good results. Parajuli et al. (2008) concluded that study had determined SWAT to be the most appropriate model for this watershed based on calibration and validation results.

In addition to Parajuli et. al. (2008), Heathman et al. (2008) studied application of SWAT and AnnAGNPS models in the St. Joseph River, in USA. Aim of the study was evaluation the performance of two water quality models in accordance to specific tasks designated in the USDA Agricultural Research Service Conservation Effects Assessment Project. According to Heathman et. al. (2008), streamflow prediction results showed that SWAT model performance had been superior to AnnAGNPS. In conclusion, they underlined that use of the SWAT model would be preferable to AnnAGNPS in terms of overall model performance and model support technology.

The nitrogen losses from land to surface waters and the source apportionment of riverine nitrogen load were estimated by two approaches, and the results had been compared by Grizzetti et al. (2005). Comparisons between SWAT and a statistical method based on the SPARROW approach were reported. While both approaches were found to be similar in statistical reliability and both estimated similar total oxidized nitrogen (TON) loads, the authors state that the statistical model should be viewed primarily as a screening tool and that SWAT is more useful for scenarios.

Dynamic Watershed Simulation Model (DWSM), Hydrologic Simulation Program-Fortran (HSPF) model (Bicknell et al., 1997) is able to simulate hydrology, sediment, and chemical yields of watersheds as SWAT model. According to Borah and Bera (2003, 2004), it is reported that SWAT model is promising than DWSM and HSPF models in the field of continuous simulations in predominantly agricultural watersheds.

In a 1999 study, Shepherd et al. evaluated 14 models and they concluded that the most suitable model for estimating phosphorus loss from a lowland watershed in the U.K was SWAT.

Borah, and Bera (2004) reviewed eleven models including AGNPS, AnnAGNPS, ANSWERS, ANSWERS-Continuous, CASC2D, DWSM, HSPF, KINEROS, MIKE SHE, PRMS, and SWAT. SWAT, HSPF and DWSM, watershed-scale hydrologic and nonpoint-source pollution models, were selected as all three models have the three major components including hydrology, sediment, and chemicals. According to

Borah and Bera (2004), SWAT, a promising model for long-term continuous simulations in predominantly agricultural watersheds while HSPF, a promising model for long-term continuous simulations in mixed agricultural and urban watersheds; and DWSM, a promising storm event (rainfall) simulation model for agricultural and suburban watersheds. SWAT and HSPF were found to be suitable for predicting yearly flow volumes, sediment, and nutrient loads.

In the article written by Borah and Bera (2003) watershed-scale hydrologic and nonpoint-source pollution models were reviewed for mathematical bases. It is reported that AGNPS, ANSWERS, DWSM, and KINEROS were useful models for analyzing single rainfall events. Van Liew et al. (2003) compared the stream flow predictions of SWAT and HSPF on eight nested agricultural watersheds within the Little Washita River basin in southwestern Oklahoma, USA. They concluded that SWAT was more consistent than HSPF in estimating stream flow for different climatic conditions and may thus be better suited for investigating the long-term impacts of climate variability on surface water resources.

Saleh and Du (2004) found that the average daily flow, sediment loads, and nutrient loads simulated by SWAT were closer than HSPF to measured values collected at five sites during both the calibration and verification periods for the upper North Bosque River watershed in Texas, USA.

Nasr et al. (2007) found that HSPF predicted mean daily discharges most accurately, while SWAT simulated daily total phosphorus loads the best, in a comparison of three models for three Irish watersheds that ranged in size from 15 to 96 km^2. SWAT estimates were also found to be similar to measured dissolved and total P for the same watershed and 73% of the 22 fields in the watershed were categorized similarly on the basis of the SWAT analysis as compared to the Pennsylvania P index (Veith et al., 2005).

Within the scope of this thesis SWAT model is selected as the nonpoint pollution model. Thus, detailed information about this model and its application is provided in the following sections.

2.2 Historical Development of SWAT Model

The SWAT model is success of thirty years of non-point modeling efforts carried out by not only Agricultural Research Service and Texas A&M University, but also by several federal agencies including the US Environmental Protection Agency, Natural Sources Conservation Service, National Oceanic and Atmospheric Administration and Bureau of Indian Affairs. The development of SWAT has started in the early 1990s by United States Department of Agriculture (USDA), Agricultural Research Service (ARS). A scheme a of SWAT developmental history, including selected SWAT adaptations is showed in **Figure 2.1.** Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980), the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987), and the Environmental Impact Policy Climate (EPIC) model (Izaurralde et al., 2006) were developed by USDA-ARS (Gassman et al., 2007). CREAMS, GLEAMS, and EPIC are known as the origin of the SWAT. In 1980s Simulator for Water Resources in Rural Basins (SWRRB) model was created to simulate management impacts on water and sediment movement for rural basins by adding processes such as daily rainfall hydrology component of CREAMS, pesticide fate component of GLEAMS, and crop growth component of EPIC.

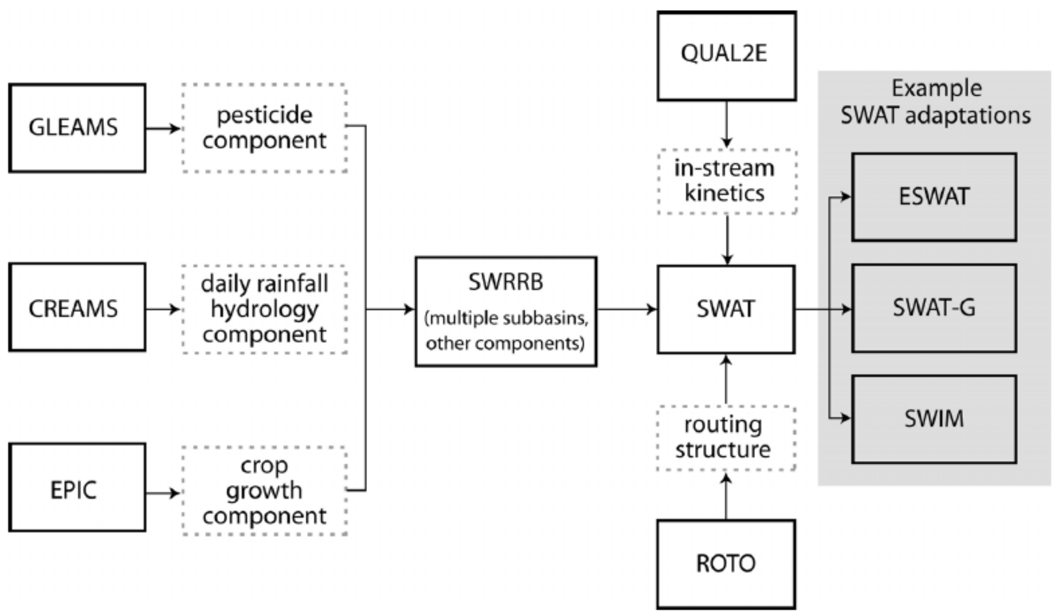

Figure 2.1: SWAT development history including selected SWAT adaptations (Gassman et al., 2007)

Additionally, USDA-SCS technology for estimating peak runoff rates, and sediment yield equations modifications were main modifications that gives SWAT capability of simulating a wide variety of watershed water quality management (Gassman et al., 2007). The result of SWRRB model modifications including QUAL2E responsible for in-stream kinetic and the Routing Outputs to Outlet (ROTO) was developed by Arnold et al. (1995) responsible for routing structure, SWAT model was generated. SWAT model was developed to simulate the impact of land management activities on water sediment, and agricultural chemical yields in the watersheds which have varying soils and land use conditions (Neitsch et al., 2005a). Besides, the model is able to successfully simulate small watersheds as well as large complex watersheds. SWAT is a physically based basin scale model that is known as computationally efficient and capable of continuous simulations (Gassman et al., 2007). SWAT requires some specific input data such as weather, soil properties, topography, vegetation, and land management practices. Thus, relation between the input and output variables is described by model. By the fact that SWAT manages to simulate large basins without time and money consumption, it is a computationally efficient model (Neitsch et al., 2005a). Continuous long-term simulation is performed by the model (up to 100 years) on a daily time-step to predict discharge, sediment, nutrient, and pesticide yields from agricultural watersheds (Neitsch et al., 2005a).

Weather, hydrology, soil properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management are the main components of the model. In SWAT watershed modeling concept includes basin and river simulations. First of all watershed is divided into sub watersheds, further sub watersheds that have components called hydrologic response units (HRUs). HRUs consist of homogeneous land use, management, and soil characteristics.

SWAT has undergone continued review and expansion of capabilities since it was created in the early 1990s (Gassman et al., 2007).

The major progresses of the SWAT are as listed below in the theoretical documentation of SWAT model (Neitsch et al., 2005a):

- SWAT 94.2: Multiple hydrologic response units (HRUs) included.
- SWAT 96.2: Management options including auto-fertilization and auto-irrigation were incorporated. Additionally, canopy storage of water, CO_2 component

for the climatic change studies of crop growth model, Penman-Monteith potential evapotranspiration equation model, lateral flow of water in the soil based on kinematic storage model, QUAL2E in-stream nutrient water quality equations and in-stream pesticide routing were included.

- SWAT 98.1: Management options such as applications of grazing and manure, and tile flow drainage were added. Furthermore, snow melt routines, in-stream water quality, nutrient cycling routines were expanded.
- SWAT 99.2: Improvements of nutrient cycling routines, rice/wetland routines, reservoir/pond/wetland nutrient removal by settling were included. Also, reach processes such as bank storage of water, routing of metals through reach were incorporated. In addition, all year references in model changed from last 2 digits of year to 4-digit year, by contribution of regression equation from USGS, urban build up/wash off equations from SWIMM was added.
- SWAT 2000: Additions including bacteria transport routines, Green&Ampt infiltration, Muskingum routing method, developments such as weather generator, elevation band processes, calculation or reading of potential evapotranspiration values of watershed, generation or reading of daily solar radiation, relative humidity, and wind speed parameters. Also model became able to simulate unlimited number or reservoirs. Additional modifications for the simulation of tropical areas performed by using Dormancy equations.
- SWAT 2005: Scenarios of weather forecast, and sub-daily precipitation generator were incorporated. Bacteria transport routines were developed. Moreover, retention parameter required in the daily curve number calculation may be a function of soil water content or plant evapotranspiration.

Besides the improvements given above, SWAT model interfaces including Windows (Visual basic), GRASS, and Arcview have been build up. Also, the ArcSWAT, ArcGIS extension is a graphical user interface built for the SWAT model. ArcSWAT interface has sensitivity analysis tool that makes the model user friendly.

In SWAT modeling concept, watershed can be divided into subwatersheds by SWAT with digital elevation model (DEM) or specified by the user. SWAT runs on a daily basis and it can be applied in watersheds up to several thousands km^2. After subwatershed generation, hydrological response units (HRUs) are created based on land use soil properties and slope of the subwatersheds. Various physical processes are possible to be simulated for watershed, subwatershed and HRUs by SWAT model.

Hydrology is the driving force for the model. For the prediction of the movement of nutrients, pesticides, sediments, hydrologic cycle have to simulate accurately characteristic of the watershed. As given in **Figure 2.2,** SWAT hydrological simulation separated into two parts including land phase and routing phase. While land phase controls amount of water, sediment, nutrient, and pesticide loading to the main channel in each subwatershed, routing phase defines the movement of water, sediments, etc., through the channel network of the watershed to the outlet (Neitsch and Diluzio, 1999).

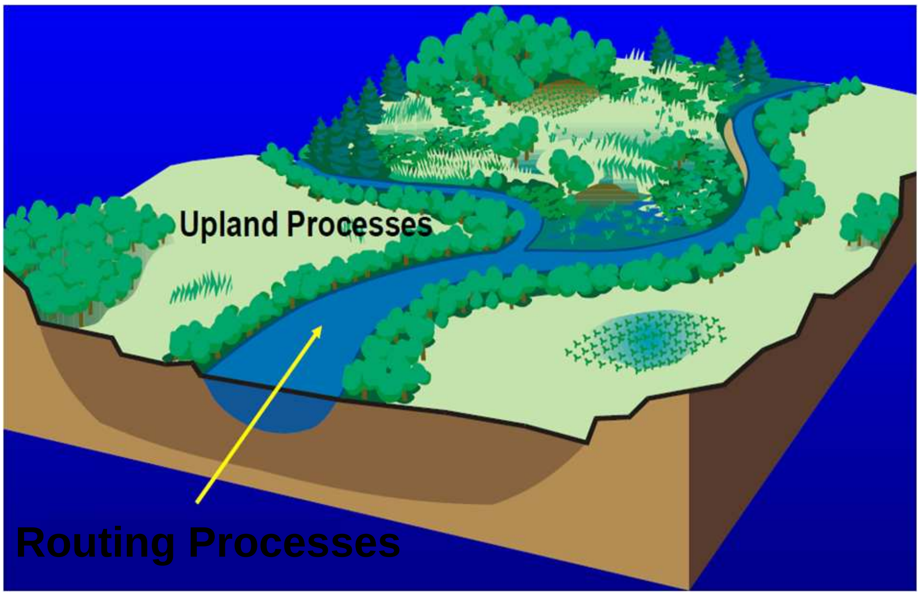

Figure 2.2: Hydrological simulation processes of SWAT model (Srinivasan, 2009)

2.3 Application of SWAT Model in Worldwide

Over the past decade SWAT applications increase rapidly in worldwide. SWAT model (Arnold et al., 1998; Arnold and Fohrer, 2005) has proven to be an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental conditions across the globe. SWAT has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences, hundreds of SWAT-related papers presented at numerous other scientific meetings, and dozens of articles published in peer-reviewed journals (Gassman et al., 2007).

SWAT model can be applied to various watersheds and for water quality modeling. For instance, national and regional scale water resource assessment considering both current and projected management conditions. An example is from Texas, USA, Bosque River Total maximum daily load (TMDL) project. The scope of the project was determination of sediment, nitrogen, and phosphorus loadings to Lake Waco from various sources including dairy waste application areas, waste treatment plants, urban areas, conventional row crops and rangeland. Numerous land management practices were simulated and analyzed (Saleh et al., 2000). Additionally, TDML was determined for Poteau River in Oklahoma/Arkansas, USA. Sediment, nitrogen and phosphorus loadings, dissolved oxygen, temperature, algae, and Carbonaceous Biochemical Oxygen Demand (CBOD) in the river were assessed (Srinivasan et al., 2000). Furthermore, application of SWAT for past and future sediment contamination by DDT was used for simulation of Yakima River basin in Washington, USA. In United States and Europe, SWAT model is being applied extensively for the assessment of the impact of global climate change on water supply and quality (Rosenberg et al., 1999).

SWAT model was used for direct assessments of anthropogenic effects, climate change, and other influences on water resources for the needs of governmental agencies particularly in the Unites States (US) and European Union (EU).

Many U.S. federal and state agencies, including the USDA within the Conservation Effects Assessment Project (CEAP) use the SWAT model adopted as part of the U.S. Environmental Protection Agency (USEPA) Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) software package.

In addition to increased applications in USA, the model has also been widely used in Europe and other regions. Four international SWAT conferences held in different countries.

Many articles published have relevant application categories such as stream flow calibration and related hydrologic analyses, climate change impacts on hydrology, pollutant load assessments, comparisons with other models, and sensitivity analyses and calibration techniques. Furthermore, strengths and weaknesses of the model are presented, and recommended research needs for SWAT are also provided (Gassman et al., 2007).

Several SWAT applications for the prediction of nutrient loads are summarized as follows:

- In the study carried by Santhi et al. (2001), successful calibration and validation of a SWAT model was made for sediment and nutrients simulations for the Bosque River watershed with the area of 4300 km^2 which is dominated by pasture, range, and row crop land uses in Texas, USA.
- Verde River Watershed 5500 square mile in the arid southwest of central Arizona, USA simulated by Tetra Tech team in 2001. They reported an excellent hydrologic calibration and what appeared to be a good representation of nutrient loading from a wide variety of natural vegetation covers.
- SWAT simulations of nutrient loading at the scale of 6-digit hydrologic units have been developed as part of the Hydrologic Unit Model for the United States (HUMUS) project (Srinivasan et al., 2000).
- The SWAT model efficiently identified critical source sediment and phosphorus areas within the Wister Lake basin. SWAT predicted 57,000 metric tons a year of sediment and 84,000 kilograms a year of total phosphorus from upland areas in the basin. This allowed identifying and contacting specific agricultural producers to recruit into their water quality program. This methodology is directly applicable to any basin that is primarily agricultural (Busteed, 2009).

2.4 Advantages and Disadvantages of the SWAT Model

As a worldwide commonly used model, SWAT has advantages and disadvantages based on hydrology, nutrient loads, data requirements etc. In comparison to other commonly used watershed models advantages of the SWAT model are (Url-1):

- SWAT explicitly incorporates elevation or orographic effects on precipitation and temperature.
- SWAT was developed for and has been widely applied to simulation of watersheds in arid regions.
- SWAT explicitly incorporates routines for agricultural diversions and irrigation.
- SWAT includes routines designed to address the impacts on flow and pollutant loading of multiple small (or large) farm ponds within a basin.
- SWAT is designed to use either observed meteorological data or statistically generated meteorology, facilitating the development of long-term analyses.

As a result of being a physically based model and using commonly available geographic data, it is claimed “Watersheds with no monitoring data could be modeled, allowing the efficient evaluation of relative impact of alternative input data (e.g., changes in management practices, climate, vegetation, etc.) on water quality” (USEPA CREM, 2004).

Although SWAT has many advantages in comparison to other watershed models, it has some limitations based on structure and finance. SWAT model has Geographic Information System interfaces such as ArcSWAT and MWSWAT. The user can use ArcGIS or Map Window Geographic Information System (MWGIS) according to their purposes as well. MWGIS is a free software and easily downloadable from the web. Besides MWSWAT has weakness such as limited ability to simulate big watersheds, some problems in delineations of watershed step. But, ArcSWAT is able to simulate large and small scaled watersheds easily, and has more tools including management of the agricultural area. In spite of the advantages of ArcSWAT interface, ArcGIS is expensive software and also may have some installation problems. In terms of its cost, ArcSWAT is a disadvantageous model. Due to the cost of the software application ArcSWAT is limited in developing countries. Besides, it is also a disadvantage for master (MSc) and (PhD) students if they do not get financial support from their university or from other institutions.

Other than the financial limitations, several structural weaknesses can also be mentioned. Although SWAT is a process-based model, it intentionally incorporates simplified representations of most processes. Thus, many parameters can be gained from readily available geospatial coverage. For instance, SWAT relies on the well-tested, semi-empirical approaches of the SCS Curve Number and MUSLE while generating the upland flow and sediment. Another structural disadvantage is noted in (Url-1) “Default SWAT algorithm may yield unrealistic results from Hydrological Response Units (HRUs) that contain a mix of urban pervious and impervious land cover because MUSLE is calculated with the peak flow from the entire HRU, using a weighted curve number, and not from the flow from the pervious section. This is equivalent to assuming that all impervious area runoff proceeds as sheet flow across the pervious sections, rather than being piped or channelized, and can result in a significant overestimation of sediment load from developed areas”.

In SWAT nutrient processes, it should be noted that nutrient loads predicted by the model can be considered as estimates of cumulative yield, rather than loads from individual events. By water and sediments, dissolved and sorbed forms of nutrients are moved from uplands to streams. Nutrient balances in the soil (as well as the cover index for erosion calculations) are determined by the results of plant growth simulation – which is considerably more complex and difficult to validate. In addition to upland nutrient processes, SWAT does not provide an accurate representation of intra-event concentrations of even conservative constituents in streams with rapid responses for the reason that both upland loads and instream routing are simulated at a daily time step. The routing time for nutrients in a reach is forced to be equal to one day. This means that rate constants are actually implemented as step-function reductions. Thus, routing within streams adds further limitations to SWAT predictions. It should be taken into consideration that the instream concentrations are not necessarily realistic representations of expected concentrations. Further, the mass transport through reaches of nonconservative parameters will be realistic only when the reach travel time approximates one day.

Furthermore, Borah and Bera reported (2004) that SWAT require a significant amount of data and empirical parameters for development and calibration.

2.5 SWAT Model Inputs

Input for SWAT is defined in several different levels including watershed, subbasin, and Hydrological Response Unit (HRU). HRU is a part of the watershed that has unique soil type, land use, and slope. Inputs defined in watershed level used to simulate processes throughout the watershed. Subbasin inputs are also set at the same value for all HRUs in the subbasin. Since each subbasin have one reach, main channel input data is defined at subbasin level. For instance, the same rainfall data is used for all HRUs, stream, any ponds or wetlands located in subbasin. HRU level inputs can be set unique values for each HRU such as management scenario that is possible to define differently based on HRU.

Within the scope of this thesis, SWAT model ArcSWAT interface is decided to be used for the application of the model in Köyceğiz Dalyan Watershed. ArcSWAT interface requires to access ArcGIS compatible raster (GRIDS) and vector datasets (shape files and feature classes) at the same time as creating a SWAT dataset. The necessary spatial datasets and database files that need to be prepared prior to running the interface are given as follows and all required ArcSWAT spatial datasets will be presented in detail in the following sections.

- Digital Elevation Model (DEM)
- Land use
- Soil properties
- Meteorological data
- Management data

2.5.1 Digital Elevation Model (DEM)

Digital elevation model is required to delineate the watershed. DEM is needed to be in ESRI GRID format. The user can prefer integer or real numbers for elevation values. Also, interface does not require identical in definition of GRID resolution and elevation units. The unit of GRID resolution must be in meters, kilometers, feet, yards, miles, and decimal degrees, whereas the unit of elevation must be defined in meters, centimeters, yards, feet, inches. An example DEM is given in **Figure 2.3**. The DEM is also used to calculate sub basin parameters, such as slope and slope length and to characterize stream network properties, i.e. channel slope, length and width (Busteed, 2009).

Figure 2.3: DEM of Lake Fork Watershed in Northeast Texas (Neitsch et al., 2005)

2.5.2 Land use and land cover

Land use/land cover map is needed to be in ESRI GRID, shape file, or feature class formats. Land use/land cover map must cover at least 95% of the simulated area. An example land use/land cover map is given in **Figure 2.4**. The categories selected in the land use and land cover map must be reclassified into SWAT database of land cover/plant types. To reclassify the categories of land use and cover, user has three options:

- building a land use/land cover look up table into the ArcSWAT interface (the interface contains USGS LULC and NLCD 1992 lookup tables)
- typing the SWAT land use/land cover codes for each category
- creating a user look up table identifies SWAT codes for different categories

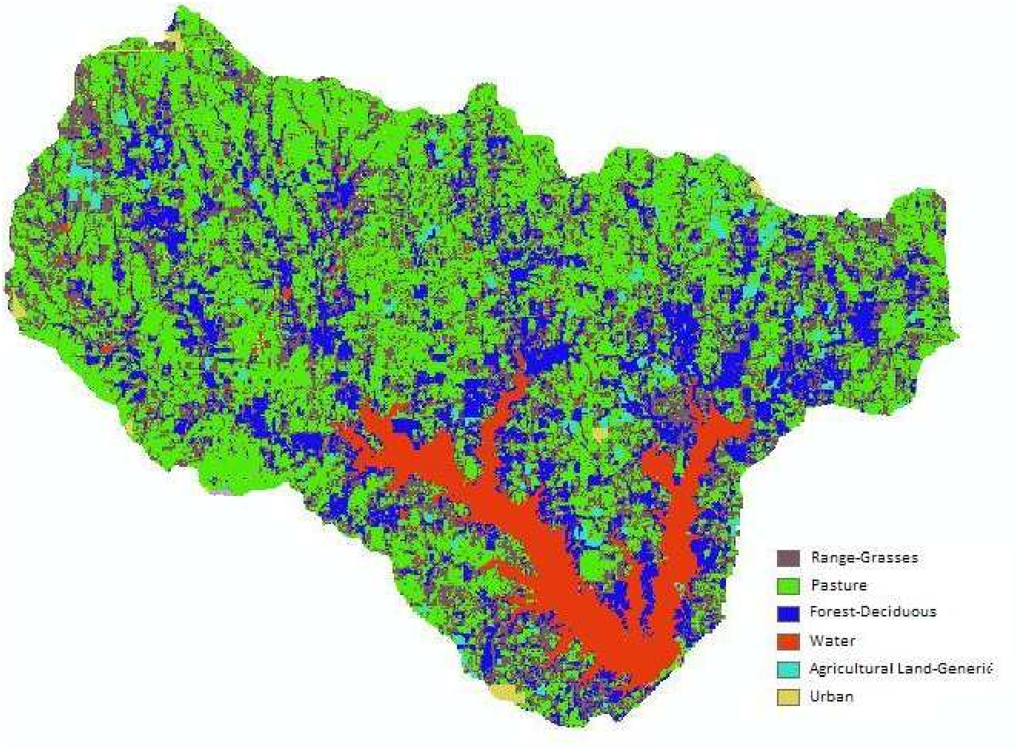

Figure 2.4: Land use/Land cover map of the Lake Fork Watershed in Northeast Texas (Neitsch et al., 2005a)

Land cover data are some of the most important GIS data used in the model. Land covers yield different runoff, nutrient loads and erosion rates (Busteed, 2009).

2.5.3 Soil properties

Soil map is needed to be one of the formats including ESRI GRID, shape file, or feature class. **Figure 2.5** shows an example view of soil map. Soil map must cover at least 95% of the simulated area. The categories specified in soil map required to be linked to the SWAT soil database. The user can add the soil types and its properties into the SWAT soil database by using ArcSWAT edit database tool or importing SWAT soil files (.sol). To link between soil map and soil database, user has four options:

- Using STATSGO polygon (MUID) number. SWAT soil database include information for the all soil phases found in a polygon and for all polygon in entire U.S. In this option (Stmuid), data for the dominant soil type is used for the map category.
- Using Stmuid+Seqn option. In this option user can choose a soil other than the dominant soil in the MUID.
- Using Name option. Model allows to specified user soil type name in soil map. In this case user must import SWAT soil file (.sol) or type the soil data into the soil database.

Using S5id option. If S5id option is selected, data for the specified soil series is used to represent the map unit. In order to use this option, U.S soil database must be installed.

Soil texture properties required for soil database are as given in **Table 2.1**

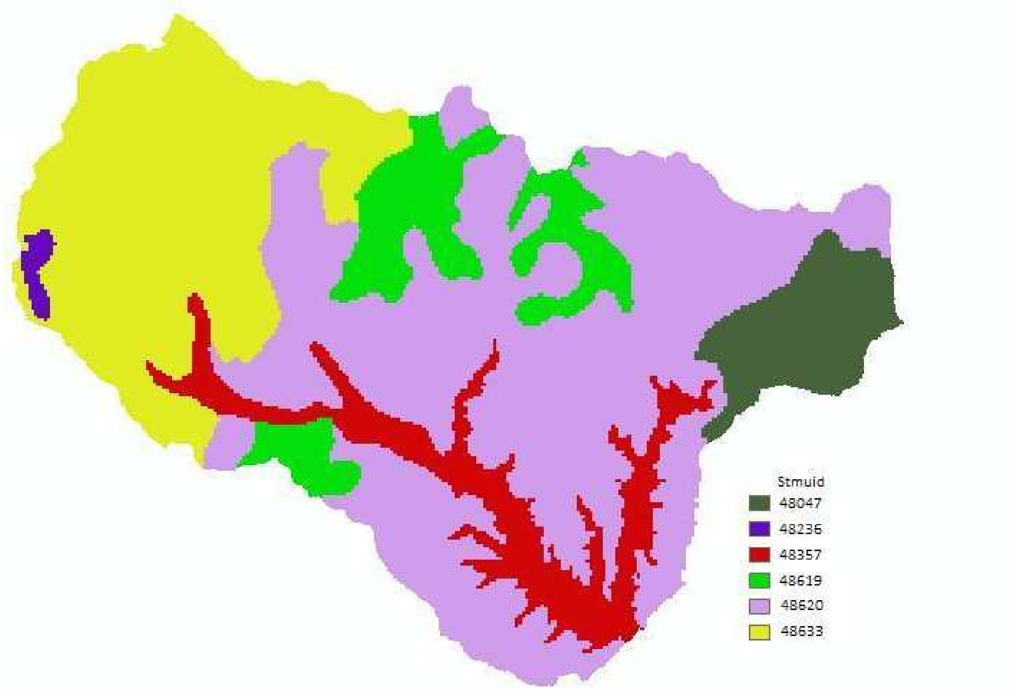

Figure 2.5: Soil map of the Lake Fork Watershed in Northeast Texas (Neitsch et al., 2005a)

Table 2.1: Soil database parameters of SWAT model

PARAMETER	DEFINITION
SNAM	The soil name is printed in HRU summary tables (optional).
NLAYERS	Number of layers (max 10, and max depth of each layer is 2,5 m)
HYDGRP	Soil hydrologic group (A, B, C,D)
SOL_ZMX	Maximum rooting depth of soil profile (mm). If no depth is specified, the model assumes the roots can develop throughout the entire depth of soil profile (required)
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded (optional).
SOL_CRK	Potential or maximum crack volume of soil profile expressed as a fraction of the total soil volume (optional).
TEXTURE	This data is not processed by the model (optional).
SOL_Z1	Depth from soil surface to bottom of the layer (mm) (required).
SOL_BD1	Soil bulk density (1,1-1,9 μ/m^3, g/cm^3) (required).
SOL_AWC1	Available water capacity of soil layer (mmH_2O/mm soil) (required).
SOL_K1	Saturated hydraulic conductivity (mm/hr) (required).
SOL_CBN1	Organic carbon content (% soil weight) (required).
CLAY1	Clay content, percentage of soil particles which are < 0.002 mm in equivalent diameter (% soil weight) (required).
SILT1	Silt content, percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 (% soil weight) (required).
SAND1	Sand content percentage of soil particles which have an equivalent diameter between 2 and 0.05 (% soil weight) (required).
ROCK1	Rock fragment content, the percent of sample which has a particle size diameter >2 mm (% total weight) (required).
SOL_ALB1	Moist soil albedo. The ratio of the amount of solar radiation reflected by body to the amount incident upon it. (fraction) (required).
USLE_K1	USLE equation soil erodibility factor (metric ton m^2 hr/ m^3 metric ton cm) (If the sand and clay content of soil is high, less erodible) (required).
SOL_EC1	Electrical conductivity (dS/m)

2.5.5 Meteorological data

Meteorological data is essential part of the inputs. For a representative simulation, obtaining accurate meteorological dataset is a vital step. Main meteorological data are precipitation and temperature. Others including solar radiation, wind velocity, relative humidity can be produced by the model based on precipitation and temperature data or user can import these data. Model requires weather generator gage location table including latitude, longitude and elevation of the weather stations close to the project area. In addition, if there is missing data, SWAT is able to generate them according to provided data.

While meteorology input files must contain data for the entire period of simulation, the record does not have to begin with the first day of simulation. SWAT is able to look up for the beginning date in the file. Thus, after uploading the data for a long period, the user can easily run the model for different time periods.

Daily or sub-daily precipitation data is required in SWAT. If SCS curve number method is used model requires daily precipitation data, whereas, sub-daily precipitation data is needed if Green&Ampt infiltration method is used. Model may read the values from observed data records or may generate the data. Model does not limit the number of precipitation gages in a simulation. Firstly, when the measured data are to be used, model requires a precipitation gage location table which should include the locations of the rain gages. One precipitation data file, for each location listed as rain gage in rain gage location table have to be prepared beforehand. The daily precipitation data is used to store the data for an individual rain gage.

SWAT needs daily maximum and minimum air temperature data. As informed above, model read the temperature data from the observed data record or they may be generated. Model does not limit the number of temperature gages used in a simulation. As with the precipitation file, model requires a temperature gage location table to provide the locations of the rain gages, when the measured data are to be used. The temperature data is used to store daily maximum and minimum temperatures for a weather station. One temperature data file, for each location listed as temperature gage in temperature gage location table have to be prepared before the simulations.

Model requires a solar radiation, wind speed, or relative humidity gage location table to provide the locations of gages, when the measured data are to be used.

SWAT requires daily solar radiation data. As noted for precipitation and temperature data, model able to read solar radiation records from observed data or generate them. It is allowed to use one solar radiation file in a simulation. But model does not limit the number of temperature gages used in a simulation. Thus, solar radiation data file may contain more than one gage data in a simulation. Solar radiation data is used to store the total daily amounts recorded at a specific station of solar radiation reaching to the ground. One solar radiation data file, for each location listed as solar radiation gage in solar radiation location table have to be prepared beforehand.

Daily wind speed values are required since Penman-Monteith method is selected to calculate potential evapotranspiration. SWAT model read the wind speed data from the observed data record or may generate it. While model does not limit the number of wind speed gages used in a simulation, one wind speed input file which is able to hold records more than one gage, may be used in a simulation. Wind velocity data is used to store the average daily wind speed recorded at a specific weather station. One wind velocity data file, for each location listed as wind velocity gage in wind velocity location table have to be prepared before the simulation.

Daily relative humidity values are required since Penman-Monteith method or Pristley-Taylor method is selected to calculate potential evapotranspiration and water stress on plant growth. SWAT model read the humidity data from the observed data record or may generate it. It is allowed to use one relative humidity file in a simulation. But model does not limit the number of relative humidity gages used in a simulation. Further, one relative humidity input file able to hold records more than one gage. Relative humidity data is used to store the fraction relative humidity recorded at a specific weather station. One relative humidity data file, for each location listed as relative humidity gage in relative humidity location table have to be prepared in advance.

2.5.5 Management data

Main aim of the watershed modeling is to evaluate the impact of human activities on a specified system. Land and water management activities play an important role and thought as the center of this assessment. SWAT management option is used specifically for a HRU. HRU management file (.mgt) contains input data for planting, harvesting, irrigation application, nutrient applications, pesticide applications, and tillage operations.

Management file is separated into two parts. First of all initial conditions or management practices that never change during the simulation are summarized. Second part includes list of management operations taking place at specific times.

General management variables that also include initial conditions are listed below:

- Initial plant growth parameters
- General management parameters
- Urban management parameters
- Irrigation management parameters
- Tile drain management parameters
- Management operations

Scheduled management operations are given below:

- Planting/beginning of growing season
- Irrigation operation
- Fertilizer application
- Pesticide application
- Harvest and kill operation
- Tillage operation
- Harvest operation
- Kill operation
- Grazing operation
- Auto irrigation and fertilizer initialization
- Street sweeping operation
- Release/impound operation
- Continuous fertilizer operation
- End of year operation

All of the management options listed above, are explained in detail in the SWAT input/output file document (Neitsch et al., 2005b)

2.6 SWAT Modeling System

SWAT can simulate a single watershed or a system of multiple hydrologically connected watersheds. Division of the watershed into subunits is the initial step of the simulation. Subunits allowed to be defined in the watershed are including, subbasins, HRUs, wetland, pond, main channels, impoundments, and point sources.

First level of subdivision is the subbasin. Subbasin is the one of the main units of SWAT model. **Figure 2.6** shows the subbasins and reaches of an example watershed system. Although minimum 1 HRU is required, unlimited numbers of HRUs are allowed to be defined in a subbasin. Also, user is able to define one pond and one wetland per subbasin if it is needed. One main channel or reach is identified for each subbasin. Impoundment is allowed to be specified on main channel network.

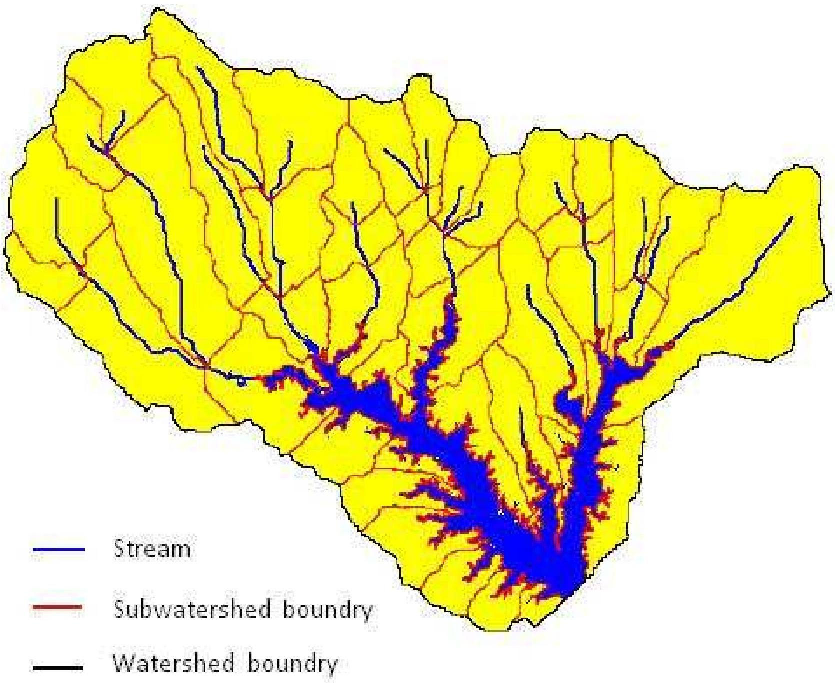

Figure 2.6: Lake Fork Watershed in Northeast Texas (Neitsch et al., 2005a)

Hydrology is essential processes for the watershed models. **Figure 2.7** shows the pathways available for water movement in SWAT. In SWAT water balance separated into two parts including land phase of hydrologic cycle and water or routing phase of hydrologic cycle. Land phase of the hydrologic cycle is as shown in **Figure 2.8**.

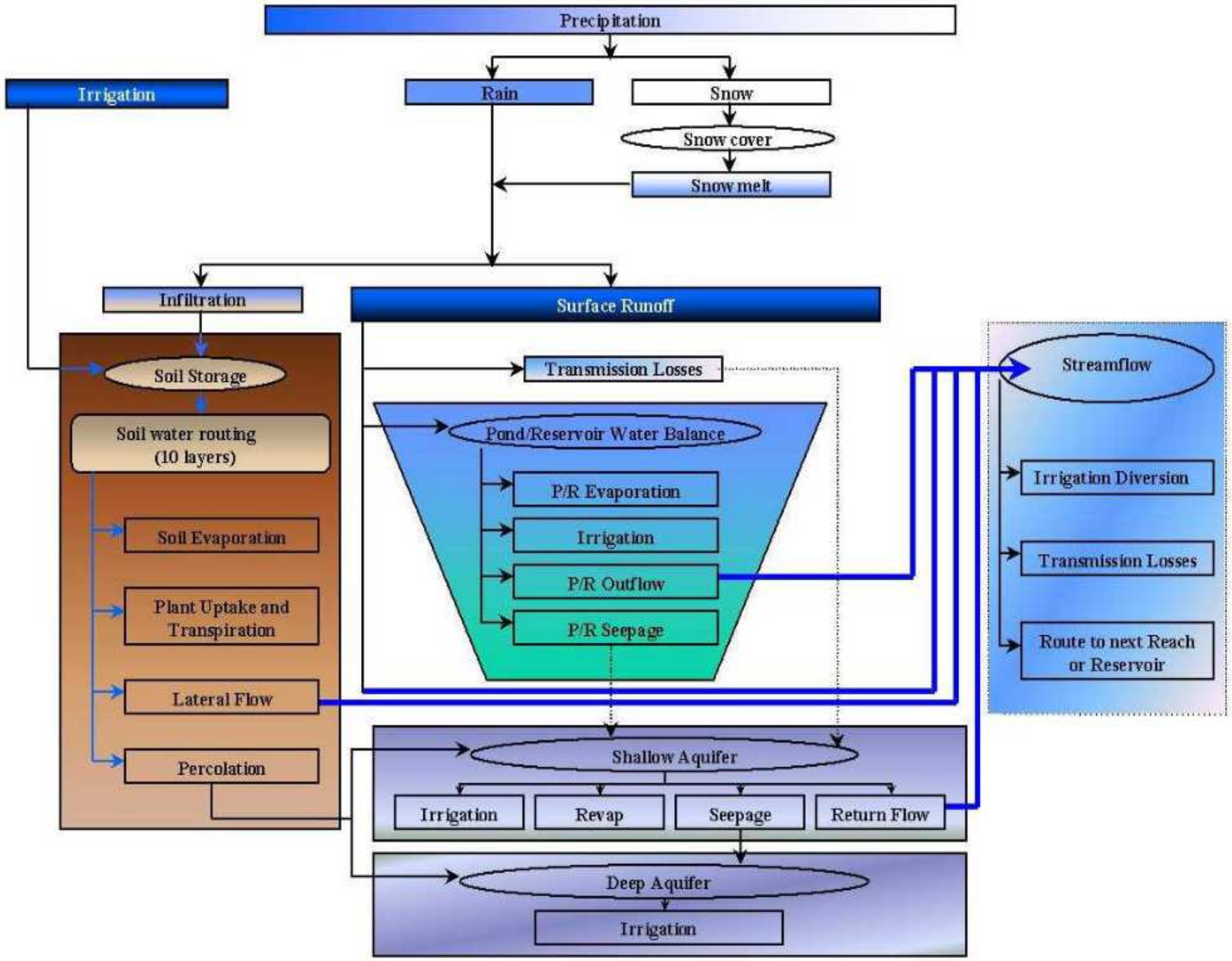

Figure 2.7: Pathways available for water movement in SWAT

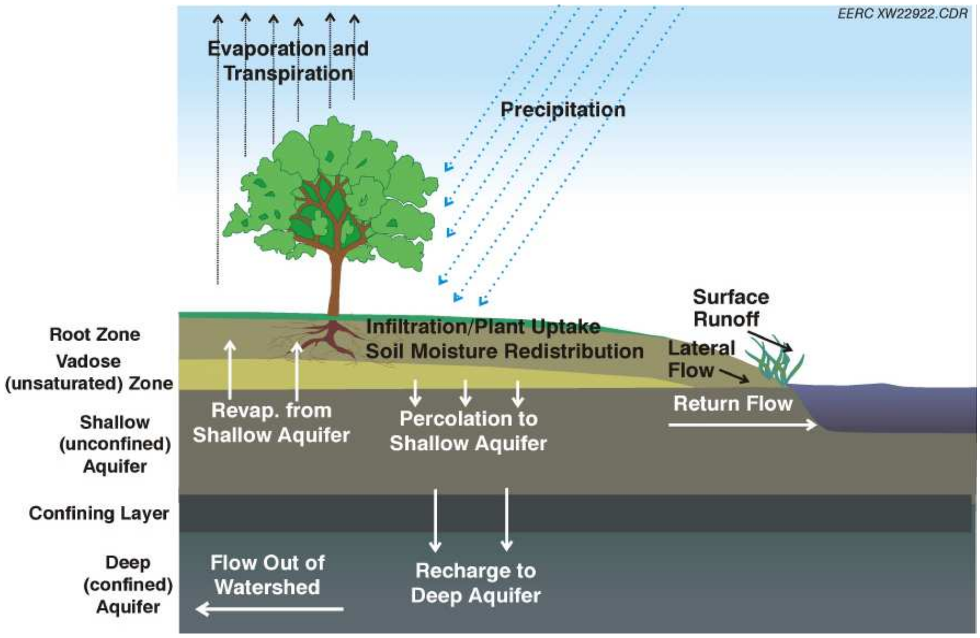

Figure 2.8: Schematic representation of land phase of the hydrologic cycle (Neitsch et al., 2005a)

In land phase hydrology, movement of water through vertical direction is simulated for root zone (soil profile), shallow (unconfined) aquifer, and deep (confined) aquifer. Water falls into the ground as rain or snow, flows through the surface, infiltrates uptaken by plants, flow laterally, and percolates to shallow aquifer. A storage routing technique is used to calculate redistribution of water between layers in the soil profile.

Recharge below the soil profile is partitioned between shallow and deep aquifers. In shallow aquifer zone, water follows three ways; it returns to the soil profile according to the water deficiencies, contributes to the main channel, or recharges to the deep aquifer. Finally it is accepted that water storage in the deep aquifer contributes the main channel somewhere out of the watershed. Besides the hydrology, transmission of the nutrients and pesticides, plant growth, and sediment transport processes are simulated for land phase. Nutrient processes will be described detailed in the following sections.

In SWAT routing phase; run off, rain, lateral flow, groundwater contribution, point discharges are the inputs of main channel water balance while outputs are evaporation, transmission losses, and extraction for human use. **Figure 2.9** shows the schematic representation of the water balance in the main channel. Other main channel routing processes are nutrient routing, pesticide routing, and sediment routing. SWAT models dissolved and adsorbed nutrients based on the in-stream kinetics adapted from QUAL2E. Pesticide routing simulation processes are settling, burial, resuspension, volatilization, diffusion, and transformation. Sediment routing includes deposition, resuspension, and erosion.

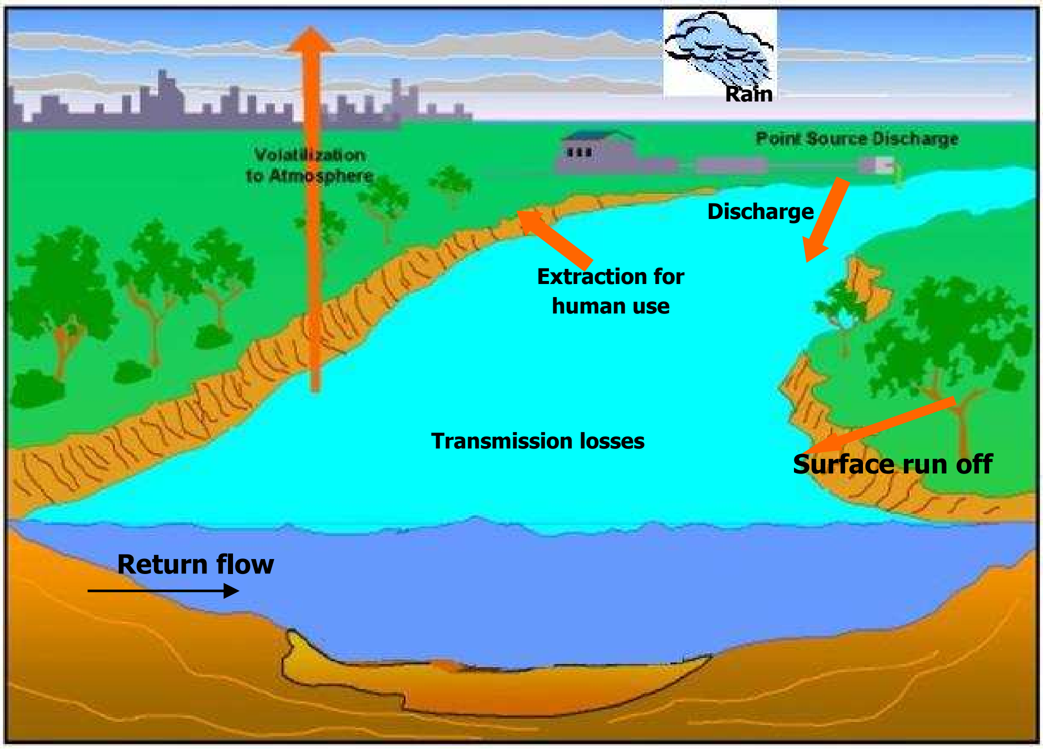

Figure 2.9: Schematic representation of routing phase of the hydrologic cycle (Neitsch et al., 2005a)

2.6.2 Delineation of watershed

To complete land phase and routing phase processes such as hydrology, transport of nutrients and pesticides, and other processes explained in previous section, firstly watershed must be delineated. By using DEM, watershed delineation tool allows the user create subwatersheds based on an automatic procedure. To perform watershed delineation ArcGIS and Spatial Analyst extension functions are used and expanded. Area and the number of the subwatersheds can be controlled with user specified parameters. Furthermore, interface allows the user to import pre-defined watershed boundaries and a stream network.

SWAT calculates total watershed dimensions from the watershed configuration given in the .fig file.

2.6.2 Hydrological Response Unit (HRU) analysis

Hydrological response units are the smallest unit of the SWAT model. The HRU is a part of subbasin consists of a unique combination of land use, soil type, and slope. After the watershed delineation step, user creates the HRUs based on optional ratios of the land use, soil type, and slope. The SWAT land use ratio, soil type ratio over subbasin area and slope ratio is possible to change between the 100-0%. This threshold determines the minimum percentage of any land cover or soil type in a sub basin that will become a HRU. By reducing these thresholds to 0%, all land covers and soil combinations in the basin are represented (Busteed, 2009).

Each HRU has its own management practices including fertilization, irrigation, crop growth etc. User can specify different management for each HRU or if it is required, one management schedule can be loaded for multiple HRUs.

It is possible that a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management (Gassman et al., 2007). In this case, each subwatershed becomes a HRU.

The overall hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers (Gassman et al., 2007)

2.6.3 Hydrology

After the precipitation falls in the land, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Canopy storage is the water intercepted by vegetative surfaces. Water from soil surface, infiltrates into the soil profile or flow as runoff. Infiltrated water may be stay in soil profile and then evapotranspired or it may move to surface water bodies via underground paths.

SWAT has three methods to estimate surface runoff from HRUs including combinations of daily or sub-hourly rainfall and the USDA Natural Resources Conservation Service (NRCS) curve number (CN) method or the Green-Ampt method.

Three options are exist for estimating potential evapotranspiration such as Penman-Monteith, Priestly-Taylor, and Hargreaves (Hargreaves et al., 1975). Also, estimated external evapotranspiration values can be input for a simulation run (Gassman et al., 2007).

If Penman-Monteith (Monteith, 1965) or Priestly-Taylor (Priestly and Taylor, 1972) evapotranspiration (ET) routines are used, Relative humidity is required. Wind speed is only needed if the Penman-Monteith method is used. Measured or generated sub-daily precipitation inputs are required if the Green-Ampt infiltration method is used. The maximum and minimum temperature inputs are required in the calculation of daily soil and water temperatures.

2.6.4 Management operations

Management operations control the plant growth cycle. Timing of the fertilizer and pesticide applications, removal of the plant biomass are organized with the management tool. SWAT model management options were listed in Section 2.6. Also, detailed information about management options and explanations of applications are included in SWAT Theoretical Documentation (Neitsch et al., 2005a). In this section, only fertilizer application will be viewed.

Fertilizer operation is the application of manure or fertilizer to the soil. Timing of the operation, type of the fertilizer/manure, amount of the fertilizer/manure, depth distribution of fertilizer application are the required data for the operation. Weight fractions of the different fertilizers and bacteria are defined in the SWAT fertilizer database. User can specify ratio of the fertilizer which is found in top 10 mm of soil. Other part of the fertilizer is assumed to be in first layer of the soil profile. According to SWAT, surface runoff interacts with the top 10 mm of soil.

By using the equations given below, SWAT calculates the amounts of different pools of nutrient added to the soil.

$$NO3_{fert} = fert_{minN} \cdot (1 - fert_{NH4}) \cdot fert \tag{2.1}$$

$$NH4_{fert} = fert_{minN} \cdot fert_{NH4} \cdot fert \tag{2.2}$$

$$orgN_{frsh,fert} = 0.5 \cdot fert_{orgN} \cdot fert \tag{2.3}$$

$$orgN_{act,fert} = 0.5 \cdot fert_{orgN} \cdot fert \tag{2.4}$$

$$P_{solution,fert} = fert_{minP} \cdot fert \tag{2.5}$$

$$orgP_{frsh,fert} = 0.5 \cdot fert_{orgP} \cdot fert \tag{2.6}$$

$$orgP_{hum,fert} = 0.5 \cdot fert_{orgP} \cdot fert \tag{2.7}$$

where NO_{3fert} is the amount of nitrate added to the soil in the fertilizer (kgN/ha), NH_{4fert} is the amount of ammonium added to the soil in the fertilizer (kgN/ha), $orgN_{frsh,fert}$ is the amount of the nitrogen in the fresh organic pool added to the soil in the fertilizer (kg N/ha), $orgN_{act,fert}$ is the amount of nitrogen in the active organic pool added to the soil in the fertilizer (kg N/ha), $P_{solution,fert}$ is the amount of phosphorus in the solution pool added to the soil in the fertilizer (kg P/ha), $orgP_{fresh,fert}$ is the amount of phosphorus in the fresh organic pool added to the soil in fertilizer (kgP/ha), $orgP_{hum,fert}$ is the amount of phosphorus in the humus organic pool added to the soil in fertilizer (kgP/ha), $fert_{minN}$ is the fraction of mineral N in the fertilizer, $fert_{NH4}$ is the fraction of mineral N in the fertilizer that is ammonium, fer_{orgN} is the fraction of mineral N in the fertilizer, fer_{orgP} is the fraction of organic P in the fertilizer, and fert is the amount of fertilizer applied to the soil (kg/ha).

SWAT has two options for fertilizer application. User can schedule fertilization or automatically SWAT applies the fertilizer. If the auto fertilizer application option is selected, nitrogen stress threshold must be specified. SWAT decides the amount and timing of the fertilizer based on the nitrogen stress parameter. When the actual plant growth is less than the nitrogen stress threshold because of the nitrogen stress, model automatically applies fertilizer to the HRU. In addition to nitrogen stress threshold, user must specify type of the fertilizer, fraction of total fertilizer applied to the soil surface, the maximum amount of fertilizer that can be applied during the year, the maximum amount of fertilizer can be applied in any one application, and application efficiency.

2.7 Model Outputs

SWAT has the following output files: summary of the input file Input.std, summary of the output file Output.std, HRU output file Output.hru, subbasin output file Output.bsn, main channel output file Output.rch.

- Input.std file prints summary of essential input values such as area, latitude, longitude, slope of the subbasin and the HRU.
- Output.std file includes watershed average loading from HRUs to the stream. Besides, average annual values of some parameters based on HRU and subbasin are printed in Output.std file.
- Output.hru file includes summarized information about each HRU. In addition file contains the parameters are given below for each HRU. **Figure 2.10** shows the scheme of hydrological output parameters for HRU and **Figure 2.11** shows the scheme of output parameters of nutrients for HRU. All outputs parameters for HRU is provided in Appendix A.

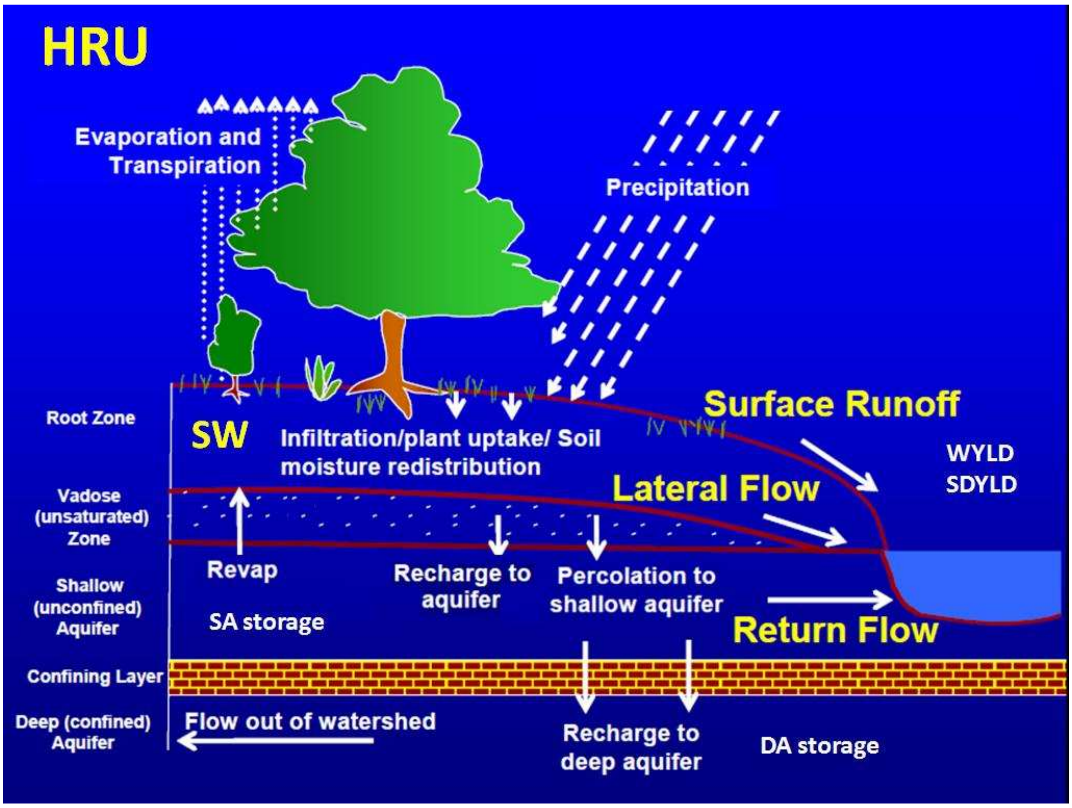

Figure 2.10: Schema of hydrological output parameters for HRU (Srinivasan, 2009)

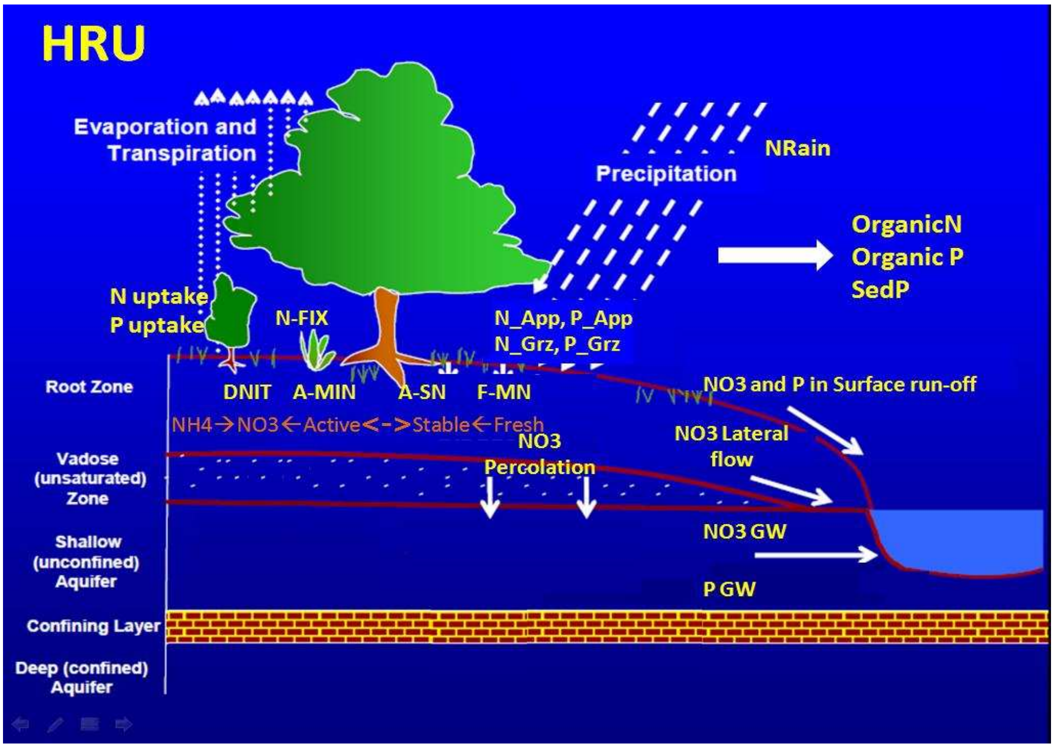

Figure 2.11: Schema of output parameters of nutrients for HRU (Srinivasan, 2009)

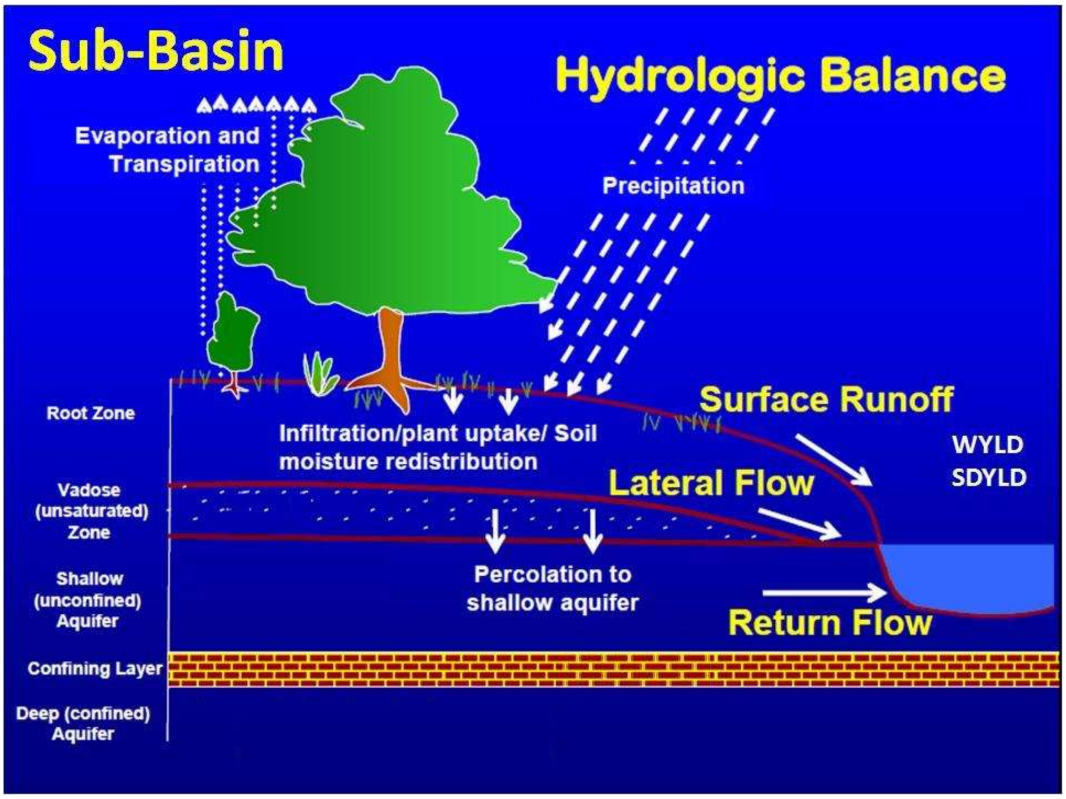

Figure 2.12: Scheme of hydrological output parameters for subbasin (Srinivasan, 2009)

- Output.bsn file includes summarized information about each subbasin. In addition file contains the parameters are given below for each subbasin. **Figure 2.12** shows the schematic of hydrological output parameters for subbasin and **Figure 2.13** shows the schematic of output parameters of nutrients for subbasin. All subbasin output parameters are provided with their symbols and definitions in Appendix A.

- Output.rch file includes summarized information for each routing reach. In addition file contains the parameters are given below for each reach. **Figure 2.14** show the output parameters of hydrological balance in the stream. **Figure 2.15** shows the nutrient routing parameters in the stream. All reach output parameters are provided with their symbols and definitions in Appendix A.

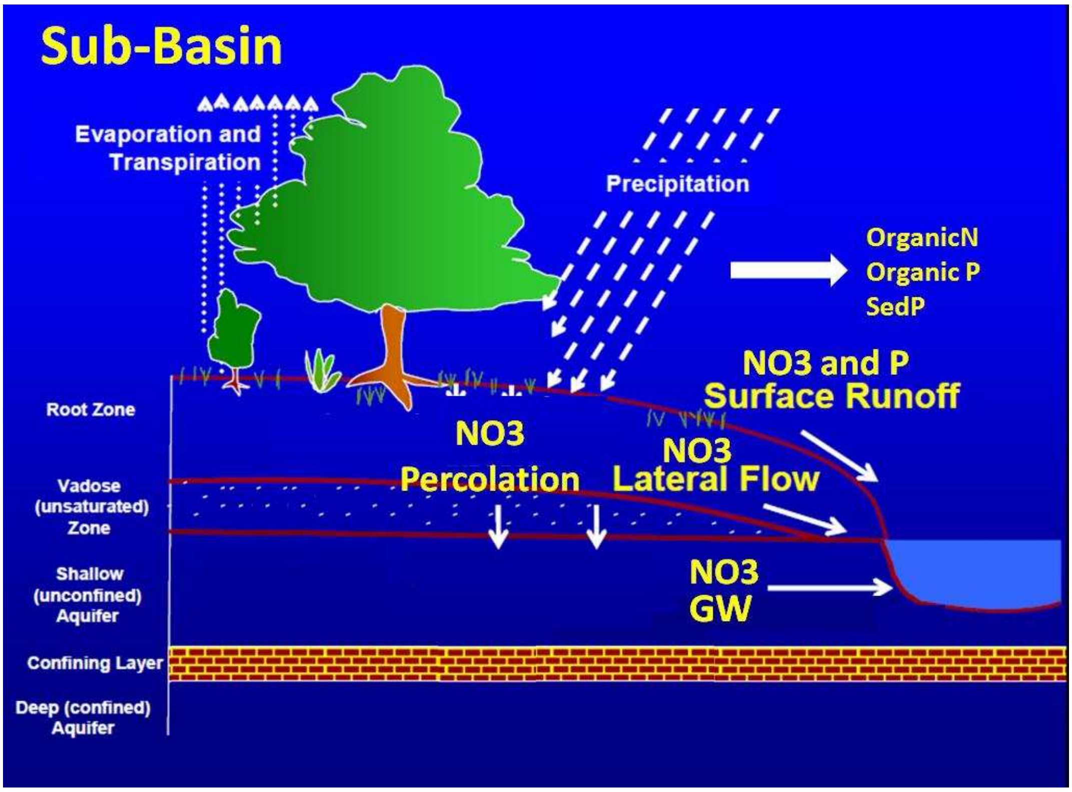

Figure 2.13: Scheme of output parameters of nutrients for subbasin (Srinivasan, 2009)

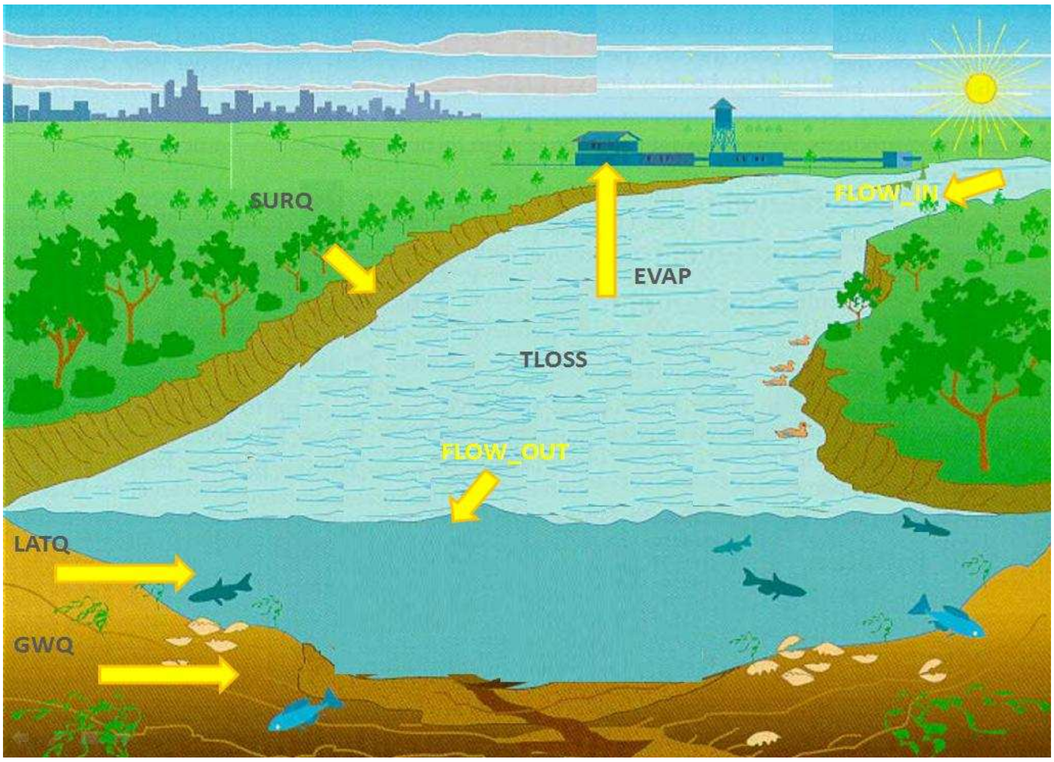

Figure 2.14: Schema of the output parameters of hydrological balance in the stream

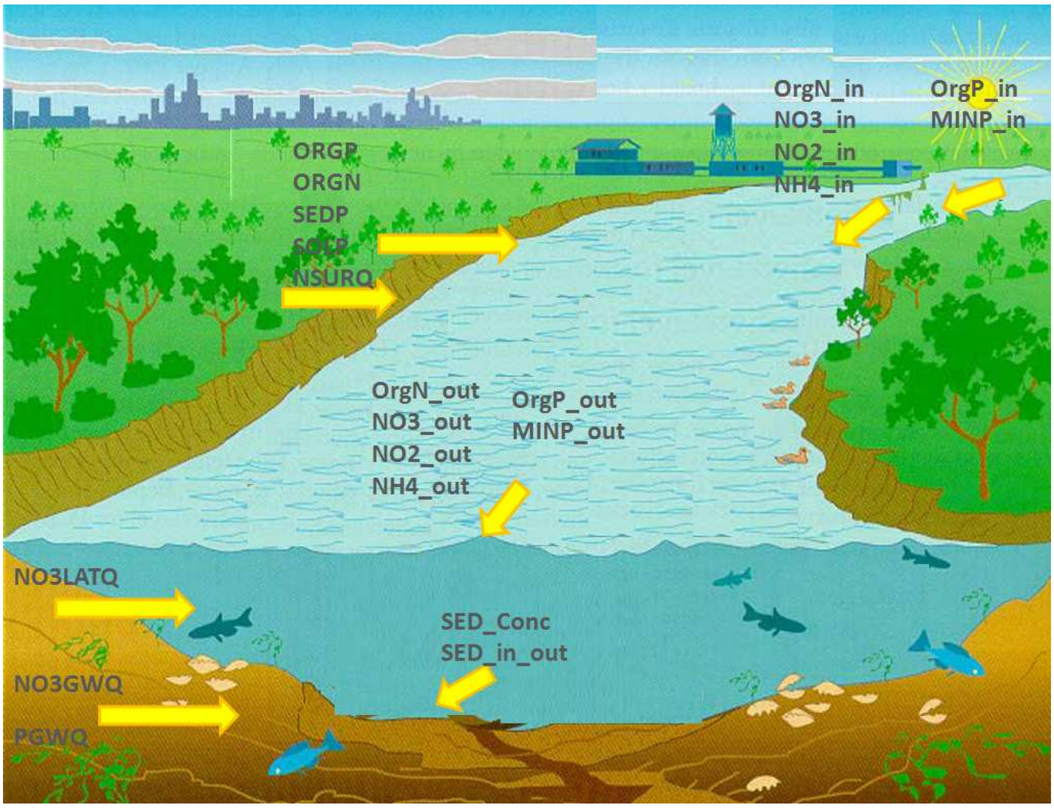

Figure 2.15: Schema of the nutrient routing parameters in the stream

2.8 Application of Model for Nutrient Loads

SWAT nutrient transport is separated into two parts including land phase and routing phase. In land phase, Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980) and Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987) are used. CREAMS model simulates the transport of the nutrients; below ground in soil profile and rooting depth, above ground movement with surface runoff and sediment. Groundwater loads is simulated by the GLEAMS model. In channel processes; QUAL2E simulates instream kinetics, Routing Outputs to Outlet (ROTO) simulates routing of the nutrients in the stream. Nitrogen and phosphorus cycles in land phase, and routing of nutrients instream process will be evaluated under the titles of nutrient transport in land and nutrient routing in stream.

2.8.1 Nutrient transport in land

SWAT simulates the nitrogen and phosphorus cycles, including plant uptake of nutrients and the mineralization of organic nutrients in plant residue. SWAT has a detailed simulation of plant growth and the effects of plant cover on nutrient balances (Url-1).

SWAT simulates the removal of water and nutrients from the root zone, transpiration, and biomass yield production based on the combination of soils and the biophysical properties of the land cover**.**

2.8.1.1 Nitrogen transport

Nitrogen is modeled with SWAT in soil profile and in the shallow aquifer (Neitsch et al., 2005a). SWAT monitors five pools of nitrogen including two inorganic and three organic **(Figure 2.16).** SWAT simulates the processes including mineralization, decomposition/immobilization, nitrification, ammonia volatilization and denitrification as given in **Figure 2.17**. In addition, processes such as nitrogen in rainfall, fixation, upward movement of nitrate, leaching, and nitrate in the shallow aquifer are simulated by SWAT.

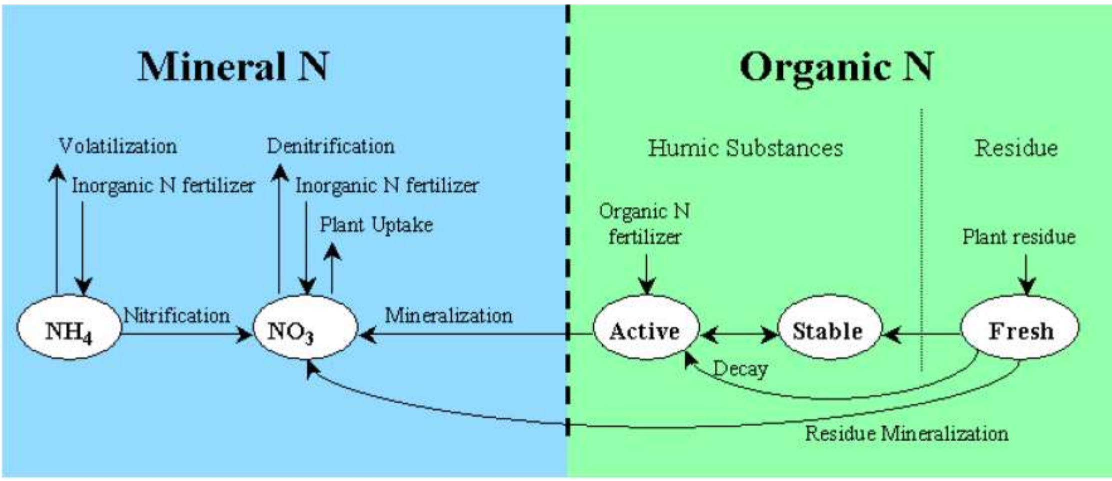

Figure 2.16: SWAT nitrogen pools simulations (Neitsch et. al., 2005a)

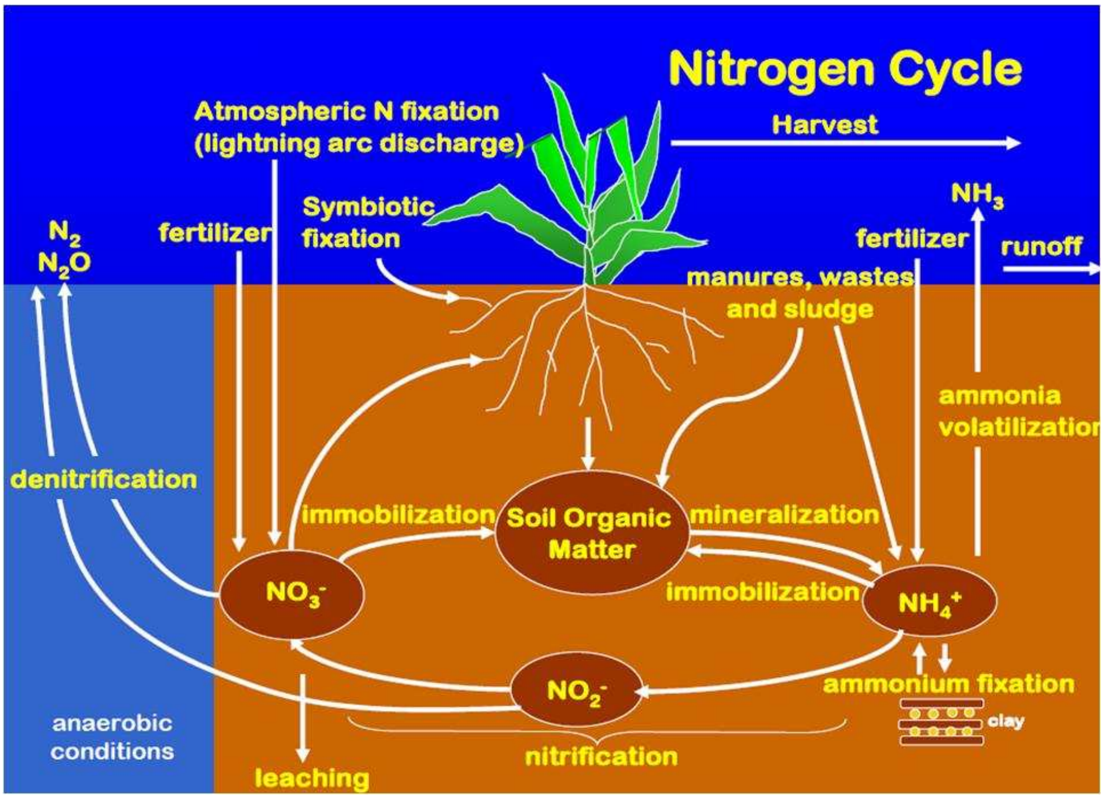

Figure 2.17: Schema of the nitrogen cycle in the soil (Neitsch et al., 2005a)

SWAT requires the initial amounts of the nitrogen. In this step, two options are available. User can define amount of nitrate and organic nitrogen contained in humic substances for all soil layers at the beginning of the simulation. Otherwise, SWAT will initialize amount of different nitrogen pools. Model use the following equations to set initial concentrations of nitrogen pools.

$$NO3_{conc,z} = 7 \cdot \exp\left(\frac{-z}{1000}\right) \quad \textbf{(2.8)}$$

where $NO3_{conc,z}$ is the initial concentration of nitrate in the soil at depth z (mg/kg or ppm), and z is the depth from soil surface (mm).

Organic nitrogen levels are calculated assuming that the C:N ratio for humic substances is 14:1. Concentration of humic organic nitrogen in a soil layer calculated with the following equation.

$$orgN_{hum,ly} = 10^4 \cdot \left(\frac{orgC_{ly}}{14}\right) \quad \textbf{(2.9)}$$

where $orgN_{hum,ly}$ is the concentration of humic organic nitrogen in the layer (mg/kg or ppm), and $orgC_{ly}$ is the amount of organic carbon in the layer (%). The humic organic nitrogen is divided into active and stable pools calculated by the equations given below:

$$orgN_{act,ly} = orgN_{hum,ly} \cdot fr_{actN} \quad \textbf{(2.10)}$$

$$orgN_{sta,ly} = orgN_{hum,ly} \cdot (1 - fr_{actN}) \quad \textbf{(2.11)}$$

$orgN_{act,ly}$ is the concentration of nitrogen in the active organic pool (mg/kg), $orgN_{hum,ly}$ is the concentration of humic organic nitrogen in the layer, fr_{actN} is the fraction of humic nitrogen in the active pool, and $orgN_{sta,ly}$ is the concentration of nitrogen in the stable organic pool (mg/kg). The fraction of humic nitrogen in the active pool is set to 0.02.

Fresh organic nitrogen pool is set to 0.15% of initial amount of residue on the soil surface for the top 10 mm. Excluding the top 10 mm of soil, nitrogen in fresh organic pool is set to zero in all layers.

$$orgN_{frsh,surf} = 0.0015 \cdot rsd_{surf} \quad \textbf{(2.12)}$$

$orgN_{frsh,surf}$ is the nitrogen in the fresh organic pool in the top 10 mm (kgN/ha), and rsd_{surf} is material in residue pool for the top 10 mm of soil (kg/ha). The ammonium pool, $NH4_{ly}$, is initialized to 0 ppm.

By using following equation, SWAT converts concentration to a mass. Model performs all calculations on a mass basis.

$$\frac{conc_N \cdot \rho_b \cdot depth_{ly}}{100} = \frac{\text{kg N}}{\text{ha}} \quad \textbf{(2.13)}$$

con_N is the concentration of nitrogen in a layer (mg/kg or ppm), ρ_b is the bulk density of the layer (µg/m^3), and $depth_{ly}$ is the depth of the layer (mm).

Fresh organic residue is decomposed into simpler organic products. Microbial conversion of plant unavailable nitrogen to inorganic, plant available nitrogen, is mineralization process. Immobilization is the conversion of plant available inorganic soil nitrogen to plant unavailable organic nitrogen by microorganisms.

Water availability and temperature factors are parameters effective for mineralization and decomposition processes. These factors are used to form the impact of temperature and water on mineralization and decomposition processes.

$$\gamma_{tmp,ly} = 0.9 \cdot \frac{T_{soil,ly}}{T_{soil,ly} + \exp\left[9.93 - 0.312 \cdot T_{soil,ly}\right]} + 0.1 \quad \textbf{(2.14)}$$

where $\gamma_{tmp,ly}$ is the nutrient cycling temperature factor for layer *ly,* and $T_{soil,ly}$ is the temperature of layer *ly* (°C). This factor always has to be above 0.1.

Nutrient cycling water factor is calculated with the following equation.

$$\gamma_{sw,ly} = \frac{SW_{ly}}{FC_{ly}} \quad \textbf{(2.15)}$$

where $\gamma_{sw,ly}$ is the nutrient cycling water factor for layer *ly* on a given day (mm), and FC_{ly} is the water content of layer at field capacity (mm). The nutrient cycling water factor is always has to be above 0.05.

Humic nitrogen is partitioned between the active and stable organic pools as given in the equation below.

$$N_{trns,ly} = \beta_{trns} \cdot orgN_{act,ly} \cdot \left(\frac{1}{fr_{actN}} - 1\right) - orgN_{sta,ly} \quad \textbf{(2.16)}$$

where $N_{trns,ly}$ is the amount of nitrogen transferred between the active and stable organic pools (kgN/ha), β_{trns} is the rate constant (1x10^{-5}), $orgN_{act,ly}$ is the amount of nitrogen in the active organic pool (kgN/ha), *fractN* is the fraction of humic nitrogen in the active pool (0.02), and $orgN_{sta,ly}$ is the amount of nitrogen in the stable pool (kgN/ha). If value of the $N_{trns,ly}$ parameter is positive, this means that nitrogen is being transferred from active pool to stable pool. A negative value of $N_{trns,ly}$ shows that nitrogen is moving from stable to active organic pool.

Humus mineralization of active N pool is calculated by using the following equation.

$$N_{mina,ly} = \beta_{min} \cdot \left(\gamma_{tmp,ly} \cdot \gamma_{sw,ly}\right)^{1/2} \cdot orgN_{act,ly} \qquad \textbf{(2.17)}$$

$N_{mina,ly}$ is the nitrogen mineralized from the humus active organic nitrogen pool (kgN/ha), β_{min} is the rate coefficient for mineralization of the humus active organic nutrients, and its set to 1×10^{-5}, $\gamma_{tmp,ly}$ is the nutrient cycling temperature factor for layer *ly*, $\gamma_{sw,ly}$ is the nutrient cycling water factor for layer *ly*, $orgN_{act,ly}$ is the amount of nitrogen in the active organic pool (kgN/ha).

Fresh organic nitrogen decomposition and mineralization processes are only occurs in the first layer of soil. Mineralization reaction for fresh organic N pool is given below.

$$N_{minf,ly} = 0.8 \cdot \delta_{ntr,ly} \cdot orgN_{frsh,ly} \qquad \textbf{(2.18)}$$

Fresh Org N pool decomposition is given below.

$$N_{dec,ly} = 0.2 \cdot \delta_{ntr,ly} \cdot orgN_{frsh,ly} \qquad \textbf{(2.19)}$$

where $N_{dec,ly}$ is the nitrogen decomposed from the fresh organic N pool (kg N/ha), $\delta_{ntr,ly}$ is the residue decay rate constant, and $orgN_{frsh,ly}$ is the nitrogen in the fresh organic pool in layer *ly* (kg N/ha).

After the transformation of the organic nitrogen pools to mineral nitrogen tool, nitrification and ammonia volatilization processes take place in. SWAT use a combination of methods developed by Reddy et al. (1979) and Godwin et al. (1984), while simulating the nitrification and ammonia volatilization processes. Soil temperature is a key factor for nitrification whereas soil temperature, depth and cation exchange capacity is a key factor for ammonia volatilization. Nitrification and volatilization occurs if the temperature of the soil layer exceeds 5°C. nitrification regulator and volatilization regulator describe the effect of the environmental factors on nitrification and volatilization. Nitrification regulator and volatilization regulator are calculated as given in the following equations.

$$\eta_{nit,ly} = \eta_{tmp,ly} \cdot \eta_{sw,ly} \quad \textbf{(2.20)}$$

$$\eta_{vol,ly} = \eta_{tmp,ly} \cdot \eta_{midz,ly} \cdot \eta_{cec,ly} \quad \textbf{(2.21)}$$

where $\eta_{nit,ly}$ is the nitrification regulator, $\eta_{vol,ly}$ is the volatilization regulator, $\eta_{tmp,ly}$ is the nitrification/volatilization temperature factor, $\eta_{sw,ly}$ is the nitrification soil water factor, η_{cec} cation exchange factor, set to a constant value *0,15,* and $\eta_{midz,ly}$ is the volatilization depth factor.

Fistly, total amount of ammonium lost to nitrification and volatilization is determined with a fist order kinetic rate equation as given below.

$$N_{nit|vol,ly} = NH4_{ly} \cdot (1 - \exp[-\eta_{nit,ly} - \eta_{vol,ly}]) \quad \textbf{(2.22)}$$

where $N_{nit|vol,ly}$ is the amount of ammonium converted via nitrification and volatilization in layer *ly* (kg N/ha), $NH4_{ly}$ is the amount of ammonium in layer *ly* (kg N/ha), $\eta_{nit,ly}$ is the nitrification regulator, and $\eta_{vol,ly}$ is the volatilization regulator.

Partition of the ammonium lost between nitrification and volatilization is defined with obtaining a fraction. By using the following equation, amount of nitrogen lost from ammonium pool in nitrification process is calculated as below.

$$N_{nit,ly} = \frac{fr_{nit,ly}}{(fr_{nit,ly} + fr_{vol,ly})} \cdot N_{nit|vol,ly} \quad \textbf{(2.23)}$$

Then, amount of nitrogen removed from the ammonium pool by volatilization is calculated:

$$N_{vol,ly} = \frac{fr_{vol,ly}}{(fr_{nit,ly} + fr_{vol,ly})} \cdot N_{nit|vol,ly} \quad \textbf{(2.24)}$$

where $N_{nit,ly}$ is the amount of nitrogen converted from NH_4^+ to NO_3^- in layer *ly* (kg

N/ha), $N_{vol,ly}$ is the amount of nitrogen converted from NH_4^+ to NO_3^- in layer *ly* (kg N/ha), $fr_{nit,ly}$ is the estimated fraction of nitrogen lost by nitrification, $fr_{vol,ly}$ is the estimated fraction of nitrogen lost by volatilization, and $N_{nit|vol,ly}$ is the amount of ammonium converted via nitrification and volatilization in layer *ly* (kg N/ha).

Denitrification is bacterial reduction of nitrate (NO_3^-) to nitrogen gas (N_2) or (N_2O) under anaerobic conditions. Water content, temperature, presence of a carbon source and nitrate, affect the denitrification process. Amount of the denitrification is simulated with the following equation by SWAT.

$$N_{denit,ly} = NO3_{ly} \cdot \left(1 - \exp\left[-\beta_{denit} \cdot \gamma_{tmp,ly} \cdot orgC_{ly}\right]\right) \quad \gamma_{sw,ly} \geq \gamma_{sw,thr} \qquad \textbf{(2.25a)}$$

$$N_{denit,ly} = 0.0 \quad \gamma_{sw,ly} < \gamma_{sw,thr} \qquad \textbf{(2.25b)}$$

where $N_{denit,ly}$ is the amount of nitrogen lost to denitrification (kg N/ha), $NO3_{ly}$ is the amount of nitrate in layer *ly* (kg N/ha), β_{denit} is the rate coefficient for denitrification, $\gamma_{tmp,ly}$ is the nutrient cycling temperature factor for layer ly calculated with equation 3:1.2.1, $\gamma_{sw,ly}$ is the nutrient cycling water factor for layer ly calculated with equation 3:1.2.2, $orgC_{ly}$ is the amount of organic carbon in the layer (%), and $\gamma_{sw,thr}$ is the threshold value of nutrient cycling water factor for denitrification to occur.

SWAT also simulates the contribution of nitrate in rainfall. As given in chemical steps, only nitrate flux (not ammonium) is simulated, and this is added directly to the soil moisture profile, not partitioned into runoff. The SWAT interface defaults this concentration to 1 mg/L (Url-1).

$$N_2 + O_2 \xrightarrow{\text{arc of electricity}} 2NO \ \text{(monoxide)}$$

$$2NO + O_2 \longrightarrow NO_2 \ \text{(dioxide)}$$

$$3NO_2 + H_2O \longrightarrow 2HNO_2 + NO \ \text{(nitric acid and monoxide)}$$

Amount of nitrate added to the soil by rainfall is calculated:

$$N_{rain} = 0.01 \cdot R_{NO3} \cdot R_{day} \qquad \textbf{(2.26)}$$

where N_{rain} is nitrate added by rainfall (kg N/ha), R_{NO3} is the concentration of nitrogen in the rain (mg N/L), and R_{day} is the amount of precipitation on a given day (mm H_2O). The nitrogen in rainfall is added to the nitrate pool in the top 10 mm of soil.

If there is not enough nitrogen in soil, SWAT simulates fixation of atmospheric N_2 by legumes.

Due to the gradient that carries dissolved nutrients with it, water will upward from lower soil profile. Upward movement occurs only from the first soil layer to top 10 mm of soil.

$$N_{evap} = 0.1 \cdot NO3_{ly} \cdot \frac{E''_{soil,ly}}{SW_{ly}} \qquad \textbf{(2.27)}$$

where N_{evap} is the amount of nitrate moving from the first soil layer to the soil surface zone (kg N/ha), $NO3_{ly}$ is the nitrate content of the first soil layer (kg N/ha), $E''_{soil,ly}$ is the amount of water removed from the first soil layer as a result of evaporation (mm H_2O), and SW_{ly} is the soil water content of the first soil layer (mm H_2O).

Soil particles are negatively charged. So they easily attract and sorb cation nutrients. After plants extract the cations which are essential for growth, soil particles release bound cations into soil solution. Retention of nitrate by soil is very short. As a result of this, nitrate is very susceptible to leaching. It is not attached or sorbed by the soil particle because nitrate is an anion.

Nitrate leaches through soil profile and reaches to groundwater system after passing the vadose zone by percolation or bypass flow. It is assumed that concentration of nitrate is not changed while it is leaching through vadose zone. SWAT simulates nitrate loadings in shallow aquifer. Also, model determines the amount of the nitrate in groundwater flow to stream.

In 1969, Venetis developed an exponential decay weighting function. This function was used in a precipitation/groundwater response model (Sangrey, 1984). SWAT applies this principle to take into consideration the time delay in aquifer recharge once the water exits from the soil profile. Same approach is used for the calculation of the nitrate movement from the soil profile to aquifer as the following equation.

$$NO3_{rchrg,i} = \left(1 - \exp\left[-1/\delta_{gw}\right]\right) \cdot NO3_{perc} + \exp\left[-1/\delta_{gw}\right] \cdot NO3_{rchrg,i-1} \qquad \textbf{(2.28)}$$

Nitrate removal from shallow aquifer governed by first order kinetics.

$$NO3_{sh,t} = NO3_{sh,o} \cdot \exp\left[-k_{NO3,sh} \cdot t\right]$$

where $NO3_{sh,t}$ is the amount of nitrate in the shallow aquifer at time t (kg N/ha), $NO3_{sh,o}$ is the initial amount of nitrate in the shallow aquifer (kg N/ha), k_{NO3} is the rate constant for removal of nitrate in the shallow aquifer (1/day), and t is the time elapsed since the initial nitrate amount was determined (days). The rate constant is related to the half-life as follows:

$$t_{1/2,NO3,sh} = \frac{0.693}{k_{NO3,sh}} \tag{2.29}$$

where $t_{1/2,NO3,sh}$ is the half-life of nitrate in the shallow aquifer (days).

After nitrate reach to the shallow aquifer, it remains in shallow aquifer, move with recharge to deep aquifer, move with groundwater flow to stream flow, move into the soil profile as a result of revap (Water returning from shallow aquifer to root zone according to moisture deficit). Following equations show the calculation of the nitrate in various way.

Nitrate remaining in the shallow aquifer:

$$NO3_{gw} = (NO3_{sh,i-1} + NO3_{rchrg,i}) \cdot Q_{gw} \Big/ \left(aq_{sh,i} + Q_{gw} + w_{revap} + w_{rchrg,dp}\right. \tag{2.30}$$

Nitrate thmoving with recharge to deep aquifer:

$$NO3_{dp} = (NO3_{sh,i-1} + NO3_{rchrg,i}) \cdot w_{rchrg,dp} \Big/ \left(aq_{sh,i} + Q_{gw} + w_{revap} + w_{rchrg,dp}\right) \tag{2.31}$$

Nitrate Moving with groundwater flow:

$$NO3_{gw} = (NO3_{sh,i-1} + NO3_{rchrg,i}) \cdot Q_{gw} \Big/ \left(aq_{sh,i} + Q_{gw} + w_{revap} + w_{rchrg,dp}\right) \tag{2.32}$$

Nitrate moving into soil zone:

$$NO3_{revap} = (NO3_{sh,i-1} + NO3_{rchrg,i}) \cdot w_{revap} \Big/ \left(aq_{sh,i} + Q_{gw} + w_{revap} + w_{rchrg,dp}\right) \tag{2.33}$$

where $NO_{3sh,i}$ is the amount of nitrate in the shallow aquifer at the end of day i (kg N/ha), $NO_{3sh,i-1}$ is the amount of nitrate in the shallow aquifer at the end of day i - 1 (kg N/ha), $NO_{3rchrg,i}$ is the amount of nitrate in recharge entering the aquifers on day i (kg N/ha), NO_{3gw} is the amount of nitrate in groundwater flow from the shallow aquifer on day i (kg N/ha), $NO3_{revap}$ is the amount of nitrate in revap to the soil profile from the shallow aquifer on day i (kg N/ha), $NO3_{dp}$ is the amount of nitrate in recharge entering the deep aquifer on day i (kg N/ha), $aq_{sh,i}$ is the amount of water stored in the shallow aquifer at the end of day i (mm H_2O), W_{rchrg} is the amount of recharge entering the aquifers on day i (mm H_2O), Q_{gw} is the groundwater flow, or base flow, into the main channel on day i (mm H_2O), W_{revap} is the amount of water moving into the soil zone in response to water deficiencies on day i (mm H_2O), and $W_{rechrg,dp}$ is the amount of recharge entering the deep aquifer on day i (mm H_2O).

Weathering, erosion cause transport of the nutrients from land to streams and water bodies (Neitsch et al., 2005a). Mineral and organic forms of the nitrogen can contribute to stream network. Nitrate may be transported with, percolation, lateral flow or surface run off. Mobile water refers to concentration of nitrate in mobile form. Concentration of nitrate in mobile water fraction is calculated as given below,

$$conc_{NO3,mobile} = \frac{NO3_{ly} \cdot \left(1 - \exp\left[\frac{-w_{mobile}}{(1-\theta_e)\cdot SAT_{ly}}\right]\right)}{w_{mobile}} \quad \textbf{(2.34)}$$

where $conc_{NO3,mobile}$ is the concentration of nitrate in the mobile water for a given layer (kg N/mm H_2O), $NO3_{ly}$ is the amount of nitrate in the layer (kg N/ha), W_{mobile} is the amount of mobile water in the layer (mm H_2O), θ_e is the fraction of porosity from which anions are excluded, and SAT_{ly} is the saturated water content of the soil layer (mm H_2O).

The amount of mobile water in the layer is the amount of water lost by surface runoff, lateral flow or percolation. For top 10 mm of soil, and for lower layers amount of total mobile water is calculated:

$$w_{mobile} = Q_{surf} + Q_{lat,ly} + w_{perc,ly} \quad \textbf{(2.35)}$$

$$w_{mobile} = Q_{lat,ly} + w_{perc,ly} \quad \textbf{(2.36)}$$

where, W_{mobile} is the amount of mobile water in the layer (mm H_2O), Q_{surf} is the surface runoff generated on a given day (mm H_2O), $Q_{lat,ly}$ is the water discharged from the layer by lateral flow (mm H_2O), and $W_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm H_2O).

Surface runoff interacts with nutrients and transport nutrients from the top 10 mm of soil. Amount of nitrate in surface run off:

$$NO3_{surf} = \beta_{NO3} \cdot conc_{NO3,mobile} \cdot Q_{surf} \tag{2.37}$$

where NO_{3surf} is the nitrate removed in surface runoff (kg N/ha), β_{NO3} is the nitrate percolation coefficient, it allows the user to set the concentration of the nitrate in surface run off to a fraction of the concentration in percolate. $conc_{NO3,mobile}$ is the concentration of nitrate in the mobile water for the top 10 mm of soil (kg N/mm H_2O), and Q_{surf} the surface runoff generated on a given day (mm H_2O). The nitrate percolation coefficient allows the user to set the concentration of nitrate in surface runoff to a fraction of the concentration in percolate.

Nitrate removed in lateral flow is calculated for top 10 mm and lower layers

$$NO3_{lat,ly} = \beta_{NO3} \cdot conc_{NO3,mobile} \cdot Q_{lat,ly} \tag{2.38}$$

$$NO3_{lat,ly} = conc_{NO3,mobile} \cdot Q_{lat,ly} \tag{2.39}$$

where $NO_{3lat,ly}$ is the nitrate removed in lateral flow from a layer (kg N/ha), β_{NO3} is the nitrate percolation coefficient, $conc_{NO3,mobile}$ is the concentration of nitrate in the mobile water for the layer (kg N/mm H_2O), and $Q_{lat,ly}$ is the water discharged from the layer by lateral flow (mm H_2O).

Nitrate moved to the underlying layer by percolation is calculated:

$$NO3_{perc,ly} = conc_{NO3,mobile} \cdot w_{perc,ly} \tag{2.40}$$

where $NO_{3perc,ly}$ is the nitrate moved to the underlying layer by percolation (kg N/ha), $conc_{NO3,mobile}$ is the concentration of nitrate in the mobile water for the layer (kg N/mm H_2O), and $W_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm H_2O).

Organic nitrogen attaches to the sediment and it is transported to the stream with surface run off.

Organic N transported with the sediment to the channel:

$$orgN_{surf} = 0.001 \cdot conc_{orgN} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{N:sed} \tag{2.41}$$

where $orgN_{surf}$ is the amount of organic nitrogen transported to the main channel in surface runoff (kg N/ha), $conc_{orgN}$ is the concentration of organic nitrogen in the top 10 mm (g N/ metric ton soil), *sed* is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area (ha), and $\varepsilon_{N:Sed}$ is the nitrogen enrichment ratio.

The concentration of organic nitrogen in the soil surface layer, $conc_{orgN}$, is calculated:

$$conc_{orgN} = 100 \cdot \frac{\left(orgN_{frsh,surf} + orgN_{sta,surf} + orgN_{act,surf}\right)}{\rho_b \cdot depth_{surf}} \qquad \textbf{(2.42)}$$

where $orgN_{frsh,surf}$ nitrogen in the fresh organic pool in the top 10mm (kg N/ha), $orgN_{sta,surf}$ is nitrogen in the stable organic pool (kg N/ha), $orgN_{act,surf}$ is nitrogen in the active organic pool in the top 10 mm (kg N/ha), ρ_b is the bulk density of the first soil layer (Mg/m^3), and $depth_{surf}$ is the depth of the soil surface layer (10 mm).

The enrichment ratio is defined as the ratio of the concentration of organic nitrogen transported with the sediment to the concentration in the soil surface layer. SWAT calculates an enrichment ratio for each storm event, or it is possible the user define a particular enrichment ratio for organic nitrogen that is used for all storms during the simulation. To calculate the enrichment ratio, SWAT uses a relationship described by Menzel (1980) in which the enrichment ratio is logarithmically related to sediment concentration. The equation used to calculate the nitrogen enrichment ratio, $\varepsilon_{N:Sed},$ for each storm event is:

$$\varepsilon_{N:sed} = 0.78 \cdot \left(conc_{sed,surq}\right)^{-0.2468} \qquad \textbf{(2.43)}$$

where $conc_{sed,surq},$ is the concentration of sediment in surface runoff (Mg sed/m^3 H_2O). The concentration of sediment in surface runoff is calculated:

$$conc_{sed,surq} = \frac{sed}{10 \cdot area_{hru} \cdot Q_{surf}} \qquad \textbf{(2.44)}$$

where *sed* is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area (ha), and Q_{surf} the amount of surface runoff on a given day (mm H_2O).

2.8.1.2 Phosphorus transport

Phosphorus is another essential nutrient for the plant growth. The most critical role of the element is energy storage. Phosphorus compounds are responsible from the storage of the energy, used in the growth and reproductive processes, obtained from the photosynthesis and metabolism of carbohydrates (Neitsch et al., 2005a). SWAT monitors six pools of phosphorus including three inorganic and three organic **(Figure 2.18).** SWAT simulates the processes including mineralization, decomposition/immobilization, and sorption of inorganic P in the soil as given in **Figure 2.19**. In addition, processes such as leaching and phosphorus in shallow aquifer are simulated by SWAT.

SWAT requires the initial amount of the phosphorus. In this step, two options are available as explained in the nitrogen initial amount calculation part.

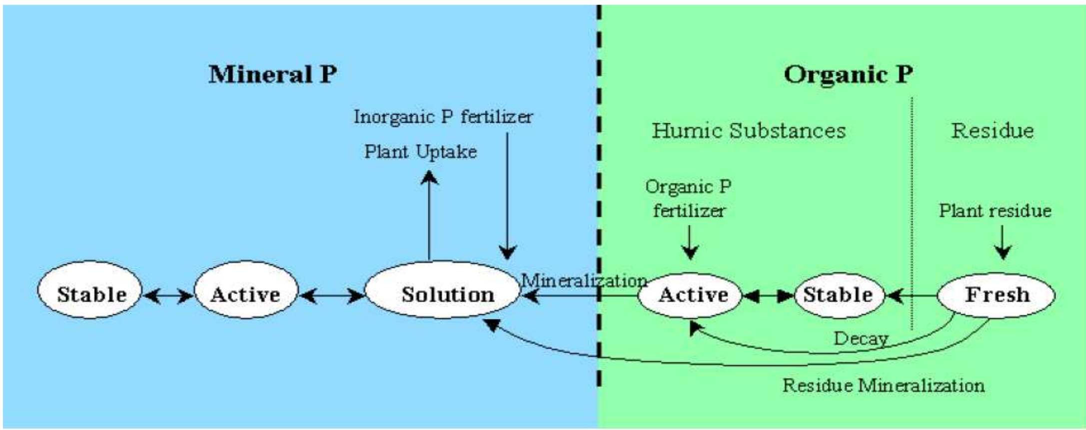

Figure 2.18: SWAT phosphorus pools simulations

User can define amount of soluble phosphorus and organic phosphorus contained in humic substances for all soil layers at the beginning of the simulation. Otherwise, SWAT initializes different nitrogen pools levels. Model use the following equations to set initial concentrations of nitrogen pools.

$$minP_{act,ly} = P_{solution,ly} \cdot \frac{1 - pai}{pai} \tag{2.45}$$

where $minP_{act,ly}$ is the amount of phosphorus in the active mineral pool (mg/kg), $P_{solution,ly}$ is the amount of phosphorus in solution (mg/kg), and pai is the phosphorus availability index. $P_{solution}$ is initially set to 5 mg/kg soil in all layers if vegetation is native vegetation (no management) and 25mg/kg soil in the plow layer if land is managed.

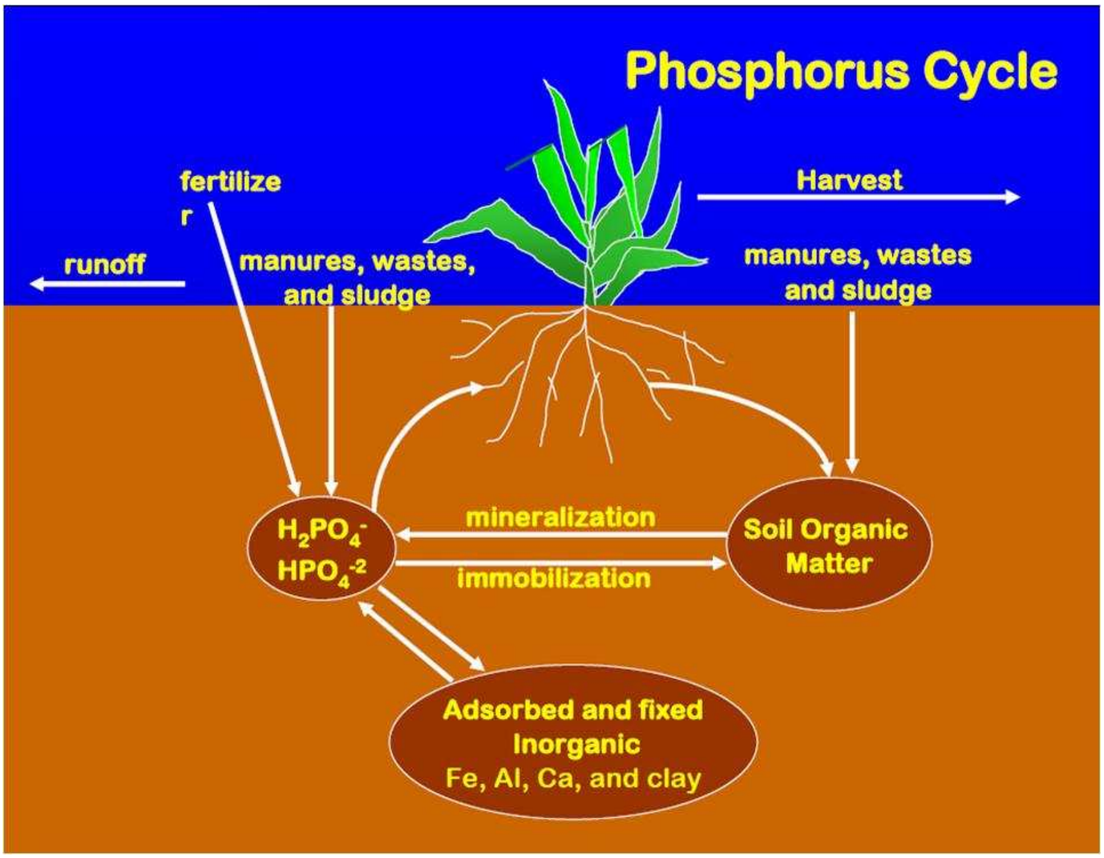

Figure 2.19: Simulated phosphorus processes with SWAT (Srinivasan, 2009)

The concentration of phosphorus in the stable mineral pool is initialized to (Jones et al., 1984):

$$minP_{sta,ly} = 4 \cdot minP_{act,ly} \quad \textbf{(2.46)}$$

where $minP_{sta,ly}$ is the amount of phosphorus in the stable mineral pool (mg/kg), and $minP_{act,ly}$ is the amount of phosphorus in the active mineral pool (mg/kg).

Organic phosphorus levels are determined assuming that the N:P ratio for humic materials. The concentration of humic organic phosphorus in a soil layer is calculated:

$$orgP_{hum,ly} = 0.125 \cdot orgN_{hum,ly} \quad \textbf{(2.47)}$$

where $orgP_{hum,ly}$ is the concentration of humic organic phosphorus in the layer (mg/kg) and $orgN_{hum,ly}$ is the concentration of humic organic nitrogen in the layer (mg/kg).

Phosphorus in the fresh organic pool is set to zero in all layers except the top 10 mm of soil. In the top 10 mm, the fresh organic phosphorus pool is set to 0.03% of the initial amount of residue on the soil surface.

$$orgP_{frsh,surf} = 0.0003 \cdot rsd_{surf} \tag{2.48}$$

where $orgP_{frsh,surf}$ the phosphorus in the fresh organic pool in the top 10mm (kg P/ha), and rsd_{surf} is material in the residue pool for the top 10mm of soil (kg/ha).

As seen in **Figure 2.19**, after the decomposition soil organic matter, mineralization and immobilization processes occur. Plant unavailable (organic) phosphorus part of the simpler organic components that are end products of the decomposition, mineralize into plant available phosphourus. Immobolization is the conversion of inorganic phosphorus to organic phosphorus. Mineralization and decomposition are dependent on water availability and temperature. Nutrient cycling temperature factor and nutrient water factor are described in nitrogen transport (Section 2.8.1.1).

Partition of the humus fraction between active and stable phosphorus pools is calculated as following equations.

$$orgP_{act,ly} = orgP_{hum,ly} \cdot \frac{orgN_{act,ly}}{orgN_{act,ly} + orgN_{sta,ly}} \tag{2.49}$$

$$orgP_{sta,ly} = orgP_{hum,ly} \cdot \frac{orgN_{sta,ly}}{orgN_{act,ly} + orgN_{sta,ly}} \tag{2.50}$$

where $orgP_{act,ly}$ is the amount of phosphorus in the active organic pool (kg P/ha), $orgP_{sta,ly}$ is the amount of phosphorus in the stable organic pool (kg P/ha), $orgP_{hum,ly}$ is the concentration of humic organic phosphorus in the layer (kg P/ha), $orgN_{act,ly}$ is the amount of nitrogen in the active organic pool (kg N/ha), and $orgN_{sta,ly}$ is the amount of nitrogen in the stable organic pool (kg N/ha).

Humus mineralization for active P pool is:

$$P_{mina,ly} = 1.4 \cdot \beta_{min} \cdot \left(\gamma_{tmp,ly} \cdot \gamma_{sw,ly}\right)^{1/2} \cdot orgP_{act,ly} \tag{2.51}$$

where $P_{mina,ly}$ is the phosphorus mineralized from the humus active organic P pool (kg P/ha), β_{min} is the rate coefficient for mineralization of the humus active organic nutrients, $\gamma_{tmp,ly}$ is the nutrient cycling temperature factor for layer *ly*, $\gamma_{sw,ly}$, is the nutrient cycling water factor for layer *ly*, and $orgP_{act,ly}$ is the amount of phosphorus in the active organic pool (kg P/ha). $P_{mina,ly}$ is contribute to solution phosphorus in the layer.

In SWAT model, fresh residue mineralization and decomposition occurs only in the first soil layer. These processes are controlled by a decay rate constant is updated daily. Decay rate constant is a function of the C:N ratio, C:P ratio, temperature and soil water. Related equations are included in phosphorus transport part of the SWAT theoretical documentation (Neitsch et al., 2005a). Mineralization of the fresh organic phosphorus pool is calculated:

$$P_{minf,ly} = 0.8 \cdot \delta_{ntr,ly} \cdot orgP_{frsh,ly} \tag{2.52}$$

where $P_{minf,ly}$ is the phosphorus mineralized from the fresh organic P pool (kg P/ha), $\delta_{ntr,ly}$ is the residue decay rate constant, and $orgP_{frsh,ly}$ is the phosphorus in the fresh organic pool in layer *ly* (kg P/ha). Phosphorus mineralized from the fresh organic pool is added to the solution P pool in the layer.

Decomposition from the residue fresh organic phosphorus pool is calculated:

$$P_{dec,ly} = 0.2 \cdot \delta_{ntr,ly} \cdot orgP_{frsh,ly} \tag{2.53}$$

where $P_{dec,ly}$ is the phosphorus decomposed from the fresh organic P pool (kg P/ha), dntrjy is the residue decay rate constant, and $orgP_{frsh,ly}$ is the phosphorus in the fresh organic pool in layer *ly* (kg P/ha). Phosphorus decomposed from the fresh organic pool is added to the humus organic pool in the layer.

The movement of phosphorus between the solution and active mineral pools is governed by the equilibration equations:

$$P_{sol|act,ly} = P_{solution,ly} - minP_{act,ly} \cdot \left(\frac{pai}{1-pai}\right) \text{ if } P_{solution,ly} > minP_{act,ly} \cdot \left(\frac{pai}{1-pai}\right)$$

$$P_{sol|act,ly} = 0.1 \cdot \left(P_{solution,ly} - minP_{act,ly} \cdot \left(\frac{pai}{1-pai}\right)\right) \text{ if } \tag{2.54}$$

$$P_{solution,ly} < minP_{act,ly} \cdot \left(\frac{pai}{1-pai}\right)$$

where $P_{sol}|_{act,ly}$ is the amount of phosphorus transferred between the soluble and active mineral pool (kg P/ha), $P_{solution,ly}$ is the amount of phosphorus in solution (kg P/ha), $minP_{act,ly}$ is the amount of phosphorus in the active mineral pool (kg P/ha), and *pai* is the phosphorus availability index. When $P_{sol}|_{act,ly}$ is positive, phosphorus is being transferred from solution to the active mineral pool. When $P_{sol}|_{act,ly}$ is negative, phosphorus is being transferred from the active mineral pool to solution. Note that the rate of flow from the active mineral pool to solution is 1/10th the rate of flow from solution to the active mineral pool.

The P availability index is then calculated:

$$pai = \frac{P_{solution,f} - P_{solution,i}}{fert_{minP}} \tag{2.55}$$

where *pai* is the phosphorus availability index, $P_{solution,f}$, is the amount of phosphorus in solution after fertilization and incubation, $P_{solution,i}$ is the amount of phosphorus in solution before fertilization, and $fert_{minP}$, is the amount of soluble P fertilizer added to the sample.

The movement of phosphorus between the active and stable mineral pools is governed by the equations if there is not an equilibrium.

$$P_{act|sta,ly} = \beta_{eqP} \cdot \left(4 \cdot minP_{act,ly} - minP_{sta,ly}\right) \text{ if } minP_{sta,ly} < 4 \cdot minP_{act,ly} \tag{2.56}$$

$$P_{act|sta,ly} = 0.1 \cdot \beta_{eqP} \cdot \left(4 \cdot minP_{act,ly} - minP_{sta,ly}\right) \text{ if if } minP_{sta,ly} > 4 \cdot minP_{act,ly}$$

where $P_{act}|_{sta,ly}$ is the amount of phosphorus transferred between the active and stable mineral pools (kg P/ha), β_{eqP} is the slow equilibration rate constant (0.0006 d^{-1}), $minP_{act,ly}$ is the amount of phosphorus in the active mineral pool (kg P/ha), and $minP_{sta,ly}$ is the amount of phosphorus in the stable mineral pool (kg P/ha).

As given in equation below SWAT simulates the phosphorus leaches from top 10 mm of soil to first layer due to the low mobility of phosphorus.

$$P_{perc} = \frac{P_{solution,surf} \cdot w_{perc,surf}}{10 \cdot \rho_b \cdot depth_{surf} \cdot k_{d,perc}} \tag{2.57}$$

where P_{perc} is the amount of phosphorus moving from the top 10 mm into the first soil layer (kg P/ha), $P_{solution,surf}$ is the amount of phosphorus in solution in the top 10 mm (kg P/ha), $w_{perc,surf}$ the amount of water percolating to the first soil layer from the top 10 mm on a given day (mm H_2O), p_b is the bulk density of the top 10 mm (Mg/m^3) (assumed to be equivalent to bulk density of first soil layer), $depth_{surf}$ is the depth of the "surface" layer (10 mm), and $k_{d,perc}$ is the phosphorus percolation coefficient (10 m^3/Mg).

Diffusion is the primary mechanism of phosphorus movement in the soil. As a result of the low mobility of solution phosphorus, surface run-off will only partitionally interact with the solution phosphorus stored in the top 10 mm of soil (Neitsch et al., 2005a). Amount of the soluble phosphorus transported with the surface run off is:

$$P_{surf} = \frac{P_{solution,surf} \cdot Q_{surf}}{\rho_b \cdot depth_{surf} \cdot k_{d,surf}} \tag{2.58}$$

where P_{surf} is the amount of soluble phosphorus lost in surface runoff (kg P/ha), $P_{solution,surf}$ is the amount of phosphorus in solution in the top 10 mm (kg P/ha), Q_{surf} is the amount of surface runoff on a given day (mm H_2O), ρ_b, is the bulk density of the top 10 mm (Mg/m^3) (assumed to be equivalent to bulk density of first soil layer), $depth_{surf}$ is the depth of the "surface" layer (10 mm), and $k_{d,surf}$ the phosphorus soil partitioning coefficient (m^3/Mg).

In addition, organic and mineral phosphorus pools attached to the soil particles are transported in sediment by surface run off. The amount of the phosphorus transported with sediment to the stream is calculated with equation developed by McElroy et al. (1976) and modified by Williams and Hann (1978).

$$sedP_{surf} = 0.001 \cdot conc_{sedP} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{P:sed} \tag{2.59}$$

where *sedPsurf* is the amount of phosphorus transported with sediment to the main channel in surface runoff (kg P/ha), $conc_{sedP}$ is the concentration of phosphorus attached to sediment in the top 10 mm (g P/ metric ton soil), *sed* is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area (ha), and $\varepsilon_{P:sed}$ is the phosphorus enrichment ratio.

$$\varepsilon_{P:sed} = 0.78 \cdot \left(conc_{sed,surq}\right)^{-0.2468} \tag{2.60}$$

where $conc_{sed,surq}$ is the concentration of sediment in surface runoff (Mg sed/m^3 H_2O). The concentration of sediment in surface runoff is calculated: ($\varepsilon_{P,sed}$: P enrichment ratio, 0 between (0-5))

$$conc_{sed,surq} = \frac{sed}{10 \cdot area_{hru} \cdot Q_{surf}} \qquad \textbf{(2.61)}$$

where *sed* is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area (ha), and Q_{surfq} the amount of surface runoff on a given day (mm H_2O).

Concentration of phosphorus attached to sediment in the soil surface layer is calculated:

$$conc_{sedP} = 100 \cdot \frac{\left(minP_{act,surf} + minP_{sta,surf} + orgP_{hum,surf} + orgP_{frsh,surf}\right)}{\rho_b \cdot depth_{surf}} \qquad \textbf{(2.62)}$$

where $minP_{act,surf}$ is the amount of phosphorus in the active mineral pool in the top 10 mm (kg P/ha), $minP_{sta,surf}$ is the amount of phosphorus in the stable mineral pool in the top 10 mm (kg P/ha), $orgP_{hum,surf}$ is the amount of phosphorus in humic organic pool in the top 10 mm (kg P/ha), $orgP_{frsh,surf}$ is the amount of phosphorus in the fresh organic pool in the top 10 mm (kg P/ha), ρ_b is the bulk density of the first soil layer (Mg/m^3), and $depth_{surf}$ is the depth of the soil surface layer (10 mm).

2.8.2 Nutrient routing in stream

QUAL2E model interactions and relationships are used in SWAT instream processes. It is assumed that nutrients can be dissolved in the stream or adsorbed to the sediment. Dissolved nutrients are transported with the water and adsorbed nutrients are deposited with the sediment on the bed of the channel (Url-1).

Soil erosion affected by climate, geology, soil type, vegetation and management, is the cause of the most of the nitrogen and phosphorus loads in river water. The form of the nitrogen transported in water is mainly organic material. Source of the soluble nitrogen (ammonium, NH_4^+ or nitrate NO_3) is natural and artificial fertilizers and wastes of human and animals. As a result of high affinity, phosphorus originating from rock erosion and fertilized soils is in river water mainly bound in the soil and humus particles. It is a fact that over fertilizing, domestic wastewater and detergents also cause dissolved phosphorus load in a form of soluble reactive phosphorus or soluble unreactive phosphorus (Rinta, 2008).

2.8.2.1 Nitrogen routing

In stream processes, organic nitrogen transformed to ammonia, nitrite, and finally nitrate in aerobic water conditions. Change in organic nitrogen pool on a given day is calculated:

$$\Delta orgN_{str} = \left(\alpha_1 \cdot \rho_a \cdot algae - \beta_{N,3} \cdot orgN_{str} - \sigma_4 \cdot orgN_{str}\right) \cdot TT \qquad \textbf{(2.63)}$$

where $\Delta orgN_{str}$ is the change in organic nitrogen concentration (mg N/L), α_1 is the fraction of algal biomass that is nitrogen (mg N/mg alg biomass), ρ_a is the local respiration or death rate of algae (day^{-1} or hr^{-1}), *algae* is the algal biomass concentration at the beginning of the day (mg alg/L), $\beta_{N,3}$ is the rate constant for hydrolysis of organic nitrogen to ammonia nitrogen (day^{-1} or hr^{-1}), $orgN_{str}$ is the organic nitrogen concentration at the beginning of the day (mg N/L), σ_4 is the rate coefficient for organic nitrogen settling (day^{-1} or hr^{-1}), and TT is the flow travel time in the reach segment (day or hr).

With the mineralization of the organic nitrogen and diffusion of ammonium from the streambed sediments, amount of the ammonium increase in the stream whereas decrease by the conversion of NH_4^+ to NO_2^- or the uptake of NH_4^+ by algae.

$$\Delta NH4_{str} = \left(\beta_{N,3} \cdot orgN_{str} - \beta_{N,1} \cdot NH4_{str} + \frac{\sigma_3}{(1000 \cdot depth)} - fr_{NH4} \cdot \alpha_1 \cdot \mu_a \cdot algae\right) \qquad \textbf{(2.64)}$$

where ΔNH_{4str} is the change in ammonium concentration (mg N/L), $\beta_{N,3}$ is the rate constant for hydrolysis of organic nitrogen to ammonia nitrogen (day^{-1} or hr^{-1}), $orgN_{str}$ is the organic nitrogen concentration at the beginning of the day (mg N/L), $\beta_{N,1}$ is the rate constant for biological oxidation of ammonia nitrogen (day^{-1} or hr^{-1}), NH_{4str} is the ammonium concentration at the beginning of the day (mg N/L), σ_3 is the benthos (sediment) source rate for ammonium (mg N/m^2-day or mg N/m^2-hr), *depth* is the depth of water in the channel (m), fr_{NH4} is the fraction of algal nitrogen uptake from ammonium pool, α_1 is the fraction of algal biomass that is nitrogen (mg N/mg alg biomass), μ_a is the local growth rate of algae (day^{-1} or hr^{-1}), *algae* is the algal biomass concentration at the beginning of the day (mg alg/L), and TT is the flow travel time in the reach segment (day or hr).

With the conversion of NH_4^+ to NO_2^- , amount of the nitrite is increased whereas it is decreased by the conversion of NO_2^- to NO_3^-. Change in nitrite amount on a given day:

$$\Delta NO2_{str} = \left(\beta_{N,1} \cdot NH4_{str} - \beta_{N,2} \cdot NO2_{str}\right) \cdot TT \tag{2.65}$$

where ΔNO_{2str} is the change in nitrite concentration (mg N/L), $\beta_{N,1}$ is the rate constant for biological oxidation of ammonia nitrogen (day^{-1} or hr^{-1}), NH_{4str} is the ammonium concentration at the beginning of the day (mg N/L), β_{N2} is the rate constant for biological oxidation of nitrite to nitrate (day^{-1} or hr^{-1}), NO_{2str} is the nitrite concentration at the beginning of the day (mg N/L), and TT is the flow travel time in the reach segment (day or hr).

Due to the oxidation of NO_2^- the amount of the nitrate is increased in the stream. Nitrate concentration in stream is decreased by uptake of NO_3^- by algae. Change in nitrate on a given day is:

$$\Delta NO3_{str} = \left(\beta_{N,2} \cdot NO2_{str} - (1 - fr_{NH4}) \cdot \alpha_1 \cdot \mu_a \cdot algae\right) \cdot TT \tag{2.66}$$

where ΔNO_{3str} is the change in nitrate concentration (mg N/L), β_{N2} is the rate constant for biological oxidation of nitrite to nitrate (day^{-1} or hr^{-1}), NO_{2str} is the nitrite concentration at the beginning of the day (mg N/L), fr_{NH4} is the fraction of algal nitrogen uptake from ammonium pool, α_1 is the fraction of algal biomass that is nitrogen (mg N/mg alg biomass), μ_a is the local growth rate of algae (day^{-1} or hr^{-1}), algae is the algal biomass concentration at the beginning of the day (mg alg/L), and *TT* is the flow travel time in the reach segment (day or hr).

2.8.2.2 Phosphorus routing

In stream phosphorus cycle is similar to nitrogen cycle. Source of the organic phosphorus is death of the algae. Algal phosphorus is mineralized to soluble pool available for uptake by algae. Also, organic phosphorus may settle.

Change of the organic phosphorus on a given day is calculated:

$$\Delta orgP_{str} = \left(\alpha_2 \cdot \rho_a \cdot algae - \beta_{P,4} \cdot orgP_{str} - \sigma_5 \cdot orgP_{str}\right) \cdot TT \tag{2.67}$$

where $\Delta orgP_{str}$ is the change in organic phosphorus concentration (mg P/L), α_2 is the fraction of algal biomass that is phosphorus (mg P/mg alg biomass), ρ_a is the local respiration or death rate of algae (day^{-1} or hr^{-1}), *algae* is the algal biomass concentration at the beginning of the day (mg alg/L), $\beta_{P,4}$ is the rate constant for mineralization of organic phosphorus (day^{-1} or hr^{-1}), $orgP_{str}$ is the organic phosphorus concentration at the beginning of the day (mg P/L), σ_5 is the rate coefficient for organic phosphorus settling (day^{-1} or hr^{-1}), and *TT* is the flow travel time in the reach segment (day or hr).

Mineralization of organic compounds and diffusion or inorganic phosphorus from the streambed is the cause of the raise in the amount of the soluble, inorganic phosphorus. But, soluble phosphorus concentration is decreased by the uptake of inorganic by algae. The variation of soluble phosphorus for a given day is:

$$\Delta solP_{str} = \left(\beta_{P,4} \cdot orgP_{str} + \frac{\sigma_2}{(1000 \cdot depth)} - \alpha_2 \cdot \mu_a \cdot algae \right) \cdot TT \qquad \textbf{(2.68)}$$

where $\Delta solP_{str}$ is the change in solution phosphorus concentration (mg P/L), $\beta_{P,4}$ is the rate constant for mineralization of organic phosphorus (day^{-1} or hr^{-1}), $orgP_{str}$ is the organic phosphorus concentration at the beginning of the day (mg P/L), σ_2 is the benthos (sediment) source rate for soluble P (mg P/m^2-day or mg P/m^2-hr), *depth* is the depth of water in the channel (m), α_2 is the fraction of algal biomass that is phosphorus (mg P/mg alg biomass), μ_a is the local growth rate of algae (day^{-1} or hr^{-1}), algae is the algal biomass concentration at the beginning of the day (mg alg/L), and *TT* is the flow travel time in the reach segment (day or hr).

3. KOYCEĞİZ DALYAN CASE STUDY AREA

Koycegiz Dalyan Watershed is selected as the study area for the implementation of the SWAT model. Koycegiz Dalyan case study is located at the southwest of Turkey within the boundary of Muğla Province (**Figure 3.1**). Watershed is placed between 36º45' and 37º15’ North latitude and 28º 22' 30" and 28º 52' 30" east longitude. With a drainage area of 1200 km^2, Koycegiz Dalyan Watershed is bounded by Mediterranean Sea in the South. Case study area includes Koycegiz Lake, Alagöl Lake, Sülüngür Lake, Dalyan Lagoon Channel, and İztuzu Beach. Koycegiz Lake, 1,38 m above the sea level, is connected to Channel system which flows down to Mediterranean Sea after creating a complex structure in the area surrounded by Alagöl and Sülüngür Lakes (Gürel, 2000).

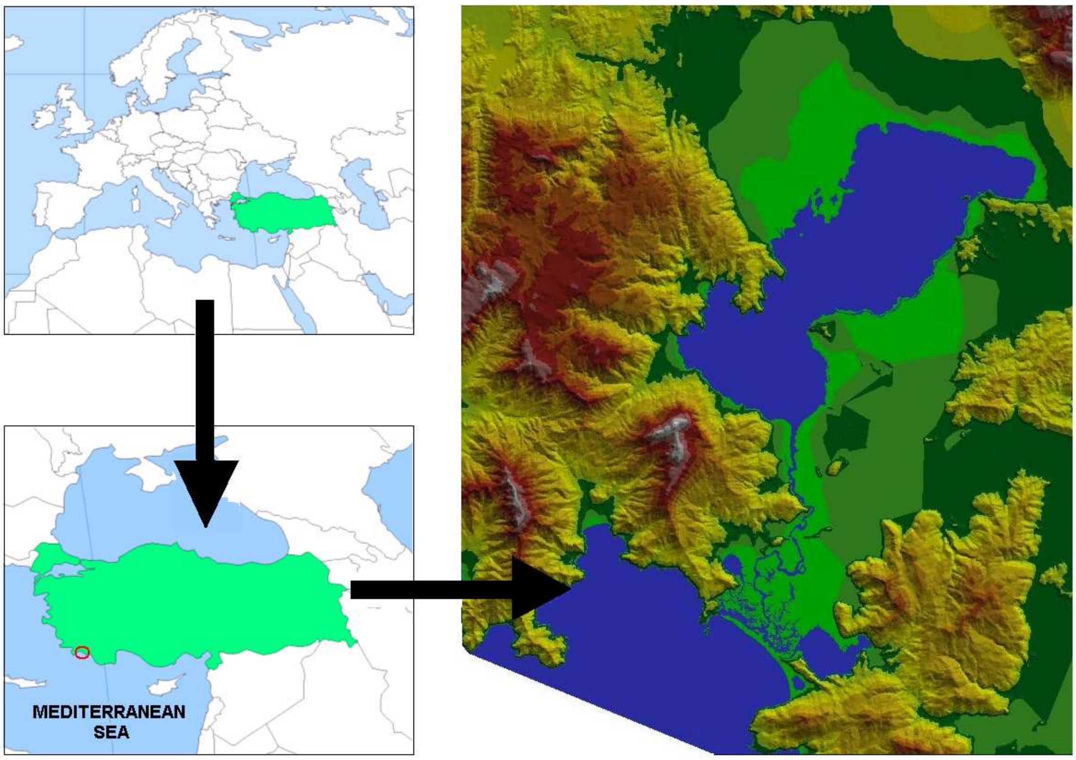

Figure 3.1: Location of the watershed in Turkey and its 3D plan view (Şeker et al. 2002)

Watershed boundary covers some parts of three sub-province including Koycegiz, Ortaca, and Ula. Total population of the watershed is 39169 according to 2009 census (**Table 3.1**). The largest town in the Lagoon drainage area is Dalyan with 4619 habitants according to 2009 census, whereas Toparlar is the largest town in the Lake drainage area with 4009 habitants. The population does not reflect a rapid and huge increase due to no significant industrial activities within the area, which is an important factor promoting high population increase. The economy is mainly based on agriculture, tourism, fishery and forestry. There are no significant industrial activities in the area.

Table 3.1: Population of the Koycegiz Dalyan Watershed based on counties

District	Village	Population
Köyceğiz	Beyobası(merkez)	2743
	Döğüşbelen(merkez)	1400
	Toparlar(merkez)	4009
	Hamitköy(merkez)	1194
	Köyceğiz(merkez)	956
	Kavakarası(merkez)	700
	Yangı(merkez)	1405
	Zaferler(merkez)	602
	Zeytinalanı(merkez)	2244
	Yeşilköy(merkez)	533
	Sultaniye(merkez)	246
	Pınar(merkez)	2827
	Yayla	314
	Çandır(merkez)	411
Ortaca	Dalyan(merkez)	4,619
	Kemaliye(merkez)	1,075
	Gölbaşı(merkez)	845
	Eskiköy(merkez)	1,345
	Okçular(merkez)	1,340
	Ekşiliyurt(merkez)	
	Gökbel(merkez)	543
Ula	Çörüş	325
	Yeşilçam	437
	Sarayyanı	565
	Kızılyaka	1402
	Portakallık	493
	Karaböğürtlen	1784
	Kıyra	494
	Çiçekli	132
	Gölcük	809
	Armutçuk	229
	Yaylasöğüt	203
	Arıcılar	126
	Turgut	468
	Kavakçalı	297
	Esentepe	433
	Çitlik	917
	Elmalı	347
TOTAL Watershed Population		**38812**

A part of the case study area was declared as Special Protection Area (SPA) by the Turkish Government in 1988. The region has historical and cultural heritage and unique biodiversity. For instance, The Iztuzu Beach is world known as breeding place for endemic species of marine turtles Caretta caretta's.

3.1 Climate

Climatic condition is one of the essential external factors effects the basin. Meteorological data is used in determining the physical, chemical and biological mechanisms taking place both on land and in water parts of the watershed.

Koycegiz Dalyan Watershed is under the influence of mediterranean climate characteristics, with a hot, dry summer season and warm, rainy winter season. . The region is controlled by the terresterial, marine or semi-marine and semi-terresterial low and high pressure systems.

Five meteorology stations are located around the watershed. The coordinates and the elevations of these meteorology stations are given in **Table 3.2.** Also, **Figure 3.2** shows the position of the meteorological stations according to catchment area.

Table 3.2: Location and elevation of the meteorology stations

Stations	**Latitude**	**Longitude**	**Elevation (m)**
Mugla	37°13′	28°22′	646
Marmaris	36°51′	28°16′	19
Fethiye	36°37′	29°07′	3
Dalaman	36°45′	28°47′	13
Koycegiz	36°58′	28°41′	24

As seen in **Figure 3.2**., only Koycegiz meteorology station is located in the boundary of the basin. Hence, this station is the most representative for meteorological parameters. According to data between 1976 and 2009 Marmaris station show higher and Fethiye show lower annual precipitation values when compared to Koycegiz station (**Figure 3.3**). Yüceil (2005) compared daily rainfall in five meteorological stations and reported that Koycegiz and Dalaman stations

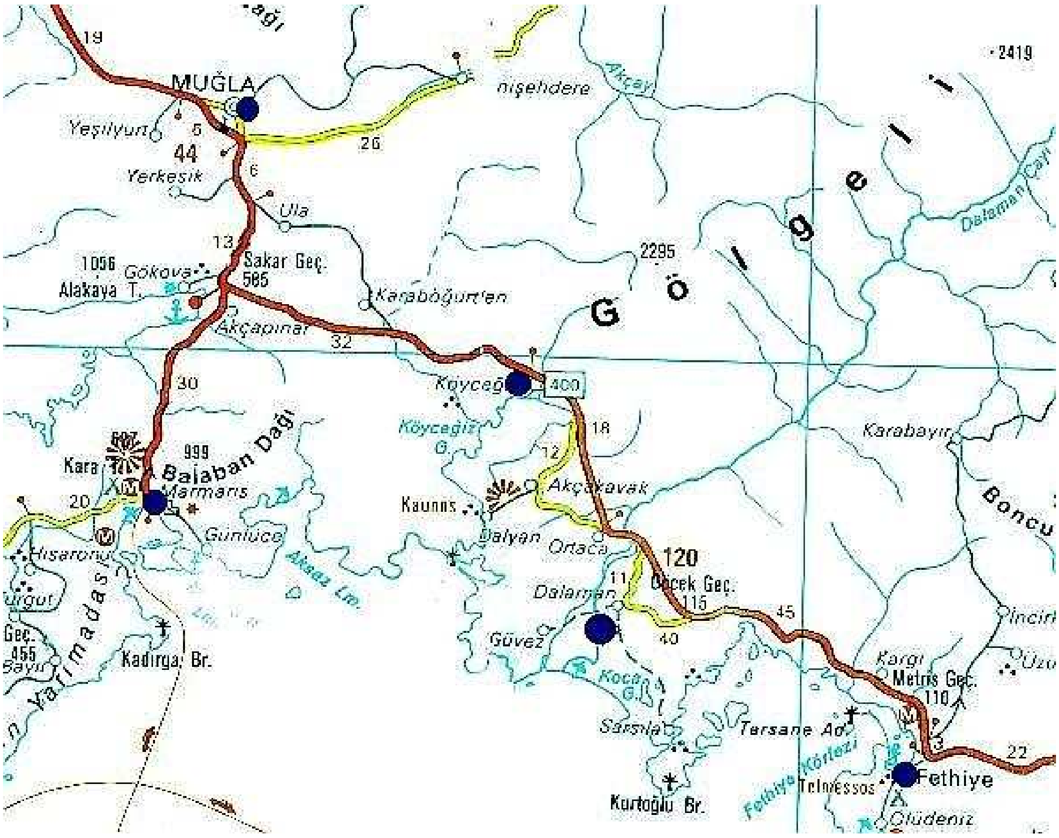

Figure 3.2: Location of the meteorological stations

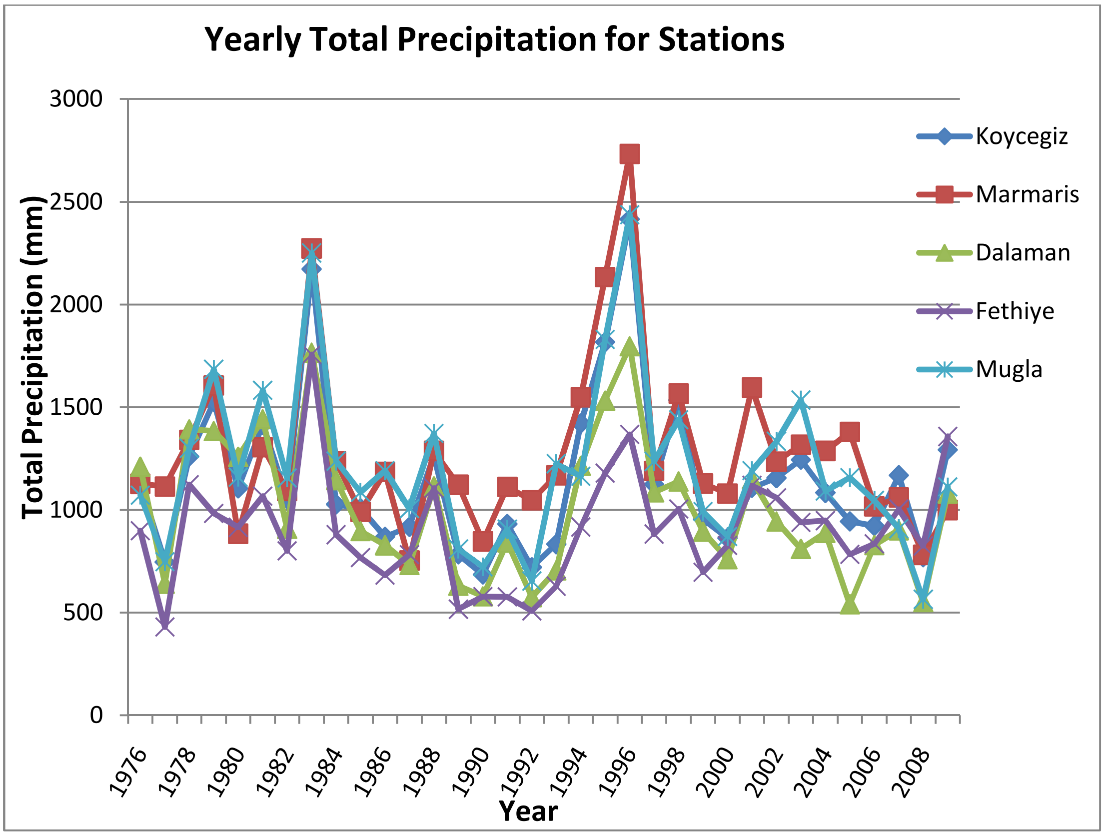

Figure 3.3: Yearly total precipitation variation for meteorology stations

demonstrated similar values closer to the average of five stations whereas Marmaris and Fethiye stations were rather distinct. In all stations, December and January are the rainiest month, on other hand; the driest two months are July and August.

In Koycegiz, yearly average precipitation is 1150 mm between the years 1976 and 2008 (**Figure 3.4**.) Maximum yearly rainfall is 2415 mm whereas minimum rainfall is 685 mm occurred in 1990.

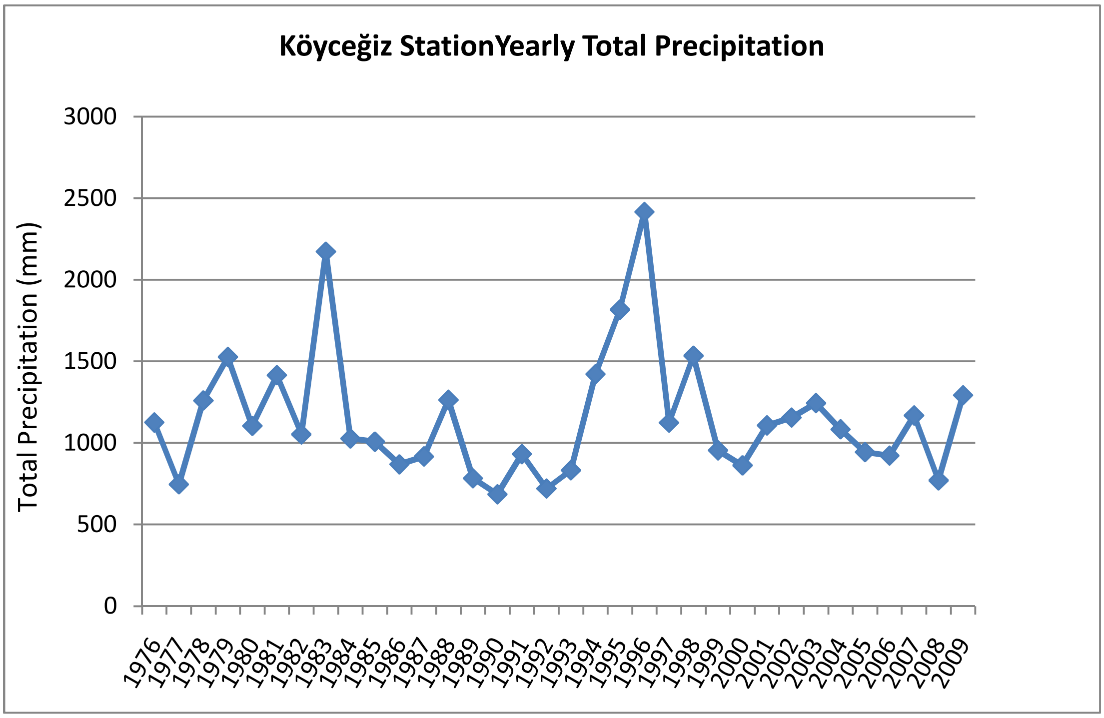

Figure 3.4: Yearly total precipitation variation for Koycegiz station

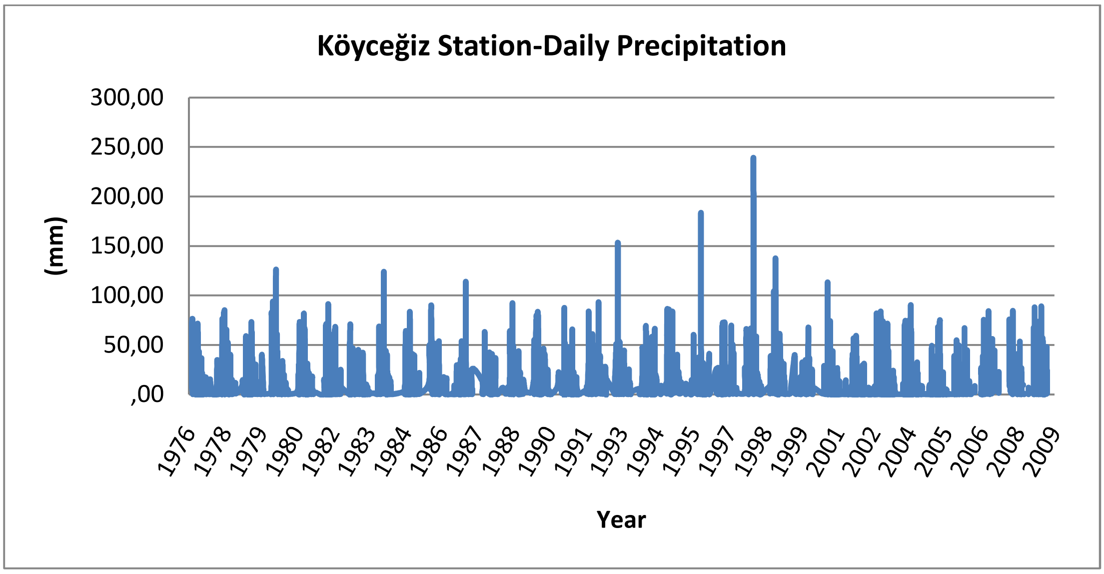

Figure 3.5. Daily precipitation data of the Koycegiz station

In **Figure 3.5**, daily precipitation data of Koycegiz station is given for 34 years. According to data it is seen that maximum daily precipitation amount is 239.2 mm in 1998. Daily temperature data of Koycegiz station is indicated in Figure 3.6. It is evaluated that maximum daily temperature is 45.6^{o}C in June, 2000 and minimum daily temperature is -6.2 in February, 2004 for last 34 years.

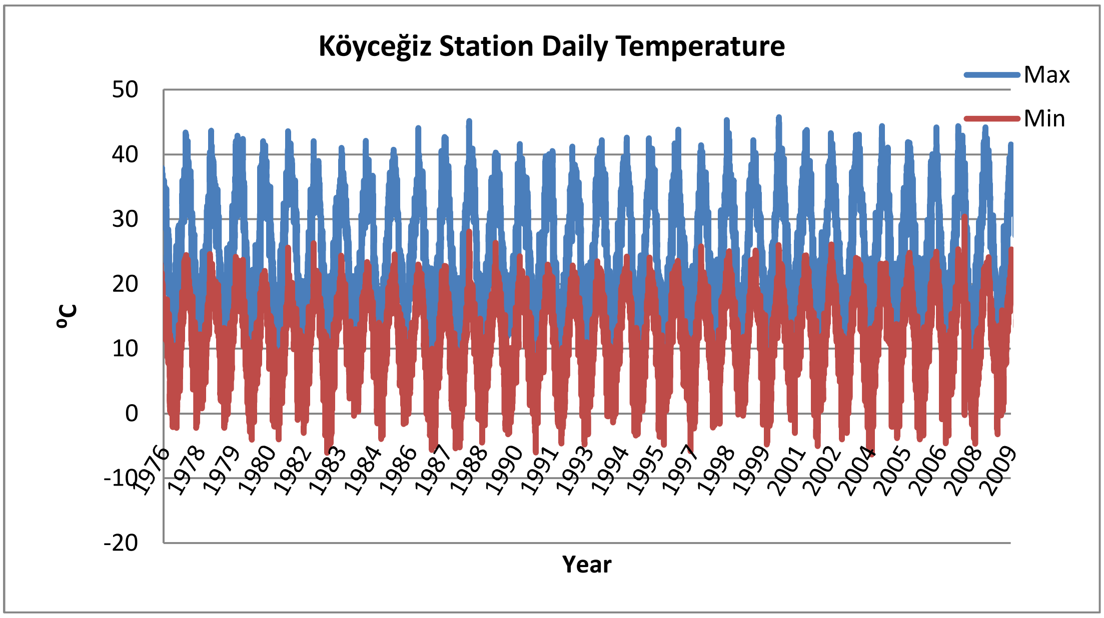

Figure 3.6: Daily temperature data of Koycegiz station

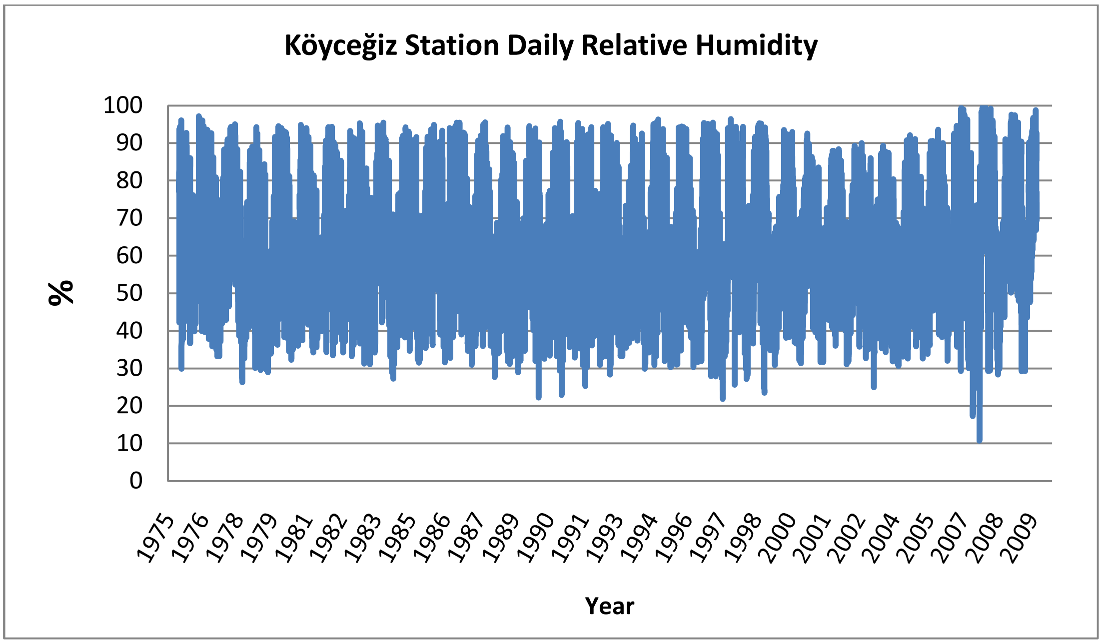

Figure 3.7: Daily relative humidity data of Koycegiz station

Daily relative humidity data of the Koycegiz station is designated in Figure 3.7. Data ranges between 99% and 11%. Average relative humidity is calculated as 62%.

In **Figure 3.8**, variation of daily solar radiation for Koycegiz station is given. Maximum daily solar radiation is 28.72 MJ/m^2 and minimum solar radiation is 0.01 MJ/m^2 between 1986 and 2005. Also, daily wind velocity is designated in **Figure 3.9**. According to data between the years 1976 and 2009, maximum wind velocity is 9 m/s in 2007.

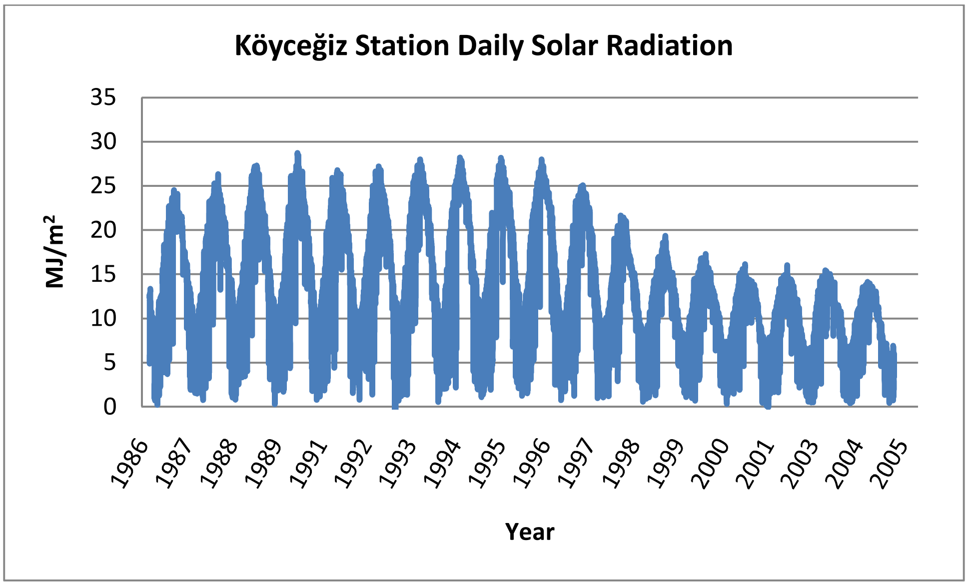

Figure 3.8. Daily solar radiation data of Koycegiz station

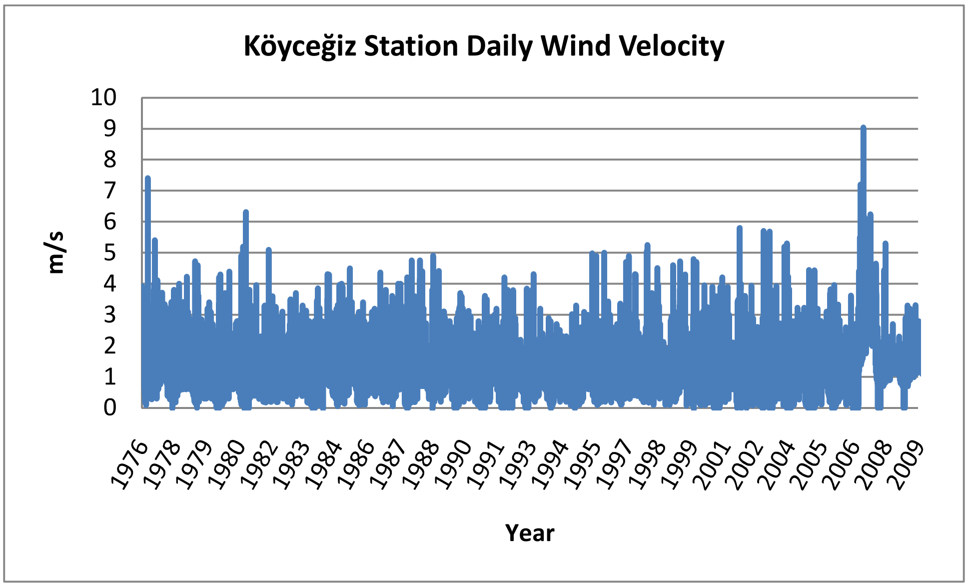

Figure 3.9. Daily wind velocity data of Koycegiz station

3.3 Land Use

Main land use of Koycegiz Dalyan Watershed is forest with a ratio of 65.6%. Region economy is dependent on agricultural activities. As given in **Table 3.3**, agricultural land is 11.7% of total watershed area. Totally 38 villages are found in the watershed and ratio of the residential area is 10%. Also, with 8604 ha area wetland is another land use category of the watershed.

Table 3.3: Land use distribution of the Koycegiz Dalyan Watershed

<table>
<tr><th>Region</th><th>Land use category</th><th>Area (ha)</th><th>Area (%)</th></tr>
<tr><td rowspan="5">Koycegiz</td><td>Forest</td><td>63569</td><td>58.1</td></tr>
<tr><td>Wetland</td><td>8604</td><td>7.9</td></tr>
<tr><td>Agricultural Land</td><td>9814</td><td>9.0</td></tr>
<tr><td>Residential</td><td>10930</td><td>10.0</td></tr>
<tr><td>Rock land</td><td>4743</td><td>4.3</td></tr>
<tr><td rowspan="3">Dalyan</td><td>Forest (ha)</td><td>8157</td><td>7.5</td></tr>
<tr><td>Agricultural Land (ha)</td><td>2970</td><td>2.7</td></tr>
<tr><td>Other (ha)</td><td>594</td><td>0.5</td></tr>
<tr><td colspan="2">TOTAL</td><td>109381</td><td>100</td></tr>
</table>

Agricultural activities are similar to Mediterranean countries in the watershed. The main crops that are produced in the area are citrus fruits such as orange, tangerine, lemon, and cotton, wheat, corn, olive, sesame and crops from horticulture (**Table 3.4**) In recent years pomegranate has been introduced into the crop pattern especially produced in the Dalyan region.

Table 3.4: Main crop types produced in the watershed

Crop	Ratio of planted area to total agricultural area (%)
Orange	23.6
Lemon	23.6
Corn	11.3
Pomegranate	10.9
Cotton	9.1
Wheat	7.9
Olive	4.3
Tangerine	1.4
Sesame	1.4

Rural land use distribution of the watershed is given in **Table 3.5.** Rural land use categories are cultivated land, pasture, forestry and not used area. Totally 81% of the watershed area is forest, and 68.6% is cultivated land. On the other hand, pasture covers 19.1% of the catchment area whereas 31.3% of total area is not used.

Table 3.5: Rural land use distribution of the Koycegiz Dalyan Watershed

Rural Land-use	Koycegiz		Dalyan	
	Area (ha)	**Ratio (%)**	**Area (ha)**	**Ratio (%)**
Cultivated land	13080	8,6	3259	60
Pasture	887	0,6	1000	18,5
Forestry	107413	70,5	568	10,5
Not used	30994	20,3	600	11
Total	**152374**	**100**	**5427**	**100**

3.4 Soil Structure

Soil structure is a vital factor for various processes such as surface run off, infiltration, crop growth, and soil water. It is a fact that knowing the soil properties provides indication while understanding complicated watersheds. Koycegiz Dalyan Watershed includes 7 major soil groups. Distribution of the soil groups based on the sub-provinces of the watershed is given in **Table 3.6**.

Brown forest soil without lime is the dominant type covering 57% of watershed area as seen in **Figure 3.10**. Color of the group varies from brown to light brown. It is known that upper zone is generally more acidic then the lower zone because of the surface wash off. Grass or shrubs are known as natural vegetation on this soil types. This soil types are composed of mainly deposits with gravels, sand and clays.

With a 23.4% covered area red-brown mediterranean soils is the second foremost soil type in the basin. As a result of medium organic content, it is perfectly mixed with minerals and well-developed soil type. Color of this type could be red or brown and they would have a shape of prismatic blocks with straight edges. Arid, humid and semi-humid climatic conditions are suitable for this type. Its material structure contains mainly hard calcite, granite on mountainous regions, clay stones, and various metamorphic crystal rocks.

Alluvial soils are located on the northwestern and southeastern banks of the Koycegiz Lake. Mineral structure of the alluvial soils is heterogeneous and dependent on the dominant geological characteristics of the streams since, they are formed by the accumulation of sediments conveyed by the streams. They are rich in lime and rather present a multi-layer texture. In the condition finely grained and high water, alluvial soils show poor infiltration characteristics. They have a tendency to have humid surface with rich organic content. On the other hand, if they are coarsely grained then they perform suitable drainage characteristics and thus dry rapidly on top layers.

Co-alluvial soils are mainly located on areas towards northeast from the Koycegiz Lake. It is generally probable to notice this soil type downhill to areas with high slope or at the entrance of valleys. The cause of the transportation of these materials to accumulate and form co-alluvial soil layers in time is gravitation, landslide, runoff and tributary streams elements.

Table 3.6: Sub-provinces and characteristic major soil groups within the basin of Koycegiz-Dalyan Lagoon System (Gonenc et al, 2002)

Major soil groups	Koycegiz Area(ha)	%	Ortaca Area(ha)	%	Ula Area(ha)	%	Total Area(ha)	%
Alluvial soils	4133	2.62	10141	35.7	1787	4.2	16061	7
Hydromorphic alluvial soils	1100	0.7	1194	4.2	162	0.38	2456	1
Colluvial soils	8610	5.3	1147	4	5017	11.7	14774	6.3
Alluvial wetlands	50	0.03	-	-	-	-	50	0.02
Brown forest soils without lime	113401	70.3	4952	17.4	13916	32.6	132269	57
Mediterranean red-brown soils	23380	14.5	10402	36.6	20628	48.3	54410	23.4
Mediterranean red soils	-	-	-	-	432	1	432	0.2
Other soil groups	4803	3.55	123	0.4	726	1.7	5652	2.4
Red yellow podsolic soils	5723		471	1.6	58	0.1	6252	2.7
TOTAL	161 200	**100**	28 430	**100**	42 726	**100**	232 356	**100**

Hydromorphic alluvial soils are slightly rare in the watershed and could be observed along the riparian of the lake and the lagoon system. These soils are formed under the dominance of water effects. Hydromorphic alluvial soils always have high water content. This is caused by founding together with high or above-surface waters.

Natural probable land cover would comprise grass, meadows, various riparian vegetation and other hydrophilic crops. Precipitation and runoff intensity dictates Particle sizes and layering of this type soil is affected by precipitation and run off intensity. On the other hand, unlike to alluvial layers they are much more irregular.

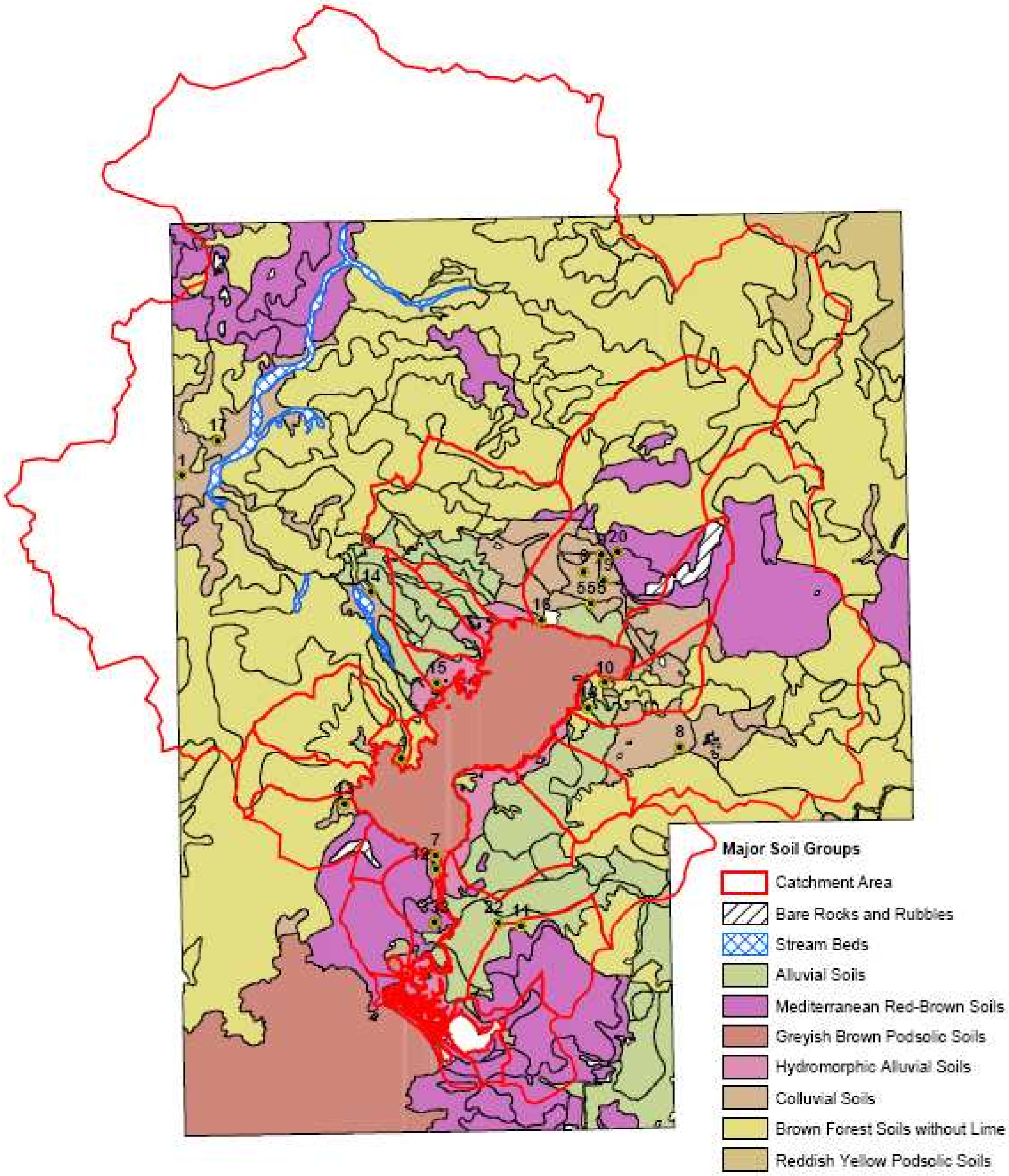

Figure 3.10: Soil groups of Köycegiz Dalyan Watershed

In addition to have well drainage characteristics, layer slopes are unique and increases towards downstream to the water resources.

Other soil types such as bare rocks without any soil cover, dry stream beds, red-yellow podsolic soil groups, mediterranean red soils are insignificantly found in the watershed.

Land capability classification, which is a method of land evaluation to indicate the specified potential use of a land. Such classification is usually presented as a thematic map with standard legends for land capability classes. There are eight standard major classes (I to VIII) universally accepted, ranking land-use potential on a "best" (I) to "worst" (VIII) basis for specified categories of agricultural uses.

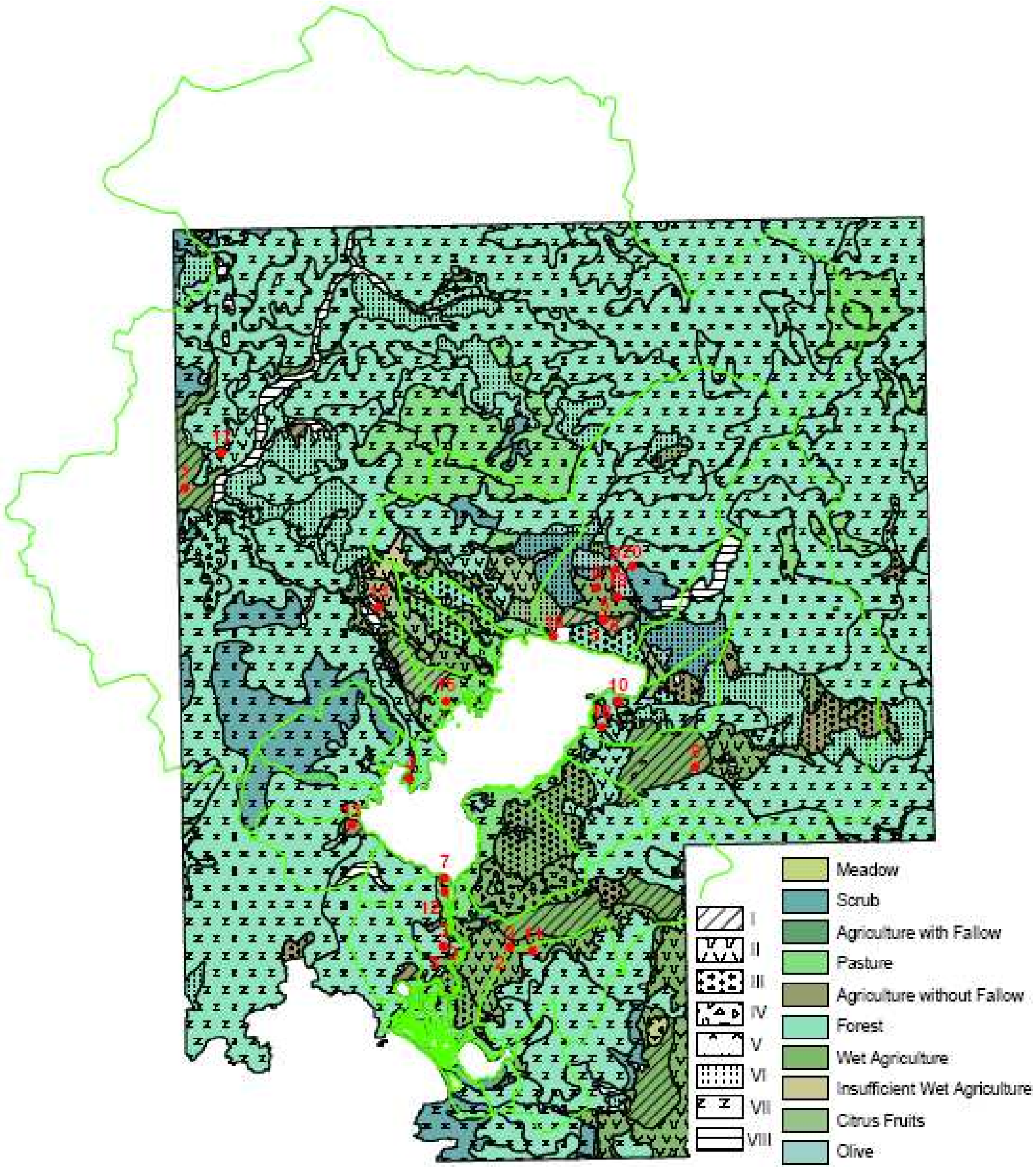

Figure 3.11: Land capability map of Koycegiz Dalyan Watershed based on land

In **Figure 3.1**1, land capability class is given with the land use map. Class I points that land suitable for regular cultivation where no special conservation measures are necessary. Class II indicates to land suitable for regular cultivation requiring simple soil conservation measures. Class III represents the land which is suitable for regular cultivation requiring intensive soil conservation measures. Class IV states land suitable for grazing and occasional cultivation requiring some erosion control measures.

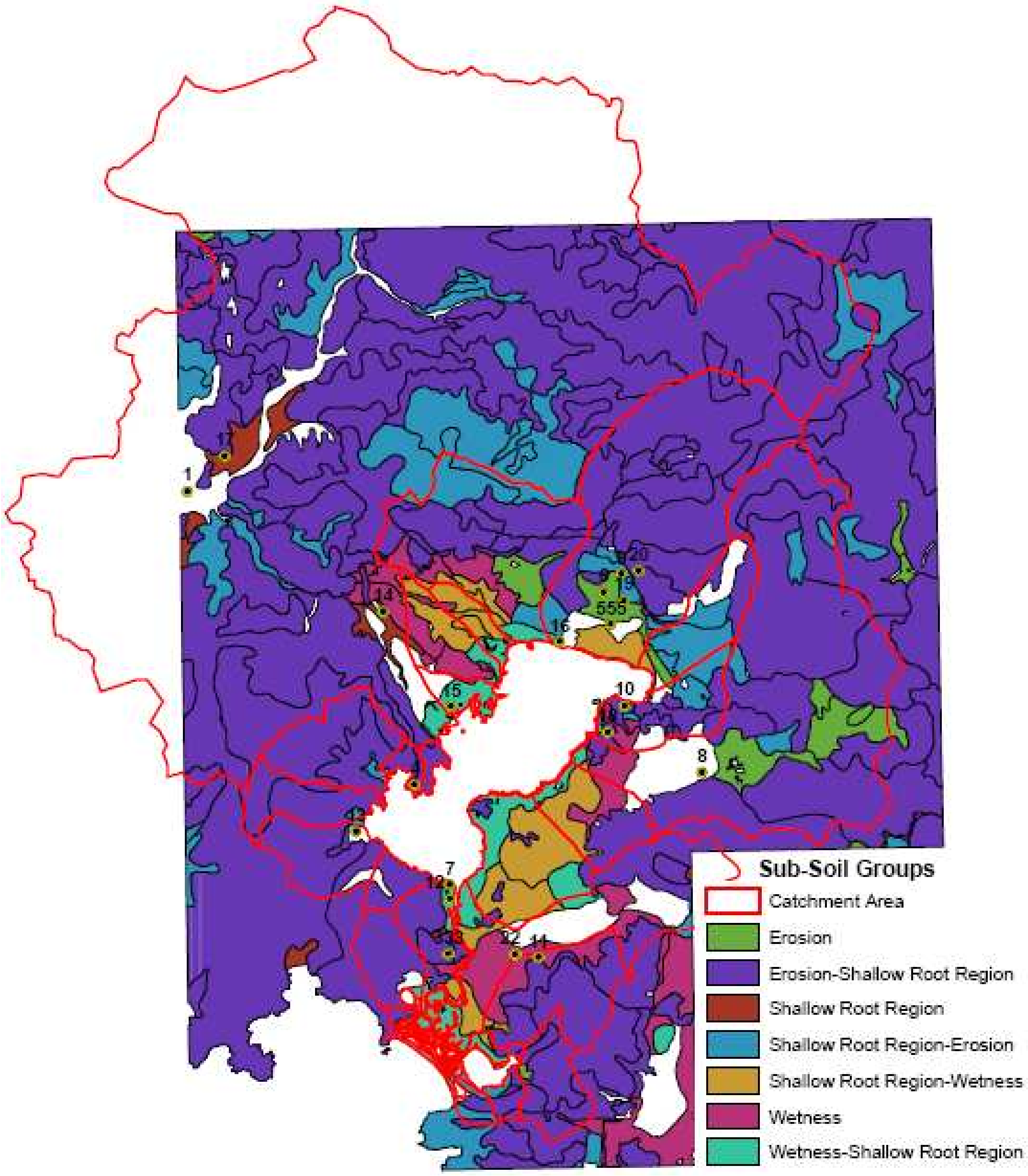

Figure 3.12. Sub-Soil groups of Koycegiz Dalyan Watershed

Class V shows that land suitable for grazing and occasional cultivation requiring intensive soil conservation works, Class VI refers land suitable for only grazing. Class VII presents land that is steep, infertile, or has shallow soils, and finally Class VIII indicates to land which should not be cultivated, and grazed (Frevert et al., 1993).

Within each of these classes, sub-classes may also be used to indicate the nature of the land-use constraints (Karagöz, 2003). United States Department of Agriculture (USDA), uses the following sub-class categories;

e: erosion hazard,

w: excess water problems,

s: soil root zone limitations (such as shallowness and stoniness)

c: climatic constraints.

Figure 3.12 shows the international soil sub-groups classification of the basin.

3.5 Pollution Sources and Loads

Pollution sources of the watershed can be summarized as domestic point sources, agricultural nonpoint pollution sources, and pollution from forest.75% of the basin is covered by forest and nearly 20% of the watershed is agricultural land. Agricultural activities and forest are the source of nonpoint pollution.

Table 3.7: Fertilizer originated monthly N load

Month	**N Load (kg/Month)**	**P Load (kg/Month)**
	With irrigation effect	**Without irrigation effect**
January	7128.2	648.5
February	19246	1668.8
March	8910.2	802.3
April	39917.6	3594.3
May	37423	3369.7
June	56669	5102.6
July	54174	4878
August	56312.3	5069.6
September	35997	3241.3
October	-	-
November	15682	1412
December	25661.3	2310.6
TOTAL (kg/year)	**356,407.30**	**32,092**

Domestic wastewaters are estimated as only point sources in the region since no industrial plant is settled in the region.

Nonpoint sources originated from forests and agricultural lands in the catchment area. Nonpoint pollution loads according to irrigation effect is given **Table 3.7** and **Table 3.8.** Fertilizers are the source of the nonpoint pollution from agriculture. Fertilisers used in the area are ammonium sulphate, potassium sulphate, potassium nitrate, triple super phosphate (TSP), diammonium phosphate (DAP) ammonium nitrate, potassium nitrate, urea and composite fertilisers.

Table 3.8: Fertilizer originated monthly P load

Month	**P Load (kg/Month)**	**P Load (kg/Month)**
	With irrigation effect	**Without irrigation effect**
January	196.26	-
February	505.07	8327.92
March	242.82	-
April	1087.85	-
May	1019.86	-
June	1544.36	-
July	1476.37	-
August	1534.65	12.54
September	981.01	-
October	-	1117.46
November	427.37	-
December	699.33	-
TOTAL (kg/year)	**9712.95**	**9712.95**

A comparison of pollution sources based on origin is showed in **Table 3.9.** According to data, it is seen that total nitrogen (TN) loads sourced from agriculture and forest are higher than domestic source. On the other hand, point and nonpoint total phosphorus (TP) loads is nearly equal.

Table 3.9: Pollution sources originated from domestic, agricultural and forest (Gonenc, 2002)

Sources	**TN (kg/year)**	**TP (kg/year)**
Domestic	90 888	34 082
Agriculture and Forest	607 603	45 388

Surface water and groundwater are used for irrigation in Koycegiz Dalyan Watershed. Irrigation activity is controlled by headman of Ministries and villages. Also, Ortaca District has an irrigation association that controls the farmers' irrigation activities. This association manages the Akkopru Dam water distribution between farmers based on irrigated area. Also, Namnam and Yuvarlakçay streams are other irrigation sources in the watershed. Drainage channels, groundwater wells are the main water sources for Dalyan region.

3.5 Hydrology, Geology, Hydrogeology

Hydrologic units of the watersheds are lakes, rivers, groundwater springs, creeks, and lagoon channel. Koycegiz Lake is the biggest one with a surface area of 54.5 km^2. It has characteristics of a slightly salty lake due to the seawater intrusion. Koycegiz Lake is fed by various water resources such as; creeks, groundwater, springs and water carried by drainage channels, and has a maximum depth of 30 m. The main streams which feed the Lake are; Namnam, Yuvarlak, Kargıcak, Yangı, Değirmendere, Çamlıdere, Kocaöz and Çakmak. With 502 km^2 drainage area, Namnam is the most important of them. Namnam Stream has an average flow rate of 10.83 m/s. The Lake is basically fed by groundwater. The hydraulic slope of groundwater is straight to the Koycegiz Lake, the sea and Dalyan Lagoon. The seasonal groundwater level variations are 0.5-6.55 m between May and November (Gönenç et al., 2002).

The only outlet of the Koycegiz Lake is the Mediterranean Sea through Dalyan Lagoon. With 14 km length and 1.5-2 m depth, Lagoon channel combines the Lake to the sea.

The area has a relatively heterogeneous geological structure. Additionally, as it is seen in Figure 3.9, geomorphology is different at the two sites of Dalyan channel. Geological structure of this system permits seawater instrusion to the Dalyan Lagoon system. There also exists hot springs in the region. Sultaniye, Velibey, Çavuş and Kokargirme are the most important ones among them. Sultaniye has a high level of radioactivity.

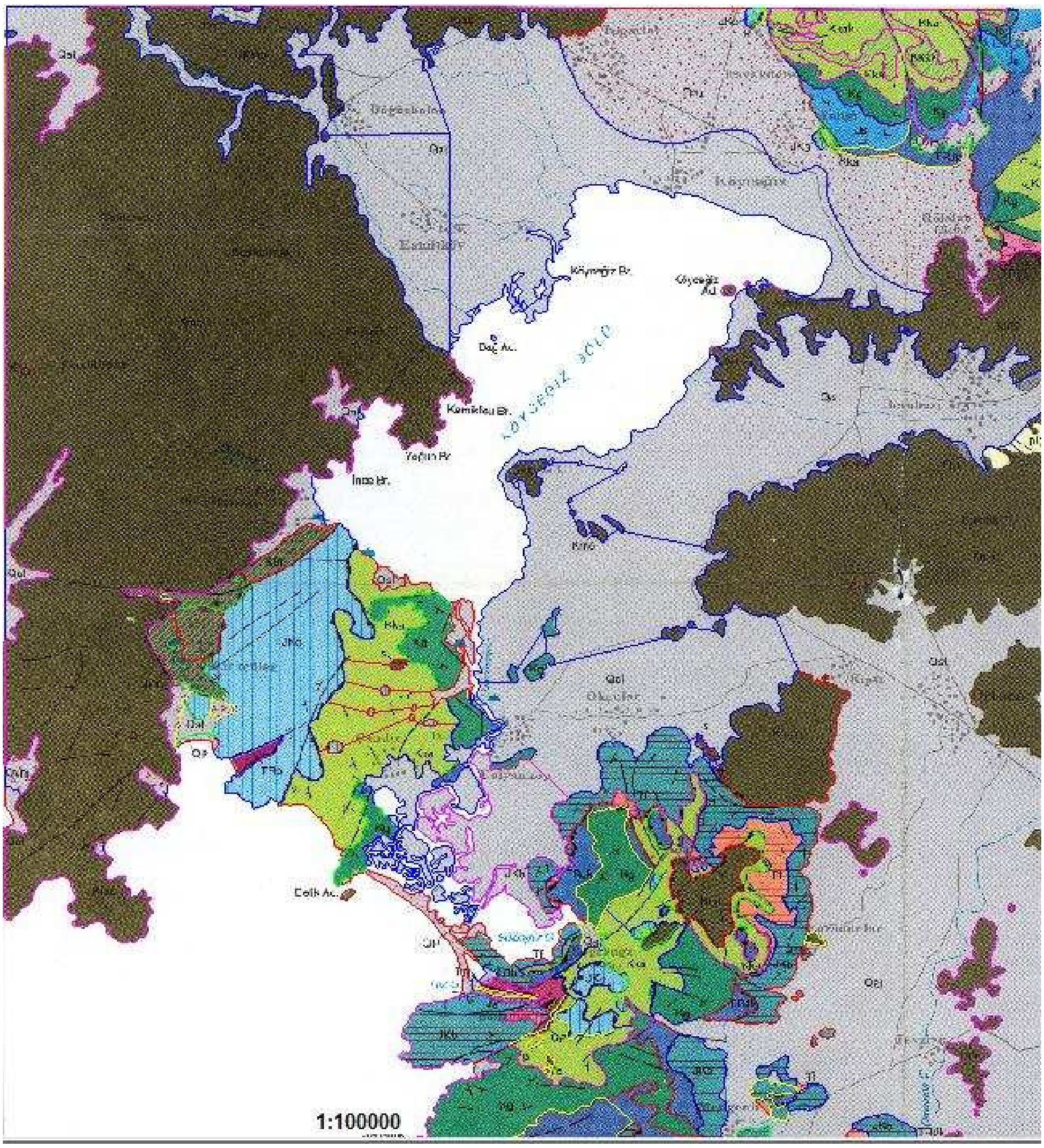

Figure 3.13: Geology map of the Koycegiz Dalyan Watershed

To understand movement of the groundwater and determine the surface run off constituents, hydrogeological structure of the watershed is significant factor. The characteristics of a system are closely related to the soil properties of land based on geological structure of the region. As a result, geology and hydrogeology of a region affect water transportation mechanisms and water constituents.

The watershed is considered as a tectonic depression zone. There are alluvial and karstic regions. Ophiolite nappe are mainly seen at the western and northern of the Koycegiz Lake whereas Lycien nappe (limestone, dolomite) are found southwest and northeast of Koycegiz Lake.

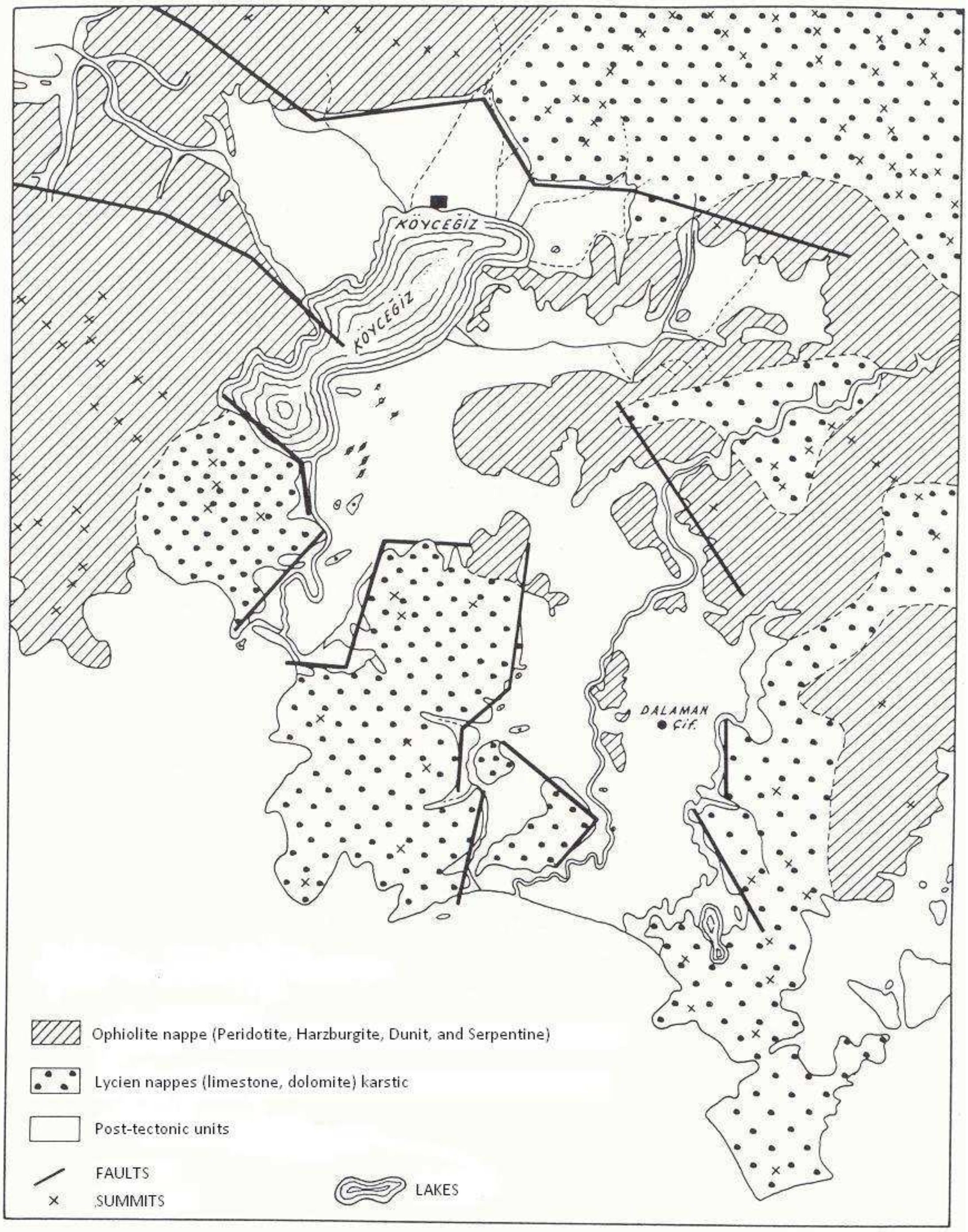

Figure 3.14: Hydrgeology map of the Koycegiz Dalyan Watershed

4. APPLICATION OF SWAT IN KOYCEGIZ DALYAN WATERSHED

Köyceğiz Dalyan System is one of the most sensitive ecosystems in Turkey with a quite complex, and dynamic structure. There is not any industrial activity in the watershed. Diffuse pollution is thought to be an important risk to the ecosystem. Agricultural activity is main source of the diffuse pollution. Thus, a study that will better estimate the amount of diffuse nutrient pollution is required. Within the scope of this study, application of SWAT model in Köyceğiz Dalyan Watershed is considered based on the model's abilities. Although the aim of this study is not to estimate nonpoint nutrient loads but application of SWAT model, this study will be the starting point to realize the target of estimating nonpoint nutrient loads.

There are several modeling studies for Köyceğiz Dalyan Watershed. Yüceil (2005) studied development of model support system for rural area non-point source modeling with HSPF model. In another study, MONERIS model was used to determine the nutrient emissions in Köyceğiz Dalyan Watershed (Adalı, 2004). Also, HSPF is used as a decision support tool for Köyceğiz Dalyan Watershed (Baloch, 2009). This study will be a complimentary study to the previous studies.

4.1 Preparation of Model Inputs

4.1.1 Digital Elevation Model (DEM)

A 90x90 m cell sized Digital Elevation Model is obtained from the SRTM (Shuttle Radar Topographic Mission) digital elevation data. There are some problems in the watershed delineation step, if the lake and the lagoon is included in DEM. Therefore, Köyceğiz Lake and Dalyan Lagoon are excluded from the DEM. WGS 1984 UTM Zone 35 N projection is used. Maximum elevation value is 2286 m, and minimum elevation value is under sea level. **Figure 4.1** shows the DEM of the Köyceğiz Dalyan Watershed.

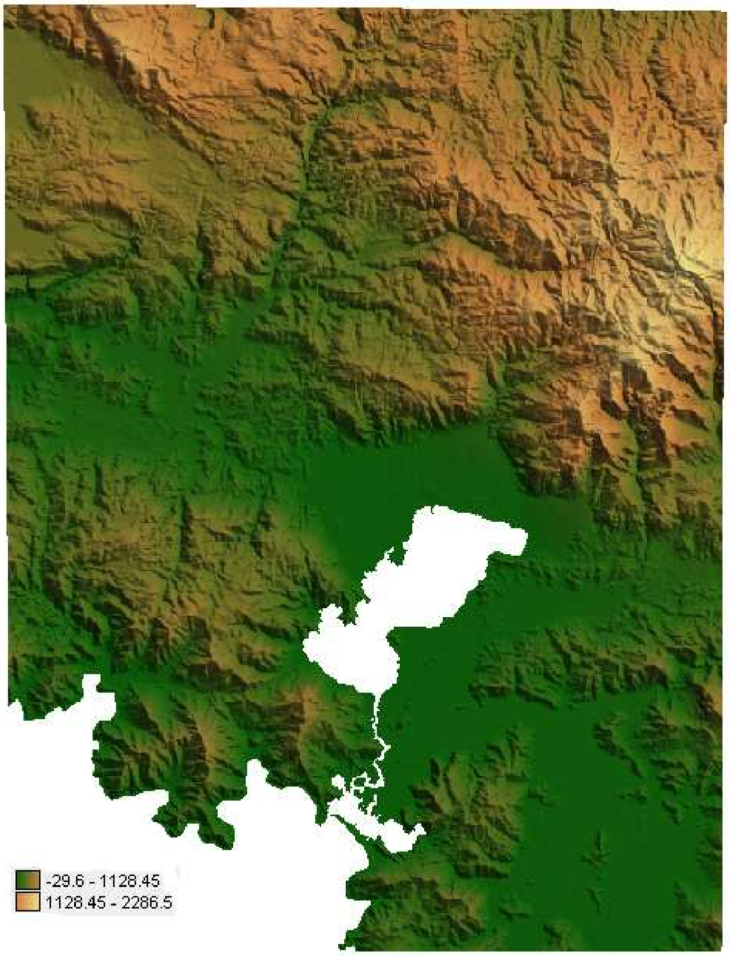

Figure 4.1: Digital Elevation Model of Köyceğiz Dalyan Watershed

4.1.3 Land use map and land use data

SWAT requires Geographical Information System (GIS) based land use map that covers the 95% of the modeled area. Land use map obtained from General Directorate of Rural Affairs of the Turkish Republic (TRGDRA). A 200x200 m cell sized land use map with a projection of WGS 1984 UTM Zone 35 N was used. Main land use categories of catchment area are forest, pasture, meadow, scrub, and agricultural land (**Figure 4.2**). Actually, SWAT model requires a land use/land cover map that includes both land use types and crop types together within a map. It means that crop names and the areas that these crops are cultivated within the agricultural area must be defined. Unfortunately, this kind of land use/land cover map did not exist for Köyceğiz Dalyan Watershed. Only two crops (olive and citrus fruits) had been defined in the land use map of the watershed. Because of this reason, mostly produced crops were selected for subcategories of the basin.

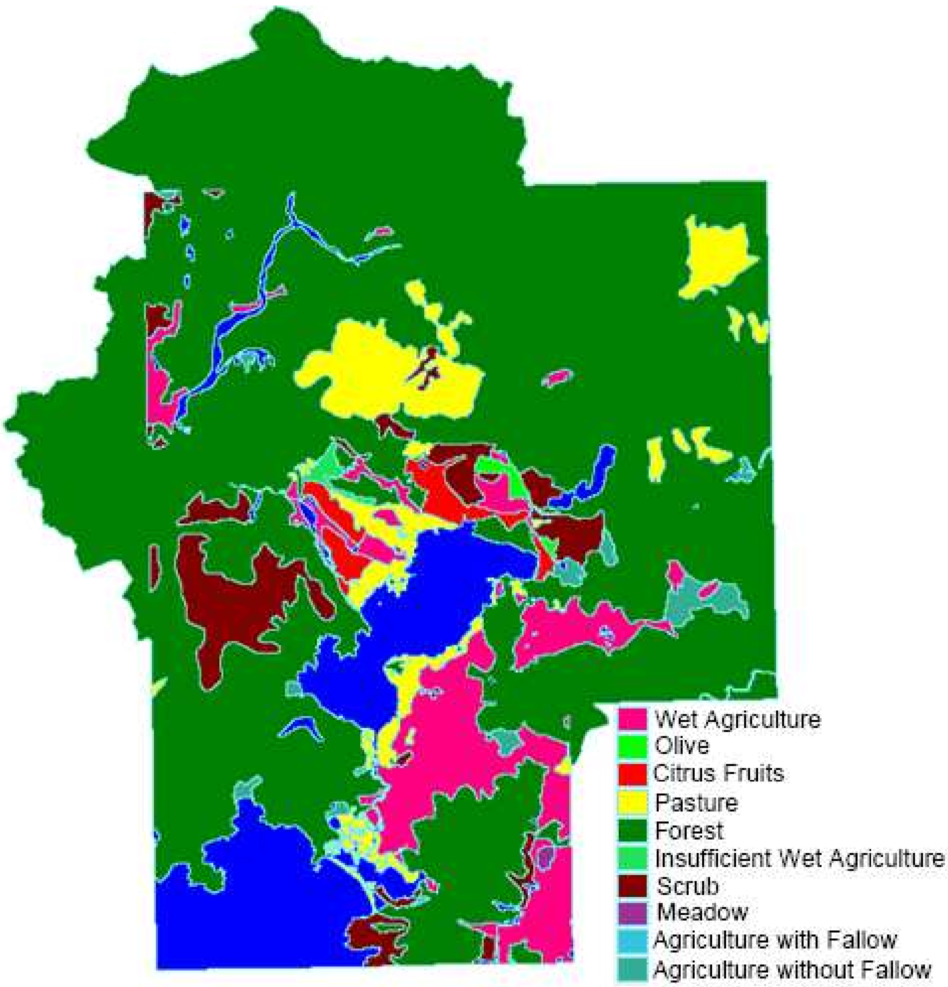

Figure 4.2: Land use map of Köyceğiz Dalyan Watershed

Crop pattern tables of Ortaca District and Köyceğiz District were gathered from District Agricultural Administrations. These tables include the produced crop type based on village and covered area. Crop pattern tables are organized according to villages (Appendix B) As a result, mostly produced crops are determined for each village. **Table 4.1** shows the distribution of crop types in Köyceğiz Dalyan Watershed. After all, village boundaries shape file superposed with land use map as given in **Figure 4.3.** Agricultural land divided into different subcategories including citrus fruits, pomegranate, corn, corn silage, cotton, tomato, bell pepper, sorghum hay, wheat, and olive. Land use map is modified based on the mostly produced crop types of the villages (**Figure 4.4**). Land use/land cover types of the catchment area were matched with SWAT crop database (**Table 4.2).**

Table 4.1: Distribution of crop types in Köyceğiz Dalyan Watershed

CROP	**AREA (ha)**	**%**
CITR	4387	39
POMG	4185	37.2
WWHT	1071	9.5
COTS	424	3.8
TOMA	333	3
OLIV	319	2.8
CORN	219	1.9
CSIL	210	1.9
SGHY	74	0.7
PEPR	23	0.2

Table 4.2: Symbols for the crops used in SWAT model database

SWAT Land use -land cover type	
Symbol	**Definition**
COTS	Cotton
TOMA	Tomato
WWHT	Wheat
CORN	Corn
CSIL	Corn silage
PEPR	Bell pepper
SHGY	Sorghum hay
PAST	Pasture
RNGE	Range grasses (Meadow)
RNGB	Range brush (Scrub)
OLIV	Olive
CITR	Citrus Fruits
PINE	Pine (Forest)
POMG	Pomegranate

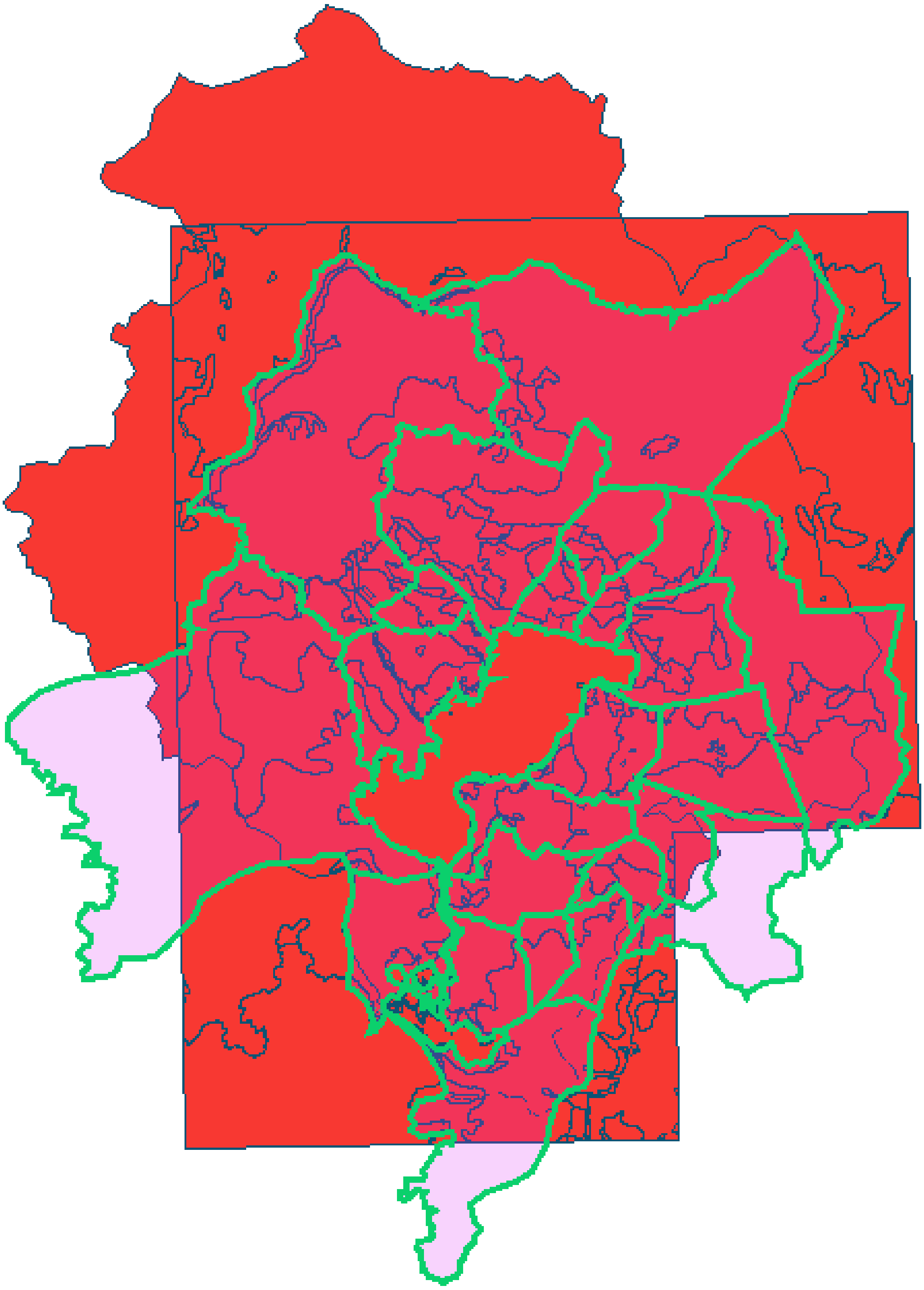

Figure 4.3: Superposed land use map and village boundaries

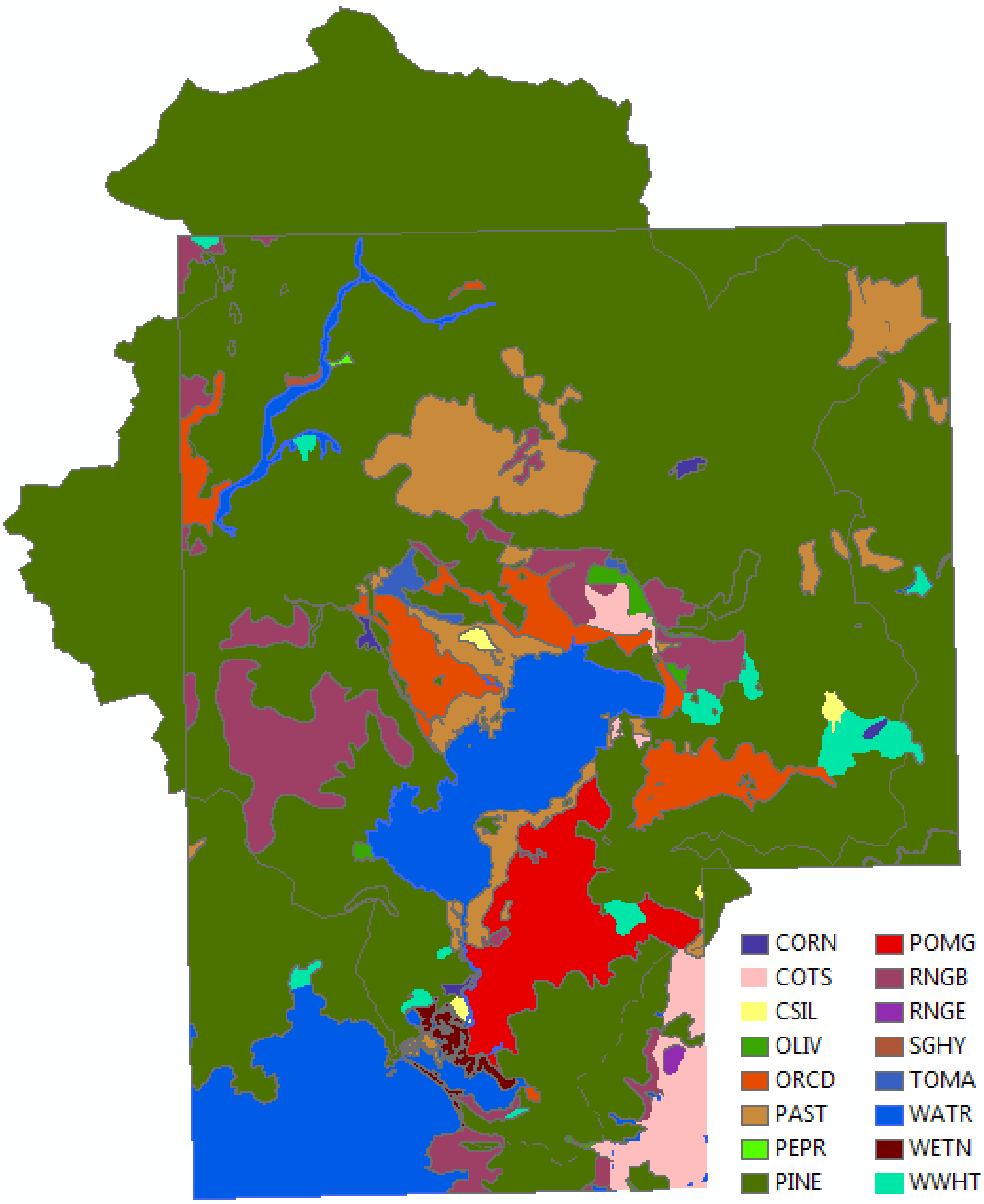

Figure 4.4: Land use/land cover map based on produced crop type

SWAT already has the crop data including harvest index, maximum leaf area index, maximum root depth, fraction of nitrogen in seed, lower limit of harvest index, etc. for numerous crop types. All required crop parameters in SWAT crop database are accessible in SWAT input, output documentation.

4.1.4 Soil map and soil data

SWAT model requires a GIS based soil map. DEM, land use map, and soil map are used in delineation of Köyceğiz Dalyan Watershed's subbasins and HRUs. Soil map is obtained from General Directorate of Rural Affairs of the Turkish Republic (TRGDRA) In this scope, a 200 x 200 m cell sized soil map was used as given in **Figure 4.5.** Main soil types of the catchment area are hydromorphic soils (H), alluvial soils (A), colluvial soils (K), brown forest soils without lime (N), Mediterranean red-brown soils (E), and reddish yellow podsolic soils (P). Characteristics of these soils were stated in Section 3.3. Soil parameters required to be identified in the SWAT soil database are listed in **Table 4.3.** Some of these parameters were obtained from the result of previous soil experiments (Yuceil, 2005) carried out in the watershed in 2004. (e.g. clay content, sand content, and silt content). Location of the soil experiment stations is given in **Figure 4.6,** whereas, soil experiment results are provided in Appendix C. Other required parameters were determined based on both experimental results and literature.

To identify the characteristics of basin soil categories, representative stations for each soil category was determined as given in **Table 4.4.** The parameter "soil name" depends on user's choice. It is needed only for the writing of outputs. Turkish standard soil category names such as A, H, N, P, K were used for the parameter "soil name" in this study.

The number of soil layers was set to 10 for each soil category. However, there was not enough data for each layer. Therefore, same values are specified for each layer. Only depth of the layers differs from each other. It is thought that this study will support following studies, and missing data for each layer will be obtained later. So, the present simulation should be run by using possible options. Consequently, it can be said that soil profile has the same properties through the depth at the moment, but the possibility of specifying different values for each layer exists.

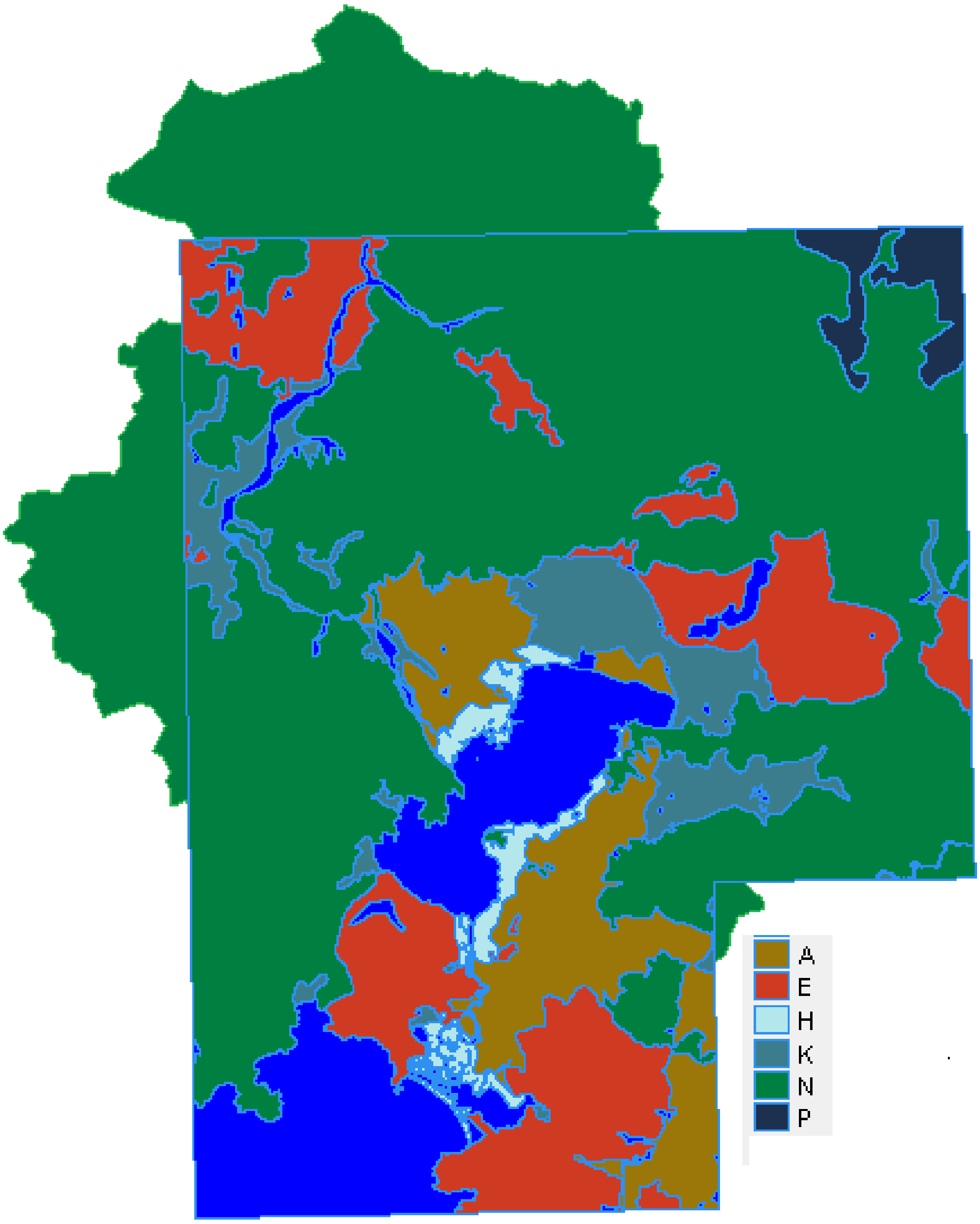

Figure 4.5: Soil map of Köyceğiz Dalyan Watershed

Table 4.3: Required soil parameters for SWAT model

PARAMETER	**DEFINITION**
SNAM	The soil name is printed in HRU summary tables
NLAYERS	Number of layers (max 10, and max depth of each layer is 2,5 m)
HYDGRP	Soil hydrologic group (A, B, C,D)
SOL_ZMX	Maximum rooting depth of soil profile (mm). If no depth is specified, the model assumes the roots can develop throughout the entire depth of soil profile
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded. If not entered, will be set 0,50
SOL_CRK	Potential or maximum crack volume of soil profile expressed as a fraction of the total soil volume
SOL_Z1	Depth from soil surface to bottom of the layer (mm).
SOL_BD1	Soil bulk density (1,1-1,9 μ/m^3, g/cm^3)
SOL_AWC1	Available water capacity of soil layer (mmH_2O/mm soil)
SOL_K1	Saturated hydraulic conductivity (mm/hr)
SOL_CBN1	Organic carbon content (% soil weight)
CLAY1	Clay content, percentage of soil particles which are < 0.002 mm in equivalent diameter (% soil weight)
SILT1	Silt content, percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 (% soil weight) (required).
SAND1	Sand content percentage of soil particles which have an equivalent diameter between 2 and 0.05 (% soil weight)
ROCK1	Rock fragment content, the percent of sample which has a particle size diameter > 2 mm (% total weight)
SOL_ALB1	Moist soil albedo. The ratio of the amount of solar radiation reflected by body to the amount incident upon it (fraction)
USLE_K1	USLE equation soil erodibility factor (metric ton m^2 hr/ m^3 metric ton cm)

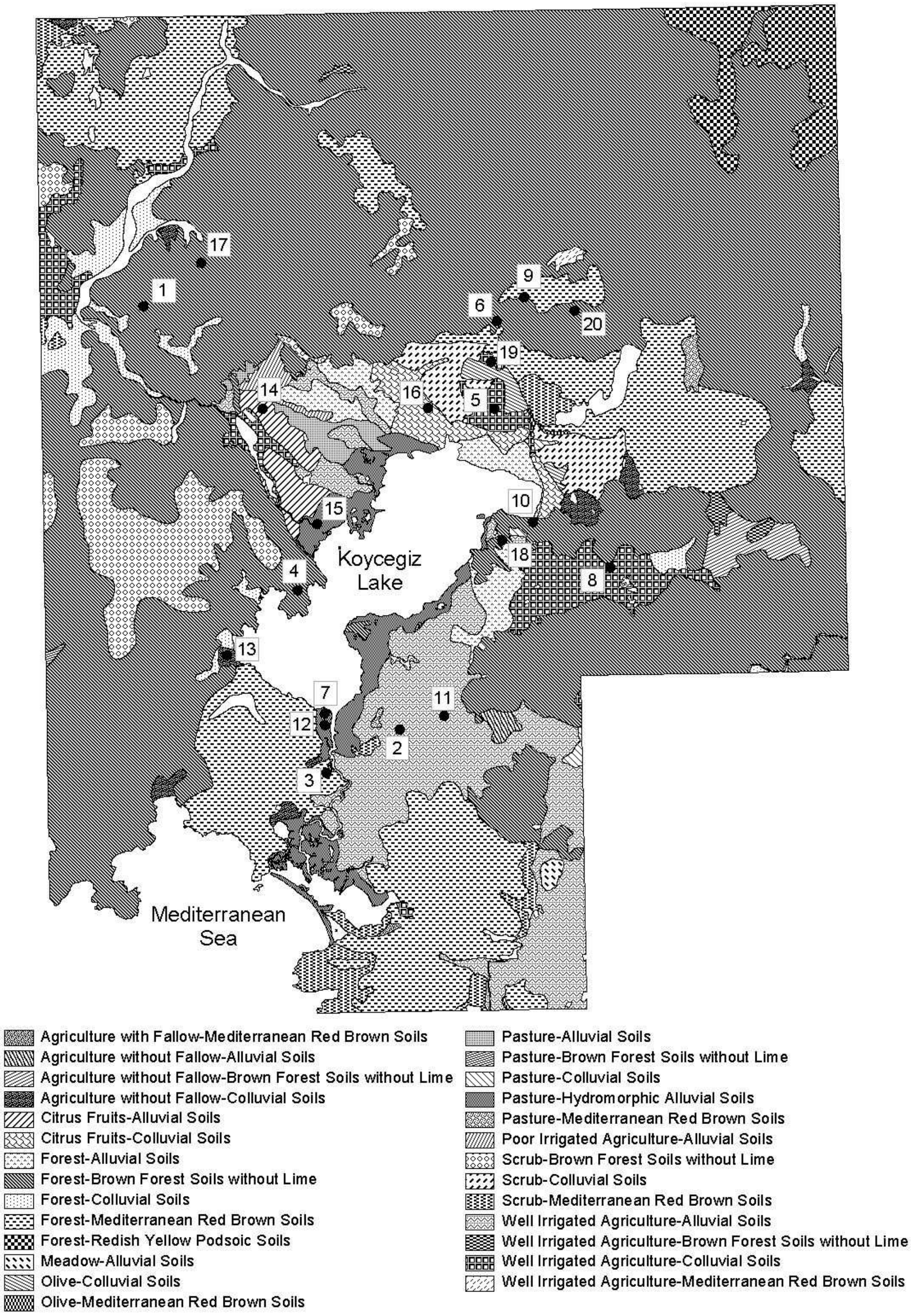

Figure 4.6: Location of the soil experiment stations

Table 4.4: Representative stations for each soil category of the basin

Soil Category	Soil name	Station number
Alluvial soils	A	2-12-3-14-15-11
Mediterranean red-brown soils	E	6-9-10-20
Hydromorphic alluvial soils	H	7
Colluvial soils	K	13-16-5-19-8-18
Brown forest soils without lime	N	4-1-17

Hydrologic soil group of the catchment soil categories were determined based on U.S. Natural Resources Conservation Service (NRCS) classification. According to NRSC soils separated into four hydrologic groups with respect to infiltration characteristics. Symbol of the groups are A, B, C, D, where group A represents the soils have high infiltration rates, and group D represents the soils have very slow infiltration rates. Based on the NRSC criteria, main soil groups were classified for Koyceğiz Dalyan Watershed as in **Table 4.5.**

Table 4.5: Hydrologic soil group of Köyceğiz Dalyan Watershed soil categories

Major soil groups	**Soil Name**	**Hydrologic soil group**
Alluvial soils	A	B
Hydromorphic soils	H	B
Colluvial soils	K	A
Brown forest soils without lime	N	D
Mediterranean red-brown soils	E	C

Maximum rooting depth of soil profile was determined according to previous soil experiment results (Yuceil, 2005). Main rock depth data was used for evaluation of maximum rooting depth parameter. As indicated in **Table 4.6,** main rock depth value exists for stations 1, 2, 4, 6, 9, 10, 13 and 17. Main rock depth values for other stations are estimated as 1000 mm.

Table 4.6: Maximum rooting depth of soil profile

Station	**Maximum Rooting Depth (SOL_ZMX) (mm)**
1	300
2	600
3	1000
4	350
5	1000
6	250
7	1000
8	1000
9	400
10	700

Station	**Maximum Rooting Depth (SOL_ZMX) (mm)**
11	1000
12	1000
13	400
14	1000
15	1000
16	1000
17	200
18	1000
19	1000
20	1000

Anion excluded and potential or maximum crack volume of soil profile, were not specified for the basin. SWAT model set these values 0,5.

In simulation, ten layers selected for each soil type. For the determination of depth from soil surface to bottom of the layer parameter, maximum rooting depth was divided into almost equal depths for each layer as given in **Table 4.7.**

Table 4.7: Depth of the soil surface to bottom of the layer for all soil categories

Station	SOL_ Z1 (mm)	SOL_ Z2 (mm)	SOL _Z3 (mm)	SOL_ Z4 (mm)	SOL_ Z5 (mm)	SOL_ Z6 (mm)	SOL_ Z7 (mm)	SOL_ Z8 (mm)	SOL_ Z9 (mm)	SOL_ Z10 (mm)
1	25	50	75	100	130	160	200	230	260	300
2	50	100	150	200	250	300	350	400	500	600
3	100	200	300	400	500	600	700	800	900	1000
4	25	50	75	100	125	150	200	250	300	350
5	100	200	300	400	500	600	700	800	900	1000
6	25	50	75	100	125	150	175	200	225	250
7	100	200	300	400	500	600	700	800	900	1000
8	100	200	300	400	500	600	700	800	900	1000
9	25	50	75	100	150	200	250	300	350	400
10	50	100	150	200	250	300	400	500	600	700
11	100	200	300	400	500	600	700	800	900	1000
12	100	200	300	400	500	600	700	800	900	1000
13	25	50	75	100	150	200	250	300	350	400
14	100	200	300	400	500	600	700	800	900	1000
15	100	200	300	400	500	600	700	800	900	1000
16	100	200	300	400	500	600	700	800	900	1000
17	20	40	60	80	100	120	140	160	180	200
18	100	200	300	400	500	600	700	800	900	1000
19	100	200	300	400	500	600	700	800	900	1000
20	100	200	300	400	500	600	700	800	900	1000

Soil bulk density (SOL_BD) parameter was calculated as given in **Table 4.8** for each soil category by using laboratory results and literature values.

SOL_BD = [1- (%sand x %pore volume of sand) + (%silt x %pore volume of silt) + (%clay x %pore volume of clay)] x 2.65

To determine the available water content, firstly a literature review was done. By using the second column of the **Table 4.9**, porosity was determined as given below.

Porosity = [Sand pore vol. (%) x Sand(%)] + [Sand pore vol. (%) x Clay(%)] + [Sand pore volume (%) x Silt (%)]/100

Table 4.8: Calculated soil bulk density data for soil experiment stations

Station No	Depth (m)	CLAY (%)	SILT (%)	SAND (%)	Soil Bulk Density (g/cm^3)
1	0	18.13	18.65	63.22	1.47
2	0	18	16.51	65.49	1.47
2	30	5.87	10.41	83.72	1.50
3	0	56.62	30.79	12.59	1.40
3	30	58.59	28.73	12.68	1.41
3	60	64.6	22.63	12.77	1.42
4	0	26	34.56	39.44	1.42
5	0	20.66	30.15	49.19	1.43
5	30	20.66	26.13	53.21	1.44
5	60	22.65	30.12	47.23	1.43
6	0	22.7	26.15	51.15	1.44
7	0	53.71	32.85	13.44	1.40
8	0	21.09	40.68	38.23	1.40
9	0	12.98	22.48	64.54	1.46
10	0	33.08	24.02	42.9	1.44
11	0	53.24	21.92	24.84	1.43
12	0	46.84	35.86	17.3	1.40
13	0	16.66	31.83	51.51	1.43
14	0	18.73	31.93	49.34	1.43
15	0	12.64	38.23	49.13	1.42
16	0	8.59	20.08	71.33	1.47
17	0	24.76	36.29	38.95	1.41
18	0	22.81	26.64	50.55	1.44
19	0	4.58	24.46	70.96	1.46
20	0	12.62	22.48	64.9	1.46

Table 4.9: Pore size of the sand, clay and silt (Schechtschabel, 2001)

Texture	Pore volume (%)	Coarse pores (%)	Medium pores (%)	Fine pores (%)
Sandy	30±10	30±10	7±5	5±3
Clay	15±10	15±10	15±7	15±5
Silty	8±5	8±5	10±5	35±10

$$AWC = (FC - WP) \times Porosity$$

where AWC is available water capacity (mmH_2O/mm soil), FC is the field capacity (%), WP is the wilting point (%). Summary of the calculated available water content is given in **Table 4.10.**

Table 4.10: Calculated available water content for each station

Station no	Depth (m)	Sand (%)	Clay (%)	Silt (%)	Field Capacity (FC) (%)	Wilting Point (WP) (%)	FC-WP (%)	Porosity (%)	AWC (mmH_2O/ mmsoil)
1	0	63.22	18.13	18.65	0.47	0.36	0.11	0.47	0.050
2	0	65.49	18.00	16.51	0.18	0.12	0.06	0.47	0.028
2	30	83.72	5.87	10.41	0.10	0.06	0.034	0.46	0.016
3	0	12.59	56.62	30.79	0.37	0.26	0.114	0.48	0.054
3	30	12.68	58.59	28.73	0.38	0.25	0.129	0.48	0.062
3	60	12.77	64.60	22.63	0.40	0.29	0.112	0.48	0.053
4	0	39.44	26.00	34.56	0.37	0.24	0.124	0.48	0.059
5	0	49.19	20.66	30.15	0.20	0.09	0.11	0.47	0.052
5	30	53.21	20.66	26.13	0.21	0.10	0.107	0.47	0.051
5	60	47.23	22.65	30.12	0.19	0.10	0.086	0.47	0.041
6	0	51.15	22.70	26.15	0.20	0.11	0.089	0.47	0.042
7	0	13.44	53.71	32.85	0.41	0.29	0.116	0.48	0.056
8	0	38.23	21.09	40.68	0.24	0.14	0.104	0.48	0.050
9	0	64.54	12.98	22.48	0.20	0.12	0.075	0.47	0.035
10	0	42.90	33.08	24.02	0.57	0.46	0.106	0.47	0.050
11	0	24.84	53.24	21.92	0.36	0.30	0.068	0.47	0.032
12	0	17.30	46.84	35.86	0.31	0.18	0.125	0.48	0.060
13	0	51.51	16.66	31.83	0.23	0.14	0.085	0.47	0.040
14	0	49.34	18.73	31.93	0.24	0.12	0.124	0.47	0.059
15	0	49.13	12.64	38.23	0.21	0.09	0.115	0.48	0.055
16	0	71.33	8.59	20.08	0.17	0.08	0.091	0.47	0.043
17	0	38.95	24.76	36.29	0.37	0.20	0.167	0.48	0.080
18	0	50.55	22.81	26.64	0.35	0.21	0.136	0.47	0.064
19	0	70.96	4.58	24.46	0.15	0.07	0.076	0.47	0.036
20	0	64.90	12.62	22.48	0.18	0.10	0.086	0.47	0.040

To determine the saturated hydraulic conductivity of basin soil categories, literature was reviewed. Radcliffe and West (2009) reported saturated hydraulic conductivity values based on soil texture as indicated in **Table 4.11.**

Table 4.11: Saturated hydraulic conductivity based on soil texture (Radcliffe and West, 2009)

Soil Textural Class	***Ks* (cm/day)**	**Soil Textural Class**	***Ks* (cm/day)**
Sand (S)	642.98	Sandy clay loam (SCL)	13.19
Loamy sand (LS)	105.12	Loam (L)	12.04
Silt	43.74	Sandy clay	11.35
Sandy loam (SL)	38.25	Silty clay loam	11.11
Silt loam	18.26	Silty clay	9.61
Clay (C)	14.75	Clay loam (CL)	8.18

Table 4.12: Selected saturated hydraulic conductivity of each station

Station No	Texture	K_{sat} (cm/day)	K_{sat} (mm/h)	Selected Value (mm/h)
1	SL	38.25	15.91	15.91
2	SL	38.25	15.91	15.91
2	LS	105.12	43.73	43.73
3	C	14.75	6.14	6.14
3	C	14.75	6.14	6.14
3	C	14.75	6.14	6.14
4	L(CL)	8.18 (12.04)	3.40 (5.01)	4.21
5	L	12.04	5.01	5.01
5	SCL(SL)	13.19 (38.25)	5.49 (15.91)	10.70
5	L	12.04	5.01	5.01
6	SCL(SL)	13.19 (38.25)	5.49 (15.91)	10.70
7	C	14.75	6.14	6.14
8	L	12.04	5.01	5.01
9	SL	38.25	15.91	15.91
10	CL	8.18	3.40	3.40
11	C	14.75	6.14	6.14
12	C	14.75	6.14	6.14
13	L	12.04	5.01	5.01
14	L	12.04	5.01	5.01
15	L	12.04	5.01	5.01
16	SL	38.25	15.91	15.91
17	L	12.04	5.01	5.01
18	SCL(SL)	13.19 (38.25)	5.49 (15.91)	10.70
19	SL	38.25	15.91	15.91
20	SL	38.25	15.91	15.91

Organic carbon content (SOL_CBN) was determined by using the organic matter content based on the equation given below. Results are provided in **Table 4.13.**

Organic matter content (% soil weight) = 1.72 x Organic carbon content

Soil albedo was determined according to studies conducted by Dobos (2003). Land cover of the alluvial soils is agricultural area. So, cropland albedo value (0.2) is selected for alluvial soils. For coniferous forest albedo value is given between 0.05-0.15 in **Table 4.14.** According to **Table 4.15,** albedo value range is 0.4-0.5 for light colored soil surfaces and range 0.4-0.5 for dark soil surfaces. As a result, albedo value of brown forest soils without lime is selected 0.1 and albedo value of Mediterranean red-brown soils is selected 0.2. Land cover of the hydromorphic soil surfaces is grassland. In addition this soil type has wet texture. Albedo for grassland

Table 4.13: Result of the organic carbon content calculations

Station No	Depth (m)	Organic Matter Content (%)	SOL_CBN (%soil weight)
1	0	2.6	1.51
2	0	2.2	1.28
2	30	1.0	0.58
3	0	2.2	1.28
3	30	1.3	0.76
3	60	1.3	0.76
4	0	5.7	3.31
5	0	1.7	0.99
5	30	1.0	0.58
5	60	1.0	0.58
6	0	2.1	1.22
7	0	2.2	1.28
8	0	1.9	1.10
9	0	1.5	0.87
10	0	3.1	1.80
11	0	1.6	0.93
12	0	3.4	1.98
13	0	3.3	1.92
14	0	1.8	1.05
15	0	1.6	0.93
16	0	1.4	0.81
17	0	2.1	1.22
18	0	2.2	1.28
19	0	1.5	0.87
20	0	1.6	0.93

Table 4.14: Albedo values for different surfaces (Davies and Idso, 1979; Oke, 1987; Campbell and Norman, 1998)

Surface	Albedo (fraction)	Surface	Albedo (fraction)
Grass	0.17 - 0.28	Sub-arctic	0.09 - 0.20
Wheat	0.16 - 0.26	Savanna	0.16 - 0.21
Maize	0.18 - 0.22	Steppe	0.2
Beets	0.18	Fresh snow	0.75 - 0.95
Potato	0.19	Old snow	0.40 - 0.70
Rain forest	0.12	Wet dark soil	0.08
Deciduous forest	0.10 - 0.20	Dry dark soil	0.13
Coniferous forest	**0.05 - 0.15**	Dry sand	0.35

is between 0.17-0.28. This group differs from the alluvial soil in terms of water content. So, a lower value (0.1) than alluvial soils is selected for hydromorphic soils. Selected albedo values for major soil groups of the watershed are given in **Table 4.16.**

Table 4.15: Approximate albedo values for different surface types (Dobos, 2003)

Natural Surface Types	**Approximated Albedo (fraction)**
Blackbody	0
Forest	0.05-0.2
Grassland and cropland	0.1-0.25
Dark colored soil surfaces	0.1-0.2
Dry sandy soil	0.25-0.45
Dry clay soil	0.15-0.35
Sand	0.2-0.4
Mean albedo for earth	0.36
Granite	0.3-0.35
Glacial ice	0.3-0.4
Light colored soil surfaces	0.4-0.5
Dry salt cover	0.5
Fresh, deep snow	0.9
Water	0.1-1
Absolute white surface	1

Table 4.16: Selected albedo values for major soil groups of the catchment area

Major soil groups	**Symbol**	**Station No**	**Albedo (fraction)**
Alluvial soils	A	2-3-11-12-14-15	0.2
Hydromorphic soils	H	7	0.15
Colluvial soils	K	13-16-5-19-8-18	0.1*,0.2#
Podzolic soils	G		0.5
Brown forest soils without lime	N	1-4-17	0.1
Mediterranean red-brown soils	E	6-9-10-20	0.2

*Forest
#Agricultural

Wischmeier and Smith (1978) defined the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. They noted that a soil type usually becomes less erodible with decrease in silt fraction, whereas increase in the sand fraction or clay fraction. Wischmeier et al. (1971) developed the following general equation to calculate the soil erodibility factor.

$$K_{USLE} = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM) + 3.25 \cdot (c_{soilstr} - 2) + 2.5 \cdot (c_{perm} - 3)}{100}$$

Table 4.17: Selection criteria for $c_{soilstr}$, c_{perm} parameters

$c_{soilstr}$		c_{perm}	
1	Very fine granular	1	Rapid (>150 mm/hr)
2	Fine granular	2	Moderate to rapid (50-150 mm/hr)
3	Medium or coarse granular	3	Moderate (15-50 mm/hr)
4	Block, platy, prismlike or massive	4	Slow to moderate (5-15 mm/hr)
		5	Slow (1-5 mm/hr)
		6	Very slow (<1 mm/hr)

Table 4.18: K_{USLE} parameter values for different stations

Station No	Depth (m)	CLAY (%)	SILT (%)	SAND (%)	M (%)	USLE_K (metric ton m^2hr /m^3metric ton cm)
1	0	18.13	18.65	63.22	6702.7	0.486726
2	0	18	16.51	65.49	6724.0	0.507771
2	30	5.87	10.41	83.72	8860.5	0.738154
3	0	56.62	30.79	12.59	1881.8	0.136292
3	30	58.59	28.73	12.68	1714.8	0.134296
3	60	64.6	22.63	12.77	1253.2	0.126442
4	0	26	34.56	39.44	5476.0	0.274273
5	0	20.66	30.15	49.19	6294.8	0.488339
5	30	20.66	26.13	53.21	6294.8	0.519828
5	60	22.65	30.12	47.23	5983.0	0.491983
6	0	22.7	26.15	51.15	5975.3	0.444666
7	0	53.71	32.85	13.44	2142.8	0.154049
8	0	21.09	40.68	38.23	6226.8	0.481247
9	0	12.98	22.48	64.54	7572.5	0.590596
10	0	33.08	24.02	42.9	4478.3	0.304067
11	0	53.24	21.92	24.84	2186.5	0.165141
12	0	46.84	35.86	17.3	2826.0	0.180257
13	0	16.66	31.83	51.51	6945.6	0.462809
14	0	18.73	31.93	49.34	6604.8	0.509686
15	0	12.64	38.23	49.13	7631.8	0.607701
16	0	8.59	20.08	71.33	8355.8	0.666053
17	0	24.76	36.29	38.95	5661.1	0.394601
18	0	22.81	26.64	50.55	5958.3	0.43908
19	0	4.58	24.46	70.96	9105.0	0.719427
20	0	12.62	22.48	64.9	7635.3	0.583005

where, K_{USLE} is the soil erodibility factor, M is the particle size parameter, OM is the organic matter percent, $c_{soilstr}$ is the soil structure code used in soil classification, c_{perm} is the profile permeability class. M is calculated with the following equation.

$$M = (m_{silt} + m_{vfs}) \cdot (100 - m_c)$$

where, m_{silt} is the percent silt content, m_{vfs} is the percent very fine sand content, and mc is the percent clay content. OM is calculated by using the equation in below.

$$OM = 1.72 \cdot orgC$$

where, orgC is the organic carbon content of the layer (%).

To define the K_{USLE} parameter for the catchment area soil groups, firstly $c_{soilstr}$, c_{perm} parameters were evaluated by using the criteria given in **Table 4.17**. Then, M value was calculated based on clay, sand and silt content by using soil experiment results. Finally, K_{USLE} parameter was determined and results are given in **Table 4.18.**

4.1.5 Slope definition

Slope is an important factor that has effect on the movement of the water, sediment, and nutrients. Model has two options: multiple slope or single slope. Multiple slope option is chosen in this study. Because, according to topographic map of the area it is seen that 3 different slope group is given. Otherwise, single slope option denotes that the mean value of the slope will be used for the whole watershed. After evaluation of slope groups, it is seen that slope mainly distribute between three groups. Therefore, number of slope classes is given 3. Lower and upper limits of the classes are given in **Table 4.19.**

Table 4.19: SWAT slope classification table

Class	Lower limit (%)	Upper limit (%)
1	0	5
2	5	30
3	30	>30

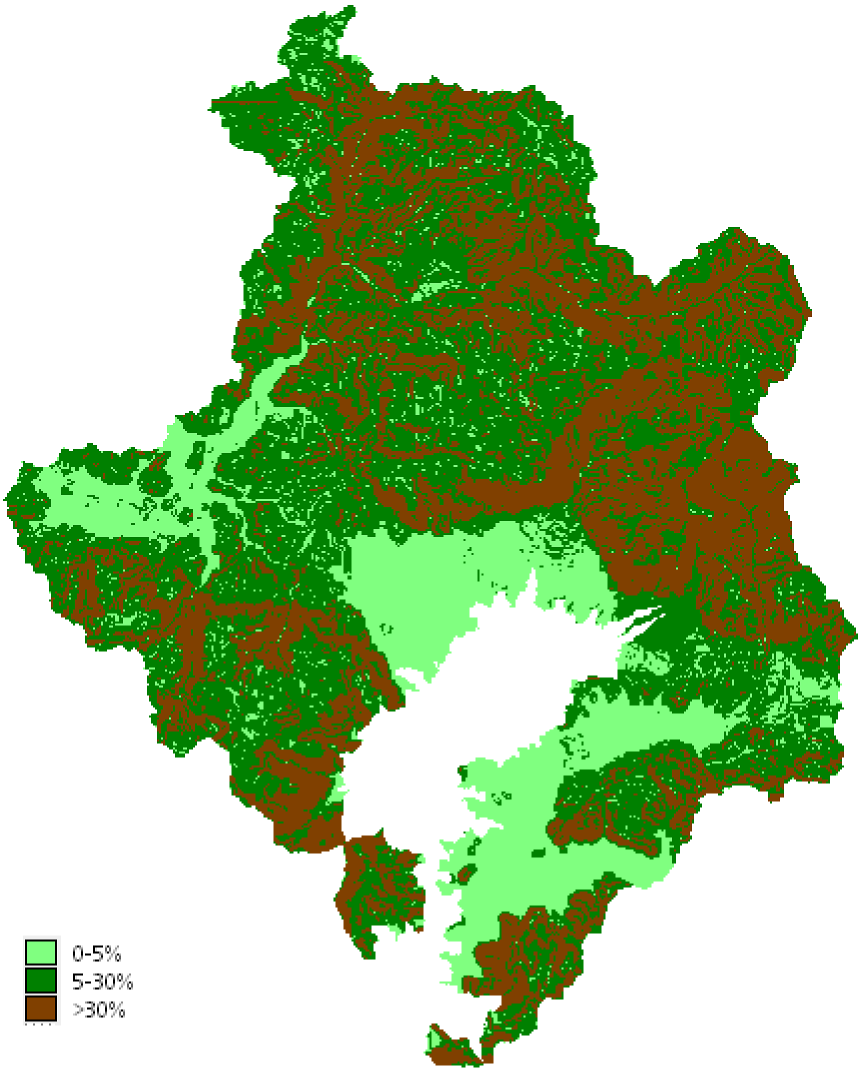

Figure 4.7: Slope map of the watershed based on defined slope groups

4.1.6 Meteorological data

SWAT requires precipitation, temperature, relative humidity, solar radiation, and wind velocity data. In addition to data tables, weather generator location table and gage location tables for each parameter are necessary input files.

Although meteorology data before the year 2000 exist, there are some missing years and parameters. For instance, minimum and maximum temperature values are required to be obtained before the year 2000 Missing data for 1976 to 2009 period was gathered from Turkish State Meteorology Works (TRSMW). Meteorology data are organized between 1976 and 2009 in xls extension. According to SWAT file extension requirement, data were converted to dbf or txt extension. Weather generator location table was generated in .dbf extension **(Table 4.20)**. Gage location tables of parameters such as precipitation (.dbf), temperature (.dbf), solar radiation (.txt), relative humidity (.txt), and wind velocity (.txt) were prepared.

Table 4.20: Weather generator location table

ID	NAME	X (coordinate)	Y (coordinate)	ELEVATION (m)
1	DAL	659196	4068622	646
2	FET	689289	4054439	19
3	KOY	649845	4092502	3
4	MAR	612930	4078981	13
5	MUG	621261	4119776	24

As an example, precipitation gage location table is given **(Table 4.21)**. Also, **Table 4.22** shows an example of meteorology data input file for Köyceğiz Station.

Table 4.21: Precipitation gage location table

NAME	X	Y	ELEVATION (m)
PREC_DAL	659196	4068622	646
PREC_FET	689289	4054439	19
PREC_KOY	649845	4092502	3
PREC_MAR	612930	4078981	13
PREC_MUG	621261	4119776	24

Table 4.22: Precipitation data of Köyceğiz Station for a small period

DATE	Precipitation (mm)
2/1/2005	7.8
2/2/2005	0.0
2/3/2005	37.0
2/4/2005	67.4
2/5/2005	1.2
2/6/2005	0.0
2/7/2005	0.0

SWAT model selects the nearest meteorological station for each subbasin according to latitude, longitude and elevation data.

4.1.6 Management operations

Evaluation of the diffuse pollution can be defined by the assessment of the impact of agricultural activities on Köyceğiz Dalyan Watershed. Main file that is used to define these activities is HRU management file. This file includes input data for following operations: planting, harvest, irrigation applications, nutrient applications, pesticide applications, and tillage applications. In addition some management operations regarding tile drains and urban areas are also included in management file. SWAT has 15 different management operations as given below.

- Planting/beginning of growing season
- Irrigation operation
- Fertilizer application
- Pesticide application
- Harvest and kill operation
- Tillage operation
- Harvest only operation
- Kill/end of growing season operation
- Grazing operation
- Auto irrigation initialization
- Auto fertilization initialization
- Street sweeping operation
- Release/impound
- Continuous fertilization
- End of year rotation flag

All listed operations are explained in SWAT input output documentation (Neitsch et al., 2005b). In this study, planting/beginning of growing season, auto irrigation initialization, fertilizer application, harvest and kill operation, harvest only operation, end of year rotation flag.

4.1.6.2 Planting and harvesting operations

SWAT model requires the date of the planting/beginning of growing season and harvesting operations. These data are obtained from Ministry of Agriculture and Rural Affairs, and Dalyan Farmer Association. Finally, management schedule is prepared as given in **Table 4.23.**

Table 4.23: Planting and harvesting schedule for crops

CROPS	MANAGEMENT	
COTTON	PLANTING_MONTH	HARVESTING_MONTH
	5	10
CITRUS FRUITS	PLANTING_MONTH	HARVESTING_MONTH
	4	2
OLIVE	PLANTING_MONTH	HARVESTING_MONTH
	5	11
CORN	PLANTING_MONTH	HARVESTING_MONTH
	5	7
TOMATO	PLANTING_MONTH	HARVESTING_MONTH
	4	8
CORN (SILAGE)	PLANTING_MONTH	HARVESTING_MONTH
	5	7
POMEGRANATE	PLANTING_MONTH	HARVESTING_MONTH
	3	10
WWHT	PLANTING_MONTH	HARVESTING_MONTH
	9	4
PEPPER	PLANTING_MONTH	HARVESTING_MONTH
	4	8
SORGHUM HAY	PLANTING_MONTH	HARVESTING_MONTH
	5	6

In addition to application month, model requires specifically operation day. Generally, start of the month or middle of the month is given for the operation timing. Harvest only and harvest and kill operation is used based on the type of the crop. For instance, if the crop is a tree such as pomegranate, harvest only operation is used. In the case crop is corn, wheat, cotton harvest and kill operation is used.

4.1.6.3 Auto irrigation initialization

Automatic irrigation operation is selected for irrigation application as the amount of irrigation water for each HRU is not known. In auto irrigation initialization, user does not have to define the amount of irrigation water for each application. Required data are starting date of irrigation period, water stress identifier, and water stress parameter. SWAT allows this operation to be triggered by plant water demand (1) or by soil water content (2). In this study, soil water content is chosen. Water stress identifier for soil water content is selected as 2. Water stress is the water content of the soil that crop starts to be under stress less than this value. Water stress is determined from Tülücü (2003) based on crop type. Selected irrigation parameters are given in **Table 4.24.**

Table 4.24: Selected auto irrigation parameters

CROPS	MANAGEMENT		
COTTON	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	5	2	0.75
CITRUS FRUITS	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	4	2	0.25
OLIVE	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	5	2	0.4
CORN	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	5	2	0.4
TOMATO	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	4	2	0.7
CORN (SILAGE)	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	5	2	0.4
POMEGRANATE	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	3	2	0.4
WWHT	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	9	2	0.3
PEPPER	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	4	2	0.7
SORGHUM HAY	AUTO_IRR_MONTH	WATER_STRESS_ID	WATER_STRESS
	5	2	0.7

4.1.6.3 Fertilizer application

Since SWAT needs management file for each HRU, amount of the applied fertilizer should be defined based on HRU. Köyceğiz Dalyan Watershed has 679 subbasins and 3906 HRUs. It is a fact that distribution of the fertilizer between HRUs manually is really time consuming. Also, it is possible to make some numerical mistakes. Therefore, a distribution program is written to define application of fertilizer for each HRU. In addition, distribution program will be required for subsequent land use scenarios. First of all, annually fertilizer sale data based on fertilizer type was gathered from Köyceğiz and Ortaca County Agricultural Administrations. Total fertilizer sale data for two counties is given in **Table 4.25** and **Table 4.26.**

Köyceğiz Dalyan Watershed boundaries do not match with the boundaries of the Köyceğiz and Ortaca Districts. Accordingly, an evaluation is required for the determination of amount of the fertilizer applied in the watershed. Total cultivated land area of the Köyceğiz and Ortaca Districts are obtained from crop pattern tables given in Appendix D.

Table 4.25: Annual fertilizer sale data in the Köyceğiz District

FERTILIZER TYPES	TOTAL AMOUNT OF FERTILIZER APPLIED IN KOYCEGIZ DISTRICT (kg/year)
A.Sulfate 21% (21-00-00)	1005500.0
A.Nitrate 26% (26-00-00)	167700.0
A.Nitrate 33 % (33-00-00)	676950.0
Urea	523750.0
TSP (00-45-00)	37000.0
DAP (18-46-00)	84000.0
COMP. 20-20-00	216600.0
COMP. 20-20-00+Zn	10000.0
COMP. 10-20-20	57950.0
P.Nitrate (13-00-46)	6425.0
P.Sulfate (00-00-50)	228200.0
COMP. 15-15-15	20500.0
COMP. 15-15-15-Zn	803450.0
Gold COMP. 15-15-15	20500.0

Table 4.26: Annual fertilizer sale data in the Ortaca District

FERTILIZER TYPES	TOTAL AMOUNT OF FERTILIZER APPLIED IN ORTACA DISTRICT (kg/year)
A.Sulfate 21% (21-00-00)	1191750.0
A.Nitrate 26% (26-00-00)	535950.0
A.Nitrate 33% (33-00-00)	987600.0
Urea	703550.0
TSP (00-45-00)	102500.0
DAP (18-46-00)	222800.0
COMP. 20-20-00	118500.0
COMP. 10-20-20	139000.0
COMP. 13-24-12	8500.0
M.A.P (11-52-00)	6200.0
P.Nitrate (13-00-46)	89650.0
P.Sulfate (00-00-50)	536400.0
Calsium nitrate (15.5-00-00)	6970.0
COMP. 15-15-15	827461.7
00-52-34	100.0

Then, total cultivated area of the watershed is calculated by SWAT. Based on the value of cultivated area, amount of the applied fertilizer in the watershed is estimated. As a result, 50% of the sold fertilizer data in Ortaca County, and 70% of sold fertilizer data in Köyceğiz is estimated to be applied in the boundary of Köyceğiz Dalyan Watershed.

Fertilizer application is defined with type of the fertilizer. It means that SWAT do not require nitrogen or phosphorus equivalent of the fertilizer. After user define the amount of applied fertilizer on HRU, model is able to calculate nitrogen and phosphorus equivalent of them. Numerous fertilizers exist in the SWAT fertilizer database including the parameters as given in **Table 4.27.** User can select the fertilizer from database. If applied fertilizer does not exist in database, user has to edit them with required fertilizer parameters.

Table 4.27: Required parameters of fertilizers in SWAT database

Parameter	**Definition**
FERTNM	Name of the fertilizer
FMINN	Fraction of mineral N (NO_3 and NH_4) in fertilizer
FMINP	Fraction of mineral P in fertilizer
FORGN	Fraction of organic N in fertilizer
FORGP	Fraction of organic P in fertilizer
FNH_3N	Fraction of mineral N in fertilizer applied as ammonia

Applied fertilizer types and SWAT fertilizer database are compared. In the Köyceğiz Dalyan watershed simulation applied fertilizers such as ammonium nitrate 33%, urea, 20-20-00, 15-15-15, 13-24-12, DAP, TSP, MAP, were available in the database. Absent fertilizers were added to the SWAT database. Required fertilizer parameters were calculated by using the N, P, K ratio of the fertilizer obtained from literature. An example calculation is given for 13-24-12 fertilizer.

13-24-12 refers to ratio of %N-%P_2O_5-%K_2O. As nitrogen ratio is 13% and P_2O_5 ratios is 24%, amount of mineral nitrogen and mineral phosphorus were calculated as given below.

$$\text{FMIN N} = \frac{13}{100} = 0.13$$

$$\text{FMIN P} = \frac{24 \text{ x } 0{,}44}{100} = 0.10$$

Added fertilizers are given with required parameters in **Table 4.28**.

Table 4.28: Additional fertilizers and its parameters

Fertilizer Type	FMIN N (kgN/kg fertilizer)	FOrgN (kgOrgN/kg fertilizer)	FMIN P (kgP/kg fertilizer)	FOrgP (kgOrgP/kg fertilizer)	FNH_3 ($kgNH_3$/kg fertilizer)
Ammonium Sulfate % 21 (21-00-00)	0.21	0	0	0	0
Ammonium Nitrate % 26 (26-00-00)	0.26	0	0	0	0
DAP (18 -46-00)	0.18	0	0.202	0	0
TSP (00-45-00)	0	0	0.198	0	0
Potassium sulfate (00-00-50)	0	0	0	0	0
Potassium nitrate (13.00.00)	0.13	0	0	0	0
Calsium nitrate (15.5-00-00)	0.15	0	0	0	0
Mono-potassium phosphate (00.52.34)	0	0	0.2288	0	0
MAP (11-52-00)	0.11	0	0.23	0	0
13.24.12	0.13	0	0.10	0	0

Next step is the determination of the fertilizer application based on product. The aim of this step is answering the following points: which fertilizer is applied, when it is applied, and which crop it is applied for. Result of this evaluation is given in **Table 4.29.**

After all, necessary estimation is distribution of fertilizer between crops. For instance, ammonium sulfate 21% is used for nitrogen requirement of numerous crops including pomegranate, citrus fruits, olive, sorghum hay, and cotton. Unfortunately, information includes amount of applied fertilizer per hectare based on crop is not exist. To solve this problem, nitrogen, phosphorus, and potassium requirement of the crops (**Table 4.30**) are compared. According to cultivated area and nutrient requirement, distribution coefficients are estimated for each crop type specifically for each fertilizer. During the estimation of the distribution coefficients, it is taken into consideration that each fertilizer is used for different aim. For instance, ammonium nitrate 33% is applied for covering the nitrogen requirement of the crops. Thus, distribution coefficient is estimated according to nitrogen requirement.

Additionally, if the applied fertilizer such as TSP intended to use for the phosphorus requirement, only phosphorus need of crop per area is evaluated. In the case that is fertilizer used for both nitrogen and phosphorus requirement of the crop, N and P need data per hectare is used in estimation of the distribution coefficient. Fertilizer distribution of the crops based on the fertilizer type is given in **Table 4.31**.

Table 4.29: Fertilizer application schedule based on crop type

FERTILIZER	CROP	MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A.SULFATE 21 % (21-00-00)	Pomegranate, citrus fruits				x	x							
	Olive		x	x									
	Sorghum hay			x									
	Cotton						x						
A.NITRATE 26% (26-00-00)	Pomegranate, citrus fruits						x						
	Sorghum hay			x									
A.NITRATE 33 % (33-00-00)	Pomegranate, citrus fruits						x						
	Tomato, bell pepper				x	x							
UREA	Corn, corn (silage)						x	x					
	Pomegranate, citrus fruits				x	x							
TSP (00-45-00)	Pomegranate, citrus fruits, wheat											x	x
DAP (18-46-00)	Pomegranate, citrus fruits											x	x
COMP. 20-20-00	Cotton, corn, wheat				x	x							
20-20-00-Zn	Pomegranate, citrus fruits					x							
COMP. 10-20-20	Cotton, corn, wheat, corn (silage)			x	x								
COMP. 13-24-12	Pomegranate, citrus fruits			x									
MAP (11-52-00)	Pomegranate,				x								
	Tomato, bell pepper			x	x								
	Citrus fruits			x									
P.NITRATE (13-00-46)	Pomegranate, citrus fruits						x	x					
	Tomato, bell pepper				x	x							
P.SÜLFAT (00-00-50)	Pomegranate, citrus fruits						x	x					
	Olive												
CALCIUM NITRATE (15.5-00-00)	Pomegranate, citrus fruits						x	x					
	Olive				x	x							
	Tomato, bell pepper			x	x								
COMP. 15-15-15	Cotton, corn (silage)				x	x							
	Olive	x	x										
	Wheat											x	
15-15-15-Zn	Pomegranate, citrus fruits				x								
00-52-34	Pomegranate, citrus fruits			x	x								
Gold COMP. 15-15-15	Olive	x	x										

Table 4.30: Nutrient requirements of crops (Tülücü, 2003)

CROP	Nitrogen Requirement (kgN/da)	Phosphorus Requirement (kgN/da)	Potassium Requirement (kgN/da)
Wheat	15	3.5-4.5	2.5-5
Cotton	10-18	2-6	5-8
Corn	20-25	9-10	-
Corn(silage)	23	9.5	20
Tomato	6-12	6-14	6-12
Bell pepper	10-17	8-20	5.5-16.8
Citrus fruits	10-20	3.5-4.5	5-16
Olive	10.5-2.5	2.7	5.5
Pomegranate	25	12.5	7.5
Sorghum hay	5.7	8-10	8-10

After all, distribution program is used to determine the amount of applied fertilizer for each HRU. Calculation steps of the distribution program are given in **Figure 4.8**. This step is repeated for each HRU. First of all, program determines the land use type of the HRU. Then location of the HRU is checked to define inside of which county's boundary it is located. According to location that county's sold fertilizer data is determined. Next step is designation of applied fertilizer types on HRU. Then program calculates the amount of applied fertilizer respect to distribution coefficients which are defined based on fertilizer type. Finally, amount of applied fertilizer amount for each fertilizer is calculated. This loop is repeated for 3906 HRUs. In this step, plant growth dynamic was not run. Therefore, it is estimated that crops uptake the nutrients. Thus, amount of the uptake fertilizer by crops was subtracted from amount of total fertilizer.

After the calculation of fertilizer operation based on HRU, all management operations are joined. It means that each fertilizer application management file combined with planting/beginning of growing season, auto irrigation initialization, harvest and kill operation or harvest only operation, end of year rotation flag.

Table 4.31: Estimated distribution coefficients of crops for each fertilizer

FERTILIZER	CROP									
	Citrus fruits	**Pomegranate**	**Corn**	**Corn (silage)**	**Tomato**	**Bell pepper**	**Wheat**	**Olive**	**Cotton**	**Sorgum hay**
21-00-00	0.8520	0.1355						0.0043	0.0077	0.0006
26-00-00	0.8623	0.1371								0.0006
33-00-00	0.8591	0.1366			0.0039	0.0004				
Urea	0.8525	0.1356	0.0057	0.0063						
00-45-00	0.7533	0.2246					0.0184	0.0037		
18-46-00	0.7703	0.2297								
20-20-00			0.0578	0.0809			0.1737		0.6876	
20-20-00-Zn	0.8415	0.1585								
10-20-20				0.2383			0.5326		0.2291	
13-24-12	0.7925	0.2075								
11-52-00	0.7592	0.2264			0.0144	0.0014				
13-00-46	0.8594	0.1367			0.0039	0.0004				
00-00-50	0.8591	0.1366						0.0043		
15.5-00-00	0.8554	0.1360			0.0039	0.0004		0.0043		
15-15-15				0.3178			0.3243	0.1333	0.2246	
15-15-15-Zn	0.9332	0.0668								
00-52-34	0.8415	0.1585								
GOLD 15-15-15								0.3300		

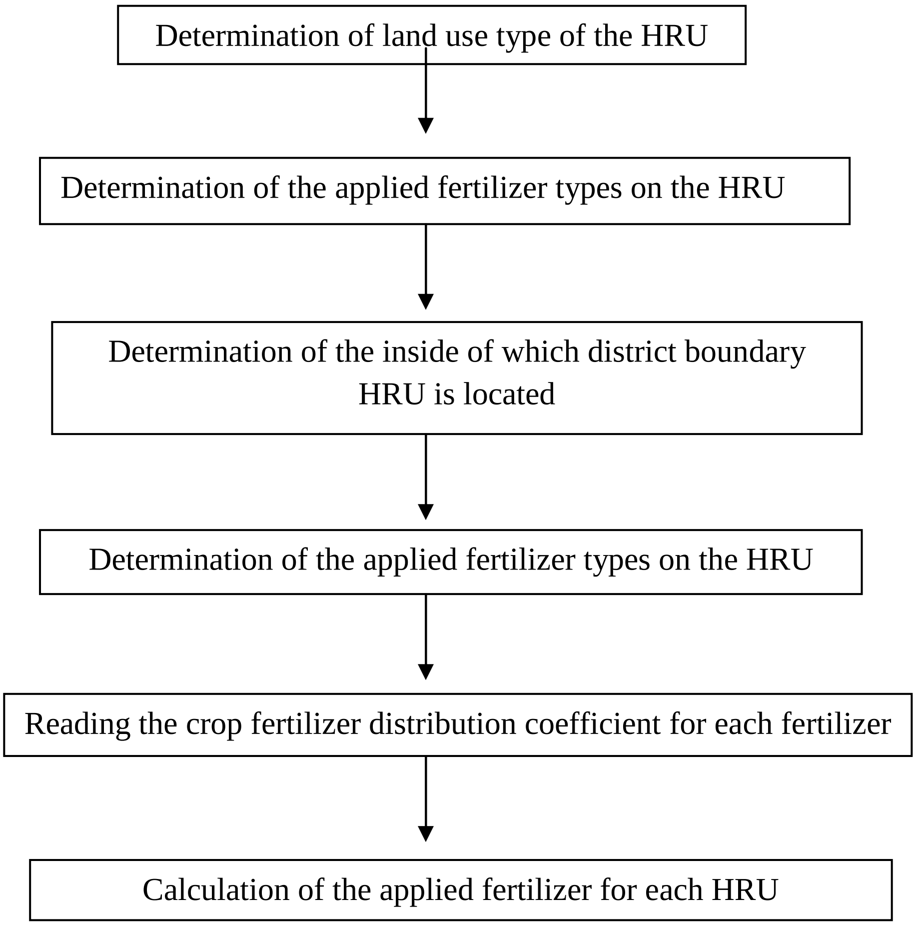

Figure 4.8: Calculation steps of the fertilizer distribution program

Totally 3906 management files are generated. An example management file view for scheduled operations is given in **Figure 4.9.**

```
Management Operations:
              33    | NROT: number of years of rotation
Operation Schedule:
  5 16          10    2             0.40000
 11  1           5                  0.00000
                   0
  5 16          10    2             0.40000
 11  1           5                  0.00000
                   0
  5 16          10    2             0.40000
 11  1           5                  0.00000
                   0
  5 16          10    2             0.40000
 11  1           5                  0.00000
                   0
  5 16          10    2             0.40000
 11  1           5                  0.00000
                   0
```

Figure 4.9: Example view of the management operations schedule

4.2 Model Set-up

4.2.1 Watershed configuration

In the watershed delineation of ArcSWAT interface, first step is opening the DEM source. The next step, stream definition part user has two options as DEM-based or pre-defined streams and watersheds. In the Köyceğiz Dalyan simulation, DEM based stream definition option was selected. Subwatershed threshold area is required. In this step, different values are tried between 1000- 50 ha. Finally, it was seen that suitable value is 75 ha. Area for the generation of flow direction and accumulation was fixed to 75 ha. By giving the area measurements small, it was made sure that watershed boundaries which is created by SWAT model was become almost same with actual watershed boundaries. Then, stream network step was finalized with the creation of streams and outlets as given in **Figure 4.6.**

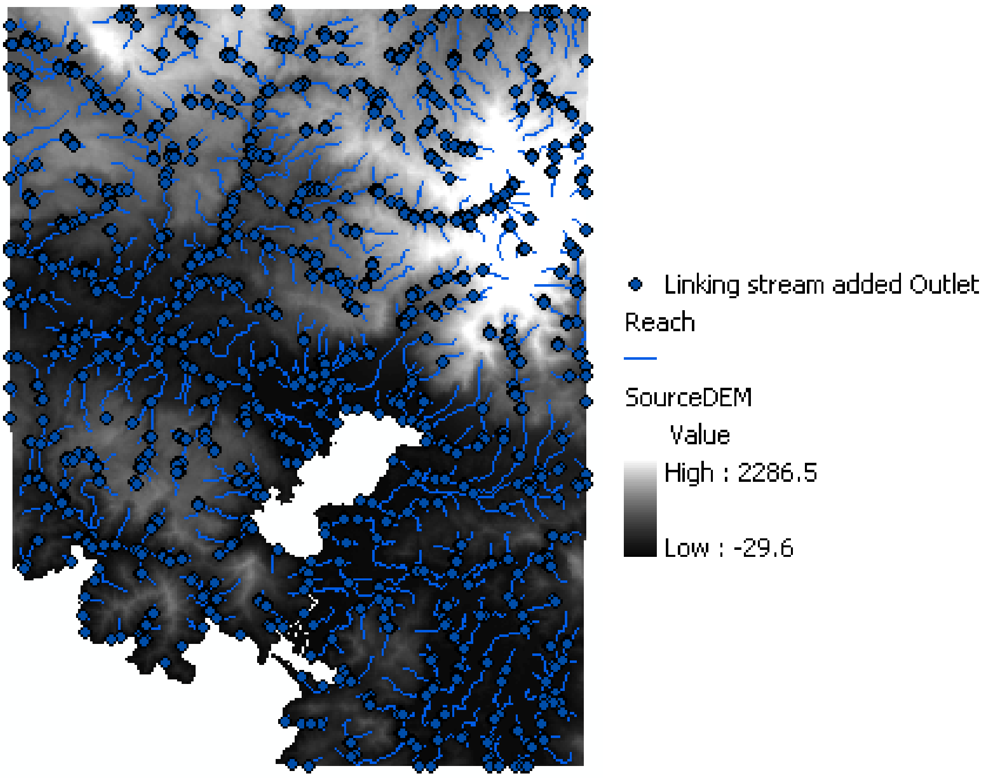

Figure 4.10: View of the stream network and outlets

As seen in **Figure 4.10,** model created extra streams and outlets for purposed watershed boundary. By choosing the outlets located around the Köyceğiz Lake and along the lagoon channel, watershed boundary were generated (**Figure 4.11**).

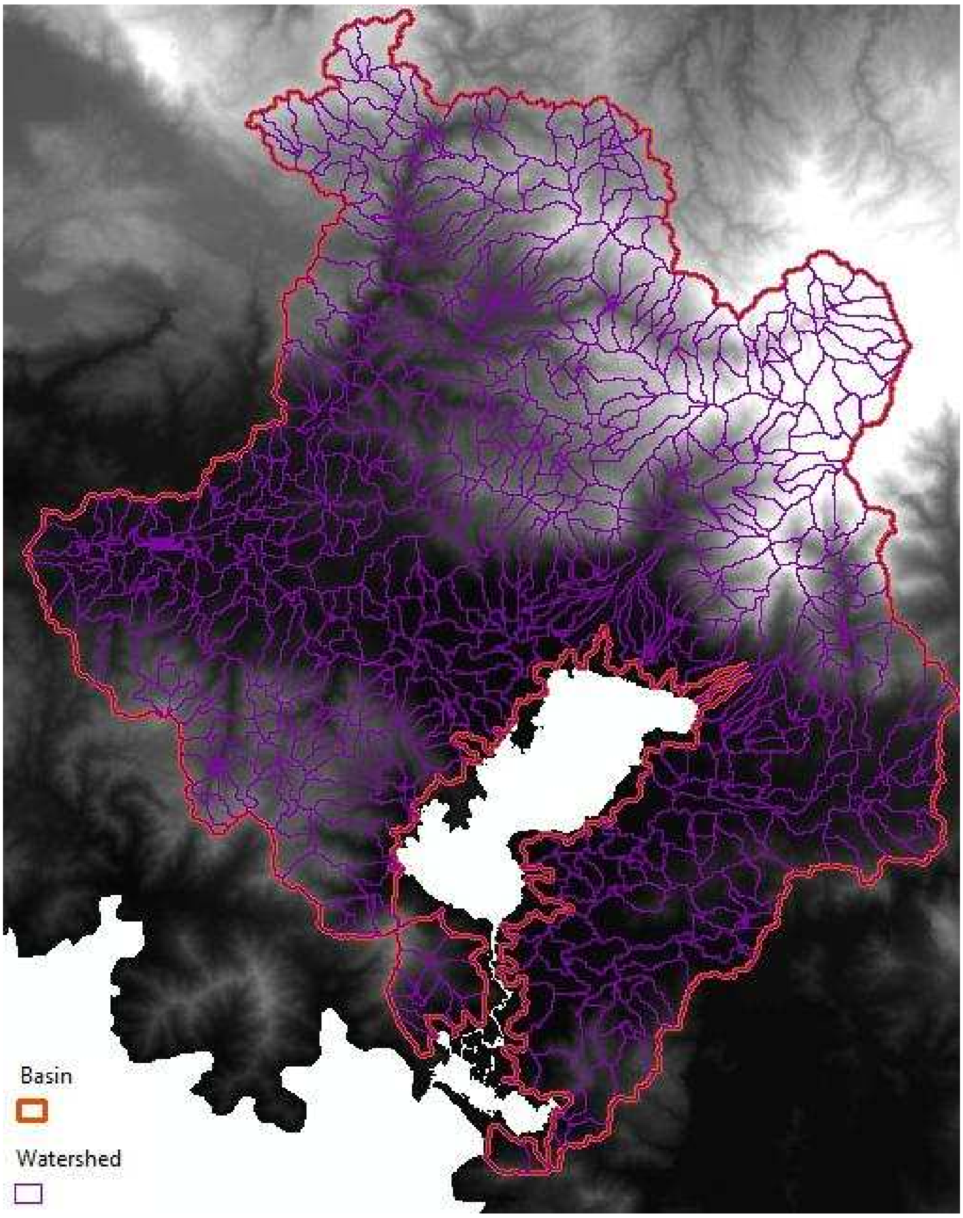

Figure 4.11: View of the Köyceğiz Dalyan Watershed and subwatersheds boundaries generated by SWAT model

4.2.2 HRU analysis

After generation of the watershed boundary, land use map, soil map and slope definition were provided to model. HRU analysis report generated by the model includes area and percentage distribution of each land use and soil class within each subbasin. These themes are then used to determine the HRU distribution in each subbasin. In addition to maps, land use look up table, soil look up table and slope groups were defined to overlay land use, soil, and slope layers. Since Köyceğiz Dalyan Watershed has three slope groups, multiple slope option was chosen in slope definition step. After overlaying process, HRU analysis report writes input tables.

Totally 679 subbasins, and reaches were created. Model creates a subbasin for each reach. Before determination of HRUs, multiple HRUs criteria is specified. If this option is not selected, each subbasin has one HRU based on the dominant land use/soil/slope combination.

In next step, 10% threshold area for land use, soil, slope was modified to define how detailed watershed would be represented. For instance, if the threshold for land use over subbasin area is set 15%, land uses occupy less than 15% of the area would be eliminated. In this case, HRU will be created for land uses occupy greater than 15% of the subbasin area. After defining 10% threshold value, it is seen that some area of the watershed is executed from the HRU areas. Therefore, threshold values are given 0 for each category including land use, soil, and slope. After defining the HRU thresholds as 0, 3906 HRUs were created and total area of the HRUs is equal to watershed area. HRU/land use/soil report includes distribution of land use and soil for each subbasin and HRU.

Information required for generating default input for model is built in this part. Firstly, weather data was defined for five meteorological station including Köyceğiz, Dalaman, Muğla, Fethiye, Marmaris. After that, write all option was used, and the following input files were generated.

- Watershed configuration file (.fig)
- Soil data (.sol)
- Weather generator data (.wgn)
- General HRU data (.sub)
- Soil chemical input (.chm)
- Stream water quality input (.swq)
- Management input (mgt)
- Main channel data (.rte)
- Groundwater data (.gw)
- Water use data (.wus)

4.2.3 Edit SWAT input

With edit SWAT input menu user is allowed to make input modifications during the model simulation and calibration processes.

4.2.4 SWAT simulation set-up

SWAT simulation menu contains commands. Period of simulation was specified between the years 1976 and 2009. Daily time step was selected for rainfall data, and monthly printout option was chosen. Generated management files are included to model input files folder. Afterward, SWAT run set up is concluded. Finally, SWAT was run successfully.

5. RESULTS AND DISCUSSIONS

In this thesis aim of the study is application of the SWAT model in a watershed in Turkey. At this scope study, SWAT model was applied for Köyceğiz Dalyan Watershed. Results are intended to be evaluated for last 10 years. However, initial conditions were not available. Therefore, the model is run between the years 1976 to 2008 in order to reduce the model sensitivity to the initial conditions. Results of the simulation are given below.

Average monthly total precipitation, surface runoff, lateral flow, and groundwater flow are presented for the entire watershed for the period 1998-2008.

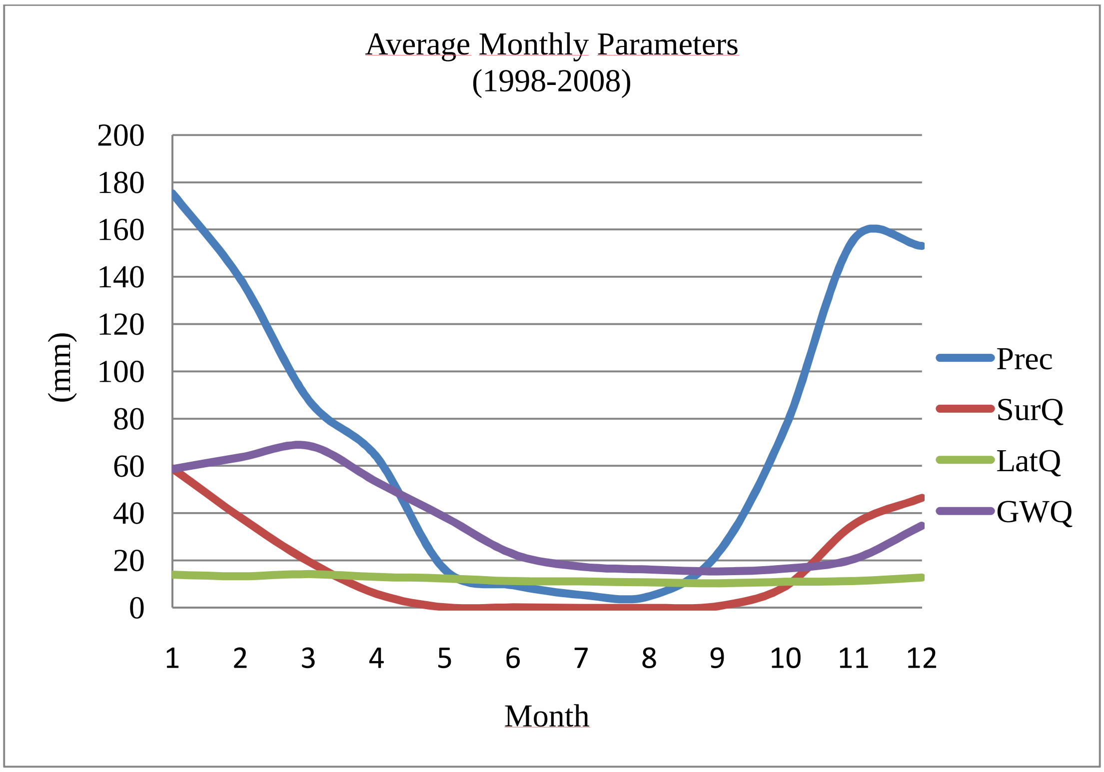

Figure 5.1: Annually average total monthly precipitation, surface runoff, lateral flow, and groundwater flow for 1998-2008

According to **Figure 5.1**, it is seen that amount of precipitation is higher in winter. Surface flow pattern is similar to precipitation. Lateral flow does not exhibit a considerable change throughout the year. Also, contribution to reaches from groundwater is highest during summer months. Average monthly total amount of water contributed from watershed to reaches is given in **Figure 5.2**. In summer months amount of water flows from the watershed is decreasing.

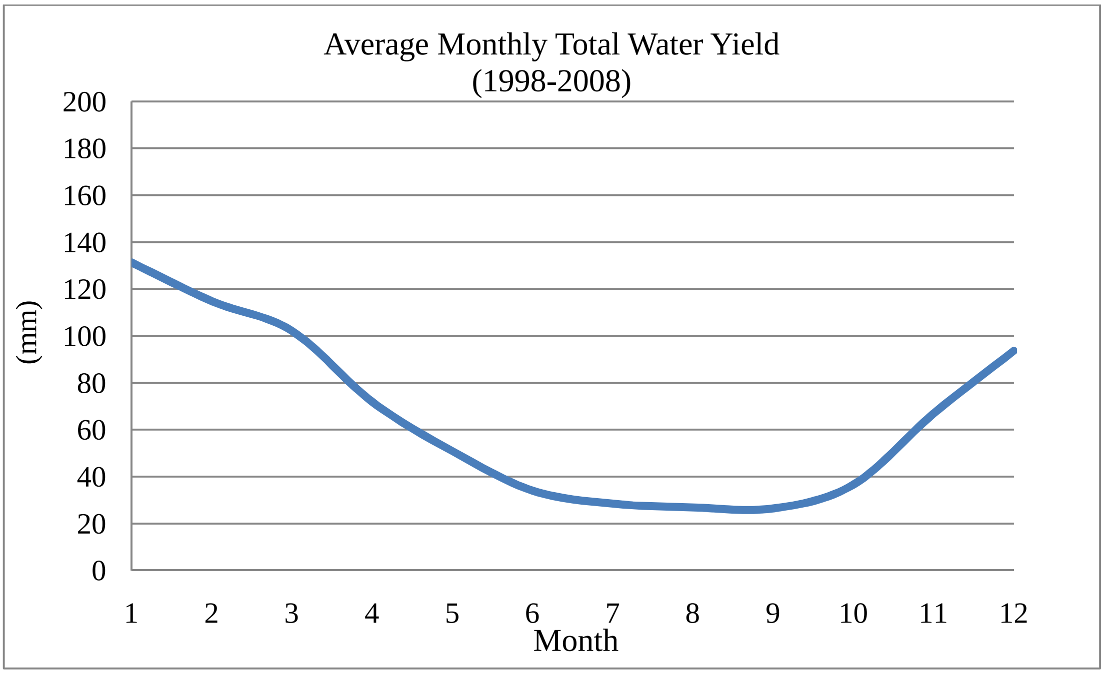

Figure 5.2: Total amount of water contributes from watershed to reaches

As illustrated in **Figure 5.3**, amount of nitrate in percolation and amount of nitrate in groundwater are estimated higher than amount of nitrate in lateral flow and surface runoff. A significant part of the nitrate that moves from basin to reaches was contributed by groundwater flow.

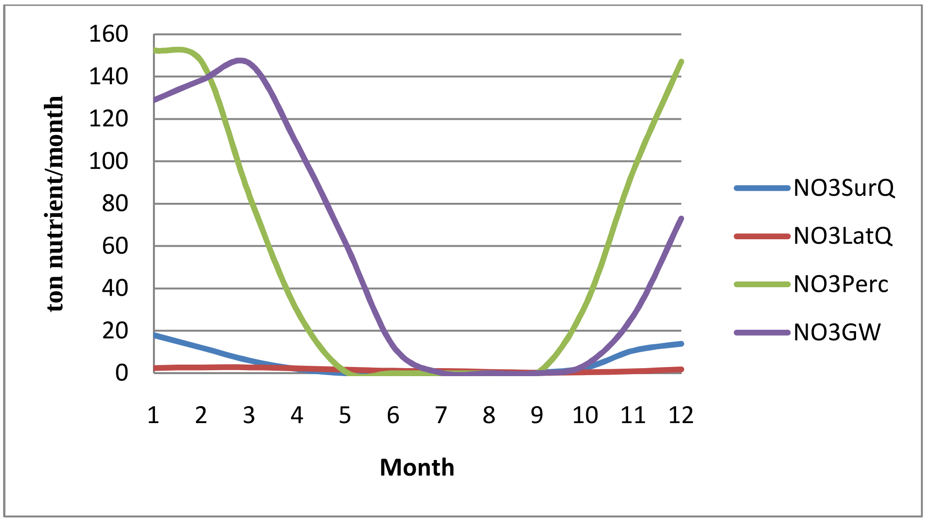

Figure 5.3: Average monthly total amount of nitrate from watershed

Main streams of the watershed are Namnam Stream (**Figure 5.4**), Yuvarlakçay Stream (**Figure 5.5**), Kargıcak Stream (**Figure 5.6**), and Sarıöz Stream (**Figure 5.7**).

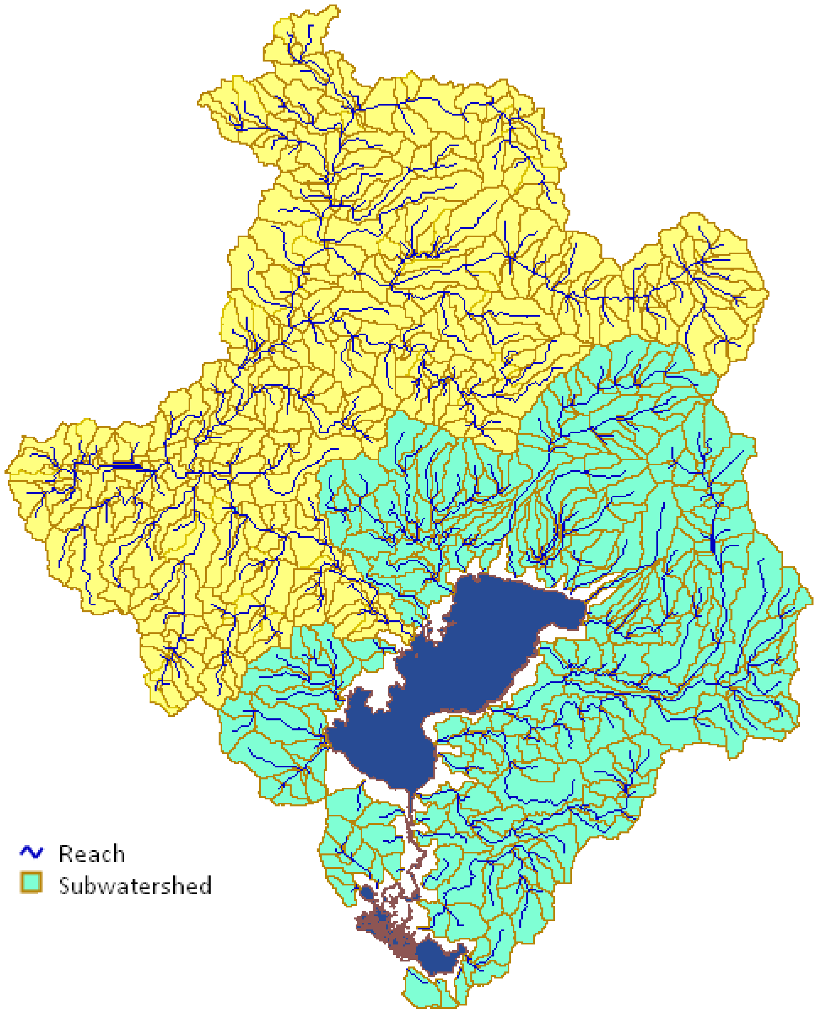

Figure 5.4: Drainage area of Namnam River

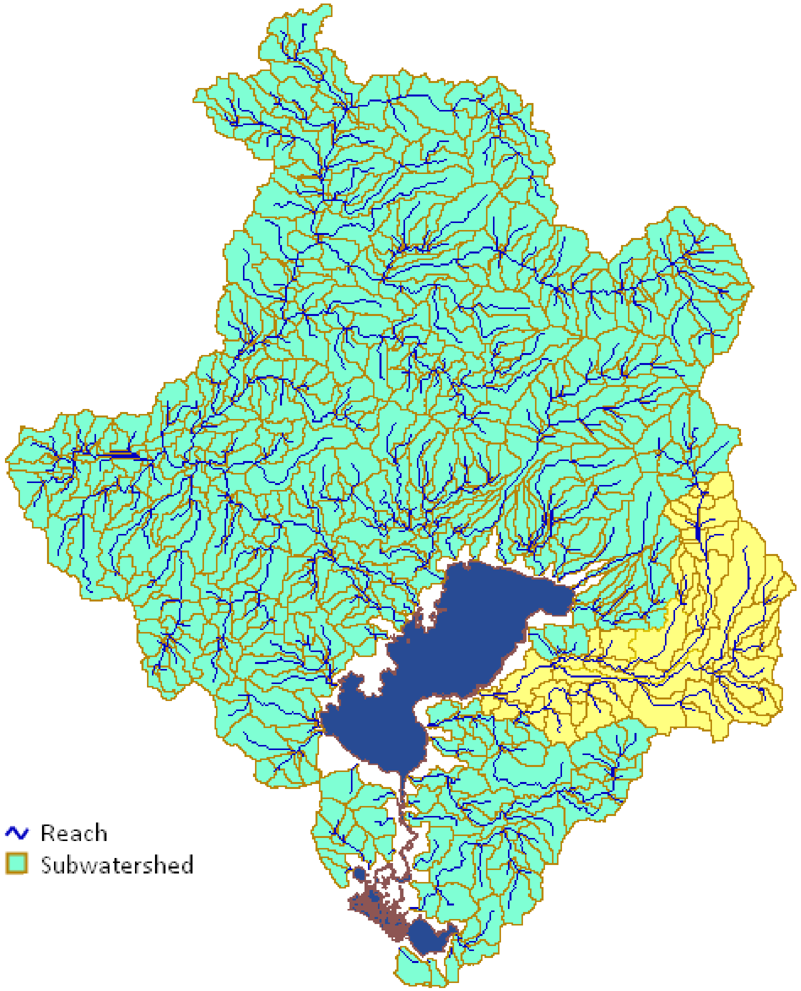

Figure 5.5: Drainage area of Yuvarlakçay River

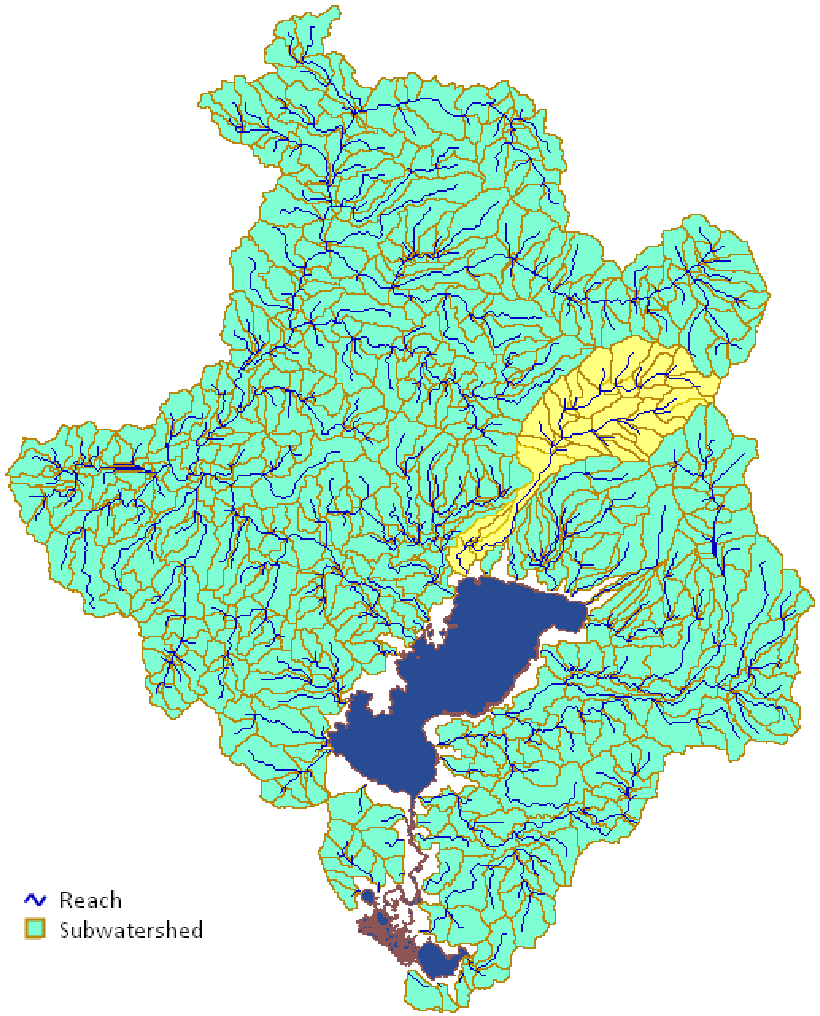

Figure 5.6: Drainage area of Kargıcak River

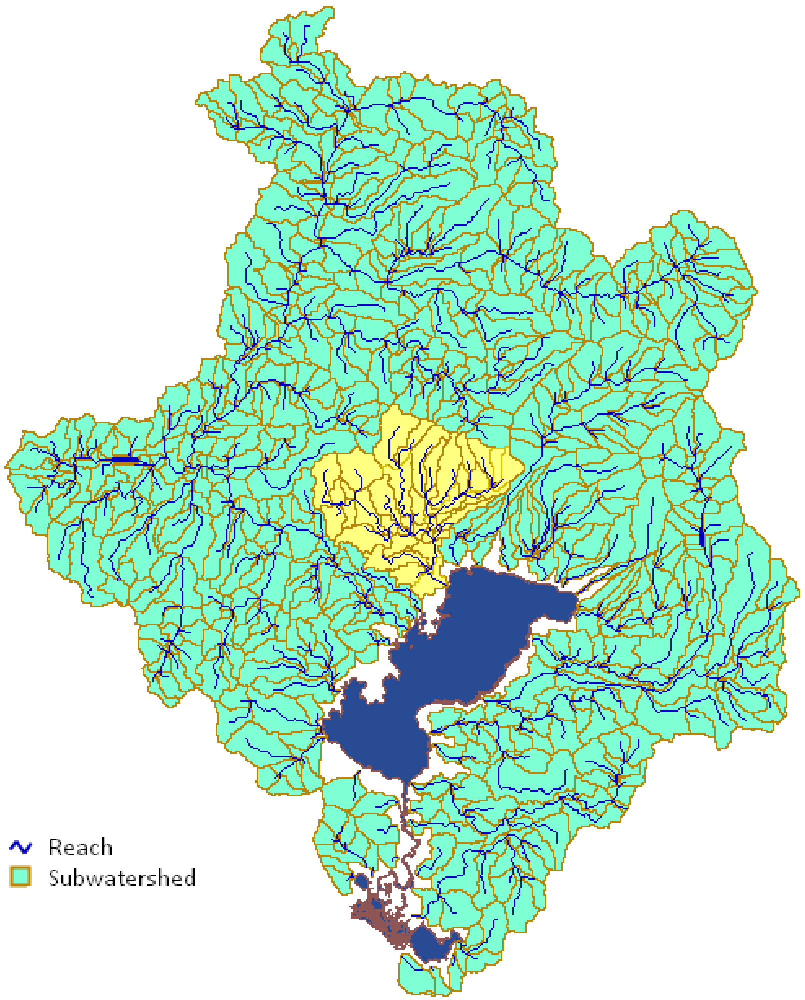

Figure 5.7: Drainage area of Sarıöz River

Drainage areas of the streams are indicated in yellow color in these figures. As indicated in **Table 5.1**, Namnam is the biggest stream in the watershed with a drainage area of 502 km^2. Average monthly flow rates of the rivers are given in **Figure 5.8** between the years 1998 and 2008. It is seen that contribution from Namnam River to Köyceğiz Lake is highest among the streams.

Table 5.1: Drainage area of main streams in the Köyceğiz Dalyan Watershed

Stream	**Drainage Area (km^2)**
Namnam	502
Yuvarlakcay	357
Sarıöz	52
Kargıcak	47

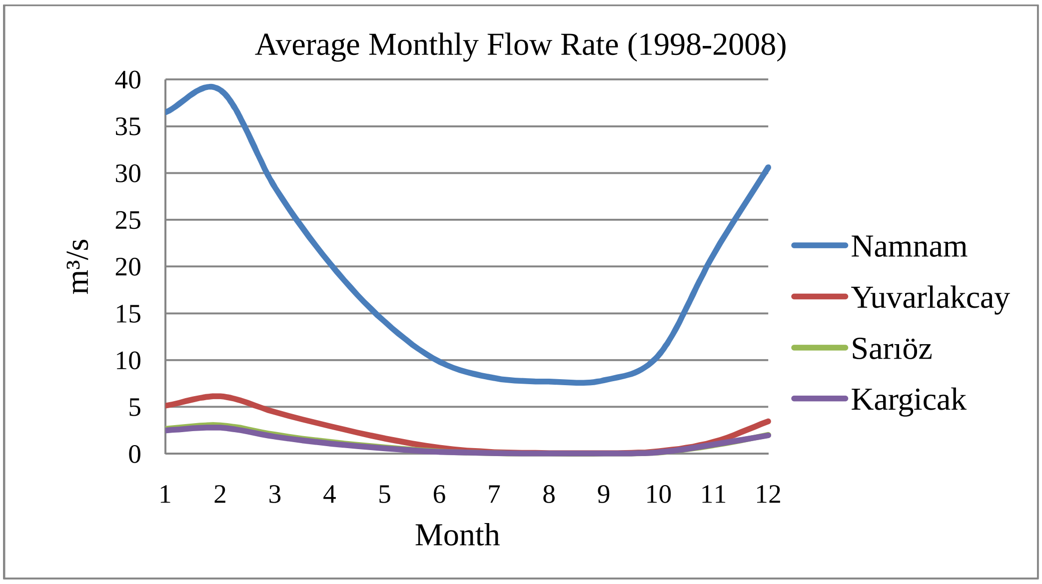

Figure 5.8: Average monthly flow rates of main rivers

Simulated flow rate of the Namnam River is compared with the measured flow rate by State Hydraulic Works (SHW). **Figure 5.9** demonstrates the comparison of the flow rate for 1996. It is seen that generally simulated flow rate is higher than measured flow rate. More graphs for different years between 1980 and 1999 are given in Appendix E. In **Figure 5.10** yearly total flow rate simulated by SWAT model and yearly total flow rate measured by SHW is compared. It is illustrated that differences between simulated and measured flow rates higher after 1984.

According to **Figure 5.9**, it is seen that amount of the average monthly nitrogen species are highest in Namnam Yuvarlak, Sarıöz, Kargıcak respectively. Amount of the average monthly phosphorus species exhibit the similar characteristics to nitrogen species (**Figure 5.10**).

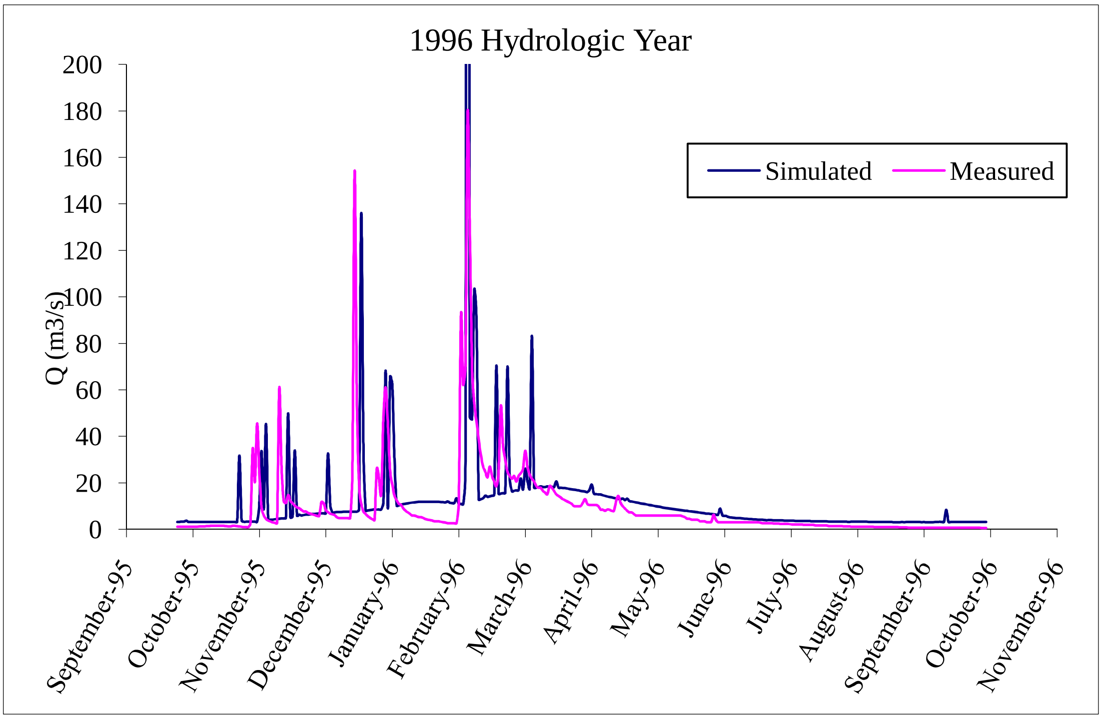

Figure 5.9: Comparison of simulated and measured flow rate of the Namnam River for 1996

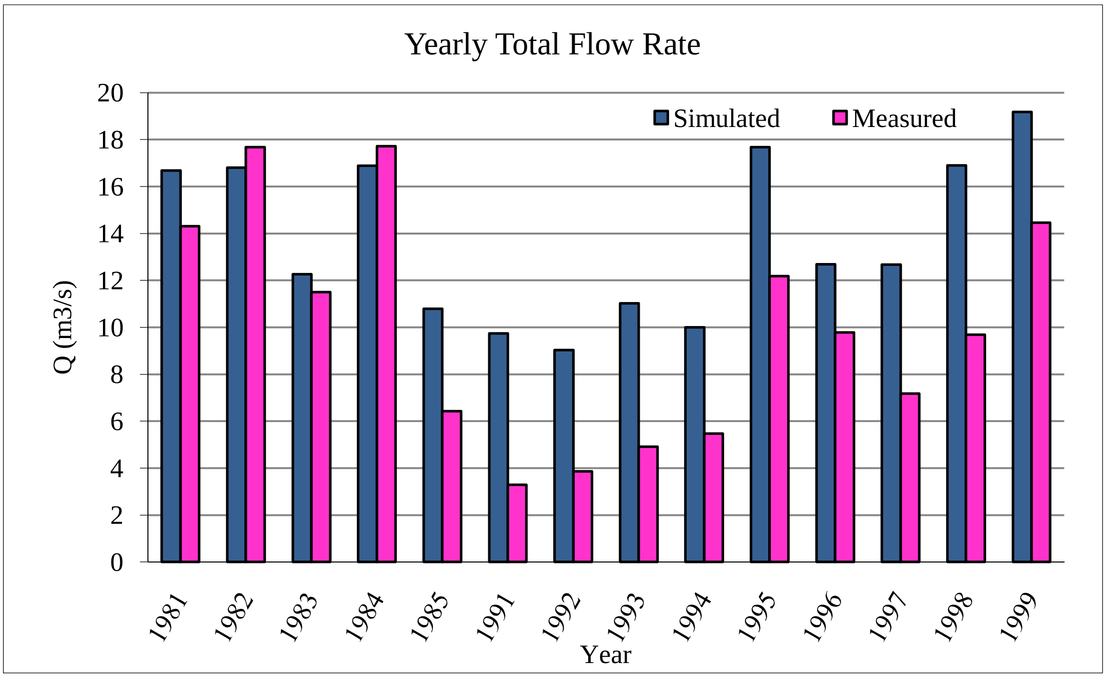

Figure 5.10: Comparison of simulated and measured yearly total flow rate of Namnam River

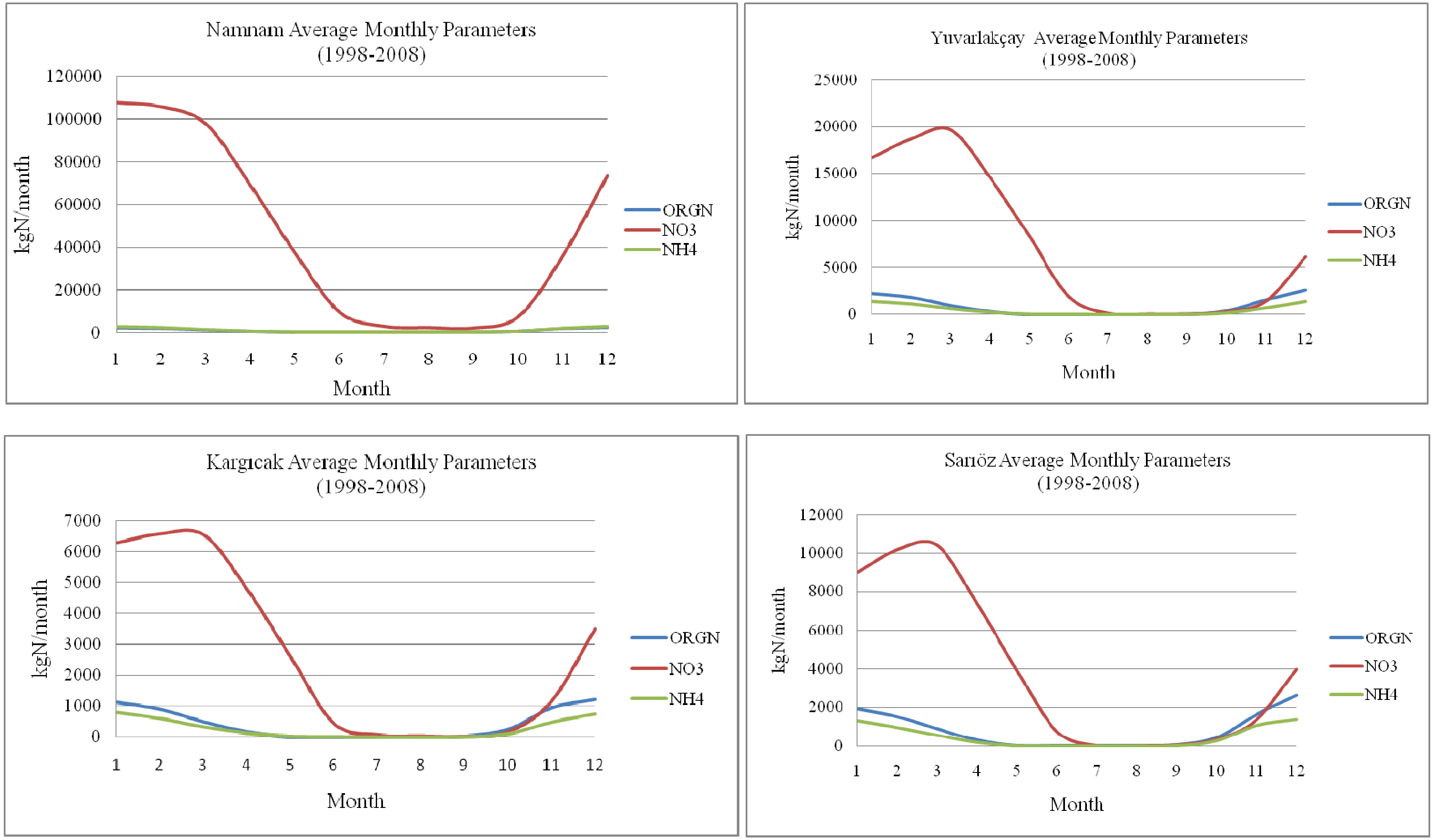

Figure 5.11: Comparison of average monthly nitrogen species amounts of the main streams in watershed for years 1998-2008

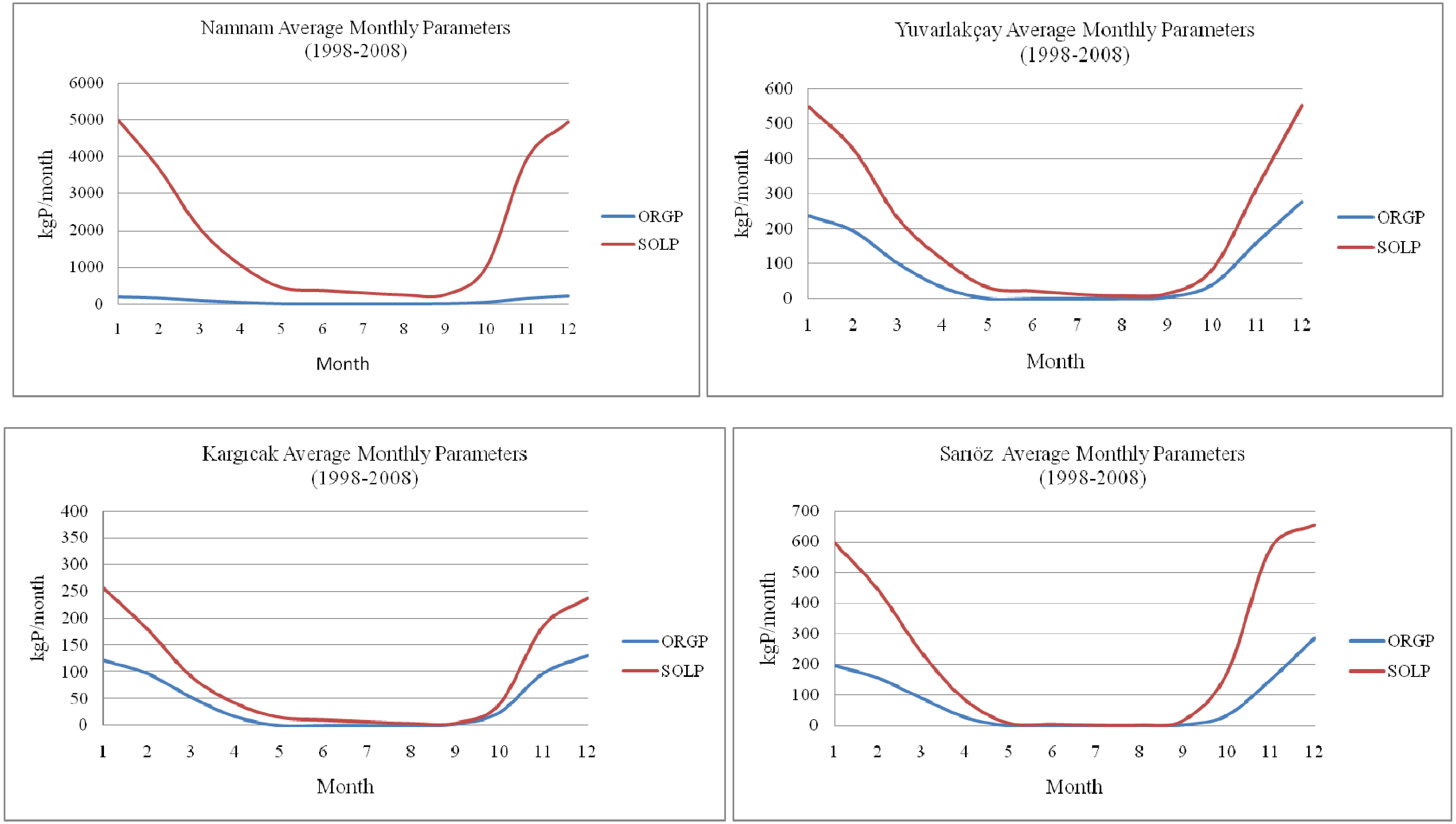

Figure 5.12: Comparison of average monthly phosphorus species amounts of the main streams in watershed for years 1998-200

According to the SWAT results, surface runoff was 270 mm for the entire watershed in 2007. Maximum surface runoff was seen in December as given in **Table 5.2.**

From **Figure 5.13**, depending on the runoff in the months before and after March, it is expected to have higher surface runoff amount in March. However the surface run off was found lower than expected. If the precipitation data for March presented in **Figure 5.13** is evaluated, it is seen that in year 2007 amount of precipitation is one of the lowest with respect to the other years. It is known that the surface runoff responds faster and stronger to precipitation than the subsurface and groundwater flow. Therefore, surface runoff calculated for March 2007 is thought to be resulted in lower surface runoff.

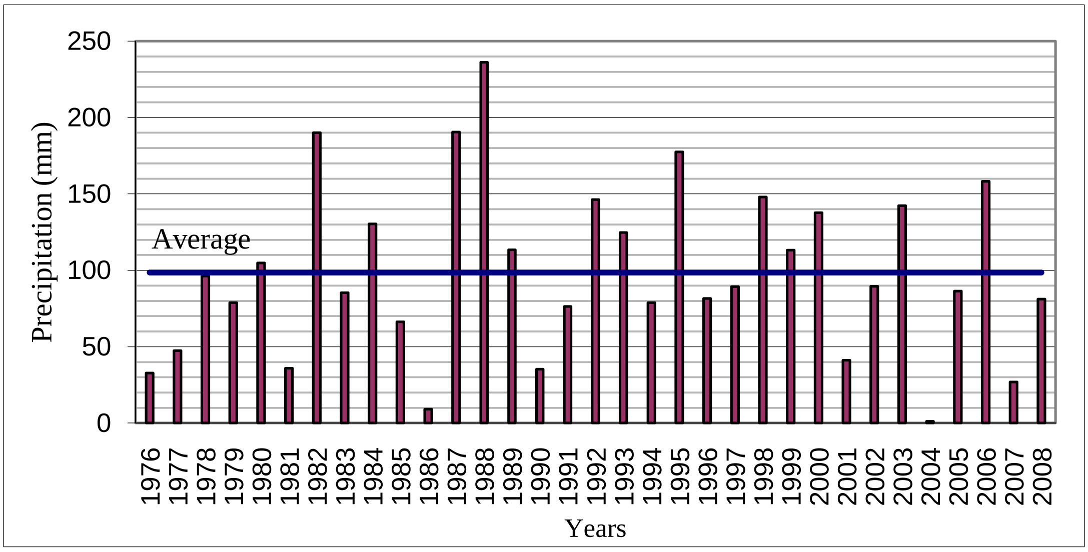

Figure 5.13: Precipitation data for March between 1976 and 2008

According to **Figure 5.12**, surface runoff is higher in winter months. After April, surface run off is decreasing considerably. Also, it is seen that surface run off is lowest in summer months. Spatial distribution of surface run off is given in **Figure 5.14** for each month. Sandras Mountain is located in Northeast of the Köyceğiz Dalyan Watershed. This region is the steepest area in the watershed that is expected to divert most of the overland flow quickly to reaches before it could infiltrate into soil. Thus, surface runoff contributed from Northeast part of the watershed is high as shown in **Figure 5.14** (Months, 1, 2, 10, 11, 12).

Also, it can be thought that an important part of the precipitation becomes surface runoff in this region. On the other hand, amount of groundwater flow is lower in this region as illustrated in **Figure. 5.14**.

Total groundwater flow for entire watershed is 327 mm in year 2007 as given in **Table 5.2.** Like surface runoff December is the month that groundwater flow is highest. According to **Figure 5.15**, at the lower elevations around Köyceğiz Lake amount of groundwater is higher in each month. As seen in **Table 5.2**, in the summer months where surface runoff contributions to the reaches are minimum, groundwater flow supports flow in the reaches.

As illustrated in **Table 5.2**, amount of lateral flow is 139 mm for the entire watershed in 2007. The lateral flow exists in each month and the amounts are similar to each other. As given in **Figure 5.16**, similar to groundwater flow, lateral flow exist in lower elevations around Köyceğiz Lake. In spite of there was very low precipitation in summer months, the lateral flow was exist. It might be considered that irrigation contributes to lateral flow.

Amount of nitrate in surface runoff was 0.77 kgN/ha for the entire watershed in 2007. Maximum amount of nitrate in surface runoff was seen in December as given in **Table 5.2.** Also, it is illustrated in **Figure 5.17** that parallel to amount of surface runoff, nitrate in surface run off higher in winter months.

Amount of nitrate in lateral flow was 0.14 kgN/ha for the entire watershed in 2007. As indicated in **Table 5.2**, similar to nitrate in surface runoff December is the month that nitrate in lateral flow is highest.

In 2007, it is calculated by the model that amount of nitrate in percolation is 8.4 kgN/ha for the entire watershed. **Table 5.2** shows that December has the higher nitrate amount in percolation with 3.62 kgN/ha. **Figure 5.18** shows the nitrate in groundwater flow for each month in 2007. It is seen that parallel to variation in nitrate in percolation, amount of nitrate in groundwater flow changes.

Amount of nitrate in lateral flow was lower than amount of nitrate in surface runoff. In this simulation, tillage management operation was not applied. Thus, higher nitrate amounts in surface runoff can be expected. Monthly spatial distribution of nitrate in lateral flow is given in **Figure 5.19.**

Table 5.2: Model monthly simulation results for the year 2007

Month	Precipitation	Surface runoff	Lateral flow	Groundwater flow	Percolation	Water yield	NO3 Surface runoff	NO3 Lateral flow	NO3 Percolati on	NO3 Groundwater flow
	(mm)						kgN/ha			
January	106.65	31.75	11.56	26.88	32.49	70.12	0.08	0.01	0.63	128.9
February	176.51	48.22	11.11	29.65	69.94	88.67	0.15	0.02	1.8	138.4
Mach	26.95	0.35	12.4	43.26	23.91	55.97	0	0.02	0.26	146.2
April	42.13	7.85	11.52	34.14	18.85	53.44	0.02	0.01	0.13	107.4
May	26.94	0.09	11.27	23.1	17.16	34.45	0	0.01	0	61.3
June	0.64	0	10.75	16.92	15.93	27.67	0	0.01	0	12.5
July	21.82	0	11.06	16.47	17.17	27.53	0	0.01	0	0.1
August	0	0	10.52	15.84	16.46	26.36	0	0	0	0
Septembe r	0.25	0	9.97	15.03	15.94	25	0	0	0	0
October	158	21.74	10.87	16.4	32.54	48.92	0.07	0	0.95	3.9
November	195.38	51.69	12.18	28.2	68.25	91.83	0.18	0.01	1.01	27.1
December	265.54	108.3	15.49	60.69	125.21	183.99	0.28	0.03	3.62	73
TOTAL	**1020.81**	**269.99**	**138.7**	**326.57**	**453.87**	**733.95**	**0.77**	**0.14**	**8.4**	**698.8**

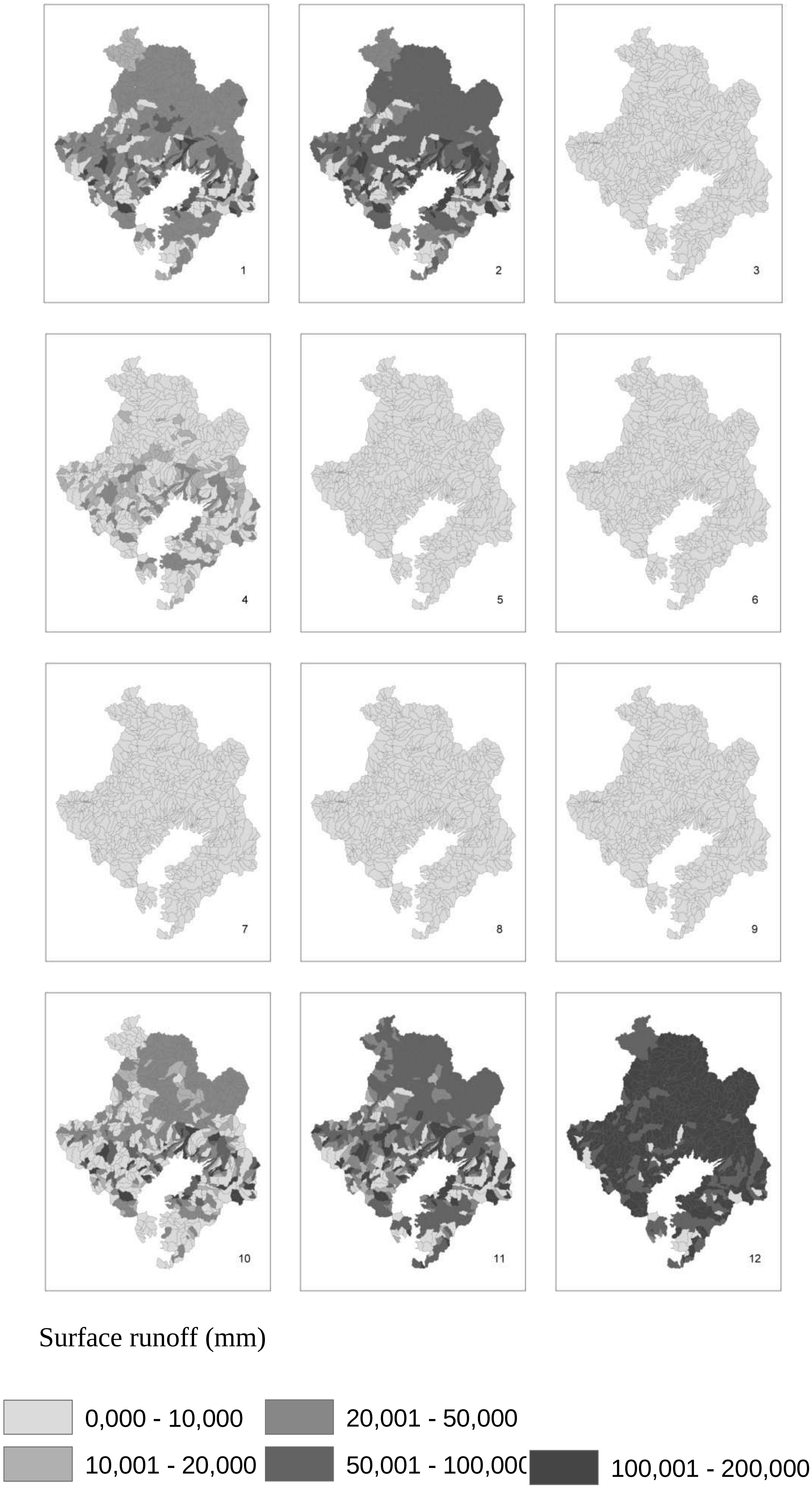

Figure 5.14: Monthly variation of surface runoff in 2007

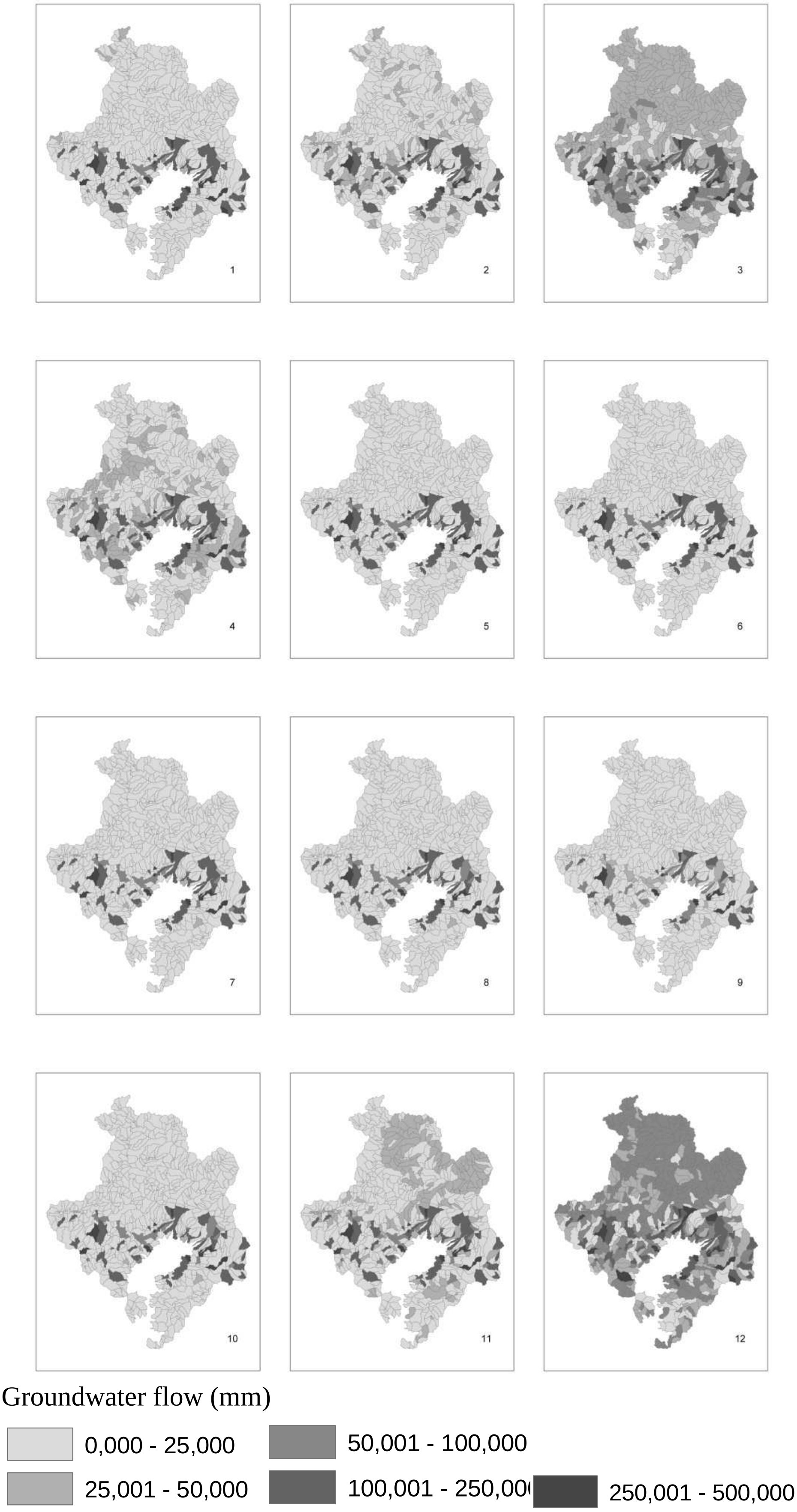

Figure 5.15: Monthly variation of groundwater flow in 2007

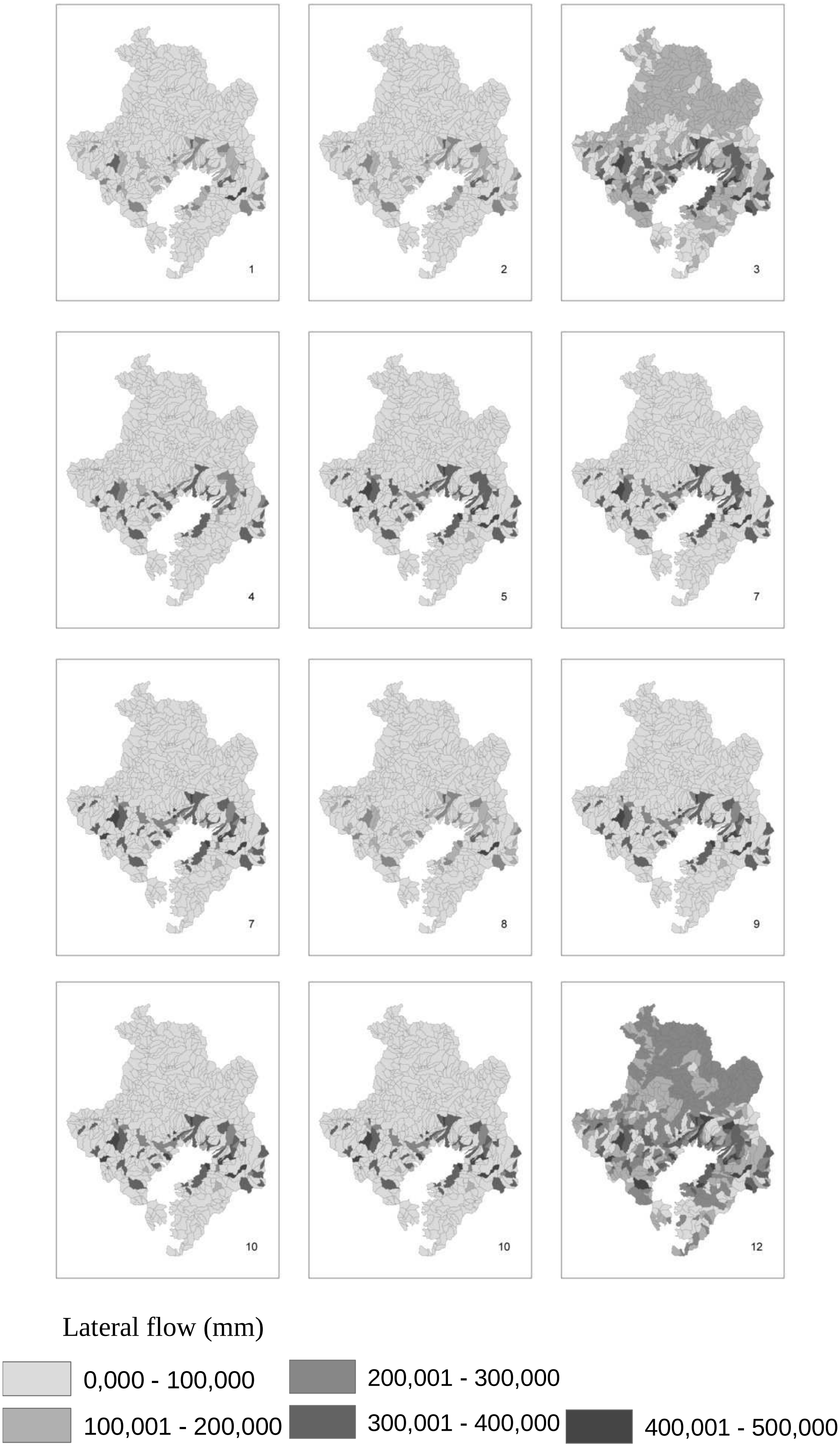

Figure 5.16: Monthly lateral flow in 2007

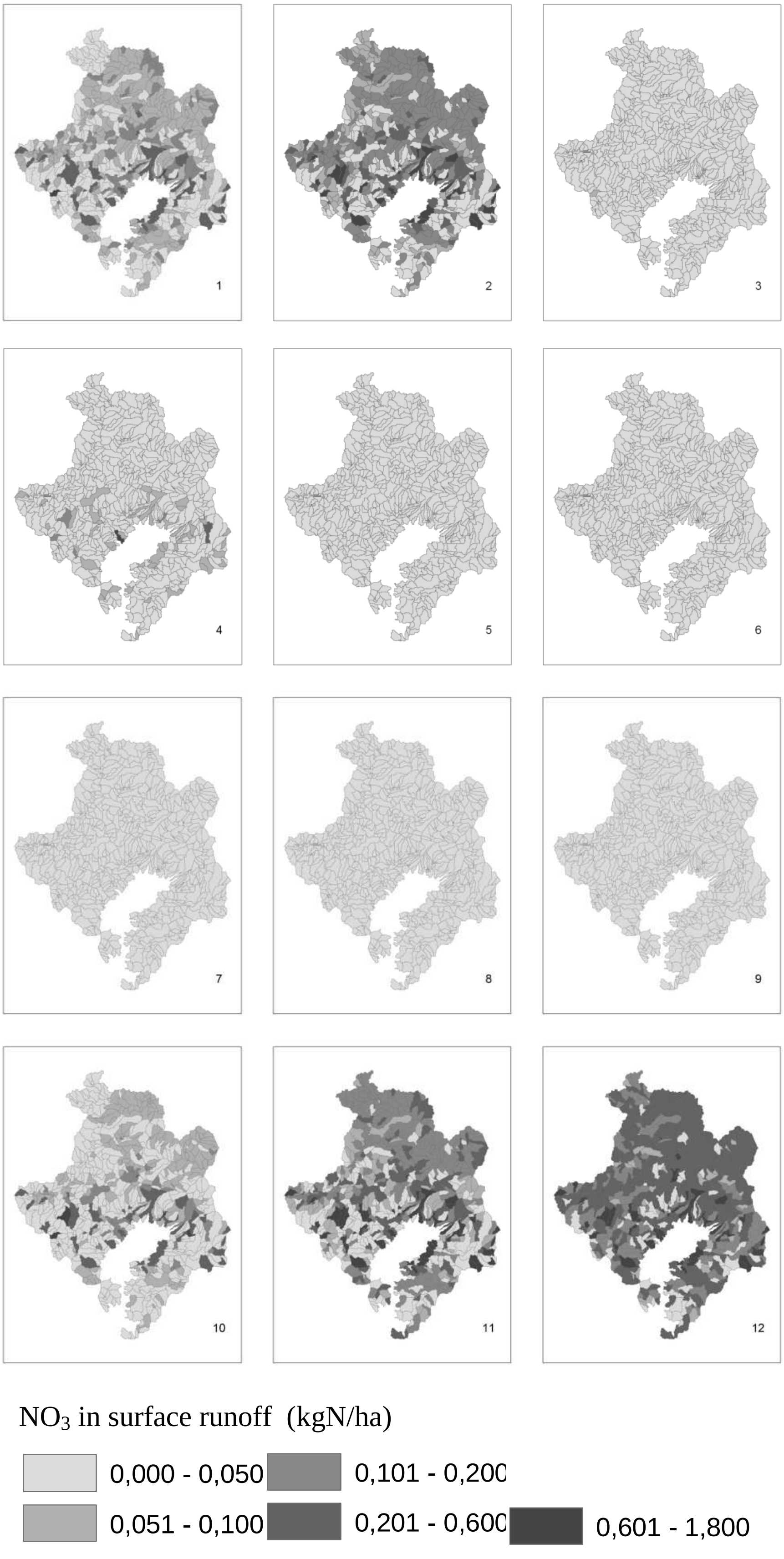

Figure 5.17: Monthly variation of amount of NO_3 in surface run off in 2007

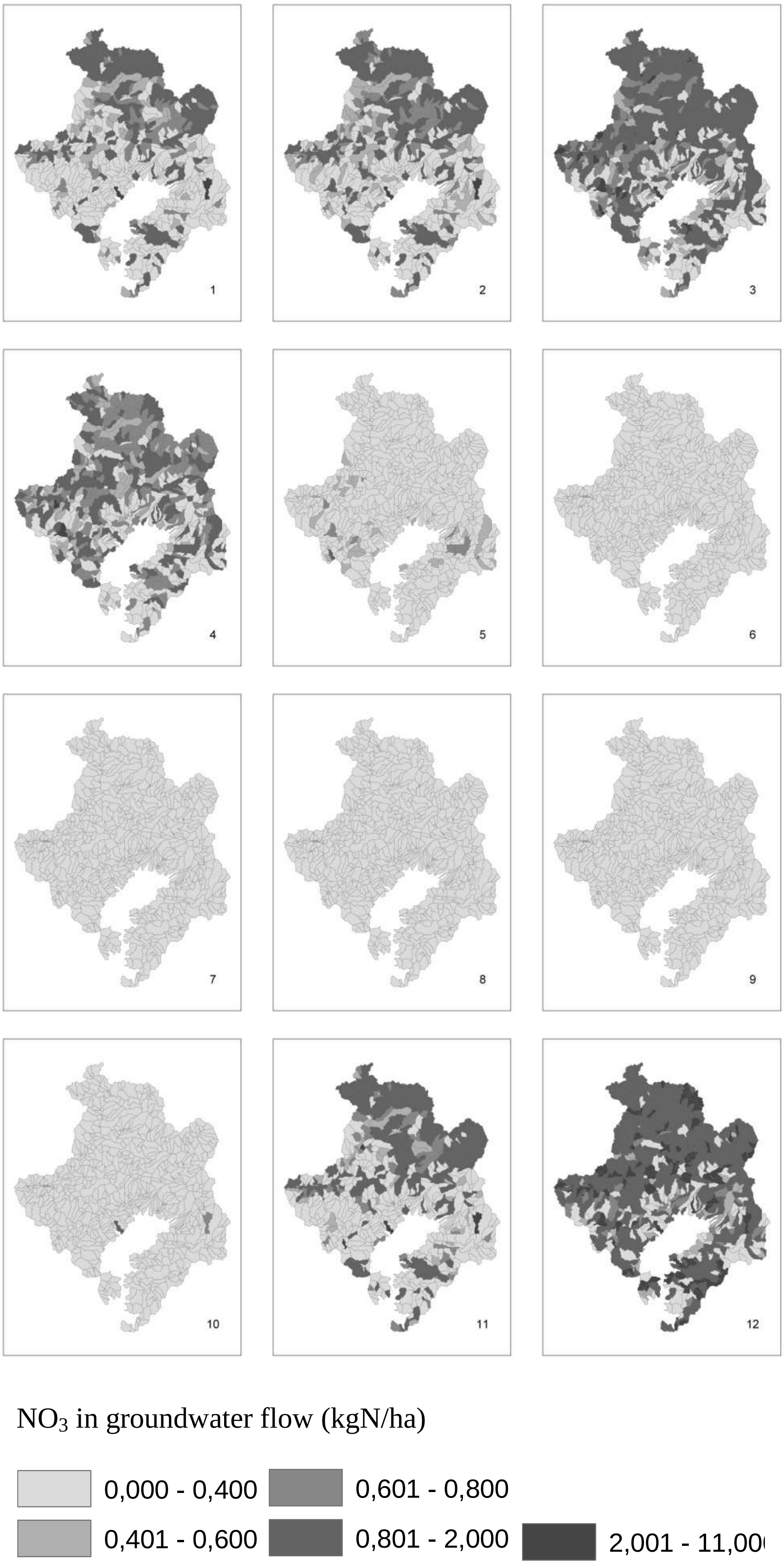

Figure 5.18: Monthly variation of amount of NO_3 in groundwater flow in 2007

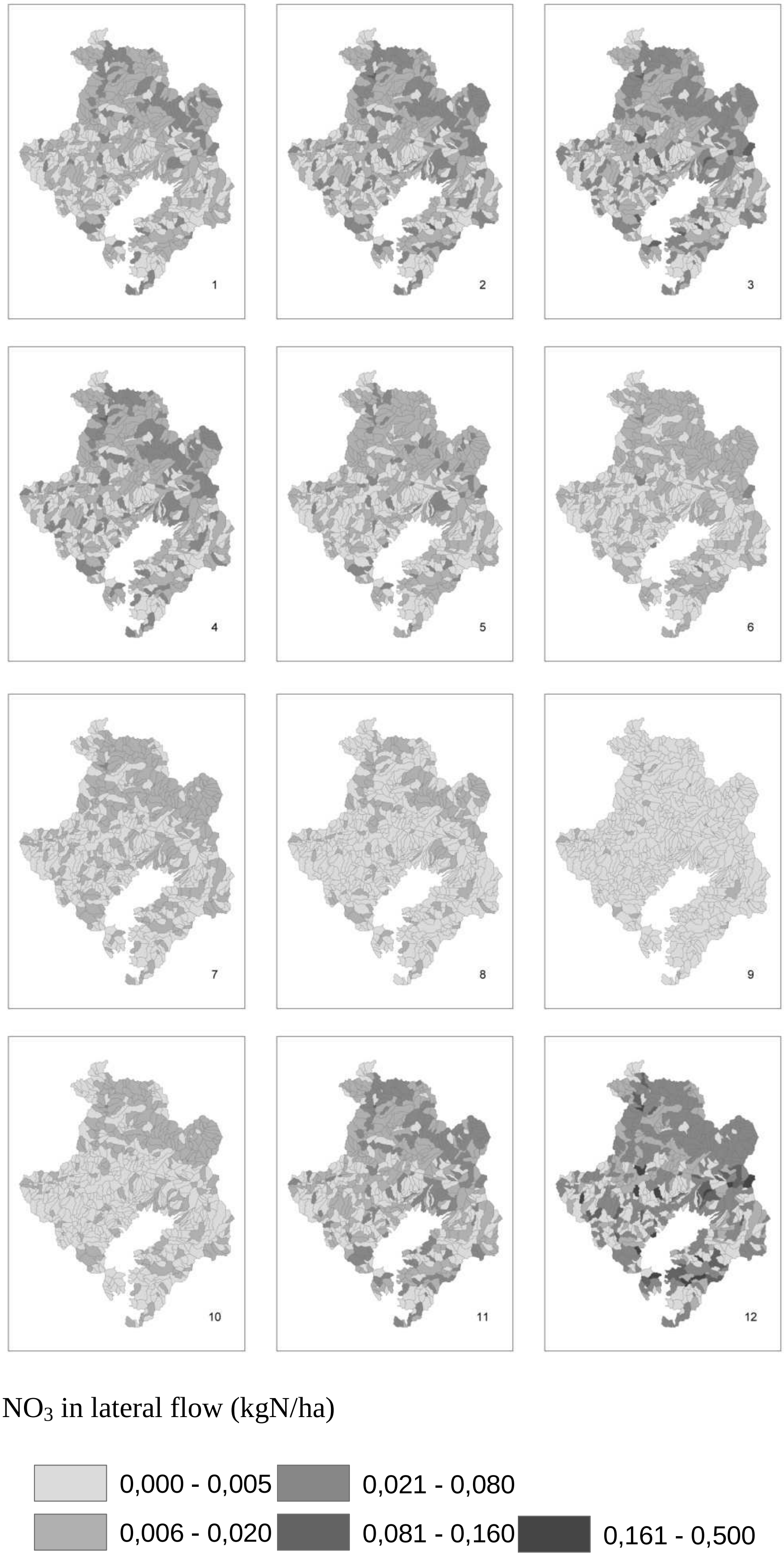

Figure 5.19: Monthly variation of amount of NO_3 in lateral flow in 2007

6. CONCLUSION AND RECOMMENDATIONS

In this study, application of the SWAT model in a watershed in Turkey is aimed. Köyceğiz Dalyan Watershed is selected as the case study area. According to the simulation results, following conclusions can be derived.

- Surface runoff flow pattern is similar to precipitation in the watershed. It decreases in summer months.
- Sandras Mountain is located in Northeast of the Köyceğiz Dalyan Watershed. Therefore, it is seen that surface runoff contribution from Northeast part of the watershed is high. It can be thought that an important part of the precipitation becomes surface runoff in this region. Thus, groundwater contribution to stream flow in this region was not high.
- Surface runoff, lateral flow, and groundwater flow are the factors that increase the amount of water yield from watershed to reaches. It is seen that contribution from groundwater flow to reaches is higher than surface runoff and lateral flow in summer months. Therefore, it can be said that even there is not precipitation, groundwater flow contributes to reach flows.
- Amount of groundwater flow is higher in the lower elevations around Köyceğiz Lake.
- In summer months very low precipitation was seen. On the other hand, the lateral flow existed in this period. It might be due to the contribution of irrigation to lateral flow.
- It should be underlined that a significant part of the nitrate that moves from watershed to the reaches was contributed by groundwater flow.
- Higher nitrate amounts in surface runoff, lateral flow, and groundwater flow was estimated in December. If it is considered that maximum precipitation occurs in December, it is seen that precipitation increases the transport of nitrate.
- According to model results, Namnam Stream is important for the system in terms of its flow and nutrient loads. Flow rate of the Namnam is the highest. In addition, it has the maximum amount of nitrogen and phosphorus species

among all streams. Nutrient loads from Namnam Stream might be important for Köyceğiz Lake water quality.

Recommendations for future studies are given as the following:

- Crop pattern map that is vital for the both hydrology and nutrient processes is required to be developed for the Köyceğiz Dalyan Watershed to carry out more representative simulations. Also, it is important for production of more representative HRUs.
- Model requires detailed irrigation data. In this study auto-irrigation option was used. In following studies, amount of applied irrigation water and irrigation sources should be determined for each HRU.
- Detailed study should be done about determination of timing, type and amount of the fertilizer based on each crop.
- Soil physical and chemical properties were obtained, gathered, derived, and added to the SWAT soil database. It should be considered that soil data were available for limited locations, and only for one soil layer. Therefore, soil analysis should be carried out for different layers and at different locations in the watershed.
- This thesis is a groundwork study for determination of the diffuse nutrient loads in Köyceğiz Dalyan Watershed. In this study, some inputs were derived from several studies from literature. In next modeling studies inputs should be measured such as soil physical properties.
- Model results were not calibrated. Therefore, field study is required for the calibration of model results.

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APPENDICES

APPENDIX A

MODEL OUTPUT PARAMETERS

HRU Output Parameters

LULC: four letter character code for the cover/plant on the HRU.

HRU: Hydrological response unit number.

GIS: GIS code reprinted from watershed configuration file (.fig).

SUB: Topographically-defined subbasin to which HRU belongs.

MGT: Management number. Used by the SWAT/GRASS interface to allow development of output maps by land use/management type.

MON: Daily time step, monthly times step, annual time step, and average annual summary lines.

AREA: Drainage area of the HRU (km^2).

PREC: Total amount of precipitation falling on HRU during time step (mm).

SNOWFALL: Amount of precipitation falling as snow, sleet or freezing rain during time step (mm).

SNOWMELT: Amount of snow or ice melting during time step (mm).

IRR: Amount of irrigation water applied to HRU during time step (mm).

PET: Potential evapotranspiration from the HRU during time step (mm).

ET: Actual evapotranspiration (soil evaporation and plant transpiration) from the HRU during time step (mm).

SW_INIT: Soil water content. For daily output, this column provides the amount of water in soil profile at the beginning of day. For monthly and annual output, this is the average soil water content for the time period (mm).

The amount of water in the soil profile at the beginning of the day is used to calculate daily curve number values.

SW_END: amount of water in the soil profile end of the time period (day, month or year) (mm).

PERC: Water percolates pass the root zone during time step (mm).

GW_RCHG: Total amount of water entering the shallow and deep aquifers (SA+DA) (mm).

DA_RCHG: Amount of water from root zone recharging the deep aquifer during time step (mm).

REVAP: Water returning from shallow aquifer to root zone according to moisture deficit during time step (mm).

SA_IRR: Amount of water removed from shallow aquifer for irrigation during time step (mm).

DA_IRR: Amount of water removed from deep aquifer for irrigation during time step (mm).

SA_ST: Amount of water in the shallow aquifer at the end of period (mm).

DA_ST: Amount of water in the deep aquifer at the end of period (mm).

SURQ_GEN: surface run off generated in the HRU during time step (mm).

SURQ_CNT: Surface run-off contribution to stream flow in the main channel during time step (mm)

TLOSS: Water losses from tributary channels in HRU via transmission through the bed. This water becomes recharge for the shallow aquifer. (Net SurQ = SurQ - Tloss)

LATQ: Water flowing laterally within the soil profile that enters the main channel during time step (mm).

GWQ: Water from shallow aquifer that enters the main channel during time step (mm).

WYLD (mm): Total amount of water leaving the HRU and entering the main channel during time step (mm). (WYLD = SurQ + LatQ+ GwQ- TLoss- pond abstractions).

DAILYCN: Average curve number for time period. Curve number adjusted for soil moisture content.

TMP_AV: Average daily air temperature for time period (°C)

TMP_MX: Maximum daily air temperature for time period (°C)

TMP_MN: Minimum daily air temperature for time period (°C)

SOL_TMP: Average soil temperature of first layer for time period (°C)

SOLAR: Average of daily solar radiation values for time period (MJ/m^2).

SYLD: Sediment from the HRU that is transported into the reach during time step (metric tons/ha).

USLE: Soil loss during time step calculated with the USLE equation (metric tons/ha).

N_APP: Total amount of nitrogen (mineral+organic) applied in regular fertilizer operations during time step (kgN/ha).

P_APP: Total amount of phosphorus (mineral+organic) applied in regular fertilizer operations during time step (kgN/ha).

NAUTO: Total amount of nitrogen fertilizer (organic + mineral) auto applied during time step (kgN/ha).

PAUTO: Phosphorus fertilizer (organic + mineral) auto applied during time step (kP/ha).

NGRZ: Nitrogen fertilizer added to soil by grazing operation (organic + mineral) during time step (kN/ha).

PGRZ: Phosphorus fertilizer added to soil by grazing operation (organic + mineral) during time step (kP/ha).

CFERTN: Nitrogen applied by continuous fertilizer operation (mineral + organic) during time step (kN/ha).

CFERTP: Phosphorus applied by continuous fertilizer operation (mineral + organic) during time step (kP/ha).

NRAIN: Nitrate added to soil profile by rain (kgN/ha).

NFIX: Amount of nitrogen fixed by legumes (kgN/ha).

F-MN: Fresh organic to mineral N. Mineralization of nitrogen from the fresh residue pool (ratio) to nitrate (80%) pool and active organic nitrogen (20%) pool during time step. A positive value donates a net gain in the nitrate and active organic pools. A negative value donates a net gain in the fresh organic pool from the nitrate and active organic pools (kgN/ha).

A-MN: Active organic to mineral N. Movement of nitrogen from the active organic pool to nitrate pool during time step (kgN/ha)

A-SN (kgN/ha): Movement of nitrogen from the active organic pool to stable organic pool during time step (kgN/ha)

F-MP: Fresh organic to mineral P. Mineralization of phosphorus from the fresh residue pool (ratio) to labile (80%) pool (P in solution) and active organic nitrogen (20%) pool during time step. A positive value donates a net gain in solution and active organic pools from fresh organic pools. A negative value donates a net gain in the fresh organic pool from the labile and active organic pools (kgP/ha).

AO-LP: Organic to labile mineral P. Movement of phosphorus between the organic pool and the labile mineral pool during time step. A positive value denotes a net gain in the labile pool from the organic pool while a negative value denotes a net gain in the organic pool from the labile pool (kgP/ha).

L-AP: Labile to active mineral P. Movement or transformation of phosphorus between the “labile pool (P in solution) and the “active” mineral pool (P sorbed to the surface soil particles) during time step. A positive value denotes a net gain in the active pool from the labile pool while a negative value denotes a net gain in the labile pool from the active pool (kgP/ha).

A-SP: Active to stable P. Movement or transformation of phosphorus between the “active” mineral pool (P sorbed to surface of soil particles) and the “stable” mineral pool (P fixed in soil) during time step. A positive value denotes a net gain in the stable pool from the active pool while a negative value denotes a net gain in the active pool from the stable pool (kgP/ha).

DNIT: Denitrification. Transformation of nitrate to gaseous compounds during time step (kgN/ha).

NUP: Plant uptake of nitrogen. Nitrogen removed from soil by plants during time step (kgN/ha).

PUP: Plant uptake of phosphorus. Phosphorus removed from soil by plants during time step (kgP/ha).

ORGN: Organic N yield. Organic N transported out of the HRU and into the reach during time step (kgN/ha).

ORGP: Organic P yield. Organic P transported out of the HRU and into the reach during time step (kgP/ha).

SEDP: Sediment P yield. Mineral phosphorus sorbed to sediment transport into the reach during time step (kgP/ha).

NSURQ: NO_3 in surface run-off. Nitrate transported with surface run off into the reach during time step (kgN/ha).

NLATQ: NO_3 in lateral flow. Nitrate transported with lateral flow into the reach during time step (kgN/ha).

NO3L: NO_3 leached from the soil profile. Nitrate that leaches past the bottom of the soil profile during time step. The nitrate is not tracked through the shallow aquifer during time step (kgN/ha).

NO3GW: NO_3 transported into main channel in the groundwater loading from HRU during time step (kgN/ha).

SOLP: Soluble P yield. Soluble mineral forms of phosphorus transported by surface runoff into the reach during the time step (kgP/ha).

PGWQ: Soluble phosphorus transported by groundwater flow into main channel during the time step (kgP/ha).

W_STRS: Water stress days during the time step (days).

TMP_STRS: Temperature stress days during time step (days).

N_STRS: Nitrogen stress days during the time step (days).

P_STRS: Phosphorus stress days during time step (days).

BIOM: Total biomass above ground and roots at the end of the time period reported as dry weight (ton/ha).

LAI: Leaf area index at the end of the time period (ton/ha).

YLD: Harvested yield. The model partitions yield from the total biomass on a daily basis (ton/ha).

BACTP: Number of persistent bacteria in surface runoff entering reach (#cfu/100 ml).

BACTLP: Number of less persistent bacteria in surface runoff entering reach (#cfu/100 ml).

Subbasin Output Parameters

SUB: Subbasin number.

GIS: GIS code reprinted from watershed configuration file (.fig).

SUB: Topographically-defined subbasin to which HRU belongs.

MON: Daily time step, monthly times step, annual time step, and average annual summary lines.

AREA: Drainage area of the subbasin (km^2).

PRECIP: Total amount of precipitation falling on HRU during time step (mm).

SNOWMELT: Amount of snow or ice melting during time step (mm).

PET: Potential evapotranspiration from the subbasin during time step (mm).

ET: Actual evapotranspiration (soil evaporation and plant transpiration) from the subbasin during time step (mm).

SW: Amount of water in the soil profile at end of the time period (day, month or year) (mm).

PERC: Water percolates pass the root zone during time step (mm).

SURQ: Surface run-off contribution to stream flow in the main channel during time step (mm)

GWQ: Water from shallow aquifer that enters the main channel during time step (mm).

WYLD: Total amount of water leaving the subbasin and entering the main channel during time step (mm). (WYLD= SurQ + LatQ+ GwQ- TLoss- pond abstractions) (mm).

SYLD: Sediment from the subbasin that is transported into the reach during time step (metric tons/ha).

ORGN: Organic N yield. Organic N transported out of the subbasin and into the reach during time step (kgN/ha).

ORGP: Organic P yield. Organic P transported out of the subbasin and into the reach during time step (kgP/ha).

SEDP: Sediment P yield. Mineral phosphorus sorbed to sediment transport into the reach during time step (kgP/ha).

NSURQ: NO_3 in surface run-off. Nitrate transported with surface run off into the reach during time step (kgN/ha).

SOLP: Soluble P yield. Soluble mineral forms of phosphorus transported by surface runoff into the reach during the time step (kgP/ha).

Reach Output Files

RCH: Reach number.

GIS: GIS number reprinted from watershed configuration (.fig).

MON: Daily time step, monthly times step, annual time step, and average annual summary lines.

AREA: Area drained by reach (km^2)

FLOW_IN: Average daily stream flow into reach during time step (m^3/s).

FLOW_OUT: Average daily stream flow out of reach during time step (m^3/s).

EVAP: Average daily rate of water loss from reach by evaporation during time step (m^3/s).

TLOSS: Average daily rate of water loss from reach by transmission through streambed during time step (m^3/s).

SED_IN: Sediment transported with water into reach during time step (metric tons).

SED_OUT: Sediment transported with water out of reach during time step (metric tons).

SEDCONC: Concentration of sediment in reach during time step during time step (mg/L)

ORGN_IN: Organic nitrogen transported with water into the reach during time step (kgN).

ORGN_OUT: Organic nitrogen transported with water out of the reach during time step (kgN).

ORGP_IN: Organic phosphorus transported with water into the reach during time step (kgP).

ORGP_OUT: Organic phosphorus transported with water out of the reach during time step (kgP).

NO3_IN: Nitrate transported with water into the reach during time step (kgN).

NO3_OUT: Nitrate transported with water out of the reach during time step (kgN).

NH4_IN: Ammonium transported with water into the reach during time step (kgN).

NH4_OUT: Ammonium transported with water out of the reach during time step (kgN).

NO2_IN: Nitrite transported with water into reach during time step (kgN).

NO2_OUT: Nitrite transported with water out of reach during time step (kgN).

MINP_IN : Mineral phosphorus transported with water into reach during time step (kgP).

MINP_OUT: Mineral phosphorus transported with water out of reach during time step (kgP).

ALGAE_IN: Algae biomass transported with water into reach during time step (kg chl-a).

ALGAE_OUT: Algae biomass transported with water out of reach during time step (kg chl-a).

CBOD_IN: Carbonaceous biochemical oxygen demand of material transported into the reach during time step (kgO_2).

CBOD_OUT: Carbonaceous biochemical oxygen demand of material transported out of reach during time step (kgO_2).

DISOX_IN: Amount of dissolved oxygen transported into reach during time step (kgO_2).

DISOX_OUT: Amount of dissolved oxygen transported out of reach during time step (kgO_2).

SOLPST_IN: Soluble pesticide transported with water into reach during time step (mg active ingredient).

SOLPST_OUT: Soluble pesticide transported with water out of reach during time step (mg active ingredient).

SORPST_IN**:** Pesticide sorbed to sediment transported with water into reach during time step (mg active ingredient).

SORPST_OUT**:** Pesticide sorbed to sediment transported with water out of reach during time step (mg active ingredient).

REACT_PST: Loss of pesticide from water by reaction during time step during time step (mg active ingredient).

VOLPST: Loss of pesticide from water by volatilization during time step during time step (mg active ingredient).

SETTL_PST: Transfer of pesticide from water to river bed sediment by settling during time step (mg active ingredient).

RESUSP_PST: Transfer of pesticide from water to river bed sediment by resuspension during time step (mg active ingredient).

DIFFUSEPST: Transfer of pesticide from water to river bed sediment by diffusion during time step (mg active ingredient).

BURYPST: Loss of pesticide from river bed sediment by burial during time step (mg active ingredient).

BED_PST: Pesticide in river bed sediment during time step (mg active ingredient).

BACTP_OUT: Number of persistent bacteria transported out of reach during time step (#cfu/100 ml).

BACTLP_OUT: Number of less persistent bacteria transported out of reach during time step (#cfu/100 ml).

CMETAL#1: Conservative metal #1 transported out of reach during time step (kg).

CMETAL#2: Conservative metal #2 transported out of reach during time step (kg).

CMETAL#3: Conservative metal #3 transported out of reach during time step (kg).

APPENDIX B

Table B.1: Crop pattern based on villages within the boundary of the Köyceğiz Dalyan Watershed

GÖKBEL		EKŞİLİYURT		**KEMALİYE**	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Wheat	602.5	Lemon	1056.8	Lemon	488.9
Olive	424.3	Orange	259.0	Orange	144.6
Lemon	93.4	Orange (Washington)	253.9	Wheat	38.3
Sesame	37.9	Tomato (Green house)	236.5	Orange (Washington)	35.2
Barley	30.1	Corn (silage)	222.6	Pomegranate	16.8
Cotton	25.0	Tomato	133.9	Corn (Grain)	14.7
Orange	23.0	Cotton	57.1	Cotton	13.5
Pomegranate	16.3	Pomegranate	52.0	Sesame	11.7
Corn (silage)	12.0	Sesame	51.0	Corn (silage)	10.8
Corn (Grain)	7.0	Corn (Grain)	37.6	Tomato (Green house)	5.9
Orange (Washington)	2.0	Wheat	21.2	Tomato	1.9
YEŞİLKÖY		**ZAFERLER**		**HAMİTKÖY**	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Orange (Washington)	116.4	Orange (Washington)	358.9	Orange (Washington)	1067.7
Mandarin	86.4	Orange	43.4	Orange	32.6
Olive	36.6	Grapefruit	8.1	Wheat	6.9
Wheat	18.9	Pomegranate	2.7	Mandarin	4.6
Fruit (Mixed)	11.5	Corn (Grain)	1.6	Corn (silage)	4.5
Vegetable (Mixed)	3.8				

DÖĞÜŞBELEN		**PINAR**		**TOPARLAR**	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Orange (Washington)	1200.9	Wheat	44.9	Orange (Washington)	1117.9
Orange	160.9	Orange (Washington)	30.0	Mandarin	552.8
Mandarin	77.7	Corn (silage)	19.8	Orange	170.8
Corn (Grain)	61.0	Corn (Grain)	14.7	Sesame	32.4
Vegetable (Mixed)	25.0	Olive	8.9	Olive	23.6
Sorghum hay	14.1	Barley	5.5	Pomegranate	21.1
Sesame	10.8	Sesame	4.6	Sorghum hay	10.7
Wheat	4.3	Vegetable (Mixed)	4.3	Vegetable (Mixed)	8.6
Oat	1.4			Wheat	7.3
				Vetch	5.6
GÖLBAŞI		**BEYOBASI**		**KAVAKARASI**	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Lemon	176.6	Orange (Washington)	1464.6	Orange (Washington)	666.7
Corn (Grain)	133.9	Orange	435.5	Cotton	248.5
Corn (silage)	91.4	Sesame	134.2	Pomegranate	111.1
Sesame	48.6	Wheat	109.6	Orange	91.5
Tomato	34.5	Olive	78.9	Sesame	79.5
Tomato (Green house)	29.4	Corn (Grain)	68.0	Wheat	79.5
Wheat	28.3	Pomegranate	30.2	Vetch	45.0
Orange	25.4	Vegetable (Mixed)	23.4	Mandarin	38.0
Orange (Washington)	21.8	Oat	19.5	Vegetable (Mixed)	12.4
Pomegranate	19.4	Fruit (Mixed)	19.5	Corn (silage)	10.0
Cotton	18.4	Corn hasıl	18.0	Lemon	8.1
Vetch	10.4	Mandarin	16.4	Tomato (Green house)	4.9
Barley	1.1	Lemon	15.4	Corn (Grain)	3.1

ESKİKÖY		**ZEYTİNALANI**		**OKÇULAR**	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Lemon	1632.9	Wheat	632.2	Lemon	1399.9
Orange	1341.7	Olive	422.1	Corn (silage)	436.7
Cotton	1313.7	Orange (Washington)	273.1	Orange	391.1
Pomegranate	1105.9	Corn (silage)	182.3	Cotton	329.8
Corn (silage)	761.0	Mandarin	74.5	Wheat	264.8
Orange (Washington)	413.5	Corn (Grain)	68.2	Pomegranate	127.7
Wheat	137.4	Sesame	26.2	Orange (Washington)	48.7
Corn (Grain)	83.3	Orange	20.1	Corn (Grain)	43.9
Tomato (Green house)	80.3	Vegetable (Mixed)	16.2	Barley	25.5
Sesame	63.9	Oat	13.2	Olive	24.6
Tomato	50.1	Barley	9.9	Sesame	18.3
Grapefruit	40.0	Tomato (Green house)	3.1	Tomato (Green house)	17.6
Barley	39.2	Tomato	2.3	Tomato	16.5
Melon	29.1	Lemon	2.2	Grapefruit	6.5

YAYLA		ÇANDIR		SULTANİYE	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Corn (Grain)	38.4	Olive	121.1	Orange (Washington)	35.7
Orange (Washington)	25.2	Pomegranate	48.6	Olive	5.1
Wheat	19.4	Corn (silage)	12.1		
Elma	16.3	Lemon	11.8		
Erik	4.9	Wheat	9.4		
Vegetable (Mixed)	3.6	Sesame	4.5		
Barley	2.4				

YANGI		KÖYCEĞİZ		DALYAN	
CROP	**AREA (da)**	**CROP**	**AREA (da)**	**CROP**	**AREA (da)**
Orange (Washington)	666.7	Orange (Washington)	797.8	Pomegranate	2164.3
Cotton	248.5	Wheat	283.3	Lemon	846.5
Pomegranate	111.1	Orange	180.8	Corn (silage)	552.0
Orange	91.5	Vetch	104.7	Cotton	449.0
Sesame	79.5	Corn (silage)	53.6	Orange	260.5
Wheat	79.5	Cotton	27.0	Wheat	125.1
Vetch	45.0	Pomegranate	26.0	Orange (Washington)	74.6
Mandarin	38.0	Mandarin	15.7	Grapefruit	73.9
Vegetable (Mixed)	12.4	Sesame	13.8	Barley	55.9
Corn (silage)	10.0	Lemon	12.6	Vetch	39.9
Lemon	8.1	Tomato (Green house)	7.1	Sesame	26.0
Tomato (Green house)	4.9	Melon	7.0	Corn (Grain)	22.0
Corn (Grain)	3.1	Vegetable (Mixed)	2.0	Melon	13.0
Pepper	0.9			Tomato	10.7
				Tomato (Green house)	8.0

APPENDIX C, Table C.1: Soil Experiment Results (1-9) (Yüceil, 2005)

Sample:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Location:	1	2	2	3	3	3	4	5	5
SampleID:	1324	1325	1326	1327	1328	1329	1330	1331	1332
Date Taken:	1/11/02	13/11/02	13/11/02	14/11/02	14/11/02	14/11/02	14/11/02	13/11/02	13/11/02
Time Taken:	15:30	15:30	15:30	09:50	09:50	09:50	11:20	13:30	13:30
Soil Depth (cm):	0-30	0-30	30-60	0-30	30-60	60-90	0-30	0-30	30-60
Water Saturation (%):	85	40	38	75	80	85	88	44	46
Salinity* (%):	0.085	0.049	**	0.226	0.690	1.090	0.059	**	**
pH*:	7.01	7.3	7.36	7.55	7.67	7.68	6.62	7.43	7.41
$CaCO_3$ (%):	4.10	14.80	13.10	16.00	19.30	21.70	0.40	0.40	2.11
P_2O_5 (kg/da):	0.9	5.4	3.0	19.0	3.0	1.1	4.1	1.7	1.0
NO_3 (ppm):	22.9	10.4	7.3	64.9	26.1	44.3	58.3	15.3	16.8
Total N (%):	0.182	0.196	0.112	0.182	0.098	0.098	0.406	0.168	0.126
Total Organics (%):	2.6	2.2	1.0	2.2	1.3	1.3	5.7	1.7	1.0
Sand (%):	63.22	65.49	83.72	12.59	12.68	12.77	39.44	49.19	53.21
Clay (%):	18.13	18.00	5.87	56.62	58.59	64.60	26.00	20.66	20.66
Silt (%):	18.65	16.51	10.41	30.79	28.73	22.63	34.56	30.15	26.13
Soil Texture:	SL	SL	LS	C	C	C	L(CL)	L	SCL(SL)
Field Capacity (%):	47.0	17.5	9.7	37.0	37.8	40.0	36.7	20.2	20.7
Wilting Point (%):	36.4	11.5	6.3	25.6	24.9	28.8	24.3	9.2	10.0
Rock Layer Depth* (cm):**	30	60					35		
Property Owner At Location:		Bayram Yollu	Bayram Yollu					Bayram Usul	Bayram Usul
Last rainfall:		11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:	Dry	Saturated	Saturated	Saturated	Saturated	Saturated	Wet	Wet	
Soil temperature (^oC):		20.3	20.3	21.0	21.0	21.0	20.0	17.8	17.8
Crop Type:	Forest	Agricultural	Agricultural	Pastures	Pastures	Pastures	Forest	Agricultural	Agricultural
Agricultural Crops:		Citrus	Citrus					Corn	Corn
Adjacent Field Crops:		Citrus	Citrus					Citrus	Citrus
Winter Crops Planted:									
Irrigation Resource:		Stream(pump)	Stream					Aquifere	Aquifere

Table C.2: Soil Experiment Results (10-18)

Sample:	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Location:	5	6	7	8	9	10	11	12	13
SampleID:	1333	1334	1335	1336	1337	1338	1339	1340	1341
Date Taken:	13/11/02	14/11/02	14/11/02	13/11/02	14/11/02	13/11/02	13/11/02	14/11/02	14/11/02
Time Taken:	13:30	16:40	10:10	15:00	16:00	14:35	16:00	09:30	10:45
Soil Depth (cm):	60-90	0-25	0-30	0-30	0-30	0-30	0-30	0-30	0-30
Water Saturation (%):	44	44	80	50	44	88	77	71	44
Salinity* (%):	**	**	0.520	0.050	**	0.136	0.093	0.590	**
pH*:	7.4	6.43	7.77	7.61	6.77	6.89	7.97	7.41	6.23
$CaCO_3$ (%):	1.20	0.00	14.80	1.60	0.00	0.00	20.50	8.20	0.00
P_2O_5 (kg/da):	0.8	1.1	13.6	4.3	1.1	1.3	28.2	14.3	2.5
NO_3 (ppm):	8.6	27.0	23.5	16.2	13.1	62.7	17.5	83.5	22.4
Total N (%):	0.112	0.182	0.196	0.126	0.112	0.154	0.112	0.252	0.238
Total Organics (%):	1.0	2.1	2.2	1.9	1.5	3.1	1.6	3.4	3.3
Sand (%):	47.23	51.15	13.44	38.23	64.54	42.90	24.84	17.30	51.51
Clay (%):	22.65	22.70	53.71	21.09	12.98	33.08	53.24	46.84	16.66
Silt (%):	30.12	26.15	32.85	40.68	22.48	24.02	21.92	35.86	31.83
Soil Texture:	L	SCL(SL)	C	L	SL	CL	C	C	L
Field Capacity (%):	18.6	20.3	40.7	24.4	19.9	56.9	36.3	30.9	22.6
Wilting Point (%):	10.0	11.4	29.1	14.0	12.4	46.3	29.5	18.4	14.1
Rock Layer Depth* (cm):**		25			40	70			40
Property Owner At Location:	Bayram Usul			Yusuf Kaplan				Salih Tutarlı	
Last rainfall:	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:		Wet	Saturated	Saturated		Wet	Saturated	Saturated	Wet
Soil temperature (^{o}C):	17.8		18.6	20.9	15.6	20.3	17.3	17.3	20.0
Crop Type:	Agricultural	Meadows	Agricultural	Agricultural	Forest	Meadows	Agricultural	Agricultural	Forest
Agricultural Crops:	Corn		Cotton	Citrus			Cotton	Cotton	
Adjacent Field Crops:	Citrus	Citrus	Cotton	Citrus			Cotton	Cotton	
Winter Crops Planted:									
Irrigation Resource:	Aquifere		Canal	Stream					

Table C.3: Soil Experiment Results (19-25)

Sample:	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Location:	14	15	16	17	18	19	20
SampleID:	1342	1343	1344	1345	1346	1347	1348
Date Taken:	14/11/02	14/11/02	14/11/02	1/11/02	13/11/02	14/11/02	14/11/02
Time Taken:	12:15	12:45	13:15	16:00	14:00	13:35	13:55
Soil Depth (cm):	0-30	0-30	0-30	0-20	0-30	0-30	0-30
Water Saturation (%):	50	47	44	77	58	44	44
Salinity* (%):	0.044	0.040	0.032	0.043	0.051	**	**
pH*:	7.92	7.83	7.7	6.63	6.62	7.22	6.88
$CaCO_3$ (%):	3.70	4.90	1.60	0.00	0.00	0.00	0.00
P_2O_5 (kg/da):	2.8	1.6	17.8	1.3	1.6	1.0	2.3
NO_3 (ppm):	21.5	3.8	5.8	25.3	41.9	10.9	20.2
Total N (%):	0.154	0.070	0.084	0.112	0.154	0.126	0.140
Total Organics (%):	1.8	1.6	1.4	2.1	2.2	1.5	1.6
Sand (%):	49.34	49.13	71.33	38.95	50.55	70.96	64.90
Clay (%):	18.73	12.64	8.59	24.76	22.81	4.58	12.62
Silt (%):	31.93	38.23	20.08	36.29	26.64	24.46	22.48
Soil Texture:	L	L	SL	L	SCL(SL)	SL	SL
Field Capacity (%):	24.1	20.5	17.2	37.0	34.6	14.6	18.4
Wilting Point (%):	11.7	9.0	8.1	20.3	21.0	7.0	9.8
Rock Layer Depth* (cm):**				20			
Property Owner At Location:	Abaz Mehmet		Erol Eroğlu			İhsan Ekinci	
Last rainfall:	11/11/02	11/11/02	11/11/02		11/11/02	11/11/02	11/11/02
Soil humidity:	Saturated	Wet	Saturated	Dry	Wet	Wet	Wet
Soil temperature (^oC):	20.8	19.8	16.0		18.4	19.8	20.4
Crop Type:	Wetlands	Wetlands	Wetlands	Forest	Agricultural	Wetlands	Agricultural
Agricultural Crops:	Citrus	Citrus	Citrus		Wheat	Olive	Wheat
Adjacent Field Crops:	Citrus	Citrus	Citrus		Wheat	Citrus	Citrus
Winter Crops Planted:					Wheat		Wheat
Irrigation Resource:	Namnam	Wetland	Stream			Stream	
*** Under water saturated conditions. ** Scarce *** Too deep if not specified.**							

APPENDIX D

Table D.1: Distribution of the crops based on villages in Köyceğiz and Ortaca Districts

CROP	VILLAGE	Number of establishments	Number of fields	Area of the ltivated land (da)	Ratio of cultivated land area with this crop in the village to total cultivated land area	Ratio of cultivated land area with this crop in the village to total cultivated land area with this crop	Ratio of cultivated land area with this crop in the village to total cultivated land area in the village
Orange (Washington)		**463**	**965**	**7,708.306**	**47.49%**		
Orange (Washington)	BEYOBASI(CENTER)	104	164	1,464.577	9.02%	19.00%	59.15%
Orange (Washington)	DOGUSBELEN(CENTER)	60	134	1,200.864	7.40%	15.58%	77.18%
Orange (Washington)	TOPARLAR(CENTER)	65	145	1,117.905	6.89%	14.50%	55.86%
Orange (Washington)	HAMITKOY(CENTER)	61	137	1,067.654	6.58%	13.85%	95.65%
Orange (Washington)	KOYCEGIZ(CENTER)	52	84	797.836	4.92%	10.35%	52.09%
Orange (Washington)	KAVAKARASI(CENTER)	34	86	666.742	4.11%	8.65%	44.10%
Orange (Washington)	YANGI(CENTER)	36	69	421.519	2.60%	5.47%	39.88%
Orange (Washington)	ZAFERLER(CENTER)	29	40	358.910	2.21%	4.66%	86.57%
Orange (Washington)	ZEYTINALANI(CENTER)	22	45	273.083	1.68%	3.54%	15.60%
Orange (Washington)	YESILKOY(CENTER)	12	23	116.362	0.72%	1.51%	42.45%
Orange (Washington)	CENTER(CENTER)	10	20	102.659	0.63%	1.33%	82.63%
Orange (Washington)	SULTANIYE(CENTER)	4	4	35.655	0.22%	0.46%	87.57%
Orange (Washington)	PINAR(CENTER)	2	2	29.970	0.18%	0.39%	21.86%
Orange (Washington)	CAYHISAR(CENTER)	5	9	25.177	0.16%	0.33%	3.52%
Orange (Washington)	CANDIR(CENTER)	1	1	17.890	0.11%	0.23%	7.94%
Orange (Washington)	EKINCIK(CENTER)	1	2	11.503	0.07%	0.15%	4.49%

Wheat (Bread)		**158**	**443**	**2,459.296**	**15.15%**		
Wheat (Bread)	ZEYTINALANI(CENTER)	46	65	632.211	3.89%	25.71%	36.13%
Wheat (Bread)	KARACAM(CENTER)	23	82	372.870	2.30%	15.16%	86.17%
Wheat (Bread)	CAYHISAR(CENTER)	29	130	325.477	2.01%	13.23%	45.54%
Wheat (Bread)	KOYCEGIZ(CENTER)	5	9	283.301	1.75%	11.52%	18.50%
Wheat (Bread)	KAVAKARASI(CENTER)	7	15	191.485	1.18%	7.79%	12.67%
Wheat (Bread)	OTMANLAR(CENTER)	20	49	177.624	1.09%	7.22%	50.72%
Wheat (Bread)	BEYOBASI(CENTER)	11	17	109.600	0.68%	4.46%	4.43%
Wheat (Bread)	DEMIRLI(CENTER)	6	16	93.459	0.58%	3.80%	83.05%
Wheat (Bread)	YANGI(CENTER)	6	10	87.848	0.54%	3.57%	8.31%
Wheat (Bread)	SAZAK(CENTER)	5	18	47.764	0.29%	1.94%	75.00%
Wheat (Bread)	PINAR(CENTER)	5	15	44.869	0.28%	1.82%	32.73%
Wheat (Bread)	EKINCIK(CENTER)	3	3	26.492	0.16%	1.08%	10.34%
Wheat (Bread)	YAYLA(CENTER)	3	4	19.446	0.12%	0.79%	22.86%
Wheat (Bread)	YESILKOY(CENTER)	3	5	18.938	0.12%	0.77%	6.91%
Wheat (Bread)	CANDIR(CENTER)	1	1	9.433	0.06%	0.38%	4.18%
Wheat (Bread)	TOPARLAR(CENTER)	2	2	7.300	0.04%	0.30%	0.36%
Wheat (Bread)	HAMITKOY(CENTER)	1	1	6.894	0.04%	0.28%	0.62%
Wheat (Bread)	DOGUSBELEN(CENTER)	1	1	4.285	0.03%	0.17%	0.28%

Orange (Other)		**70**	**125**	**1,245.742**	**7.67%**		
Orange (Other)	BEYOBASI(CENTER)	23	37	435.535	2.68%	34.96%	17.59%
Orange (Other)	KOYCEGIZ(CENTER)	9	16	180.816	1.11%	14.51%	11.81%
Orange (Other)	TOPARLAR(CENTER)	15	24	170.773	1.05%	13.71%	8.53%
Orange (Other)	DOGUSBELEN(CENTER)	6	18	160.891	0.99%	12.92%	10.34%
Orange (Other)	YANGI(CENTER)	4	10	110.243	0.68%	8.85%	10.43%
Orange (Other)	KAVAKARASI(CENTER)	4	5	91.456	0.56%	7.34%	6.05%
Orange (Other)	ZAFERLER(CENTER)	3	4	43.357	0.27%	3.48%	10.46%
Orange (Other)	HAMITKOY(CENTER)	5	6	32.554	0.20%	2.61%	2.92%
Orange (Other)	ZEYTINALANI(CENTER)	5	5	20.117	0.12%	1.61%	1.15%
Mandarin (Other)		**79**	**176**	**1,009.575**	**6.22%**		
Mandarin (Other)	TOPARLAR(CENTER)	39	98	552.775	3.41%	54.75%	27.62%
Mandarin (Other)	YANGI(CENTER)	12	24	132.870	0.82%	13.16%	12.57%
Mandarin (Other)	YESILKOY(CENTER)	4	17	86.420	0.53%	8.56%	31.53%
Mandarin (Other)	DOGUSBELEN(CENTER)	8	13	77.726	0.48%	7.70%	5.00%
Mandarin (Other)	ZEYTINALANI(CENTER)	10	14	74.536	0.46%	7.38%	4.26%
Mandarin (Other)	KAVAKARASI(CENTER)	3	4	37.966	0.23%	3.76%	2.51%
Mandarin (Other)	BEYOBASI(CENTER)	2	2	16.352	0.10%	1.62%	0.66%
Mandarin (Other)	KOYCEGIZ(CENTER)	2	2	15.700	0.10%	1.56%	1.03%
Mandarin (Other)	CENTER(CENTER)	1	1	10.600	0.07%	1.05%	8.53%
Mandarin (Other)	HAMITKOY(CENTER)	1	1	4.630	0.03%	0.46%	0.41%

Olive		**65**	**127**	**862.346**	**5.31%**		
Olive	ZEYTINALANI(CENTER)	34	52	374.566	2.31%	43.44%	21.40%
Olive	EKINCIK(CENTER)	7	38	178.538	1.10%	20.70%	69.66%
Olive	CANDIR(CENTER)	6	7	121.145	0.75%	14.05%	53.74%
Olive	YANGI(CENTER)	4	7	67.084	0.41%	7.78%	6.35%
Olive	BEYOBASI(CENTER)	2	2	30.971	0.19%	3.59%	1.25%
Olive	CAYHISAR(CENTER)	5	11	24.811	0.15%	2.88%	3.47%
Olive	TOPARLAR(CENTER)	1	2	23.550	0.15%	2.73%	1.18%
Olive	YESILKOY(CENTER)	3	3	21.919	0.14%	2.54%	8.00%
Olive	PINAR(CENTER)	2	2	8.920	0.05%	1.03%	6.51%
Olive	KARACAM(CENTER)	2	2	5.780	0.04%	0.67%	1.34%
Olive	SULTANIYE(CENTER)	1	1	5.062	0.03%	0.59%	12.43%
Corn (Silage)		**27**	**53**	**415.122**	**2.56%**		
Corn (Silage)	ZEYTINALANI(CENTER)	10	23	182.250	1.12%	43.90%	10.41%
Corn (Silage)	CAYHISAR(CENTER)	6	14	85.485	0.53%	20.59%	11.96%
Corn (Silage)	KOYCEGIZ(CENTER)	3	3	53.637	0.33%	12.92%	3.50%
Corn (Silage)	YANGI(CENTER)	3	6	33.007	0.20%	7.95%	3.12%
Corn (Silage)	PINAR(CENTER)	2	2	19.800	0.12%	4.77%	14.44%
Corn (Silage)	BEYOBASI(CENTER)	2	2	14.340	0.09%	3.45%	0.58%
Corn (Silage)	CANDIR(CENTER)	1	1	12.073	0.07%	2.91%	5.36%
Corn (Silage)	KAVAKARASI(CENTER)	1	1	10.000	0.06%	2.41%	0.66%
Corn (Silage)	HAMITKOY(CENTER)	1	1	4.530	0.03%	1.09%	0.41%

Corn (Grain)		**69**	**128**	**550.260**	**3.39%**		
Corn (Grain)	OTMANLAR(CENTER)	12	20	118.656	0.73%	21.56%	33.88%
Corn (Grain)	CAYHISAR(CENTER)	12	35	95.286	0.59%	17.32%	13.33%
Corn (Grain)	YANGI(CENTER)	12	15	74.467	0.46%	13.53%	7.04%
Corn (Grain)	ZEYTINALANI(CENTER)	10	18	68.200	0.42%	12.39%	3.90%
Corn (Grain)	BEYOBASI(CENTER)	14	16	68.036	0.42%	12.36%	2.75%
Corn (Grain)	DOGUSBELEN(CENTER)	3	7	61.018	0.38%	11.09%	3.92%
Corn (Grain)	YAYLA(CENTER)	3	6	38.430	0.24%	6.98%	45.18%
Corn (Grain)	PINAR(CENTER)	3	6	14.696	0.09%	2.67%	10.72%
Corn (Grain)	SAZAK(CENTER)	1	1	3.360	0.02%	0.61%	5.28%
Corn (Grain)	KAVAKARASI(CENTER)	1	1	3.053	0.02%	0.55%	0.20%
Corn (Grain)	DEMIRLI(CENTER)	1	1	2.120	0.01%	0.39%	1.88%
Corn (Grain)	ZAFERLER(CENTER)	1	1	1.568	0.01%	0.28%	0.38%
Corn (Grain)	KARACAM(CENTER)	1	1	1.370	0.01%	0.25%	0.32%
Pomegranate		**17**	**28**	**250.408**	**1.54%**		
Pomegranate	KAVAKARASI(CENTER)	6	11	111.139	0.68%	44.38%	7.35%
Pomegranate	CANDIR(CENTER)	1	3	48.640	0.30%	19.42%	21.58%
Pomegranate	BEYOBASI(CENTER)	3	4	30.247	0.19%	12.08%	1.22%
Pomegranate	KOYCEGIZ(CENTER)	1	1	26.000	0.16%	10.38%	1.70%
Pomegranate	TOPARLAR(CENTER)	3	5	21.058	0.13%	8.41%	1.05%
Pomegranate	CENTER(CENTER)	1	1	6.909	0.04%	2.76%	5.56%
Pomegranate	YANGI(CENTER)	2	2	3.715	0.02%	1.48%	0.35%
Pomegranate	ZAFERLER(CENTER)	1	1	2.700	0.02%	1.08%	0.65%

Sesame		**36**	**52**	**351.740**	**2.17%**		
Sesame	BEYOBASI(CENTER)	11	14	134.221	0.83%	38.16%	5.42%
Sesame	KAVAKARASI(CENTER)	9	11	79.467	0.49%	22.59%	5.26%
Sesame	TOPARLAR(CENTER)	2	2	32.410	0.20%	9.21%	1.62%
Sesame	YANGI(CENTER)	4	10	28.744	0.18%	8.17%	2.72%
Sesame	ZEYTINALANI(CENTER)	3	4	26.248	0.16%	7.46%	1.50%
Sesame	DEMIRLI(CENTER)	1	2	14.658	0.09%	4.17%	13.03%
Sesame	KOYCEGIZ(CENTER)	2	2	13.810	0.09%	3.93%	0.90%
Sesame	DOGUSBELEN(CENTER)	2	2	10.777	0.07%	3.06%	0.69%
Sesame	PINAR(CENTER)	2	2	4.580	0.03%	1.30%	3.34%
Sesame	CANDIR(CENTER)	1	1	4.455	0.03%	1.27%	1.98%
Sesame	CAYHISAR(CENTER)	1	2	2.370	0.01%	0.67%	0.33%
Vetch		**8**	**19**	**186.703**	**1.15%**		
Vetch	KOYCEGIZ(CENTER)	3	3	104.700	0.65%	56.08%	6.84%
Vetch	KAVAKARASI(CENTER)	2	2	45.000	0.28%	24.10%	2.98%
Vetch	CAYHISAR(CENTER)	1	4	21.343	0.13%	11.43%	2.99%
Vetch	TOPARLAR(CENTER)	1	3	5.611	0.03%	3.01%	0.28%
Vetch	BEYOBASI(CENTER)	1	5	5.154	0.03%	2.76%	0.21%
Vetch	EKINCIK(CENTER)	1	2	4.895	0.03%	2.62%	1.91%
Cotton		**9**	**20**	**286.569**	**1.77%**		
Cotton	KAVAKARASI(CENTER)	6	14	248.458	1.53%	86.70%	16.43%
Cotton	KOYCEGIZ(CENTER)	1	1	26.999	0.17%	9.42%	1.76%
Cotton	CAYHISAR(CENTER)	1	4	8.012	0.05%	2.80%	1.12%

Olive (Oil)		**18**	**21**	**184.622**	**1.14%**		
Olive (Oil)	BEYOBASI(CENTER)	2	2	47.964	0.30%	25.98%	1.94%
Olive (Oil)	ZEYTINALANI(CENTER)	5	6	47.564	0.29%	25.76%	2.72%
Olive (Oil)	YANGI(CENTER)	5	6	35.500	0.22%	19.23%	3.36%
Olive (Oil)	EKINCIK(CENTER)	2	2	26.000	0.16%	14.08%	10.14%
Olive (Oil)	YESILKOY(CENTER)	1	1	14.664	0.09%	7.94%	5.35%
Olive (Oil)	KARACAM(CENTER)	2	2	10.290	0.06%	5.57%	2.38%
Olive (Oil)	CAYHISAR(CENTER)	2	2	2.640	0.02%	1.43%	0.37%
Vegetable (Mixed)		**37**	**52**	**164.929**	**1.02%**		
Vegetable (Mixed)	YANGI(CENTER)	4	4	26.058	0.16%	15.80%	2.47%
Vegetable (Mixed)	DOGUSBELEN(CENTER)	1	1	25.000	0.15%	15.16%	1.61%
Vegetable (Mixed)	BEYOBASI(CENTER)	8	12	23.358	0.14%	14.16%	0.94%
Vegetable (Mixed)	CAYHISAR(CENTER)	5	10	18.198	0.11%	11.03%	2.55%
Vegetable (Mixed)	ZEYTINALANI(CENTER)	6	7	16.208	0.10%	9.83%	0.93%
Vegetable (Mixed)	KAVAKARASI(CENTER)	3	5	12.433	0.08%	7.54%	0.82%
Vegetable (Mixed)	SAZAK(CENTER)	2	3	10.670	0.07%	6.47%	16.75%
Vegetable (Mixed)	TOPARLAR(CENTER)	3	3	8.580	0.05%	5.20%	0.43%
Vegetable (Mixed)	EKINCIK(CENTER)	1	1	7.136	0.04%	4.33%	2.78%
Vegetable (Mixed)	PINAR(CENTER)	1	1	4.270	0.03%	2.59%	3.11%
Vegetable (Mixed)	YESILKOY(CENTER)	1	1	3.792	0.02%	2.30%	1.38%
Vegetable (Mixed)	OTMANLAR(CENTER)	1	2	3.626	0.02%	2.20%	1.04%
Vegetable (Mixed)	YAYLA(CENTER)	1	1	3.600	0.02%	2.18%	4.23%
Vegetable (Mixed)	KOYCEGIZ(CENTER)	1	1	2.000	0.01%	1.21%	0.13%

Barley		**15**	**36**	**98.028**	**0.60%**		
Barley	KARACAM(CENTER)	3	9	40.830	0.25%	41.65%	9.44%
Barley	CAYHISAR(CENTER)	6	16	28.389	0.17%	28.96%	3.97%
Barley	ZEYTINALANI(CENTER)	2	2	9.857	0.06%	10.06%	0.56%
Barley	OTMANLAR(CENTER)	2	4	8.616	0.05%	8.79%	2.46%
Barley	PINAR(CENTER)	2	3	5.456	0.03%	5.57%	3.98%
Barley	BEYOBASI(CENTER)	1	1	2.480	0.02%	2.53%	0.10%
Barley	YAYLA(CENTER)	1	1	2.400	0.01%	2.45%	2.82%
Oat		**13**	**13**	**80.423**	**0.50%**		
Oat	YANGI(CENTER)	3	3	34.490	0.21%	42.89%	3.26%
Oat	BEYOBASI(CENTER)	3	3	19.487	0.12%	24.23%	0.79%
Oat	ZEYTINALANI(CENTER)	2	2	13.208	0.08%	16.42%	0.75%
Oat	OTMANLAR(CENTER)	1	1	4.810	0.03%	5.98%	1.37%
Oat	CAYHISAR(CENTER)	1	1	3.200	0.02%	3.98%	0.45%
Oat	DEMIRLI(CENTER)	1	1	2.300	0.01%	2.86%	2.04%
Oat	KARACAM(CENTER)	1	1	1.570	0.01%	1.95%	0.36%
Oat	DOGUSBELEN(CENTER)	1	1	1.358	0.01%	1.69%	0.09%
Apple (Other)		**7**	**10**	**49.068**	**0.30%**		
Apple (Other)	OTMANLAR(CENTER)	1	3	20.951	0.13%	42.70%	5.98%
Apple (Other)	YAYLA(CENTER)	3	4	16.325	0.10%	33.27%	19.19%
Apple (Other)	CAYHISAR(CENTER)	2	2	10.792	0.07%	21.99%	1.51%
Apple (Other)	SAZAK(CENTER)	1	1	1.000	0.01%	2.04%	1.57%

Lemon		**9**	**9**	**59.282**	**0.37%**		
Lemon	BEYOBASI(CENTER)	3	3	15.381	0.09%	25.95%	0.62%
Lemon	KOYCEGIZ(CENTER)	1	1	12.617	0.08%	21.28%	0.82%
Lemon	CANDIR(CENTER)	2	2	11.807	0.07%	19.92%	5.24%
Lemon	CAYHISAR(CENTER)	1	1	9.160	0.06%	15.45%	1.28%
Lemon	KAVAKARASI(CENTER)	1	1	8.088	0.05%	13.64%	0.53%
Lemon	ZEYTINALANI(CENTER)	1	1	2.229	0.01%	3.76%	0.13%
Fruits (Mixed)		**4**	**4**	**30.987**	**0.19%**		
Fruits (Mixed)	BEYOBASI(CENTER)	1	1	19.475	0.12%	62.85%	0.79%
Fruits (Mixed)	YESILKOY(CENTER)	3	3	11.512	0.07%	37.15%	4.20%
Sorghum Hay		**2**	**3**	**29.663**	**0.18%**		
Sorghum Hay	DOGUSBELEN(CENTER)	1	1	14.075	0.09%	47.45%	0.90%
Sorghum Hay	TOPARLAR(CENTER)	1	1	10.650	0.07%	35.90%	0.53%
Sorghum Hay	BEYOBASI(CENTER)	1	1	4.938	0.03%	16.65%	0.20%
Tomato (green house)		**12**	**13**	**26.709**	**0.16%**		
Tomato (Green house)	CAYHISAR(CENTER)	2	3	8.370	0.05%	31.34%	1.17%
Tomato (Green house)	KOYCEGIZ(CENTER)	2	2	7.114	0.04%	26.64%	0.46%
Tomato (Green house)	KAVAKARASI(CENTER)	3	3	4.901	0.03%	18.35%	0.32%
Tomato (Green house)	ZEYTINALANI(CENTER)	2	2	3.050	0.02%	11.42%	0.17%
Tomato (Green house)	YANGI(CENTER)	1	1	1.542	0.01%	5.77%	0.15%
Tomato (Green house)	BEYOBASI(CENTER)	1	1	1.189	0.01%	4.45%	0.05%
Tomato (Green house)	CENTER(CENTER)	1	1	0.543	0.00%	2.03%	0.44%

Decoration plant		**1**	**4**	**41.984**	**0.26%**		
Decoration plant	TOPARLAR(CENTER)	1	4	41.984	0.26%	100.00%	2.10%
Corn		**5**	**9**	**36.438**	**0.22%**		
Corn	BEYOBASI(CENTER)	2	2	17.895	0.11%	49.11%	0.72%
Corn	OTMANLAR(CENTER)	2	6	9.976	0.06%	27.38%	2.85%
Corn	TOPARLAR(CENTER)	1	1	8.567	0.05%	23.51%	0.43%
Apple (Starking)		**1**	**3**	**20.840**	**0.13%**		
Apple (Starking)	CAYHISAR(CENTER)	1	3	20.840	0.13%	100.00%	2.92%
Bean		**3**	**4**	**15.504**	**0.10%**		
Bean	CAYHISAR(CENTER)	1	2	11.040	0.07%	71.21%	1.54%
Bean	ZEYTINALANI(CENTER)	2	2	4.464	0.03%	28.79%	0.26%
Melon		**2**	**2**	**9.931**	**0.06%**		
Melon	KOYCEGIZ(CENTER)	1	1	7.047	0.04%	70.96%	0.46%
Melon	CAYHISAR(CENTER)	1	1	2.884	0.02%	29.04%	0.40%
Plum		**3**	**3**	**8.882**	**0.05%**		
Plum	YAYLA(CENTER)	1	1	4.860	0.03%	54.72%	5.71%
Plum	CENTER(CENTER)	1	1	3.522	0.02%	39.65%	2.83%
Plum	YESILKOY(CENTER)	1	1	0.500	0.00%	5.63%	0.18%
Pepper (Green, banana)		**4**	**4**	**8.296**	**0.05%**		
Pepper (Green, banana)	BEYOBASI(CENTER)	2	2	4.600	0.03%	55.45%	0.19%
Pepper (Green, banana)	OTMANLAR(CENTER)	1	1	2.783	0.02%	33.55%	0.79%
Pepper (Green, banana)	KAVAKARASI(CENTER)	1	1	0.913	0.01%	11.01%	0.06%

Grapefruit		**1**	**1**	**8.050**	**0.05%**		
Grapefruit	ZAFERLER(CENTER)	1	1	8.050	0.05%	100.00%	1.94%
Tomato		**2**	**2**	**6.758**	**0.04%**		
Tomato	BEYOBASI(CENTER)	1	1	4.505	0.03%	66.66%	0.18%
Tomato	ZEYTINALANI(CENTER)	1	1	2.253	0.01%	33.34%	0.13%
Clover		**2**	**2**	**5.581**	**0.03%**		
Clover	CAYHISAR(CENTER)	1	1	3.840	0.02%	68.80%	0.54%
Clover	EKINCIK(CENTER)	1	1	1.741	0.01%	31.20%	0.68%
Eggplant		**2**	**2**	**4.587**	**0.03%**		
Eggplant	BEYOBASI(CENTER)	1	1	2.701	0.02%	58.88%	0.11%
Eggplant	CAYHISAR(CENTER)	1	1	1.886	0.01%	41.12%	0.26%
Walnut		**3**	**5**	**3.607**	**0.02%**		
Walnut	PINAR(CENTER)	1	3	2.457	0.02%	68.12%	1.79%
Walnut	SAZAK(CENTER)	1	1	0.890	0.01%	24.67%	1.40%
Walnut	CAYHISAR(CENTER)	1	1	0.260	0.00%	7.21%	0.04%
Bean		**1**	**1**	**3.162**	**0.02%**		
Bean	OTMANLAR(CENTER)	1	1	3.162	0.02%	100.00%	0.90%
Water Melon		**1**	**1**	**2.750**	**0.02%**		
Water Melon	CAYHISAR(CENTER)	1	1	2.750	0.02%	100.00%	0.38%
Green Bean		**1**	**1**	**2.085**	**0.01%**		
Green Bean	PINAR(CENTER)	1	1	2.085	0.01%	100.00%	1.52%
Olive		**1**	**1**	**1.870**	**0.01%**		
Olive	CAYHISAR(CENTER)	1	1	1.870	0.01%	100.00%	0.26%

Black-eyed pea		**1**	**1**	**0.820**	**0.01%**		
Black-eyed pea	KAVAKARASI(CENTER)	1	1	0.820	0.01%	100.00%	0.05%
Broad bean		**1**	**1**	**0.580**	**0.00%**		
Broad bean	CAYHISAR(CENTER)	1	1	0.580	0.00%	100.00%	0.08%
KOYCEGIZ TOTAL			2344	16,231.503			

APPENDIX E

Graphs Shows The Comparison of Simulated and Measured Flow Rate of the Namnam River

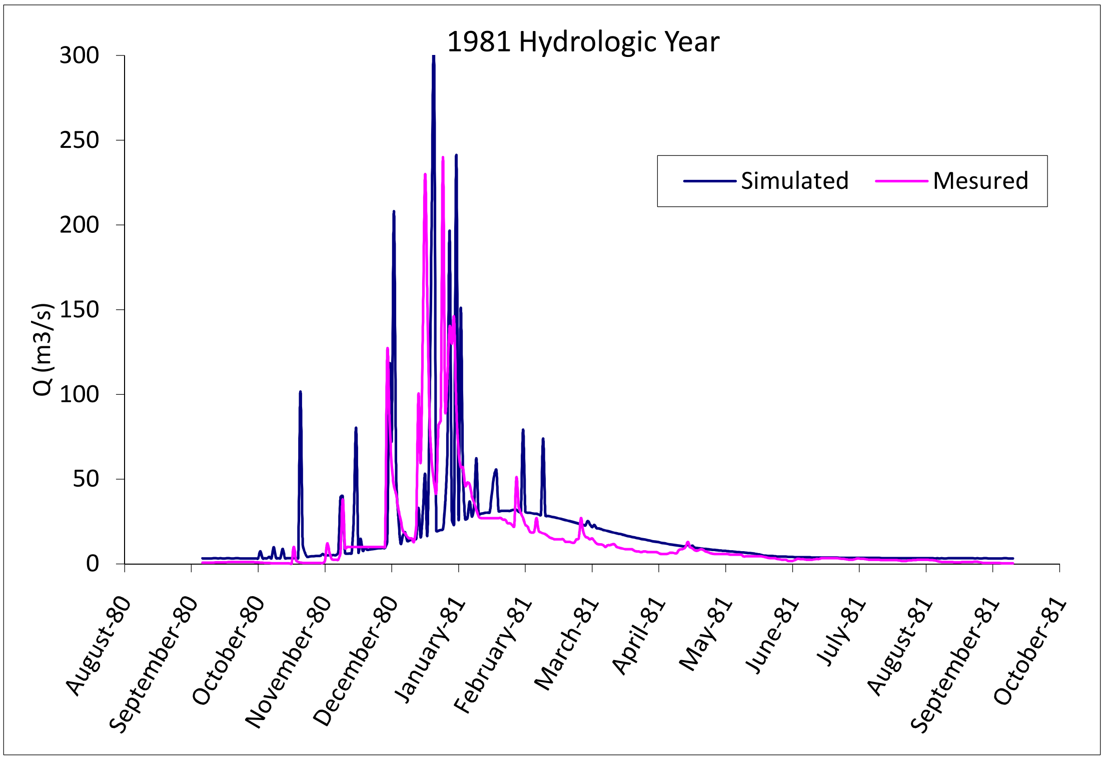

Figure E.1: Comparison of simulated and measured flow rate for 1981

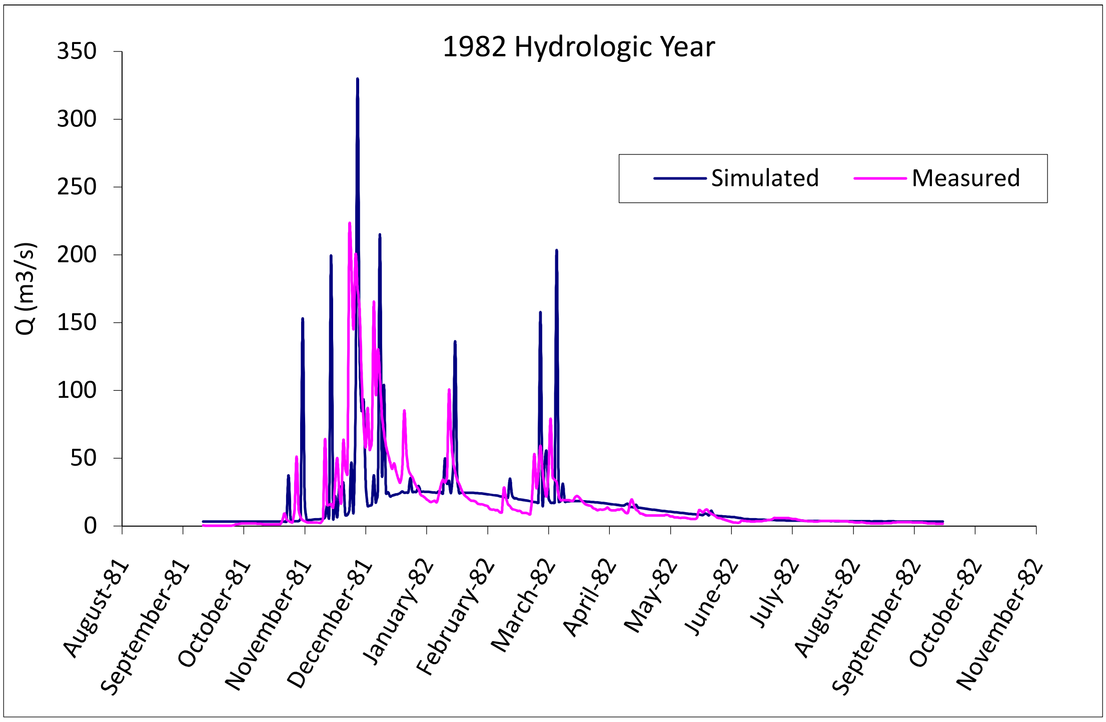

Figure E.2: Comparison of simulated and measured flow rate for 1982

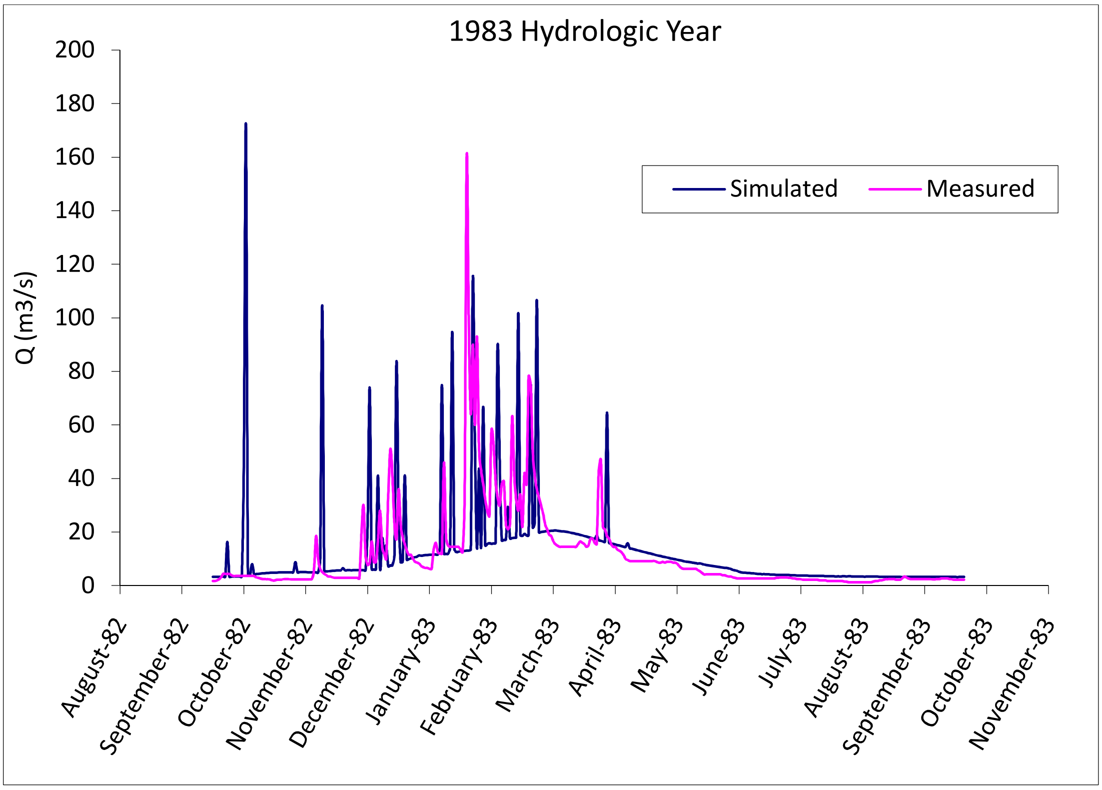

Figure E.3: Comparison of simulated and measured flow rate for 1983

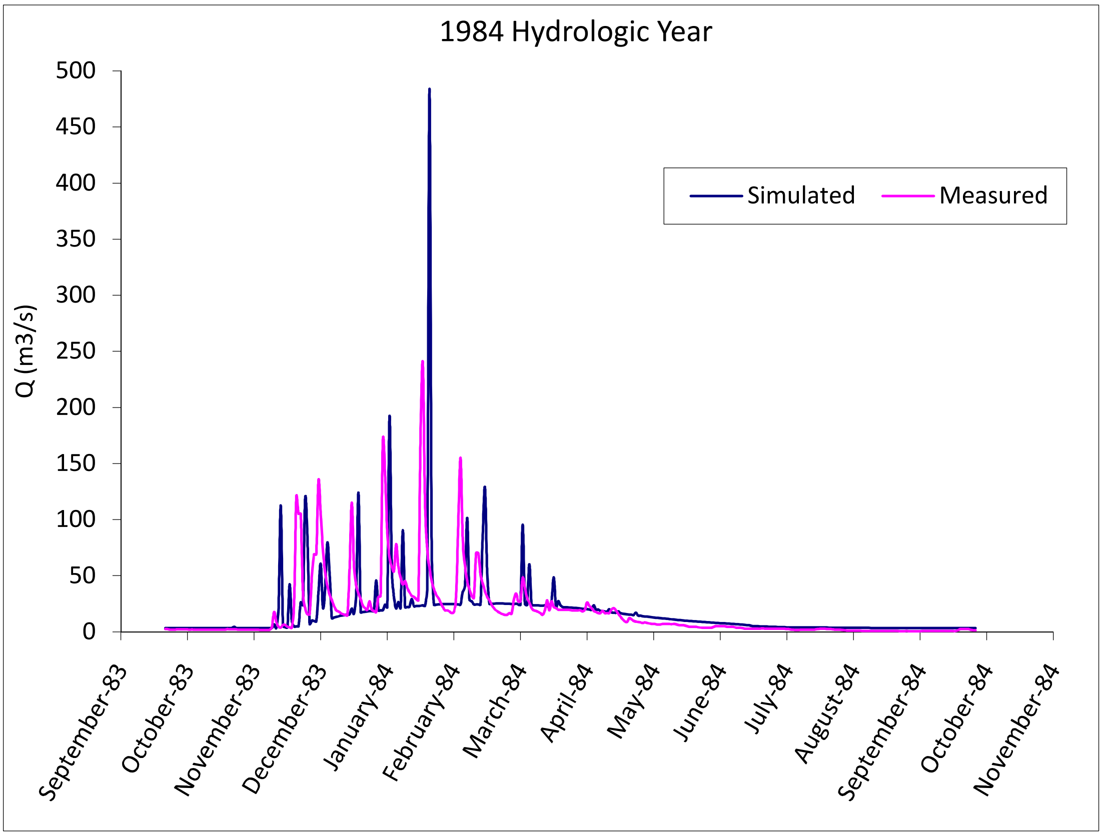

Figure E.4: Comparison of simulated and measured flow rate for 1984

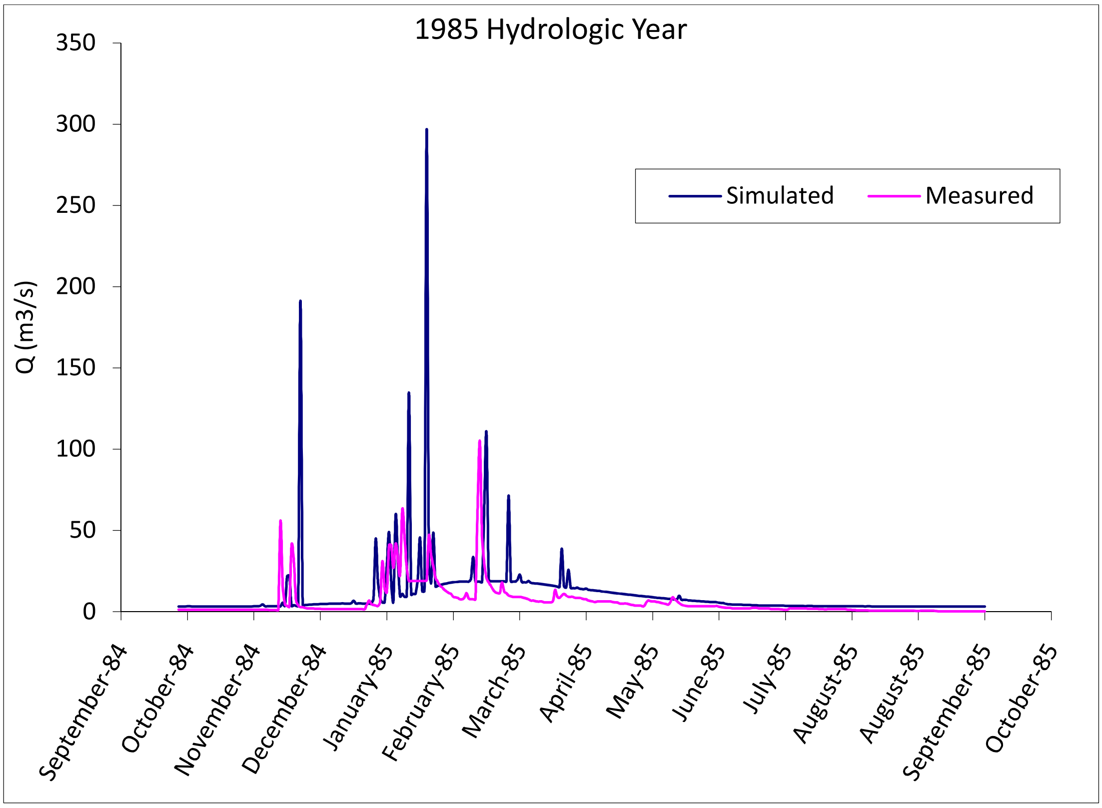

Figure E.5: Comparison of simulated and measured flow rate for 1985

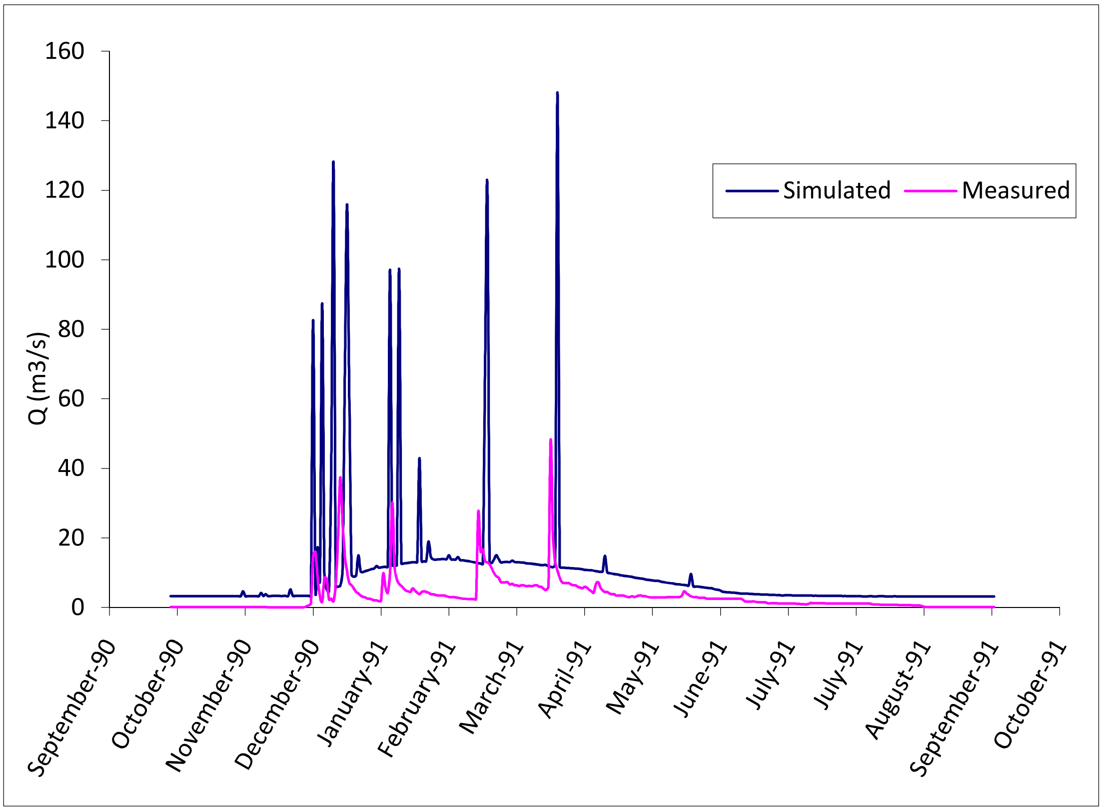

Figure E.6: Comparison of simulated and measured flow rate for 1991

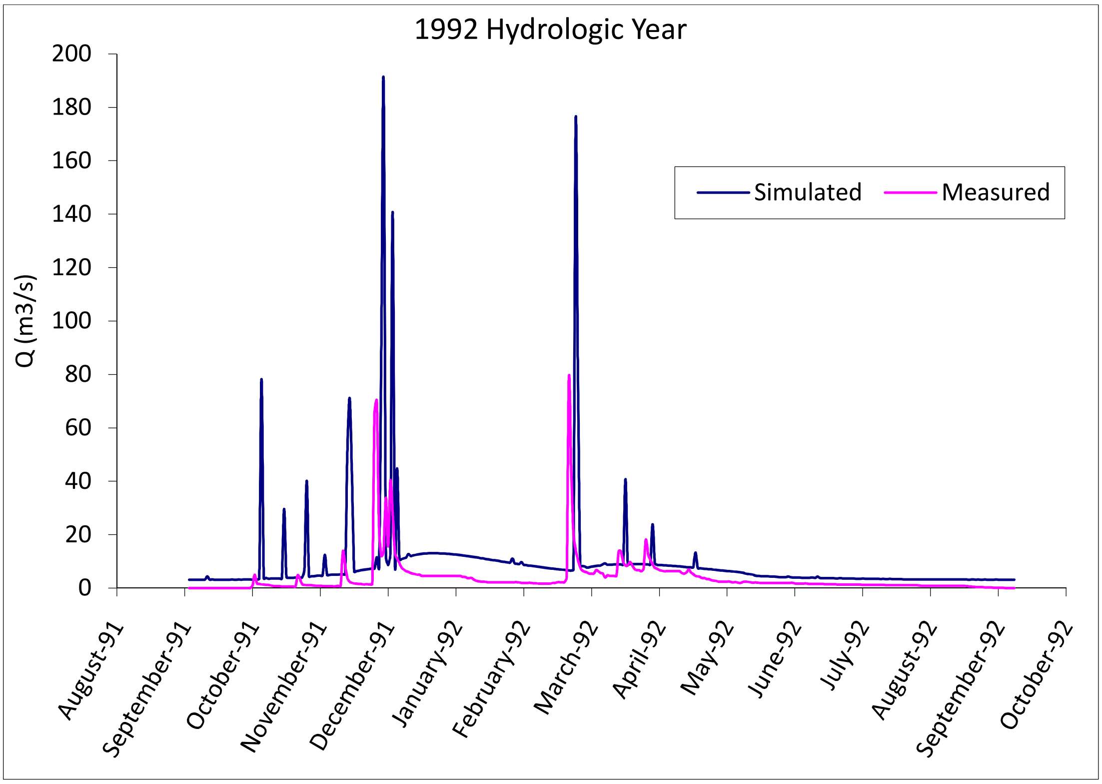

Figure E.7: Comparison of simulated and measured flow rate for 1992

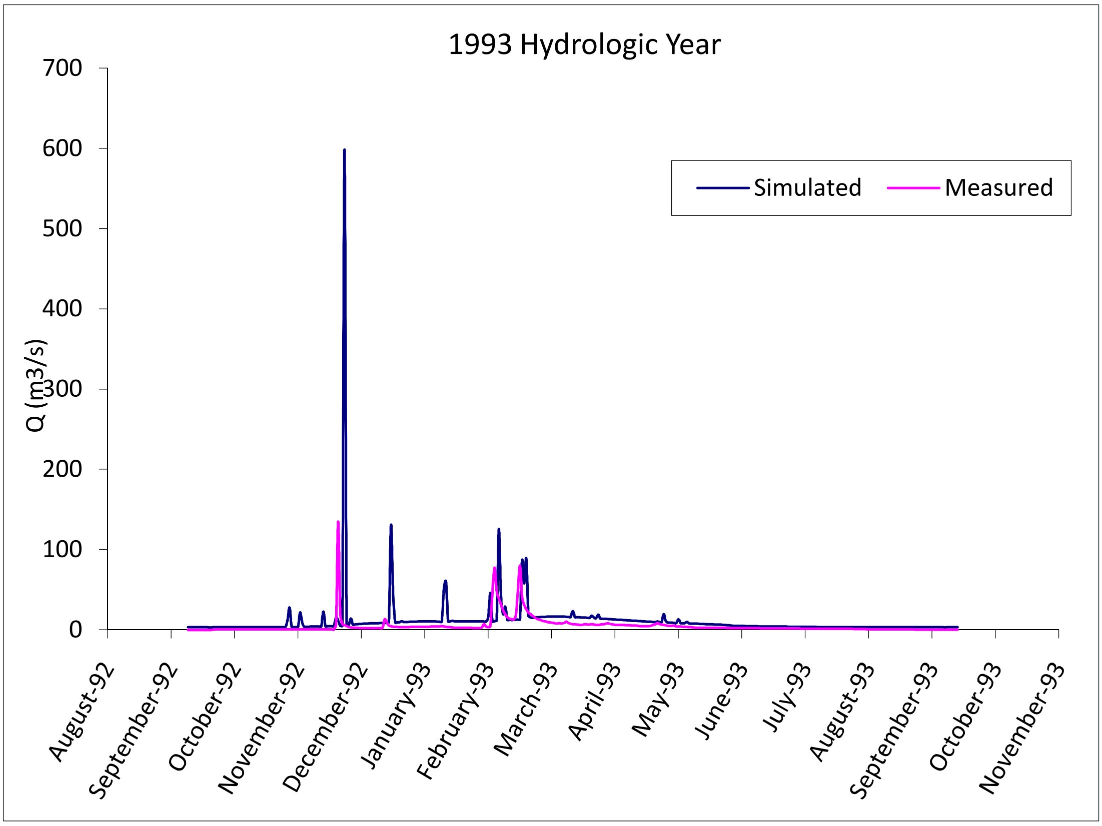

Figure E.8: Comparison of simulated and measured flow rate for 1993

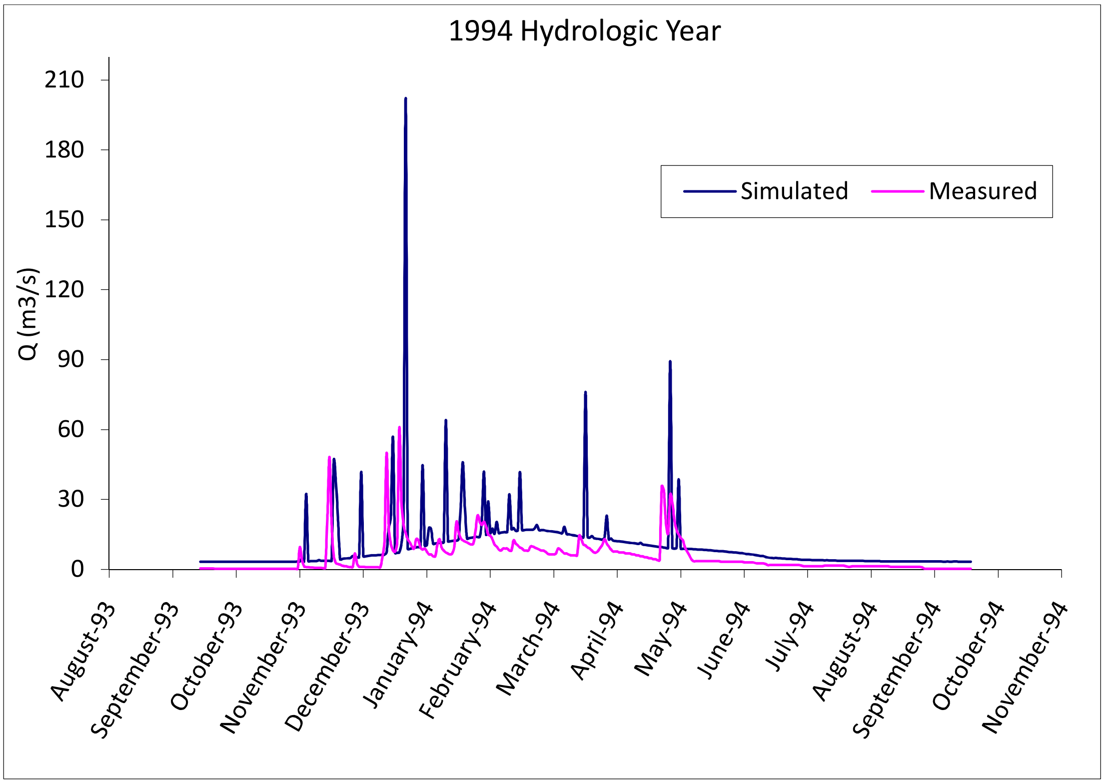

Figure E.9: Comparison of simulated and measured flow rate for 1994

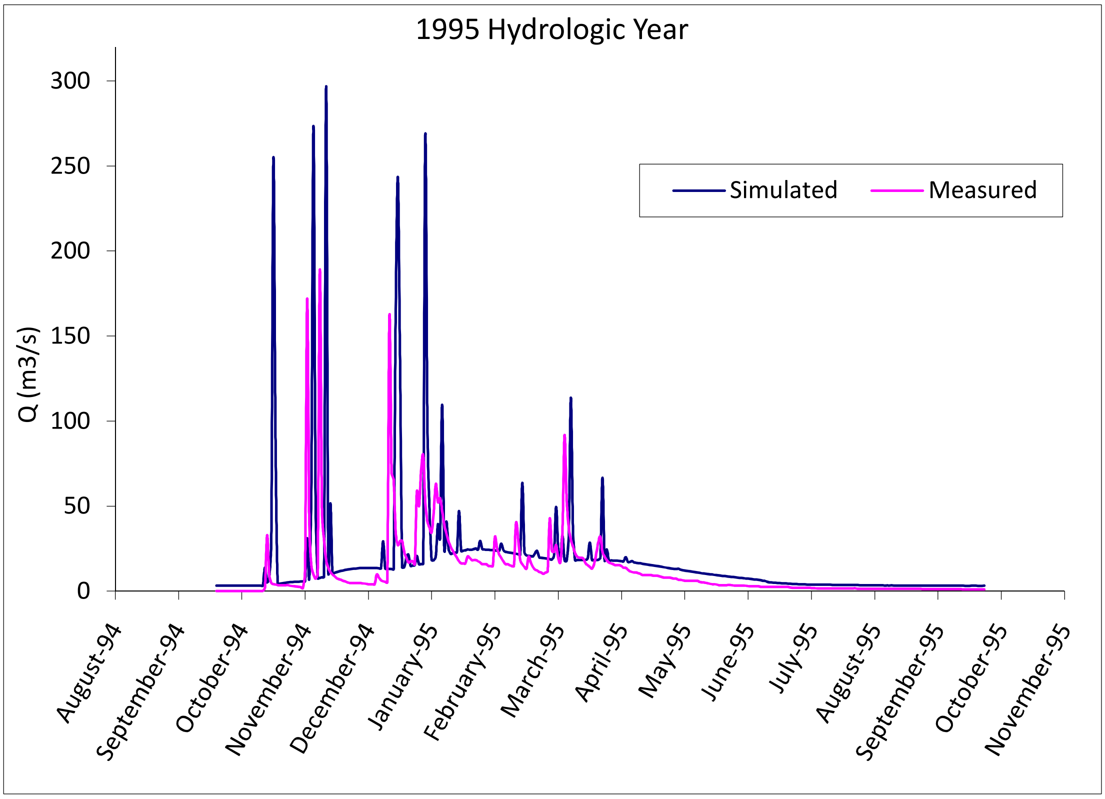

Figure E.10: Comparison of simulated and measured flow rate for 1995

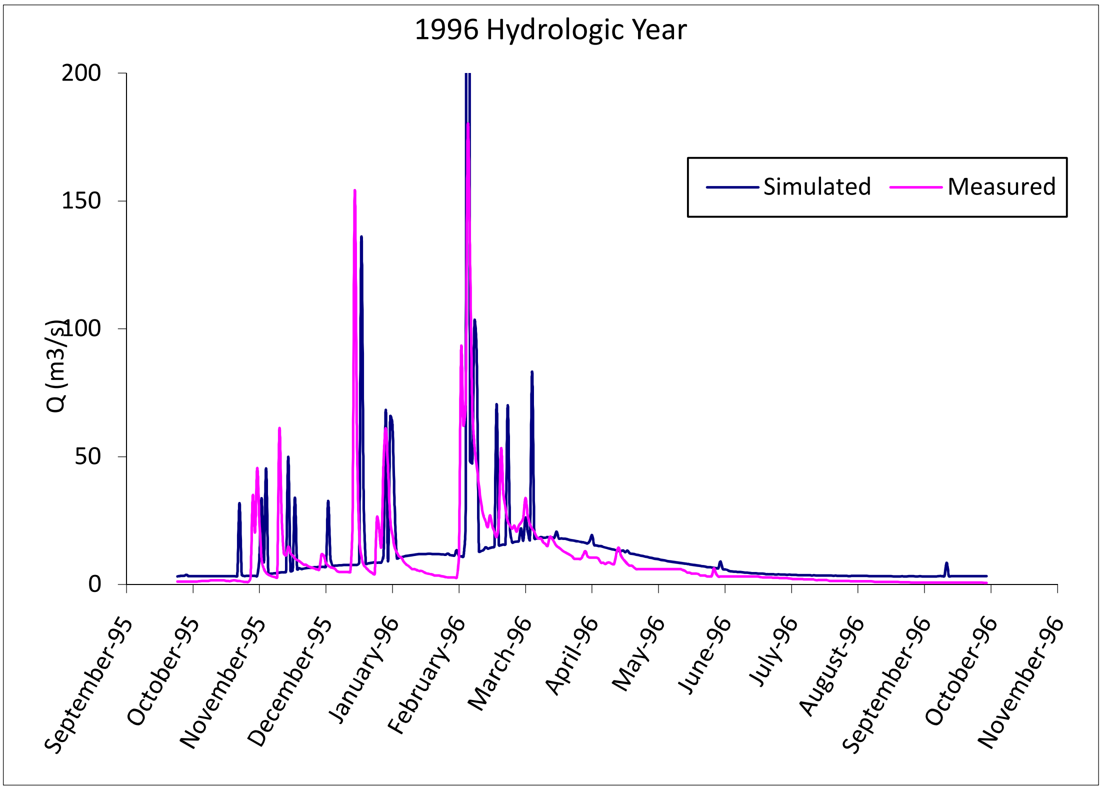

Figure E.11: Comparison of simulated and measured flow rate for 1996

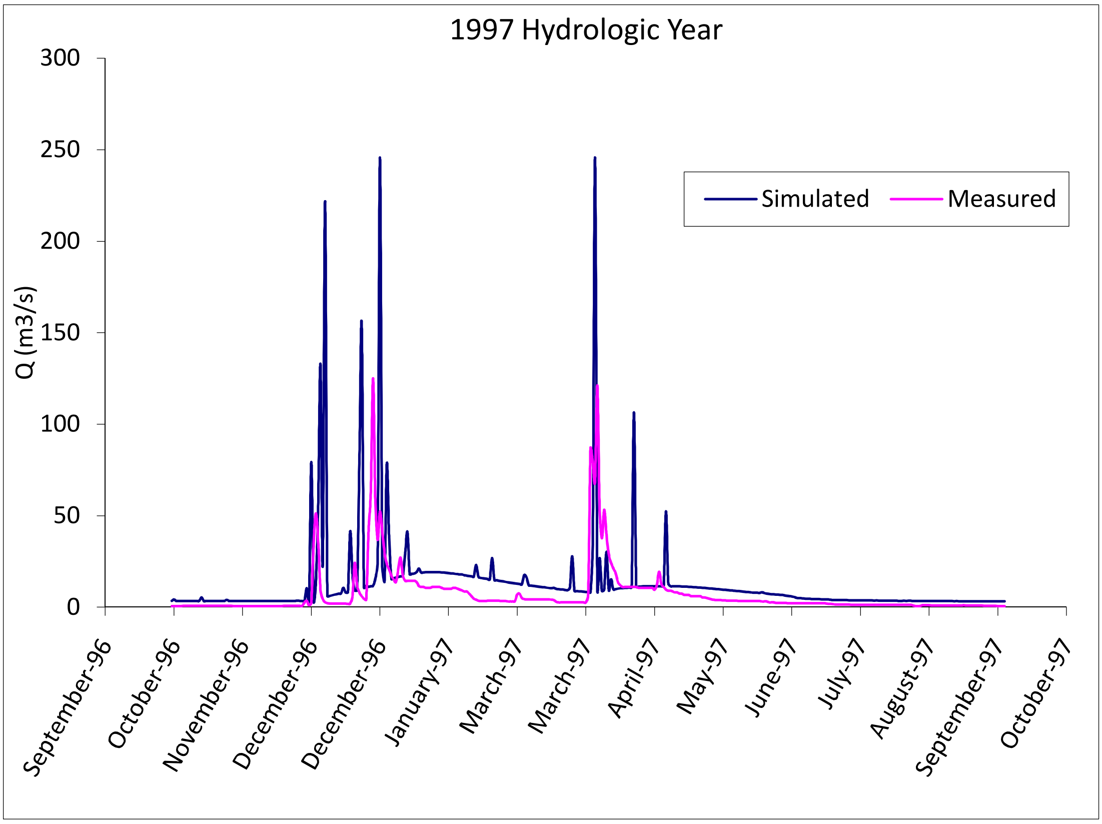

Figure E.12: Comparison of simulated and measured flow rate for 1997

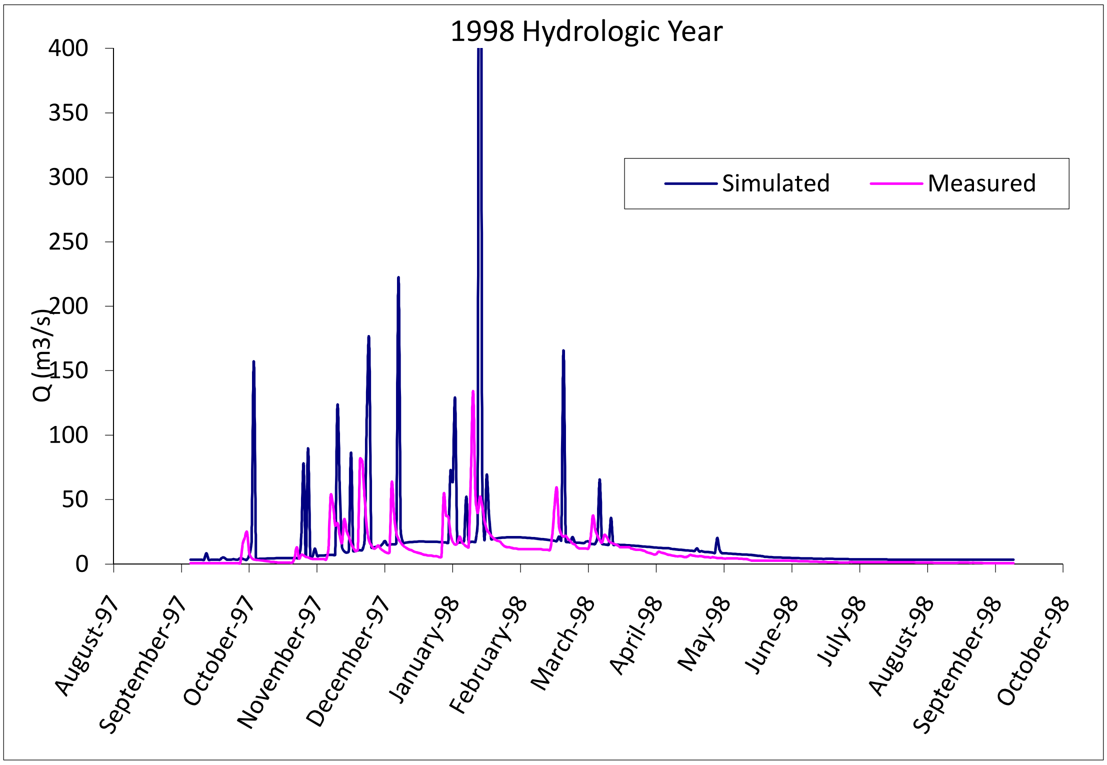

Figure E.13: Comparison of simulated and measured flow rate for 1998

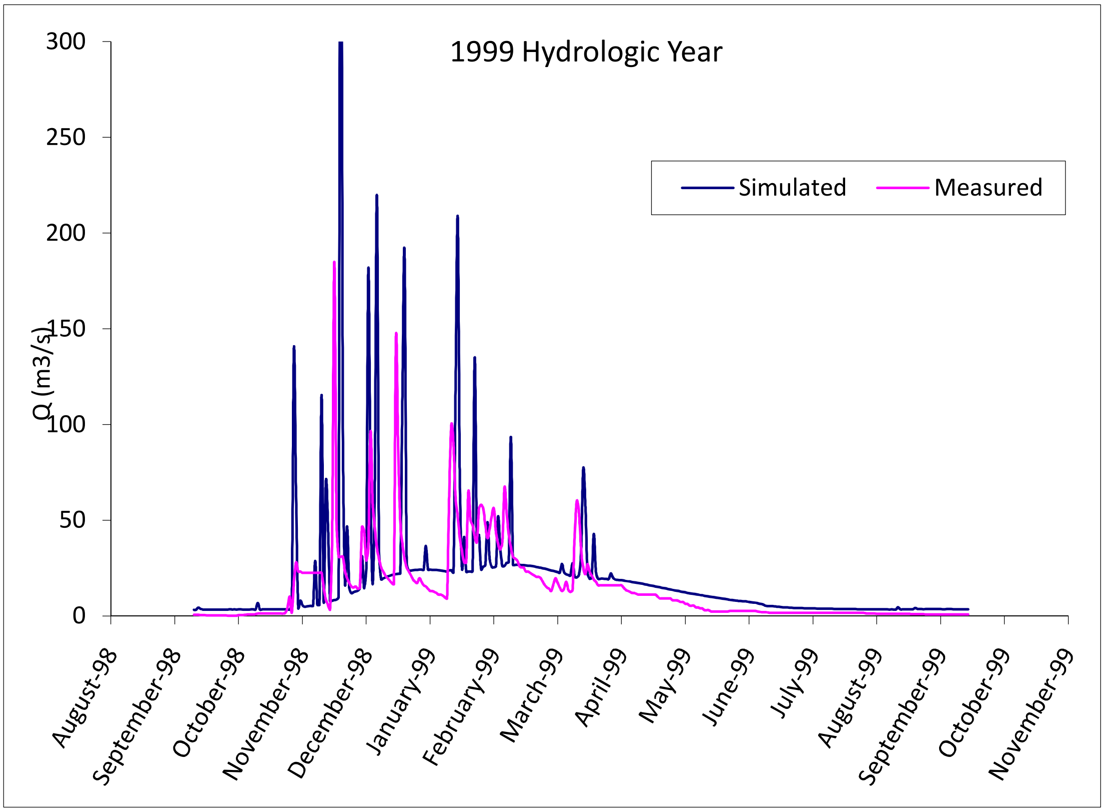

Figure E.14: Comparison of simulated and measured flow rate for 1999

CURRICULUM VITAE

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