INVESTIGATION OF NON-POINT SOURCE POLLUTION POTENTIAL IN THE WATERSHED OF PORSUK DAM RESERVOIR

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ELİF KÜÇÜK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ENVIRONMENTAL ENGINEERING

JUNE 2013

Approval of the thesis:

INVESTIGATION OF NON-POINT SOURCE POLLUTION POTENTIAL IN THE WATERSHED OF PORSUK DAM RESERVOIR

submitted by **ELİF KÜÇÜK** in partial fulfillment of the requirements for the degree of **Master of Science in Environmental Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen _____
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Faika Dilek Sanin _____
Head of Department, **Environmental Engineering**

Assoc. Prof. Dr. Ayşegül Aksoy _____
Supervisor, **Environmental Engineering Dept., METU**

Examining Committee Members:

Assist. Prof. Dr. Emre Alp _____
Environmental Engineering Dept., METU

Assoc. Prof. Dr. Ayşegül Aksoy _____
Environmental Engineering Dept., METU

Assoc. Prof. Dr. Elçin Kentel _____
Civil Engineering Dept., METU

Assist. Prof. Dr. Tuba Hande Ergüder _____
Environmental Engineering Dept., METU

Assist. Prof. Dr. Barış Kaymak _____
Environmental Engineering Dept., METU

Date: June 17, 2013

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all the material and results that are not original to this work.

Name, Last name: Elif Küçük

Signature:

ABSTRACT

INVESTIGATION OF NON-POINT SOURCE POLLUTION POTENTIAL IN THE WATERSHED OF PORSUK DAM RESERVOIR

Küçük, Elif
M.Sc., Department of Environmental Engineering
Supervisor: Assoc. Prof. Dr. Ayşegül Aksoy

June 2013, 177 pages

The achievement of good water quality status depends not only on point source control, but also on minimizing the contribution of non-point sources on pollution. Although non-point source pollution includes numerous components, agriculture has been considered as the primary activity responsible from deterioration in the quality of water resources. In this thesis, a hypothetical assessment was conducted to assess the relative impacts of different agricultural practices on the Watershed of the Porsuk Dam Reservoir (PDR). For this purpose, geographic information system (GIS) integrated Soil Water Assessment Tool (ArcSWAT2009) was used. Model performance was evaluated via Nash-Sutcliffe (NSE) and absolute percent deviation between simulated and observed yearly average flow values. Following manual calibration process, vulnerable areas for phosphorus transport were determined for ten different agricultural practice scenarios. These scenarios were developed to understand the effects of varying fertilizer and irrigation rates, land use changes and point source phosphorus loads on "soluble mineral forms of phosphorus transported by surface runoff into reaches" (SOLP). The most effective management scenario in terms of reduction in SOLP loads was determined as the combination of 50% and 20% decrease in fertilizer and irrigation rates, respectively. The corresponding decrease in the overall SOLP load to the PDR was calculated as 40%. In this scenario, mostly fertilizer reduction was effective in SOLP reduction. The most critical sub-basin that is responsible for the considerable SOLP load was determined. Moreover, other sub-basins which can be considered as the high concern areas within the watershed to control SOLP loads were identified.

Keywords: Non-point source pollution, SWAT, Porsuk Dam Reservoir, phosphorus, modeling

ÖZ

PORSUK BARAJ GÖLÜ HAVZASI'NDAKİ NOKTASAL KAYNAKLI OLMAYAN KİRLENME POTANSİYELİNİN ARAŞTIRILMASI

Küçük, Elif
Yüksek Lisans, Çevre Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Ayşegül Aksoy

Haziran 2013, 177 sayfa

İyi su kalitesi statüsüne ulaşılması sadece noktasal kaynakların kontrolüne değil aynı zamanda noktasal olmayan kaynakların kirliliğe olan katkısının en aza indirgenmesine de bağlıdır. Noktasal kaynaklı olmayan kirlilik çok sayıda bileşen içermesine rağmen, su kaynaklarının kalitesinin bozulmasında tarım ana faaliyet olarak kabul edilmiştir. Bu tezde farklı tarımsal uygulamaların Porsuk Baraj Gölü Havzası'ndaki göreceli etkilerini belirlemek için kuramsal bir çalışma yürütülmüştür. Bu amaçla coğrafi bilgi sistemi ile bütünleşmiş Soil Water Assessment Tool (ArcSWAT2009) kullanılmıştır. Model performansı Nash-Sutcliffe (NSE) ve ölçüm ve simülasyon akım sonuçları arasındaki mutlak yüzde değişim kullanılarak değerlendirilmiştir. Kalibrasyonu takiben, fosfor taşınımı yönünden hassas alanlar, on farklı tarımsal uygulama senaryoları için belirlenmiştir. Bu senaryolar değişen gübre ve sulama uygulama miktarlarının, arazi kullanımındaki değişikliklerin ve noktasal kaynaklı fosfor yükünün "yüzey akışı ile nehir kollarına taşınan çözünmüş mineral fosfor formuna" (ÇÖZP) olan etkilerini anlamak için geliştirilmiştir. ÇÖZP yükündeki azalma açısından en etkili senaryo, gübre ve sulama miktarlarının sırasıyla %50 ve %20 azaltıldığı kombinasyon olarak belirlenmiştir. Bu kombinasyona tekabül eden, Porsuk Baraj Gölü'ne taşınan toplam ÇÖZP yükündeki azalma %40 olarak hesaplanmıştır. Bu senaryoda, ÇÖZP yükündeki azalmada daha çok gübredeki azalma etkili olmuştur. Hatırı sayılır ölçüde ÇÖZP yükünden sorumlu, en kritik alt havza belirlenmiştir. Ayrıca, ÇÖZP yükünü kontrol etmek için önem arz eden alanlar olarak düşünülen diğer alt havzalar da belirlenmiştir.

Anahtar Kelimeler: Noktasal kaynaklı olmayan kirlilik, SWAT, Porsuk Baraj Gölü, fosfor, modelleme

To My Beloved Family

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following people for their tremendous help and support. Without their encouragement and guidance, I would never have been able to realize this work.

First and foremost, I would like to express my greatest appreciation to my thesis supervisor Assoc. Prof. Dr. Ayşegül Aksoy for her patience, unlimited support, enthusiasm, and valuable comments. I feel motivated and encouraged whenever I talk to her.

I would also like to thank to my committee members Assist. Prof. Dr. Emre Alp, Assoc. Prof. Dr. Elçin Kentel, Assist. Prof. Dr. Tuba Hande Ergüder and Assist Prof. Dr. Barış Kaymak for their encouragement, insightful comments and valuable suggestions.

I would like to extend my gratitude to the financial support from The Scientific and Technological Research Council of Turkey (TUBITAK) BIDEB without whose financial support this study would not be possible.

I would like to thank Firdes Yenilmez for introducing me to the SWAT as well for her precious assistance in the preparation and completion of this study. I would also like to thank Assist. Prof. Dr. Serdar Göncü, Ömer Güngör and Emre Hepgüneş for their help while working with ArcSWAT.

My thanks go as well to my best friend Pelin Deniz for her motivation, encouragement and especially for all the fun we have had in the last eight years. She was always there to cheer me up whenever I needed.

I would like to express my sincere gratitude to the people who give a magic touch to my life. Mayıs Kurt, Zeynep Malkaz, Şule Özkal, and Başak Utku, I am very grateful for your eternal friendship, moral support, and great contributions.

I am truly and deeply indebted to Ebru Koçak, Selcen Ak, İlker Balcılar, Selen Atiker, Çağatay Erşan, Güray Doğan and Nilüfer Ülgüdür for helping me in getting through tough times. I am so lucky to have met you.

I also thank to my colleagues Tolga Pilevneli and Onur Yüzügüllü for their support, motivation and encouragement.

Last but not the least, I send heartfelt thanks to my parents, Fatma and Ramazan Küçük and my brother, Afşın Küçük. They put faith in me all through my life and without their support and encouragement nothing would be possible. I am so glad that I have you.

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LIST OF ABBREVIATIONS

A	Alluvial Soils
AGNPS	Agricultural Non-point Source pollution model
AGRC	Agricultural Land-Close-Grown
AGRL	Agricultural Land-Generic
ALPHA_BF	Base-flow Alpha Factor
AMP	Peak Rate Adjustment Factor for Sediment Routing in the Sub-basin
ANION_EXCL	Fraction of Porosity from Which Anions Are Excluded
AnnAGNPS	Annualized Agricultural Non-point Source model
ANSWERS	Areal Non-point Source Watershed Environment Response Simulation
AOX	Adsorbable Organic Halogene
ArcSWAT	Geographic Information System Integrated Soil Water Assessment Tool
AWC	Available Water Capacity
B	Brown Earth Soils
BACTKDDB	Bacteria partition coefficient
BACTLPDB	Less-persistent bacteria concentration in manure/fertilizer
BACTPDB	Persistent bacteria concentration in manure/fertilizer
BIOMIX	Biological Mixing Efficiency
BLAI	Maximum potential leaf area index
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
C	Clay
CANMX	Maximum Canopy Storage
CASC2D	CASCade of planes in 2-Dimensions
CBOD	Carbonaceous Biochemical Oxygen Demand
CE	Chestnut Soils
CH_K(2)	Channel Effective Hydraulic Conductivity
CH_N(1)	Manning's n Value for the Tributaries
CH_N(2)	Manning's n Value for the Main Channel
CHESS	Climate Hydrochemistry and Economics of Surface-water Systems
CK	Bare Rock and Debris
CL	Clay Loam
CLAY	Clay Content
CMN	Rate Factor for Humus Mineralization of Active Organic Nutrients
CN2	Initial SCS Runoff Curve Number for Moisture Condition II
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems
CSAs	Critical Source Areas
D	Reddish Chestnut Soils
DEM	Digital Elevation Model
DEWPT	Average daily dew point temperature for each month or relative humidity
DO	Dissolved Oxygen
DWSM	Dynamic Watershed Simulation Model
ELEVATION	Elevation of Rain Gage
EPCO	Plant Uptake Compensation Factor
EPIC	Erosion Productivity Impact Calculator

ERORGP	Phosphorus Enrichment Ratio for Loading with Sediment
ESCO	Soil Evaporation Compensation Factor
ESWAT	Extended SWAT
ET	Evapotranspiration
EUROHARP	European Harmonized Procedures for Quantification of Nutrient Losses from Diffuse Sources
FERTNM	Fertilizer name
FMINN	Mineral nitrogen (NO_3 and NH_4) fraction in fertilizer
FMINP	Mineral phosphorus fraction in fertilizer
FNH3N	Mineral nitrogen fraction in fertilizer applied as ammonia
FORGN	Organic nitrogen fraction in fertilizer
FORGP	Organic phosphorus fraction in fertilizer
FRST	Forest Mixed
GIS	Geographic Information System
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GPS	Global Positioning Systems
GSSHA	Gridded Surface Hydrologic Analysis
GW_DELAY	Groundwater Delay Time
GW_REVAP	Groundwater Revap Coefficient
GWLF	Generalized Watershed Loading Function
GWQMN	Threshold Depth of Water in the Shallow Aquifer Required for Return Flow to Occur
H	Hydromorphic Soils
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HRUs	Hydrologic Response Units
HSPF	Hydrological Simulation Program – FORTRAN
HUMUS	Hydrologic Unit Modeling for the United States
HYDGRP	Soil Hydrologic Group
ID	Gage Identification Number
IFNUM	Fertilizer identification number
K	Colluvial Soils
KFI	Kütahya Fertilizer Industry
KINEROS2	KINematic runoff and EROSion
KWWTP	Kütahya Wastewater Treatment Plant
L	Loam
LH	Latin Hypercube
LS	Loamy Sand
LUCODE	Land Use Code
M	Brown Forest Soils
MIKE SHE	European Hydrological System model
MUSLE	Modified Universal Soil Loss Equation
N	Brown Forest without Lime Soils
NAME	Gage Name
NLAYERS	Number of Layers in Soil Profile
NO_3-N	Nitrate Nitrogen
NPERCO	Nitrate Percolation Coefficient
NSE	Nash-Sutcliffe efficiency
NSURQ	Nitrate transported with surface runoff into the reach
OAT	One factor At a Time
OECD	Organization of Economic Co-Operation and Development
PAST	Pasture
PBIAS	Percent Bias
PCPD	Average number of days of precipitation in month

PCPMM	Average or mean total monthly precipitation
PCPSKW	Skew coefficient for daily precipitation in month
PCPSTD	Standard deviation for daily precipitation in month
PDR	Porsuk Dam Reservoir
PET	Potential Evapotranspiration
PHOSKD	Phosphorus Soil Partitioning Coefficient
PPERCO	Phosphorus Percolation Coefficient
PR_W1	Probability of a wet day that follows a dry day in the month
PR_W2	Probability of a wet day that follows a wet day in the month
PRF	Peak Rate Adjustment Factor for Sediment Routing in the Main Channel
PRMS	Precipitation-Runoff Modeling System
PSP	Phosphorus Availability Index
QUAL2E	Enhanced Stream Water Quality Model
R^2	Coefficient of Determination
RAIN_YRS	The number of years of maximum monthly 0.5 h rainfall data used to define values for RAIN_HHMX(1)–RAIN_HHMX(12).
RAINHHMX	Maximum 0.5 hour rainfall in entire period of record for month
RCHRG_DP	Deep Aquifer Percolation Fraction
REVAPMN	Threshold Depth of Water in the Shallow Aquifer Required for Revap or Percolation to the Deep Aquifer to Occur
RNGE	Range-Grasses
ROCK	Rock Fragment Content
ROTO	Routing Outputs to Outlet
RSR	Root Mean Square Error to the Standard Deviation of Measured Data
S	Sand
SAND	Sand Content
SC	Sandy Clay
SCL	Sandy Clay Loam
SCODE	Soil Code
SCS	Soil Conservation Service
SFTMP	Snowfall temperature
SGBT	Sugar Beet
SHW	State Hydraulic Works
SI	Silt
SIC	Silty Clay
SICL	Silty Clay Loam
SIL	Silt Loam
SILT	Silt Content
SL	Sandy Loam
SLOPE	Average Slope Steepness
SLSUBBSN	Average Slope Length
SMFMN	Melt factor for snow on December 21
SMFMX	Melt factor for snow on June 21
SMTMP	Snow melt base temperature
SNAM	Soil Name
SOL_ALB	Moist Soil Albedo
SOL_AWC	Available Water Capacity of the Soil Layer
SOL_BD	Moist Bulk Density
SOL_CBN	Organic Carbon Content
SOL_CRK	Potential or Maximum Crack Volume of the Soil Profile Expressed as a Fraction of the Total Soil Volume
SOL_EC	Electrical Conductivity
SOL_K	Saturated Hydraulic Conductivity

SOLP	Soluble mineral forms of phosphorus transported by surface runoff into the reach
SOL_Z	Depth from Soil Surface to Bottom of Layer
SOL_ZMX	Maximum Rooting Depth of Soil Profile
SOLARAV	Average daily solar radiation for month
SPCON	Linear Parameter for Calculating the Maximum Amount of Sediment That Can Be Re-entrained During Channel Sediment Routing
SPEXP	Exponent Parameter for Calculating Sediment Re-entrained in Channel Sediment Routing
Station Name	Weather Station Name
SURLAG	Surface Runoff Lag Coefficient
SWAT	Soil Water Assessment Tool
SWDR	Soil Moisture Distribution and Routing model
SWIM	Soil and Water Integrated Model
SWMM	Storm Water Management Model
SWRRB	Simulator for Water Resources in Rural Basins
T	Temperature
TDS	Total Dissolved Solids
TEMPQSIM	Evaluation and improvement of water quality models for application to temporary waters in southern European catchments
TEXTURE	Texture of Soil Layer
TIMP	Snow pack temperature lag factor
TLAPS	Temperature lapse rate
TMDL	Total Maximum Daily Load
TMPMN	Average or mean daily minimum air temperature for month
TMPMX	Average or mean daily maximum air temperature for month
TMPSTDMN	Standard deviation for daily minimum air temperature in month
TMPSTDMX	Standard deviation for daily maximum air temperature in month
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
TUBITAK	The Scientific and Technological Research Council of Turkey
U	Brown Earth without Lime Soils
UBP	Phosphorus Uptake Distribution Parameter
UCOM	Commercial
UIDU	Industrial
UINS	Institutional
URHD	Residential-High Density
URLD	Residential-Low Density
US	United States
USDA	United States Department of Agriculture
USDAARS	United States Department of Agriculture Agricultural Research Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
USLE_K	USLE Equation Soil Erodibility Factor
UTM	Universal Transverse Mercator
WATR	Water
WELEV	Elevation of Weather Station
WEPP	Water Erosion Prediction Project
WETF	Wetlands-Forested
WETN	Wetlands-Non-Forested
WHO	World Health Organization

WLATITUDE	Latitude of Weather Station
WLONGITUDE	Longitude of Weather Station
WNDAV	Average daily wind speed in month
XPR	X Coordinate in the Defined Projection
Y	High Mountain Pasture Soils
YPR	Y Coordinate in the Defined Projection

CHAPTER 1

INTRODUCTION

Although all sources of pollution should be reduced to control water quality, currently only point source pollution can easily be brought under control by regulatory mechanisms effectively. Therefore, the relative importance of non-point source pollution in water quality management has increased. As a result, there is a continuous shift towards modeling, managing and monitoring of non-point source pollution to accomplish sustainable watershed management in water quality control studies (Zhang and Xu, 2011).

Even though non-point source pollution includes various components, agriculture has practically been considered as the primary activity responsible for the impairment in the quality of water resources and reduction in water availability (Chambers et al., 2012). United States Environmental Protection Agency (USEPA) (2007) stated that 45% of streams and rivers and 47% of lakes and reservoirs did not meet their functional requirements in the United States (US) in 2002. The main source of deterioration in the water quality in streams and rivers was found as agricultural production in the same study. Furthermore, USEPA (2009) claimed that water quality deterioration in 60% of the impaired rivers and 50% of the surveyed lakes resulted from agricultural activities. Main water quality problems associated with agricultural activities are due to erosion, salinization, nutrients and pesticide pollution (Zalidis et al., 2002). Moreover, agriculture has been thought as the most important leading cause of anthropogenic eutrophication which is a process occurring in an aquatic ecosystem due to the natural and artificial addition of nutrients, especially phosphorus and nitrogen. It is the major and widespread problem of freshwaters and growing problem for coastal waters and estuaries (Mason, 2002). For example, a program conducted in 1997 in the Chesapeake Bay which is the most productive and largest bay in the US revealed that main water quality concern of the Bay is eutrophication. Analyses done within the scope of the program showed that 68% of the nitrogen and 77% of the phosphorus reaching the Bay were attributed to non-point source pollution. Since agriculture creates a major pollution stress (Cestti et al., 2003), care should be taken in agricultural land use planning in order to better protect the water quality.

Non-point source pollution models play an important role in the specification of pollution transport processes, testing the effectiveness of the land use and management scenarios, and identification and prioritization of critical source areas (CSAs). CSAs are the areas within the watershed subjected to considerable and non-proportional pollutant loads. Features of the area including soil type, land use, slope, management, and closeness to streams have a significant impact on formation of the CSAs (White et al., 2009). These are considered as the high concern areas within the watershed to control non-point source pollution. White et al. (2009) compared the pollutant loads from agricultural CSAs and the average loads from

agricultural areas. They concluded that the former was responsible for more than four times greater pollutant loads than the latter. Pionke et al. (2000) aimed to assess the contribution of CSAs to the total pollution monitored in a relatively small watershed. Result of that study showed that 98% of the total sediment loss resulted from 6% of the watershed area and 11% of the area was responsible from the great majority of the phosphorus loads. Likewise, according to the result of the study conducted by White et al. (2009), 22% of the sediment and phosphorus loads from agricultural watershed were attributed to 5% of the watershed area. As can be seen, a relatively small area within a watershed can be responsible from the great majority of the pollutant loads. Therefore, studies conducted at the watershed scale should focus on these areas for an effective watershed management.

The Watershed of the PDR is located in the northeast region of Western Anatolia with a drainage area of 5104 km^2. The land use in the watershed is dominated by agriculture which covers 42% of the watershed area (AKS Consulting, 2010). Porsuk Dam, the most important structure in the watershed, is used for flood control, as domestic, industrial and drinking water supply, and to irrigate agricultural areas. However, water qualities of both the river and reservoir have been impaired by various domestic and industrial point sources and agricultural non-point sources. In a study conducted by State Hydraulic Works (SHW), it was seen that reservoir behaved as a hypertrophic water body based on the classification criteria specified by the Organization of Economic Co-operation and Development (OECD) (SHW, 2001). This situation was approved by the study carried out by Muhammetoğlu et al. (2005) and AKS Consulting (2011). The latter study showed that phosphorus is the limiting nutrient in the reservoir. One of the main contributors to phosphorus loadings in the watershed was determined as agricultural activities (AKS Consulting, 2011). Agricultural activities have become a significant threat for the water quality in the reservoir. However, within the scope of the Determination of Special Provisions for the Watershed of the PDR, non-point source pollution from agricultural activities was not considered due to the lack of data regarding the beginning and ending of the growing season, timing and amounts of fertilizer applications, pesticide and irrigation applications, crop management and rotation, and timing of tillage operations. With the inspiration drawn from that work, the main objectives of this study are to conduct a hypothetical assessment for non-point source pollution from agricultural activities in the Watershed of the PDR and to evaluate the relative impacts of different agricultural practices. For this purpose ArcSWAT2009 was used. SWAT is a physically based, distributed, continuous time, long-term, spatially explicit watershed scale model. The reason behind the model selection is that SWAT is the most preferred model for agricultural watersheds (Borah and Bera, 2003). Furthermore, it is capable of the identification and prioritization of critical areas within the watershed (Srinivasan et al., 1998; Ghebremichael et al., 2010; Ouyang et al., 2008). Besides, the model allows accounting for various land uses, irrigation alternatives, and crops. Since phosphorus is the pollutant of concern in this study with respect to eutrophication control, critical areas were determined in which care should be taken to prevent phosphorus transport. The results are expected to contribute to the integrated watershed management for the area.

CHAPTER 2

LITERATURE REVIEW & THEORETICAL BACKGROUND

2.1 Watershed Modeling

The challenge of understanding and managing water quality problems is growing. This challenge provides researchers with an opportunity for carrying out water quality assessment studies. Due to the difficulties in conducting field experiments, collection of long-term data for watersheds with mixed land uses and soil to associate water quality improvements to specific Best Management Practices (BMPs), and uncertainties in measured data, there has been a steady shift towards watershed-based modeling approach to assess watershed response to hydrologic inputs and land management, and effectiveness of BMPs (Gitau and Chaubey, 2010; Santhi et al., 2006). As it is well known, an area of land draining water, sediment and dissolved materials into a common outlet is called a watershed (Ji, 2008). Within a watershed, alterations in the climate, land use, soil, topography and geological conditions are experienced and watershed based modeling approach is able to take these alterations into account (Santhi et al., 2006). It can be concluded that integrated water management of large areas should be fulfilled with a watershed-based modeling approach.

In order to achieve the successful development and implementation of an integrated watershed plan and the control of pollutant loading to a stream, it is necessary to identify and characterize sources of pollution since there is a co-existence between point and non-point sources in the environment (Ongley et al., 2010). However, the pathways and temporal dynamics of them are rather different. For example, point source pollution can be considered as almost constant on a daily basis whereas non-point source pollution depends on the hydrologic cycle and agricultural practices (Salvetti et al., 2008). Furthermore, unlike point source pollution whose impact on water body is more critical during low flow conditions, non-point source pollution plays a critical role especially during or following storm events (Ji, 2008). Pollution characterization and quantification studies provide information regarding relative magnitude and impact of each source on in-stream water quality (USEPA, 2008).

The achievement of water quality standards depends not only on the control of point source pollution but also mostly on the control of the non-point source pollution. Unlike point source pollution, random and intermittent occurrence, complex mechanisms and processes, uncertain discharge channels and amounts, variable spatial and temporal pollution loads, and difficulties in monitoring, simulation and control are main challenges associated with the evaluation and control of non-point source pollution (Shen et al., 2012). Besides different characteristics, there is a significant difference in pollutant concentrations originating from point and non-point sources. Although each non-point source may not individually be

considered as a significant threat, in overall non-point sources have considerable adverse effects on water quality. Table 2.1 indicates the typical values of total nitrogen (TN) and total phosphorus (TP) concentrations resulting from point and non-point sources. Even though runoff from agricultural lands, runoff from urban areas, atmospheric deposition, and seepage from groundwater are classified as major non-point pollution sources, agriculture is considered as the leading one (Ji, 2008). It is quite difficult to simulate non-point source pollution because of its nature. However, non-point source pollution modeling can be important and demanded to attain sustainable management and conservation of natural resources within watersheds.

Table 2.1 Sources and concentrations of TN and TP resulting from point and non-point sources (FISRWG, 1998)

Sources	**Total Nitrogen (mg/L)**	**Total Phosphorus (mg/L)**
Urban runoff	3-10	0.2-1.7
Livestock operations	6-800	4-5
Atmosphere (wet deposition)	0.9	0.015
90% forest	0.06-0.19	0.006-0.012
50% forest	0.18-0.34	0.013-0.015
90% agriculture	0.77-5.04	0.085-0.104
Untreated wastewater	35	10
Treated wastewater	30	10

2.1.1 Non-point Source Pollution Modeling

Computer modeling has been considered as a major tool to evaluate and control non-point source pollution. Physically based and distributed watershed modeling approaches have been adopted widely for non-point source pollution modeling (White et al., 2010; Leon et al., 2001). In physically based modeling approach, the factors leading to spatial and temporal variations in non-point source pollution loads are considered (Ouyang et al., 2010). Furthermore, given that contributors of the non-point source pollution are distributed throughout a watershed, distributed modeling approach enables to locate them in a watershed (Leon et al., 2001).

Non-point source pollution models are able to identify the main source and migration path, estimate pollution load and their effects on receiving environment, and evaluate the effects of various land use and management alternatives for non-point sources and impacted watersheds (Shen et al., 2012). In other words, these models are capable of simulating precipitation, erosion, sediment and nutrients transported through surface runoff, processes to which non-point sources are subjected to and the estimation of the pollutant loadings at the outlet (Lai et al., 2011). In spite of these abilities, due to the aforementioned characteristics, it is hard to make predictions related to non-point source pollution; therefore, model simulations may not be precise as desired. In order to eliminate uncertainties, it may be more appropriate to prefer less complex models (Palmer, 2001).

The very first step in a modeling study is the model selection. Alternative models should be overviewed and compared in terms of their capabilities, advantages, drawbacks, performances, and contributions in different cases. This section provides an overview and comparison of commonly used non-point source pollution models that have varying complexity, resolution in time and space, and input data requirements. It can be claimed that the intended use of the model in parallel with the aim of the study, the resource and model limitations, expected accuracy, physical characteristics of the catchment, the requirement of scenario analysis as well as the quality, quantity, and availability of data should be taken into consideration when making a decision on the model selection (Schoumans et al., 2009; Borah and Bera, 2004).

There are numerous watershed scale hydrologic and non-point source pollution models that are available to assess the impact of alterations in land use, land cover, management practices, or climatic conditions on water resources and water quality at watershed scales. Based on the reviews provided by Singh and Woolhiser (2002), Borah and Bera (2003), Kalin and Hantush (2003), Singh and Frevert (2006), and Oogathoo (2006), it can be stated that the most commonly used watershed scale models are Agricultural Non-point Source pollution model (AGNPS)/ Annualized Agricultural Non-point Source model (AnnAGNPS), Areal Non-point Source Watershed Environment Response Simulation (ANSWERS/ANSWERS-2000), Gridded Surface Hydrologic Analysis (GSSHA)/ CASCade of planes in 2-Dimensions (CASC2D), Hydrologic Engineering Center's Hydrologic Modeling System (HEC- 1/HEC-HMS), Hydrological Simulation Program – FORTRAN (HSPF), KINematic runoff and EROSion (KINEROS2), the European Hydrological System model (MIKE SHE), Precipitation-Runoff Modeling System (PRMS), Water Erosion Prediction Project (WEPP), Dynamic Watershed Simulation Model (DWSM), and Soil and Water Assessment Tool (SWAT) (Daniel et al., 2011). Table A.1 and Table A.2 in Appendix A summarize some of the continuous and single event watershed scale hydrologic and non-point source pollution models with their components or capabilities, temporal scale, watershed representation, procedures to compute rainfall excess or water balance on overland planes, overland runoff, subsurface flow, channel runoff, reservoir flow, overland sediment, channel sediment, reservoir sediment, chemicals, and BMPs simulations. In addition, Shen et al. (2012) prepared an overview related to the agricultural non-point source pollution models that are used in China. Table 2.2 shows the advantages and disadvantages of these models.

Table 2.2 Agricultural non-point source pollution models that are commonly used in China (Shen et al., 2012)

Model	**Major modules of model**	**Advantages**	**Disadvantages**
AGNPS	Hydrology, erosion, sediment transportation, chemical transportation	Can simulate spatial distribution of soil erosion within the catchments and the impact of erosion on water quality; calculation process can be completed directly by computer	Distributed model, the simulation is based on the unit grid, requires a large number of input parameters. Application is restricted in some areas in which detailed information is lacking.
ANSWERS	Runoff, infiltration, sediment transportation, evapotranspiration	Predicted results of runoff and sediment are identical with observed data.	Erosion module is empirical to a great extent. Cannot simulate many sub-processes.
CREAMS	Hydrology, soil erosion, chemical transportation	Cannot only forecast single rainfall events, but also average value of long-term rainfall.	Cannot be used for larger-scale river basins. Cannot provide process information and lacks some simulation functions.
HSPF	Climate, hydrology, nutrients, sediment transportation, water quality	Can simulate the detailed processes of runoff formation. Good at continuous time steps. Predicted results are satisfactory	Detailed description of the lack of space. Many parameters are not suitable for areas lacking research based information.
SWAT	Climate, surface and underground runoff, soil type, sediment, nutrients, pesticides, vegetation growth, agriculture management	Considers the process of conflux and sediment confluence. Develops soil and water conservation modules combined with GIS. Easy to use.	Cannot be used to simulate single flood events. Need to modify database when used in different study areas.

In addition to the aforementioned models, statistical models are available for simulation of the impacts of non-point source pollution. Although data requirement and calibration time can be reduced with the application of statistical models, physically based models can represent the processes that take place in the watershed more accurately (Grizzetti et al., 2005).

SWAT is the most favorable model especially for agricultural and forest land uses with its ability of continuous simulation. It mainly bases on Simulator for Water Resources in Rural Basins (SWRRB). Moreover, it has the characteristics of Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS), Groundwater Loading Effects of

Agricultural Management Systems (GLEAMS), Erosion Productivity Impact Calculator (EPIC), and Routing Outputs to Outlet (ROTO) (Borah and Bera, 2003). In addition, if the focus of the study is not only water yield but also sediment and pollutant transport, and data is readily available, Vigerstol and Aukema (2011) recommended the use of SWAT. Jayakrishnan et al. (2005) declared that SWAT shows great potential when the consideration is to carry out analysis for watershed management and decision making in a reasonable time and acceptable costs. Ouyang et al. (2010) stated that SWAT is able to easily incorporate local weather variables, soil properties, topography, vegetation, and land management scenarios when compared to other non-point source pollution models**.** Moreover, Fiseha et al. (2012) selected SWAT for the estimation of the hydrological components in the Upper Tiber watershed because of its being public, simplicity in spatial data handling and wide applicability. Furthermore, Borah and Bera (2003) concluded that SWAT can be considered as the most practicable model if the aim is the long-term behavior of agricultural watersheds (Lam et al., 2010). Because of its availability, flexibility, computational efficiency, adaptability to different hydro-meteorological soil and land use conditions, and user-friendliness in terms of input data handling (Bekiaris et al., 2005; Lam et al., 2010). SWAT was selected as the simulation model in this study. Summary of the applications by SWAT based on the review carried out by Borah and Bera (2004) is given in Table B.1 in the Appendix B.

2.1.1.1 Soil Water Assessment Tool (SWAT)

SWAT is a physically based, distributed, continuous time, long-term, spatially explicit watershed-scale model. It was developed by Dr. Jeff Arnold at the United States Department of Agriculture Agricultural Research Service (USDAARS) Grassland, Soil, and Water Research Laboratory in Temple, Texas in the early 1990s to mainly simulate the impact of agricultural management practices on water, sediment, nutrient and agricultural chemical yields in large un-gaged basins (Zhang, 2005; Di Luzio et al., 2002; Arnold et al., 1998; Neitsch et al., 2002; Borah and Bera, 2003). The data and computation requirements of SWAT can be enormous and demanding because of its physical base, but geospatial technologies including GIS, global positioning systems (GPS), and remote sensing provide significant advances in data generation, preparation and management (Daniel et al., 2011). Spatial and temporal variations of an event with respect to fixed geographic entities can easily be analyzed by interfacing geospatial technologies with watershed models (Martin et al., 2005). Moreover, Gassman et al. (2007) declared that more accurate and efficient SWAT configurations can be attained with the development of GIS and other interfaces since they are able to simplify watershed discretization and parameter assignment by converting spatial environmental data into model inputs. The main parts of a GIS interface in SWAT are a pre-processor that enables to generate sub-basin topographic and input parameters, an editor, and a post-processor allowing for the display of graphical and tabular results (Martin et al., 2005). Use of temporally and spatially accurate input data enables to make more accurate recommendations. Cotter et al. (2003) performed a study to determine the effects of Digital Elevation Model (DEM), land use, and soil types in different spatial resolutions on the uncertainty of SWAT model outputs including flow, sediment, nitrate nitrogen (NO_3-N), and TP transport. That study revealed the desired minimum GIS data resolutions for DEM, land use, and soil data to obtain acceptable model results, which are given in Table 2.3. For

example, a change in DEM resolution may lead to a change in topographical characteristics because the lower the resolution, the flatter and more simple the terrain will be. As a result, model outputs especially related to quick flows are affected (Heuvelmans, 2005).

Table 2.3 Desired minimum GIS data resolutions to satisfy less than 10% output error (Cotter et al., 2003)

Output	**Minimum Input Data Resolution (m)**		
	DEM	**Land Use**	**Soils**
Flow	300	1000	1000
Sediment	30	30	500
NO_3-N	200	500	500
TP	30	300	500

High resolution information about agricultural activities and agricultural land use practices (i.e. length of the growing season, fertilizer application, irrigation techniques, etc.), enable obtaining more accurate SWAT simulations (USEPA, 2008; Vigerstol and Aukema, 2011). Moreover, representativeness of the input parameters and quality of DEM which was reported as the most critical input to the SWAT model by Cotter et al. (2003) and Di Luzio et al. (2005) have a significant impact on the prediction accuracy of SWAT (Pisinaras et al., 2010; Geza and McCray, 2008). Ndomba et al. (2008) claimed that the length of the simulation period has also an important effect on the reliability of the model result. That is, the longer the simulation period leads to more reliable results by providing better representation in climatic variation (Huevelmans, 2005). Bossa et al. (2012) intended to analyze the impacts of different soil mapping approaches and soil data aggregation on the sediment yield and hydrology via SWAT. In that study, it was revealed that soil mapping approaches and soil data aggregation have a significant influence on the model simulation.

The essential difference between SWAT and other physical models is the ability of SWAT to divide the watershed into sub-basins and hydrologic response units (HRUs) (Bekiaris et al., 2005). HRU is the smallest unit, having unique land use, soil and slope properties, to be able to compute hydrologic processes used for delineation of the watersheds. SWAT uses DEM for automatic delineation. Delineation process is achieved based on topography and user defined threshold drainage area. Threshold drainage area determines the number of sub-basins and the level of detail that is considered in the hydrologic analysis (Geza and McCray, 2008). Heuvelmans (2005), Mamillapalli et al. (1996) and Thieken et al. (1999) stated that the lower the threshold value for the drainage area, the better the model performance is, despite higher computational demand. The logic behind the subdivision of a watershed is to generate homogenous areas in terms of climatic conditions, soil, land use, slope, and management characteristics (Daniel et al., 2011; Pisinaras et al., 2010; Tuppad et al., 2010; Wang et al., 2010). Therefore, spatial heterogeneity can be overcome by this way. Furthermore, watershed characteristics containing land use distribution and diversity, locations of critical areas, gaging and water quality monitoring stations, physical features such as lakes, dams and point sources, changes in topography, soil type distribution, and areas in which different management practices can be implemented should also be taken into

account when dividing the watershed into sub-basins (USEPA, 2008). After estimation of the runoff, sediment, nutrient, pollutant, and pesticide loads for each HRU separately, the total runoff and loadings for the basin can be determined through aggregation (Lee et al., 2010; Abbaspour et al., 2007; Bharati and Jayakody, 2011; Bouraoui et al., 2005; Coffey et al., 2010; Yang et al., 2009; White et al., 2010; Jha et al., 2010).

Watershed delineation, HRU definition, locating weather stations, preparing and inputting data belonging to input parameters, editing SWAT databases, scenarios management, model execution, mapping, reporting and automatic calibration (if desired) are the main steps that are performed by SWAT. The basic input requirements of the model are digital elevation, land use, land cover, soil, climate, and hydrographic maps (Huang et al., 2009). In addition to the basic inputs, specifications regarding groundwater, water use, management, pond and stream water quality data, and simulation period are required for simulations (Setegn et al., 2010; Winchell et al., 2010). Moreover, there are databases integrated into SWAT that can be used to obtain climate, soils, and plant growth parameters. Although default values for several parameters are also available, using site-specific measured values increase model accuracy by providing improved watershed representation (Gitau and Chaubey, 2010). Aforementioned parameters and information related to the management techniques including the beginning and the ending of the crop growing season, timing and amounts of fertilizer application, pesticide and irrigation applications, and timing of tillage operations are kept in the look-up table of the model and necessary coefficients during simulation are automatically obtained from the database (Ongley et al., 2010).

It is crucial to confirm the hydrologic cycle simulated by model with the hydrologic cycle monitored within the watershed in order to obtain an accurate estimation in terms of the transport of nutrient, sediment, and pesticide because the leading mechanism is the water balance. On the other hand, climate conditions and land uses were found as the next most important factors since they affect the hydrologic cycle and runoff values (Li et al., 2012; IPCC, 2001).Water balance mechanism in SWAT within each HRU is given in Figure 2.1

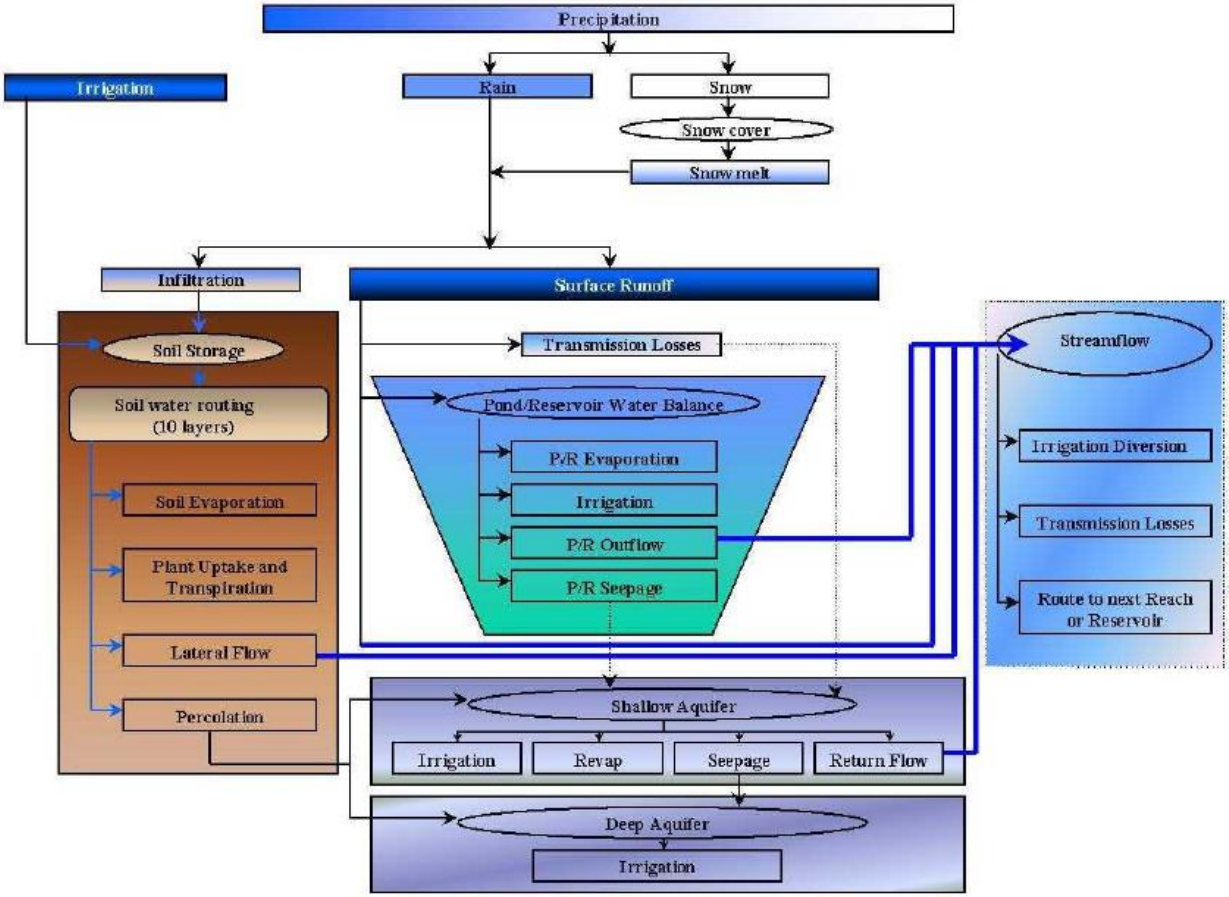


Figure 2.1 Water balance mechanism in SWAT (Neitsch et al., 2011)

In SWAT hydrologic cycle simulation is accomplished in two phases; land phase and routing phase. The former focuses on the amount of water, nutrient, pesticide and sediment loadings to the main channel in each sub-basin whereas the latter deals with the transport of them throughout the channel network of the watershed to the outlet. (Neitsch et al., 2011) Water balance equation, the basis of the land phase hydrologic cycle, is given in Equation 2.1 (Neitsch et al., 2011). Figure 2.2 describes the land phase of the hydrologic cycle adopted in SWAT schematically. As can be seen in Figure 2.2, hydrology covers the surface runoff, lateral subsurface flow, percolation, ground water flow, snowmelt, evapotranspiration (ET), transmission losses from streams, and losses resulting from ponds (Wang et al., 2010; Arnold and Fohrer, 2005; Gitau and Chaubey, 2010).

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

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of ET on day i (mm H_2O), w_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

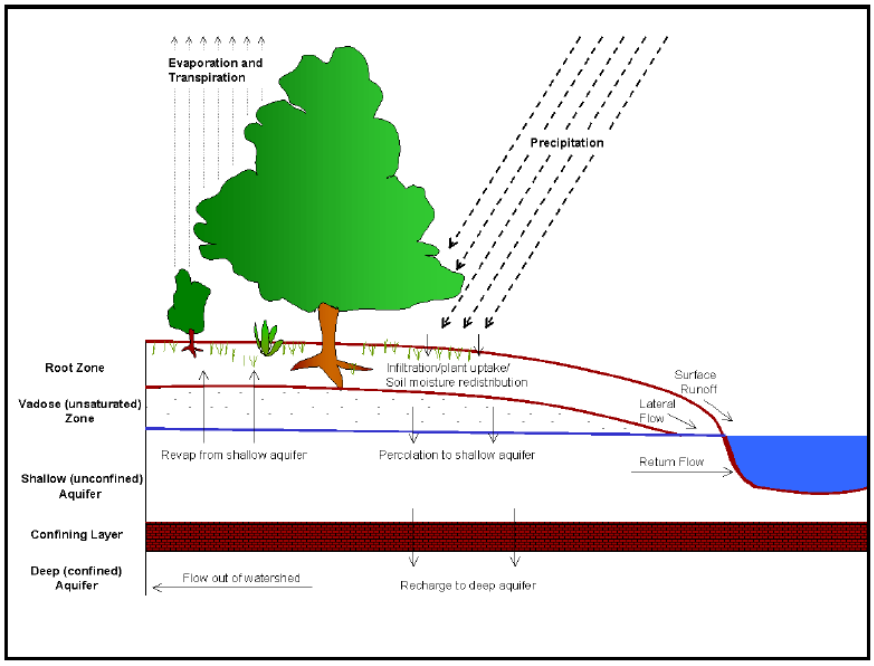


Figure 2.2 Schematic representation of the hydrologic cycle (Neitsch et al., 2011)

Surface runoff can be predicted by means of daily calculated Soil Conservation Service (SCS) curve number or hourly Green–Ampt infiltration method based on the temporal resolution of input rainfall data. The SCS curve number is commonly used and generally accepted method for the estimation of direct runoff volume for a given rainfall event due to its simplicity, comprehensibility and applicability (Soulis et al., 2009). This method is directly related to the permeability of soil, land use and soil water conditions which are the

main watershed characteristics responsible for the runoff formation (Neitsch et al., 2011). In addition to SCS curve number and Green–Ampt infiltration methods, modified Rational Formula can be used for the estimation of peak runoff (Abbaspour et al., 2007).

ET is the main water removal mechanism from a watershed. It is a general term that covers evaporation from the soil and plant canopy, transpiration and sublimation. ET can be estimated via Hargreaves, Priestley-Taylor or Penman-Monteith methods depending on data availability. Although data requirement of Penman-Monteith method is high, it is considered as the best (Heuvelmans, 2005). It requires air temperature, relative humidity, solar radiation and wind speed. Indeed, those are some of the parameters that are essential for SWAT simulations (Heathman et al., 2008; White et al., 2010; Lam et al., 2010). However, if some of those are missing, then one of Hargreaves and Priestley-Taylor methods which require less weather related data can be used.

Two main processes involved in sediment transport are deposition and degradation (Tripathi et al., 2005). Sediment and erosion yield are simulated within SWAT via Modified Universal Soil Loss Equation (MUSLE) whereas modification of Bagnold's sediment transport equation is used for channel sediment routing (Wang et al., 2010; Tripathi et al., 2005). MUSLE considers surface runoff, peak flow rate, soil erodibility, crop management, erosion control practice, length of slope, and steepness factors (Bouraoui et al., 2005). Besides sediment, movement and transformation of the complete cycle of nitrogen and phosphorus can be simulated via SWAT using the routines developed for the Enhanced Stream Water Quality Model (QUAL2E) (Gassman et al., 2007). SWAT can handle several forms of nitrogen and phosphorus including nitrate, soluble phosphorus, organic nitrogen, and organic phosphorus as nutrients sub-components in the sub-basin (Huang et al., 2009). Nutrient inputs that are considered in SWAT can be divided into two categories including natural sources like organic matter mineralization, bacteriological fixation, and wet deposition and anthropogenic sources. Anthropogenic sources can be further divided into two parts containing non-point sources (i.e. fertilizer, manure or residue application) and point sources (i.e. discharge from wastewater treatment plants) (Abbaspour et al., 2007; Ullrich and Volk, 2009- Neitsch et al., 2002; Lam et al., 2010). While the simulated nitrogen cycle contains ammonium and nitrate as the inorganic forms and fresh, stable, and active organic nitrogen, SWAT can track six different forms of phosphorus (Arnold and Fohrer, 2005; Ullrich and Volk, 2009). These are stable, active, and fresh organic phosphorus and stable, active, ad soluble inorganic phosphorus and main processes involved in phosphorus transport are runoff and erosion (Radcliffe at al., 2009). Nitrogen and phosphorus transformations modeled in SWAT are indicated in Figure 2.3 and Figure 2.4, respectively.

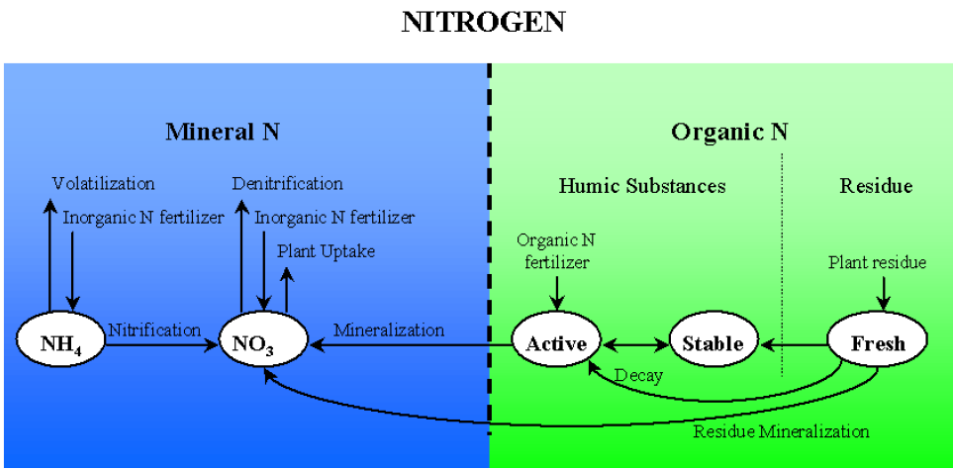


Figure 2.3 Nitrogen transformation simulated in SWAT (Neitsch et al., 2010)

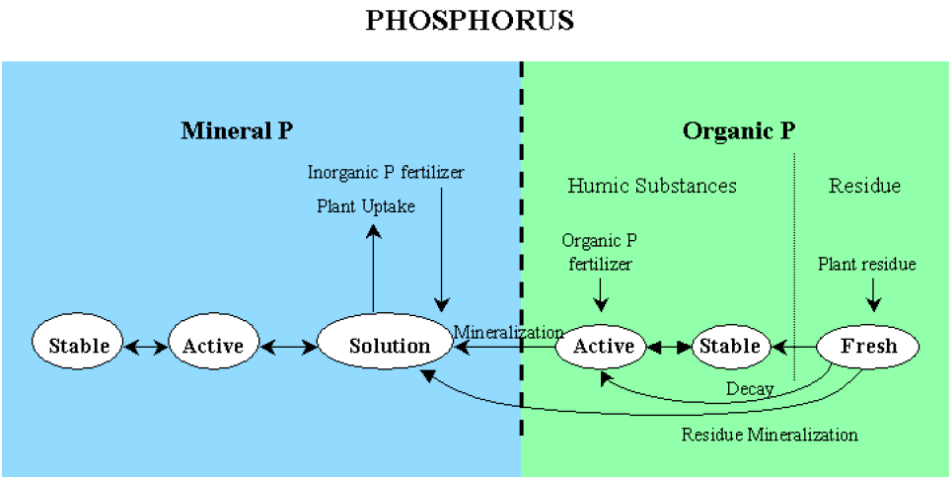


Figure 2.4 Phosphorus transformation simulated in SWAT (Neitsch et al., 2010)

Although pesticide simulation was not considered within the scope of this study, SWAT has also a pesticide module. The simulation of pesticide transport in SWAT is based on GLEAMS, one of the contributors to SWAT (Arnold et al., 1998). Instead of simulating the stress on plant growth due to the presence of weeds, insects, and other pests, SWAT concentrates on the movement of applied chemicals in the watershed (Neitsch et al., 2010). Moreover, this movement depends on the solubility and degradation half-life of the chemical and soil organic carbon adsorption coefficient (Neitsch et al., 2010). Fate of pesticide covers degradation, volatilization, leaching, accumulation on eroded sediment, and transport in surface runoff and sub-surface flow (Gassman et al., 2007). Figure 2.5 points out these pesticide transformation mechanisms simulated in SWAT.

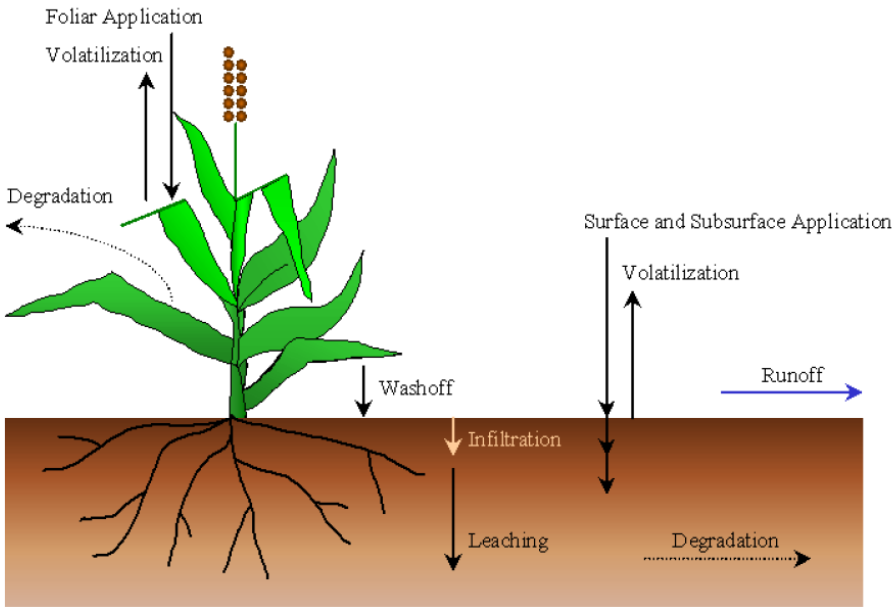


Figure 2.5 Pesticide transformation simulated within a SWAT sub-basin (Neitsch et al., 2010)

Sensitivity, calibration, validation, and uncertainty analysis confirmed by means of graphical and statistical procedures are crucial for the assessment of model simulation result (Gassman et al., 2007; Huang et al., 2009). The aim of sensitivity analysis is to determine the sensitivity of the outputs to variations in given input parameters. Sensitivity analysis can be performed via using different methods, but SWAT uses the combination of the Latin Hypercube (LH) and One factor At a Time (OAT) algorithm. Sensitive parameters identified by means of sensitivity analysis are commonly preferred as the calibration parameters. A logical order should be followed during parameter modification in order to reduce the impacts of correlation between model parameters and predicted outputs and uncertainty resulting from measurements (Madsen, 2003). The working principle of SWAT is to calibrate flow first. After that, sediment and various pollutants should be checked, respectively (Neitsch et al., 2002a, b; USEPA, 2008). Moreover, Meng et al. (2010) stated that the simulation accuracy is directly proportional with the number of stations that are used for calibration of the model. Frequently used parameters in model calibration are listed in Table 2.4 based on the comprehensive review conducted in literature.

Table 2.4 Calibration parameters used by SWAT modelers (White and Chaubey, 2005)

Output Variable	**Calibration Parameters**		
Flow	Maximum Canopy Storage (CANMX)[4] Soil Evaporation Compensation Factor (ESCO)[3,5,6] Soil Properties[1] Groundwater Parameters[5]	Crop Growth Routine[5] Revap Coefficient[2,3,4] Available Water Capacity (AWC)[6,7]	Curve Number[1,2,3,4,5,6,7] Soil Bulk Density[5] Plant Uptake Compensation Factor (EPCO)[3] Soil Hydraulic Conductivity[5]
Sediment	Peak Rate Adjustment Factor for Sediment Routing in the Sub-basin (AMP)[4] Manning's n Value for the Main Channel (CH_N2)[4] Average Slope Length (SLSUBBSN)[4] USLE Equation Soil Erodibility Factor (USLE_K)[4]	Channel Cover[5] MUSLE Parameters[5] Linear Parameter for Calculating the Maximum Amount of Sediment That Can Be Re-entrained During Channel Sediment Routing (SPCON)[3,4] Average Slope Steepness (SLOPE)[4]	Channel Erosion[5] Peak Rate Adjustment Factor for Sediment Routing in the Main Channel (PRF)[4] Exponent Parameter for Calculating Sediment Re-entrained in Channel Sediment Routing (SPEXP)[3,4] Manning's n Value for the Tributaries (CH_N1)[4]
TP	Fraction of Porosity from Which Anions Are Excluded (ANION_EXCL)[4] Phosphorus Percolation Coefficient (PPERCO)[3,4] Phosphorus Uptake Distribution Parameter (UBP)[4]	Phosphorus Enrichment Ratio for Loading with Sediment (ERORGP)[4] Phosphorus Availability Index (PSP)[4] Phosphorus Soil Partitioning Coefficient (PHOSKD)[3,4]	Initial Soil Concentration[3] Moist Bulk Density (SOL_BD)[4]
TN	Rate Factor for Humus Mineralization of Active Organic Nutrients (CMN)[5]	Initial Soil Concentration[3]	Nitrate Percolation Coefficient (NPERCO)[3,4]

[1]Arnold and Allen (1996), [2]Srinivasan et al. (1998), [3]Santhi et al. (2001b), [4]Cotter (2002), [5]Kirsch et al. (2002), [6]Arnold et al. (2000), [7]Arnold et al. (1999)

Moriasi et al. (2007) carried out a comprehensive review study concerning model application and recommended model evaluation methods. The model evaluation method selection criteria considered in that study were robustness in terms of applicability to various constituents, models, and climatic conditions, being commonly used, accepted, and recommended in the literature and identified strengths in model evaluation. Based on that review, it can be recommended that models can be evaluated by NSE, percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR) as well as the graphical techniques. In addition to these methods, coefficient of determination, objective functions, autocorrelation, cross-correlation, nonparametric tests and t-test were suggested by Arnold et al. (2012) for SWAT simulations. General performance ratings are given in Table 2.5. As can be seen in Table 2.5, PBIAS is constituent dependent whereas the same performance ratings for RSR and NSE can be used for all constituents.

Table 2.5 General performance ratings for recommended statistics for a monthly time step (Moriasi et al., 2007)

Performance Rating	**RSR**	**NSE**	**PBIAS (%)**		
			Stream flow	**Sediment**	**N, P**
Very good	0.00≤RSR≤0.50	0.75<NSE≤1.00	PBIAS<±10	PBIAS<±15	PBIAS<±25
Good	0.50≤RSR≤0.60	0.65<NSE≤0.75	±10≤PBIAS<±15	±15≤PBIAS<±30	±25≤PBIAS<±40
Satisfactory	0.60≤RSR≤0.70	0.50<NSE≤0.65	±15≤PBIAS<±25	±30≤PBIAS<±55	±40≤PBIAS<±70
Unsatisfactory	RSR>0.70	NSE≤0.50	PBIAS≥±25	PBIAS≥±55	PBIAS≥±70

Apart from sensitivity analysis and calibration, there are some uncertainties that are encountered when conducting modeling studies. These uncertainties can be related to the impacts of wetlands and reservoirs on hydrology and chemical transport, surface and groundwater interactions, occurrences of landslides, and large constructions such as roads, dams, tunnels and bridges, uncertain wastewater discharges into water streams from point sources, and undeclared fertilization, irrigation and water diversions, and other activities in the river flood plains such as agricultural activities and dumping of construction materials (Abbaspour et al., 2007).

2.1.1.1.1 Versions of SWAT

Williams et al. (2008) revealed that owing to continued review and expansion of capabilities, the previous versions of the model, SWAT94.2, 96.2, 98.1, 99.2, 2000, 2005, and 2009, are subjected to significant enhancements. First of all, multiple HRUs were included into the SWAT94.2 version. Then, auto-fertilization, auto-irrigation, canopy storage of water, addition of carbon dioxide (CO_2) component to crop growth model to simulate climate change, Penman-Monteith potential ET equation, lateral flow of water in the soil based on kinematic storage model, in-stream nutrient water quality equations from QUAL2E, and in-stream pesticide routing were incorporated into SWAT96.2. In this way, constituent interactions and relationships specified in the QUAL2E model containing nutrient cycle, algae production, and benthic oxygen demand are adopted by in-stream water quality algorithms of SWAT (Bekiaris et al., 2005; Lam et al., 2010). The enhancements made in SWAT98.1 version can be classified as improvements in the snowmelt routines and in-stream water quality, expansion of nutrient cycling routines, addition of grazing, manure applications, and tile flow drainage. After development of SWAT98.1, with the improvements made in nutrient cycling and rice/wetland routines and addition of reservoir/ pond/wetland nutrient removal by settling, bank storage of water in reach, routing of metals through reach, urban build-up/wash-off and regression equations specified by Storm Water Management Model (SWMM) and United States Geological Survey (USGS), respectively, SWAT99.2 was developed. SWAT2000 includes bacteria transport routines, Green &Ampt infiltration, Muskingum routing method, and modified dormancy calculations for proper simulation in tropical areas, improved weather generator and elevation band processes, revision of all potential evapotranspiration (PET) methods and simulation of unlimited number of reservoirs. Moreover, SWAT2000 is able to handle or generate daily solar radiation, relative humidity, and wind speed as well as capable of reading and calculation of PET values for watershed. On the other hand, bacteria component, potholes, curve number index method and auto-calibration, sensitivity, and uncertainty analysis component were

included into SWAT2005. Furthermore, soluble phosphorus transported was enabled through the soil profile via percolation, lateral flow, drainage system, and groundwater. In order to achieve more realistic interactions, SWAT2005 simulates forest growth throughout its entire life. There is also an improvement in the tile flow so as to model water table and drawdown resulting from tile drain (Williams et al., 2008; Gassman et al., 2007). SWAT2009 was developed with the improvements made in bacteria transport routines and wet and dry deposition of nitrate and ammonium, inclusion of weather forecast scenarios, and sub-daily precipitation generator, revision regarding vegetative strip model, and the modeling of on-site wastewater systems (Neitsch et al., 2010). In parallel with the historical development, some modified SWAT models like SWAT-G, Extended SWAT (ESWAT), and Soil and Water Integrated Model (SWIM) have been adapted (Zhang et al., 2011). Schematic diagram of historical development and aforementioned SWAT adaptations are pointed out in Figure 2.6.

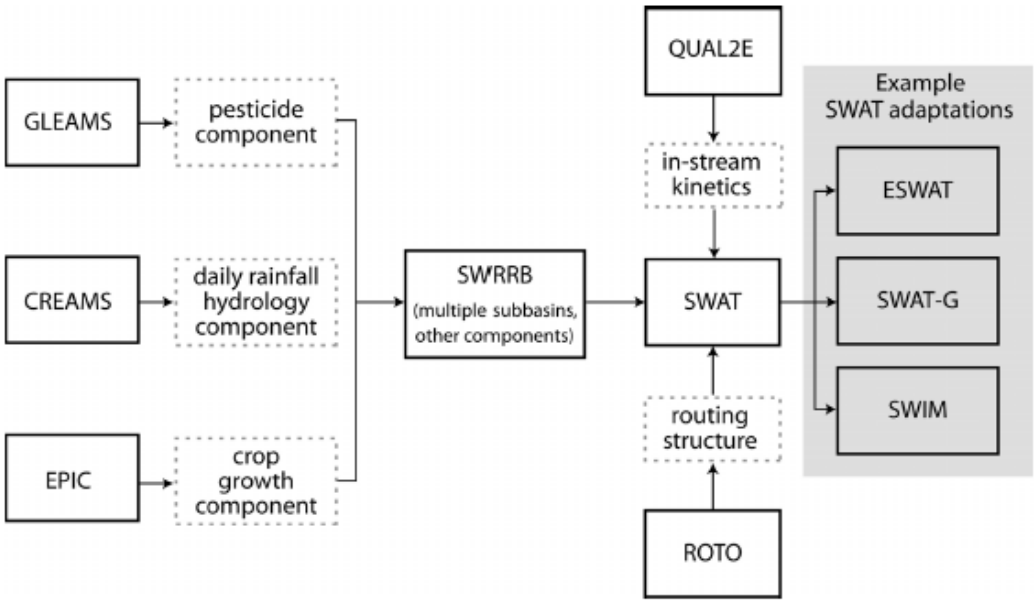


Figure 2.6 Schematic diagram of historical development and adaptations of SWAT (Gassman et al., 2007)

2.1.1.1.2 SWAT Applications

SWAT was a part of Hydrologic Unit Modeling for the United States (HUMUS) project which was conducted to model the hydrologic and pollutant loss effects of agricultural and municipal water use, tillage and cropping system trends, and other scenarios. Moreover, SWAT was used within the scope of United States Department of Agriculture (USDA) Conservation Effects Assessment Project carried out to measure the environmental benefits of conservation practices at both the national and watershed scales (Mausbach and Dedrick, 2004). Apart from the applications managed in US, SWAT has been used in Europe as well (Gassman et al., 2007). For example, SWAT was one of the models that used within the scope of Climate Hydrochemistry and Economics of Surface-water Systems (CHESS) project and European Harmonized Procedures for Quantification of Nutrient Losses from

Diffuse Sources (EUROHARP) project to determine climate change impacts on watersheds and evaluate whether the model was able to simulate non-point source nitrogen and phosphorus losses to freshwaters and coastal regions. Evaluation and improvement of water quality models for application to temporary waters in southern European catchments (TEMPQSIM) project also assesses the ability of SWAT to model intermittent stream conditions in southern Europe (Gassman et al., 2007). Overview of major application categories of SWAT studies in the literature, including applications of ESWAT, SWAT-G, SWIM, and other SWAT adaptations as well, are shown in Table 2.6.

Table 2.6 Overview of major application categories of SWAT studies (Gassman et al., 2007)

Primary Application Category	**Number of Studies**		
	Hydrologic Only	**Hydrologic and Pollutant Transport**	**Pollutant Transport Only**
Calibration and/or Sensitivity analysis	15	20	2
Climate change impact	22	8	-
GIS interface descriptions	3	3	2
Hydrologic assessments	42	-	-
Variation in configuration or data input effects	21	15	-
Comparisons with other models or techniques	5	7	1
Interface with other models	13	15	6
Pollutant assessments	-	57	6

2.1.1.1.3 Specific SWAT Applications

SWAT is preferable especially for the assessment of what-if scenarios and determination of critical areas in the watershed and making suggestion regarding BMPs (Srinivasan et al., 1998). As mentioned above, critical areas in the watershed can be either responsible for high amounts of runoff, soil and nutrient losses or subjected to considerable amount of non-proportional pollution. Therefore, instead of implementing watershed management programs for the whole watershed, it may be more reasonable to focus on the management of the critical areas within the watershed (Besalatpour et al., 2012). Ghebremichael et al. (2010) carried out a study concerning the identification and quantification of CSAs of phosphorous loss. In this study, CSAs were defined as the areas that are subjected to significant non-proportional losses. Moreover, leading causes of these significant non-proportional phosphorus losses were listed as runoff, erosion, soil types, and management practices (Pote et al., 1996, 1999; Sharpley, 1995; Sharpley et al., 1996; Pionke et al., 1997; Gburek and Sharpley, 1998). Ouyang et al. (2008) aimed to simulate non-point nutrient pollution with SWAT to determine the influence of the precipitation on pollution load, to identify critical pollution areas, and to recommend management alternatives. Both studies that are conducted by Ghebremichael et al. (2010) and Ouyang et al. (2008) concluded that SWAT can

successfully identify critical areas within the watershed. Niraula (2010) compared the effectiveness of SWAT and Generalized Watershed Loading Function (GWLF) for identification of CSAs. The CSAs capture efficiency of SWAT was found higher than that of GWLF in this study. Srinivasan et al. (2005) also used SWAT for the identification of CSAs in terms of runoff generation. In this study, they compared the results predicted by SWAT and Soil Moisture Distribution and Routing model (SWDR). It was understood that SWAT represents real situation better than SWDR (White et al., 2009). Tesfahunegn et al. (2012) identified critical areas in terms of erosion and tested management strategies for the control of runoff, sediment and soil nutrient losses using SWAT. It was concluded that SWAT can be favored in studying the most effective management alternatives to control soil degradation due to erosion.

Rosenberg et al. (1999), Chanasyk et al. (2003), Zhang et al. (2003), and Chen and Chen (2004) claimed that the basic applications of SWAT are flow and sediment transport simulations in large watersheds. The studies conducted by Chanasyk et al. (2003), Spruill et al. (2000) and Arnold et al. (2000) showed that flow and nutrient transport can be simulated in the watersheds ranging between 0.015 km^2 and 598,538 km^2 (White et al., 2010).

De Girolamo and Lo Porto (2012) aimed to identify the current status of water quality and develop land management alternatives via SWAT. The criteria that were taken into account during the evaluation of management alternatives were the impacts on water quality, crop yields, and economic benefits. In that study, rational use of fertilizers was recommended in order to control the surface water pollution resulting from non-point nutrients.

In addition to the aforementioned application areas, SWAT is able to assess ecosystem services, in-stream flows, flood risk and hydropower potential, to quantify climate change impacts and to determine Total Maximum Daily Load (TMDL) (Neitsch et al., 2004, 2005; Kusre et al., 2010; Gassman et al., 2005).

In the light of abovementioned information about SWAT, it can be deduced that SWAT can be considered as ideal for the simulation of agricultural catchments provided that the known rates of fertilizer and pesticides are applied and applications of different agricultural management practices are essential for meeting water quality standards (Zhang, 2005; Bulut, 2005).

CHAPTER 3

STUDY AREA

Watershed of the PDR is located in the northeast region of Inner Western Anatolia (Figure 3.1). It has the characteristics of Aegean, Marmara, and Central Anatolia Regions. It is also considered as a sub-basin of the Sakarya Watershed. It remains within the boundaries of five provinces including Kütahya, Eskişehir, Afyonkarahisar, Bilecik, and Uşak (Figure 3.2). On the other hand, residential districts that are included in the boundaries of the watershed are Eskişehir Merkez, Bozüyük, İnönü, Tavşanlı, Kütahya Merkez, Aslanapa, İhsaniye, Altıntaş, Gediz, Dumlupınar, Afyon Merkez, Banaz and Sinanpaşa (Figure 3.3). The drainage area of the watershed is 5104 km^2 (AKS Consulting, 2010).

Figure 3.1 Location of the PDR (GeoData, 2012)

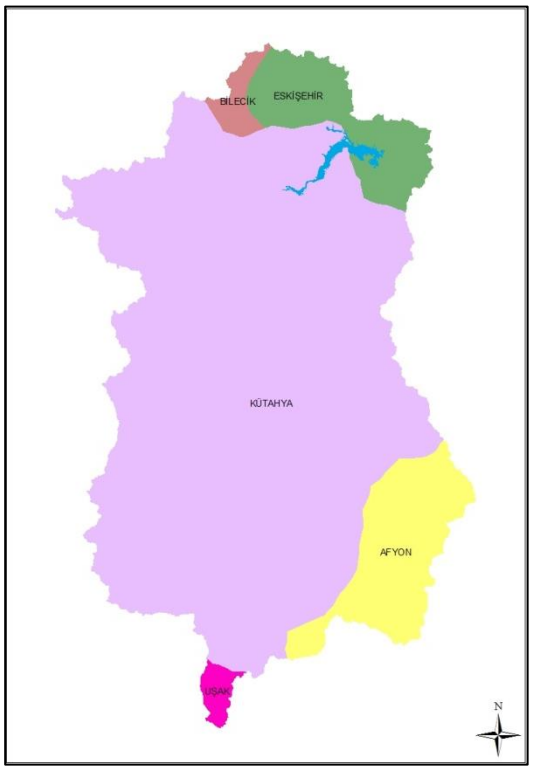


Figure 3.2 Provincial borders located within the Watershed of PDR

Figure 3.3 Districts borders located within the Watershed of PDR

The most important water structure in the watershed is the Porsuk Dam and its reservoir on the Porsuk River with a capacity of 525 million m^3 (Figure 3.1). The reservoir and the irrigation area served are 23.4 km^2 and 410.2 km^2, respectively (Semerci, 2006). The depth of water in the reservoir varies between 4.5 and 25 m (Bilge et al., 1997). All rivers in the basin, except the Kargın Creek, discharge into the PDR which was constructed to control flood and supply water for domestic and industrial usage and irrigation. PDR is the main drinking water resource of Eskişehir. It can be stated that Eskişehir is the most affected province by adverse water quality in the dam waters. Another purpose of the reservoir is to provide irrigation water for agricultural purposes in the watershed. In order to satisfy the annual domestic demand of Eskişehir, approximately 1.5 m^3/s of water release is required from the reservoir. Irrigation demand between May and September increases up to 10-20 m^3/s (Güngör and Göncü, 2012).

Porsuk River which is the main stream within the boundaries of the watershed is monitored by SHW and Electrical Power Resources Survey and Development Administration via stream gages and water quality monitoring stations (Albek, 2003). These monitoring studies concentrate on the three regions including Kütahya, PDR, and Eskişehir (Selki, 2008; Efelerli and Büyükerşen, 2008).

Besides water quantity, water qualities in both Porsuk River and dam reservoir are of concern. Water quality of both the river and reservoir have been deteriorated by several domestic and industrial point sources such as solid waste disposal site, Kütahya Sugar and Sugar-beet Factory, Kütahya Slaughterhouse, Kütahya Fertilizer Industry (KFI), Kütahya Magnesite Industry, and Seyitömer Thermal Power Plant and land-based non-point source pollution including mainly agriculture and aquifers composed of metalliferous rocks (Kavaf and Nalbantcilar, 2007).

3.1 Climate

The Watershed of PDR has the characteristics of both temperate and continental climate. Precipitation is mostly observed during winter and spring since the Central Anatolian precipitation regime is dominant. While the coldest month is January, the hottest months are July and August. The Kütahya meteorological station is the only station that has made observations for many years within the boundaries of the watershed. In addition to the Kütahya meteorological station, Eskişehir Anatolia, Afyonkarahisar Region and Bozüyük meteorological stations are close by. Information regarding these meteorological stations is given in Table 3.1. Their locations are shown in Figure 3.4. The most representative meteorological station for weather parameters is Kütahya meteorological station. Daily precipitation and average temperature data of Kütahya station are given in Figure 3.5 and Figure 3.6 between the years 1995 and 2010.

Table 3.1 Meteorological stations in and around the study area
(URL 3, 2012)

Station Number	**Code**	**Station Name**	**Elevation (m)**	**Latitude**	**Longitude**
17155	KUTH	Kütahya	969	39.4171N	29.9891E
17123	LTBY	Eskişehir Anatolia	787	39.8119N	30.5287E
17190	AFBL	Afyonkarahisar Region	1034	38.7380N	30.5604E
17702	BOZY	Bozüyük	754	39.9039N	30.0525E

Figure 3.4 Locations of the meteorological stations (Google Earth, 2012)

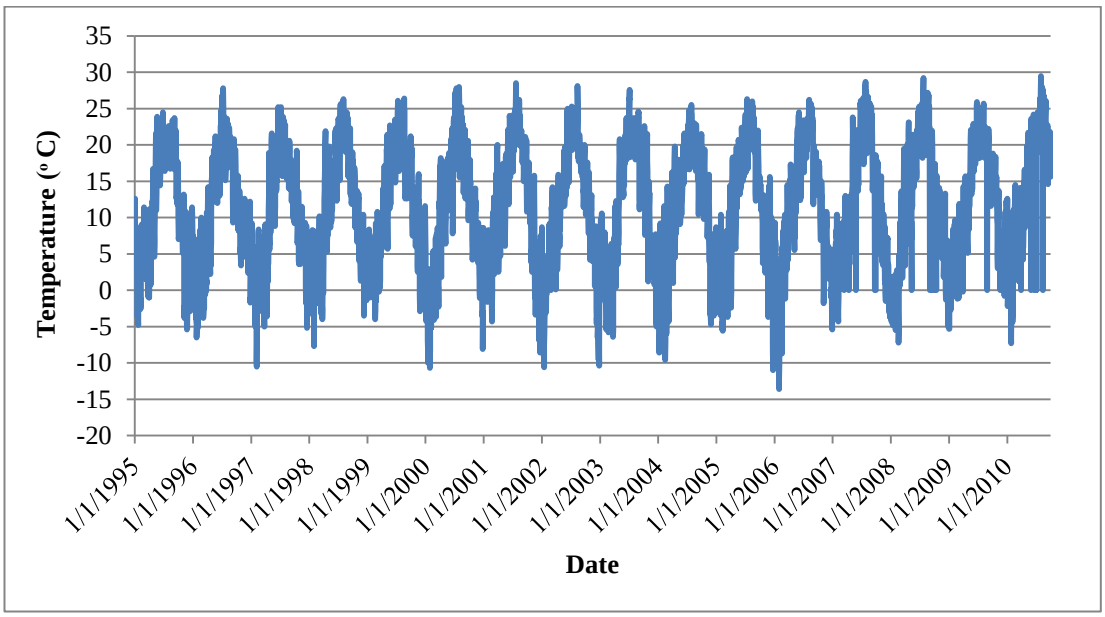


Figure 3.5 Daily average temperature data of Kütahya station

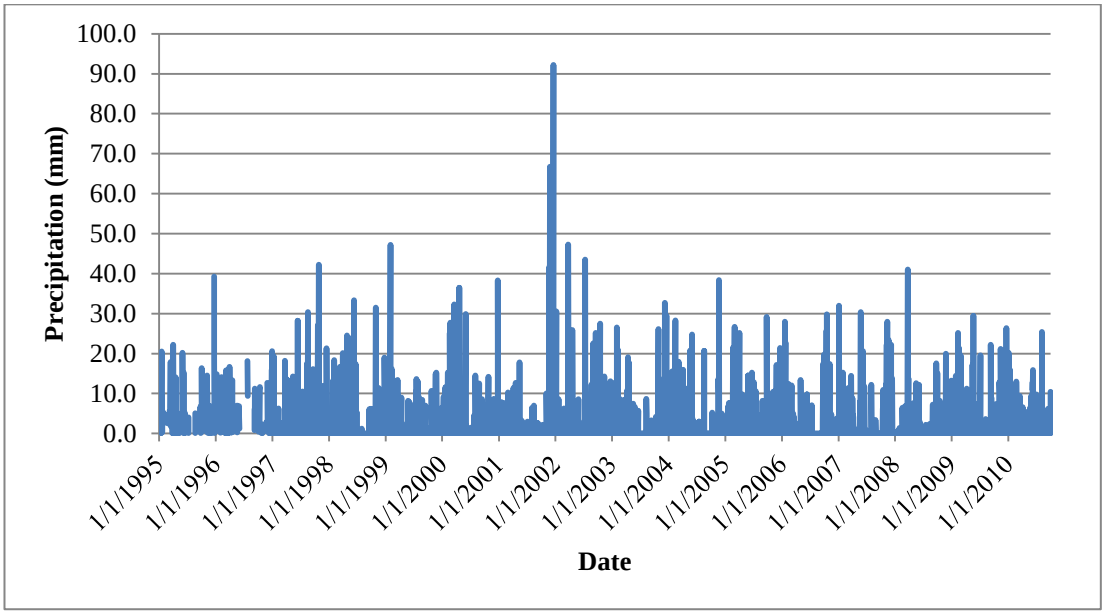


Figure 3.6 Daily precipitation data of Kütahya station

3.2 Land Use

Land use in the watershed is dominated by agriculture due to high fertility of soil (SHW 1980, 2001). The majority of the agricultural lands are located in Kütahya, Köprüören, Aslanapa, Altıntaş, İhsaniye, İnönü and Dumlupınar. All area occupied by Altıntaş and Dumlupınar is located within the watershed whereas the majority of Kütahya Merkez, İnönü and İhsaniye are within the borders of the watershed. Moreover, all agricultural lands in Aslanapa are located within the study area. Considering the relative areas occupied by these

districts in the watershed and land use, the focus in this study is on the areas including these districts. Information specific to these districts will be given in the following section. Forestry is another dominant land use type in the watershed. The major specie creating in the forests present in the study area is black pine. Oak, juniper, calabrian pine, scotch pine, and beech are the other species. Table 3.2 gives the areas in ha (1 ha = 0.01 km^2) for main land use and land cover categories in the area. Moreover, Figure 3.7 which was prepared using ArcMap depicts their distributions throughout the watershed.

Table 3.2 Areas for main land use and land cover categories in the study area (AKS Consulting, 2010)

Land uses and land covers	**Area (ha)**	**Area (%)**
Agricultural	212,657	41.66
Forest	192,593	37.73
Woodland	33,581	6.58
Pasture	31,905	6.25
Shrubbery	13,748	2.69
Stony Area	7,338	1.44
Residential	7,088	1.39
Mining Sites	3,624	0.71
Water	2,826	0.55
Plain	1,840	0.36
Industrial	1,480	0.29
Military Site	644	0.13
Wetland	614	0.12
Residual Storage	247	0.05
Urban Land	206	0.04
Solid Waste Storage Area	44	0.01
Marshy Place	31	0.01
Rural Land	16	0.00
Wastewater Treatment Plants	7	0.00
Total	510,489	100.00

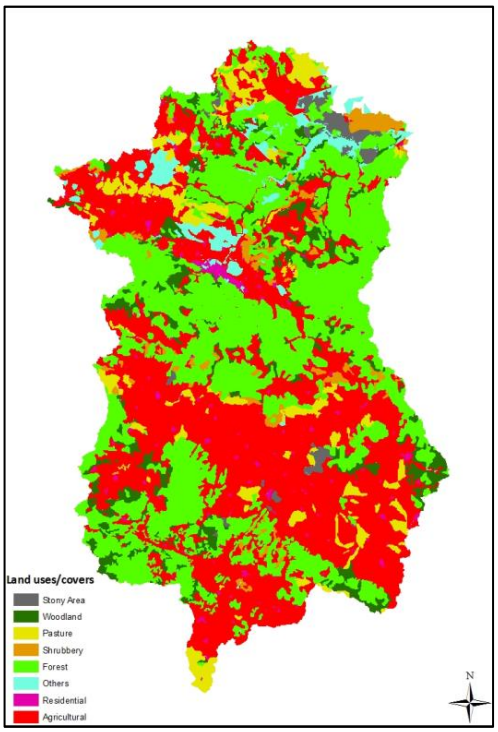


Figure 3.7 Distribution of the land uses and land covers

As mentioned before, this study focuses on the potential impacts of non-point source pollution due to agricultural activities. The majority of the agricultural lands appear in Kütahya, Köprüören, Aslanapa, Altıntaş, İhsaniye, İnönü and Dumlupınar. Therefore, this section includes information regarding land uses, irrigation status, fertilizer and pesticide consumptions in the provinces and their districts. The land use of Kütahya, Eskişehir, and Afyonkarahisar, are classified in Table 3.3. Table 3.4 summarizes the distribution of the agricultural areas located in the districts of Kütahya, Eskişehir, and Afyonkarahisar.

Table 3.3 Land use of Kütahya, Eskişehir and Afyonkarahisar with respect to Turkey

	Agricultural Land (ha)	**Forest-Shrubbery (ha)**	**Grassland (ha)**	**Other (ha)**	**Total (ha)**	**Reference**
Kütahya	409,488	612,592	88,209	77,211	1,187,500	Kütahya Provincial Directorate of Food, Agriculture, and Livestock (2011)
Eskişehir	582,505	331,263	325,851	125,581	1,365,200	Eskişehir Provincial Directorate of Food, Agriculture, and Livestock (2011)
Afyonkarahisar	536,268	291,269	232,329	331,997	1,391,863	Afyonkarahisar Provincial Directorate of Food, Agriculture, and Livestock (2010)
Türkiye	26,968,000	20,703,000	20,500,000	10,184,700	78,355,700	Kütahya Provincial Directorate of Food, Agriculture, and Livestock (2011)

Table 3.4 The distribution of the agricultural areas of the districts of Kütahya, Eskişehir and Afyonkarahisar

	Total area used (ha)	**Arable crops area (ha)**	**Vegetable gardens area (ha)**	**Orchard area (ha)**	**Fallow area (ha)**	**Dead space (ha)**	**Total agricultural area (ha)**	**Reference**
Merkez	70,186	62,059	1,584	308	6,235	17,594	87,780	Kütahya Provincial Directorate of Food, Agriculture, and Livestock (2011)
Altıntaş	23,122	15,397	30.0	97.5	7,597	16,258	39,380	
Aslanapa	18,840	18,481	44.2	4.2	311	7,337	26,177	
Dumplupınar	71,767	64,500	745	522	6,000	42,903	11,467	
İnönü	-	133,756	677	237	-	-	134,670	Eskişehir Provincial Environment Situation Report, 2010
İhsaniye	-	28,511	135	346	3,138	2,982	35,113	Afyonkarahisar Provincial Directorate of Food, Agriculture, and Livestock (2010)

The distributions of the agricultural areas as well as the basic crops that are produced vary in different districts. Cereal is commonly produced in Kütahya whereas hashish, potato, cherry, black cherry, sunflowers, and sugar beet are the basic crops of Afyonkarahisar. In addition to sunflower and sugar beet, the main agricultural products of Eskişehir include wheat, barley, corn, and tomato. However, the basic crops that are produced within the study area are wheat and sugar beet. Cultivation area for wheat is about 79% of the total cultivated area in the watershed. For sugar beet, it is approximately 3%. Table 3.5 shows the production data of wheat and sugar beet with respect to districts located within the watershed (AKS Consulting, 2011). Despite the high fertility of soil, considerable amounts of fertilizers and pesticides are applied to agricultural lands as well as irrigation water with the belief this would increase productivity (Kavaf and Nalbantcilar, 2007). Annual water consumption versus water requirements of these three crops are given in Table 3.6. On the other hand, Table 3.7 and Table 3.8 present the irrigation status of the agricultural lands within two provinces and districts of Kütahya and Afyonkarahisar, respectively. Chemical fertilizer consumption amounts in the districts of Kütahya in 2009 and Eskişehir in 2010 are provided in Table 3.9.

Table 3.5 Production data of wheat and sugar beet with respect to districts located within the boundaries of the study area (AKS Consulting, 2011)

	Merkez		**Altıntaş**		**Aslanapa**		**Dumlupınar**		**İhsaniye**	
	Area* (ha)	**Product (ton)**	**Area (ha)**	**Product (ton)**	**Area (ha)**	**Product (ton)**	**Area (ha)**	**Product (ton)**	**Area (ha)**	**Product (ton)**
Wheat	47,300	124,980	17,000	39,100	11,000	38,500	3,550	7,700	10,000	25,500
Sugar Beet	1,531	61,240	1,550	65,100	488	19,520	15	607	190	665

*Area represents cultivated area.

Table 3.6 The amount of water to be supplied for wheat and sugar beet (AKS Consulting, 2011)

	Actual annual water consumption (mm)	**Annual amount of water that should be supplied (mm)**		
		Surface irrigation	Sprinkling	Drip irrigation
Wheat	478.5	785	628	477
Sugar Beet	792	1,295	1,036	791

Table 3.7 Irrigation status of the agricultural lands of Kütahya and Eskişehir

	Kütahya		**Eskişehir**	
	Area (ha)	**Percentage (%)**	**Area (ha)**	**Percentage (%)**
Irrigated agricultural lands	72,216	17.6	136,333	23.4
Non-irrigated agricultural lands	337,272	82.4	446,172	76.6
Total	409,488	100	582,505	100
Reference	Kütahya Provincial Directorate of Food, Agriculture, and Livestock (2011)		Eskişehir Provincial Directorate of Food, Agriculture, and Livestock (2011)	

Table 3.8 Irrigation status of the agricultural lands of the districts of Kütahya and Afyonkarahisar

	Total irrigable area (ha)	**Percentage (%)**	**Irrigations conducted by the state (ha)**	**Irrigations conducted by the public (ha)**	**Total irrigated area (ha)**	**Reference**
Merkez	28,500	14.16	6,828	3,500	10,328	Kütahya Provincial Directorate of Food, Agriculture, and Livestock (2011)
Altıntaş	21,000	10.14	851	10,745	11,596	
Aslanapa	15,000	7.45	1,266	1,020	2,287	
Dumplupınar	3,000	1.49	675	60	735	
İhsaniye	32,468	-	-	-	2,645	Afyonkarahisar Provincial Directorate of Food, Agriculture, and Livestock (2010)

Table 3.9 Chemical fertilizer consumption amounts (ton) in the districts of Kütahya in 2009 and Eskişehir in 2010

	21% $(NH_4)_2SO_4$	**26% $(NH_4)NO_3$**	**33% $(NH_4)NO_3$**	**Urea**	**TSP**	**DAP**	**20.20.0**	**20.20.0 +Zn**	**15.15.15**	**15.15.15 +Zn**	**12.30.12**	**KNO_3**	**20% P_2O_5**	**Total**	**Reference**
Merkez	78	2,327	404	936	33	695	2,016	79	11	0	612	86	-	7,277	Kütahya Provincial Environment Situation Report, 2009
Altıntaş	28	1,379	1,221	305	20	638	1,507	370	0.9	30	0	324	-	5,822	
Aslanapa	18	957	442	254	0	643	1,517	120	0	0	241	190	-	4,382	
Dumplupınar	15	549	172	43	0	38	454	16	0.6	0	18	0	-	1,305	
İnönü	55	179	484	67	-	194	226	74	0.1	-	-	-	2.75	1,282	Eskişehir Provincial Environment Situation Report, 2010

3.3 Soil Characteristics

Great soil groups of the study area are alluvial soils, brown earth soils, chestnut soils, reddish chestnut soils, hydromorphic soils, colluvial soils, brown forest soils, brown forest without lime, brown earth without lime, high mountain pasture soils, and bare rock and debris. Alluvial soils (A) spreads on a large area including the stream beds in Kütahya, Köprüören, Aslanapa, and Altıntaş plains. They do not associate with a particular climate and vegetation type. Indeed, they are appropriate for any kind of vegetation in any climate type. Brown earth soils (B) are found in the north of Kütahya and Köprüören plains, the southwest of Aslanapa plain, and the north, south and southeast of Altıntaş plain. Dominant soil colors of brown earth soils are pale brown, dark yellowish brown and dark greyish brown. The vegetation cover on brown earth soils is generally grasses and shrubs. Chestnut soils (CE) appear in the northwest of the watershed. Natural vegetation associated with this type of soil is grasses, shrubs, and wide-ringed timbers. Reddish chestnut soils (D) are located in the middle of the watershed. They resemble to chestnut soils in many aspects. Hydromorphic soils (H) appear only in Aslanapa plain. Pasture, reed, and hydrophilic plants generate the natural vegetation cover over them. If necessary precautions regarding drainage can be taken, then forage crops and water resistant trees can be cultivated. Colluvial soils (K) occupy a small space in the watershed. The soil color depends on the main material from which they are formed. They do not associate with a particular climate and vegetation type. Wide range of vegetation can be cultivated on colluvial soils. The dominant great soil group in the watershed is brown forest soils (M). They spread over a large area; 58.93% of the watershed, except plains. Soils classified as brown forest without lime (N) soils are located on the east of the watershed. Main vegetation cover is deciduous forests. Brown earth without lime (U) soils is located in İhsaniye, Kadımürsel, Üçlerkayası, Tatarmuhat, Hacıbeyli, and Karacaahmet. Natural vegetation cover on these soils is grasses and shrubs. High mountain pasture soils (Y) appear only in the southwest of the watershed. Grass, reed, and flowering plants are the main vegetation cover. Due to cold climate, the productivity of these soils may decrease. They are commonly associated with lands for grazing. Bare rock and debris (CK) constitute a large portion, especially around the PDR. The land is covered by rocks in these areas. They are classifies as non-arable; therefore, they lack vegetation cover. Great soil groups of the study area and their percentages in total are presented in Table 3.10. Figure 3.8 which was prepared in the ArcGIS environment demonstrates their distributions throughout the watershed. Physico-chemical characteristics of the great soil groups will be provided in Section 4.2.2.

Table 3.10 Great soil groups of the study area and their percentages in total (AKS Consulting, 2010)

Great Soil Groups	Area (ha)	Area (%)
A	43,006	8.47
B	56,950	11.22
CE	4,998	0.98
D	15,957	3.14
H	456	0.09
K	5,924	1.17
M	300,785	59.26
N	42,510	8.37
U	18,733	3.69
Y	211	0.04
CK	18,075	3.56
Total	507,605	100.00

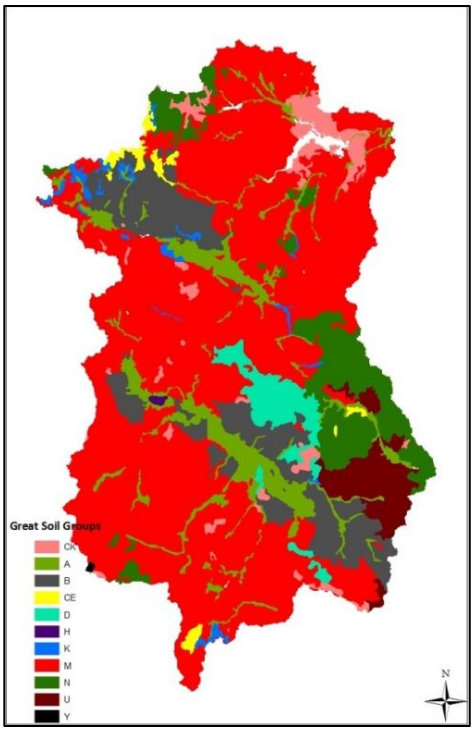


Figure 3.8 Distribution of the great soil groups

3.3.1 Land Use Capability Classification

Land use capability determines the suitability of the land for the growth of agricultural crops (Alparslan and Aydöner, 2004). Climate, soil, and topographical conditions are taken into consideration in classification of land use capability (General Directorate of Agricultural Reform, Ministry of Food, Agriculture, and Livestock, 2012). There are eight land use capability

classes. The first two of these, Class I and Class II, are the most suitable lands for agriculture. Class III and Class IV are classified as the lands where agriculture can be practiced with some restrictions. On the other hand, the remaining classes, Class V, Class VI, Class VII, and Class VIII, are mostly suitable for pasture and forest land use. Moreover, they represent the lands that can be opened to industrial and residential use. Land use capability classes of the watershed and their sharing in total are given in Table 3.11. Based on the information given in Table 3.11, Figure 3.9 was prepared using ArcMap. This figure provides a visual representation for the distribution of these classes within watershed.

Table 3.11 Land use capability classes of the study area
(AKS Consulting, 2010)

Land Use Capability Classes	**Area (ha)**	**Area (%)**
Class I	24,074	4.74
Class II	67,596	13.32
Class III	57,478	11.32
Class IV	56,730	11.18
Class V	493	0.10
Class VI	83,160	16.38
Class VII	200,000	39.40
Class VIII	18,074	3.56
Total	507,605	100.00

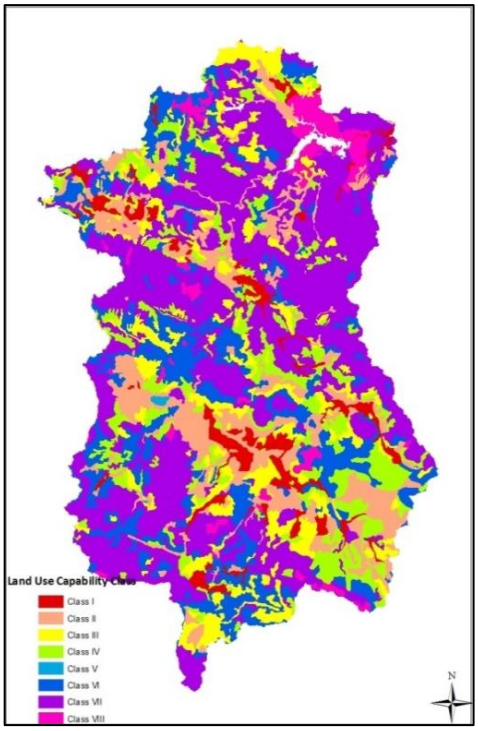


Figure 3.9 Distribution of the land use capability classes

3.3.2 Erosion

There are various factors leading to the erosion including water, wind, wave, glacial movement, and snowslide (AKS Consulting, 2010). The most common erosion type observed in the study area is the one due to water flow. It rarely occurs at alluvial soils in the plain bases and rocky areas whereas severe and extreme erosion is observed in other places. Table 3.12 indicates erosion status in the study area. Figure 3.10 displays the erosion map of the study area.

Table 3.12 Erosion status of the watershed (AKS Consulting, 2010)

Erosion Degree	**Area (ha)**	**Area (%)**
No erosion	22,250	4.38
Degree 1 (very little)	59,154	11.65
Degree 2 (tolerable)	108,967	21.47
Degree 3 (severe)	143,135	28.20
Degree 4 (extreme)	174,099	34.30
Total	507,605	100.00

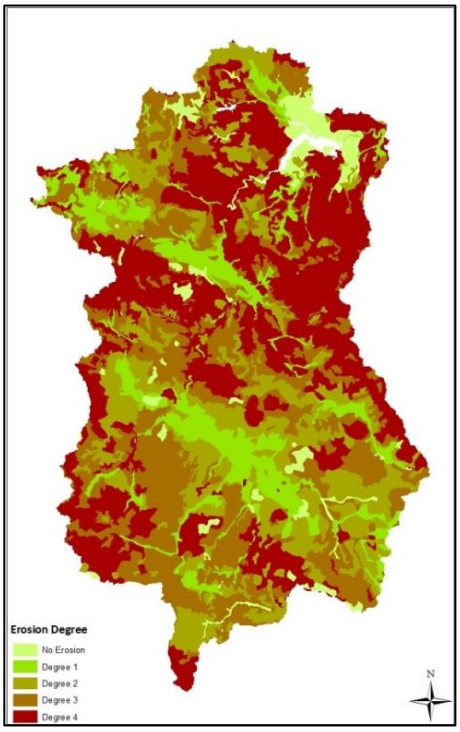


Figure 3.10 Erosion map of the watershed

3.4 Water Quality History of the Study Area

Many studies have been conducted to reveal the water quality problems and their underlying causes in and around the study area. Most of the studies conducted in and around the study area

focused on the determination of heavy metal content. Yücel et al. (1995) found unacceptable levels of heavy metal pollution in the Porsuk River according to the limits specified for drinking water in World Health Organization (WHO) in 1984. In this study, they determined the main areas that are responsible for the heavy metal pollution as Felent Creek, exit of Kütahya, and entrance and exit of Eskişehir. Semerci (2006) found higher levels of Fe, Mn, Cd, Pb, Ni, Cr, and Co and pesticide concentrations than the limit values in the sediments of Porsuk River. Kavaf and Nalbantcilar (2007) also analyzed both surface and groundwater in the Kütahya plain in terms of Ag, Al, As, B, Br, Ca, Cd, Cu, Fe, Hg, K, Li, Mg, Na, Ni, P, Pb, S, U and Zn contents. In this study, different degrees of contamination were observed for these elements and all the waters exceeded the limit values defined by USEPA in 2003. Çiçek and Koparal (2001) compared the Pb, Cr and Cd content of dam water with Table I in the Water Pollution Control Regulation (Water Pollution Control Regulation, 2004). According to the results obtained from this study, dam water was classified as Class I, Class II and Class III in terms of lead, chrome and cadmium, respectively. The study carried out by Özyurt et. al. (2004) may explain the reason for this situation. They analyzed discharge waters of various plants that are located in Kütahya and inflow to the Porsuk River and found that heavy metal levels of samples exceeded limit values specified in Water Pollution Control Regulation (Water Pollution Control Regulation, 2004). Ocak et al. (2002) studied the ecotoxicological and morphological effects of Porsuk River on agricultural crops and heavy metal contents of crops including Fe, Zn, Cd, Ni, Pb and Cr. Heavy metal accumulation in terms of Ni and Cr in agricultural crops was found higher than the control groups. Iron and chrome concentrations of water samples from Porsuk River were found as high. Kutlu et al. (2004) conducted a study in order to determine the impacts of mutagenicity potential of Porsuk River and its sediments on bacteria. This study indicated that heavy metal concentrations of both surface water and sediment exceeded the limit values specified in Inland Water Resources Classes (Water Pollution Control Regulation, 2004). The main conclusion drawn from above mentioned studies is that Porsuk River and its sediment were subjected to heavy metal pollution in terms of Cu, Cd, Pb, Al and Ni.

SHW (2001) modeled Porsuk River by using QUAL2E to reveal the current situation of Porsuk River and to recommend solutions for water quality improvements. Water quality classes of the stations which were derived from the model results for winter conditions are given in Table 3.13. This represents the worst case compared to summer conditions. Orak (2006) determined the pollution profile in Porsuk River via fuzzy logic in which similar results were obtained compared to the study carried out by SHW (2001). A recent study conducted by AKS Consulting (2010) also obtained similar water quality profiles for temperature (T) and NO_3-N (Table 3.14) compared to the study conducted by SHW (2001). However, they observed different water quality profiles for other parameters (Table 3.14). Water quality observation stations located both on the Porsuk River and its tributaries are depicted in Figure 3.11.

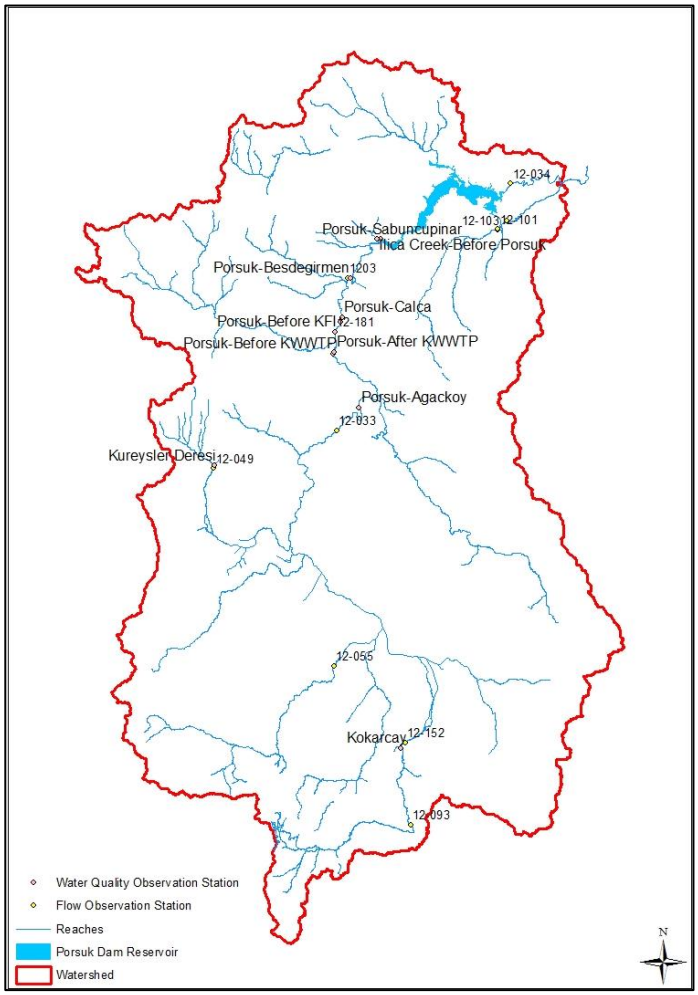


Figure 3.11 Water quality and stream flow observation stations located both on the Porsuk River and its tributaries

Table 3.13 Water quality classes of Porsuk River for winter conditions (SHW, 2001)

Station Name	**T (^oC)**	**DO** (mg/L)**	**BOD*** (mg/L)**	**NH_4-N (mg/L)**	**NO_2-N (mg/L)**	**NO_3-N (mg/L)**	**TP (mg/L)**	**Fecal Coliform (No/100mL)**
Agackoy	I	I	I	I	II	I	II	III
Before KWWTP*	I	I	I	IV	II	I	II	IV
After KWWTP*	I	II	III	IV	IV	I	IV	IV
After Felent	I	II	III	IV	IV	I	IV	IV
Before KFI	I	II	III	IV	IV	I	IV	IV
After KFI	I	II	III	IV	IV	I	IV	IV
Calca	I	II	III	IV	IV	I	IV	IV
Besdegirmen	I	III	III	IV	IV	I	IV	IV
Sabuncupinar	I	III	III	IV	IV	I	IV	IV
Outlet of PDR	I	I	I	II	III	I	IV	I

*Kütahya Wastewater Treatment Plant, **Dissolved Oxygen, ***Biochemical Oxygen Demand

Table 3.14 Water quality profile along the stations located both on the Porsuk River and its tributaries (AKS Consulting, 2011)

Station Name	**T (^oC)**	**DO (mg/L)**	**BOD (mg/L)**	**NH_4-N (mg/L)**	**NO_2-N (mg/L)**	**NO_3-N (mg/L)**	**TP (mg/L)**	**Fecal Coliform (No/100mL)**
Beginning of Porsuk	I	II	I	I	IV	I	II	II
After KWWTP	I	II	III	IV	IV	I	III	III
Felent Creek-Before Porsuk	I	III	IV	IV	IV	I	III	III
After KFI	I	III	II	IV	IV	I	III	III
After Industrial Area	I	IV	II	IV	IV	I	III	III
After Seyitömer Thermal Power Plant	I	II	I	I	IV	I	III	III
Ilica Creek-Before Porsuk	I	II	I	I	III	I	III	III
Inlet of PDR-Porsuk	I	III	II	IV	IV	I	III	III
Inlet of PDR-Kunduzlu	I	I	I	I	III	I	II	II
Outlet of PDR	I	I	I	II	IV	I	III	I

Although SHW (1998) and Koyuncu et al. (2005) (as cited in Semerci, 2006) declared that the size of agricultural pollution within the watershed was uncertain, SHW (2002) and Efelerli and Büyükerşen (2008) (as cited in Bakış et al., 2011) listed leading causes of water quality deterioration as partially treated and untreated wastewaters of Kütahya, wastewater of KFI, Kütahya Sugar Factory, slaughterhouse wastes, and fertilizers and pesticides resulting from agricultural activities. Besides, Yerel (2010) assessed the surface water quality of Porsuk River

via multivariate statistical techniques and pointed out that a considerable impact of urban, industrial, and agricultural discharge on water quality were experienced in the east part of the region.

"River Basin Management for the Sakarya Basin" was one of the projects taking place in Turkey in the scope of the NATO Science for Stability Program. The purpose of this project was to implement theoretical water resource systems planning techniques to real case studies in Turkey. Within the scope of the project, MODQUAL model was used to simulate the water quality of the Porsuk River Basin in Turkey and test management alternatives. It was stated that although conventional wastewater treatment provides limited improvements in water quality, reasonable water quality improvement can be achieved with the implementation of tertiary treatment for industries. (Tanik et al., 2005)

Arslan (2008) intended to investigate the potential of GIS-based multivariate statistical analysis for water quality assessment studies and determined water quality classes in accordance with the related regulations. Therefore, in this study, water quality values including flow rate, temperature, DO, BOD, NH_3-N, NO_3-N, NO_2-N, and PO_4-P obtained from the water quality monitoring stations located along the Porsuk River were evaluated via GIS. As a result of this study, water quality maps were prepared. According to these maps, water quality classes in upstream and downstream of Porsuk Dam were determined as Class IV. Bakış et al. (2011) determined both groundwater and surface water quality within the Porsuk Watershed as Class IV.

Muhammetoğlu et al. (2005) tested management alternatives specified for Porsuk River and PDR by using QUAL2E and BATHTUB for river and reservoir modeling, respectively. They observed high concentrations of nitrogen and phosphorus compounds in the entrance of Porsuk Reservoir. According to OECD classification criteria, it was stated that the reservoir behaved as a hypertrophic lake. Due to the presence of high seasonal algal blooms, epilimnion was found to be supersaturated with DO; on the other hand, anoxic conditions predominated below the epilimnion. In addition, Koçal (2006) aimed to analyze the water quality of the Porsuk Dam in terms of eutrophication via Nutrient and GROWA models. The main conclusion drawn in this study was that fertilization should be applied consciously because fertilizers applied to agricultural areas can be transported into Porsuk River and Dam Reservoir. Moreover, water quality alterations in the reservoir due to increase in water usage was investigated by developing scenarios. Model results indicated that the water quality of the dam is not affected significantly by the increase in water usage. On the other hand, Güngör and Göncü (2012) simulated the Lower Porsuk Stream Watershed by using SWAT in order to identify optimal strategies regarding water management and evaluated the impacts of different irrigation scenarios on the flow regime. The result of this study showed that with the aid of drip irrigation, which is a replacement for furrow and sprinkler irrigation, 87% increase could be achieved in stream flows. Therefore, Güngör and Göncü (2012) claimed that the water stress due to the irrigation demand can be reduced by applying more effective irrigation practices.

In addition to the surface water quality, SHW (1975), Özbek (1976), Kaçaroğlu (1991), Kaçaroğlu and Gunay (1997a and b), Bakış (1996), Özçelik (1998) and EGDE (1999) (as cited in Yuce, 2006), Yuce et al. (2004) and Yuce et al. (2006) investigated groundwater quality and pollution as well. The results obtained from these studies indicated serious groundwater pollution in both the Eskişehir plain and Porsuk River Basin. Besides, determining the impacts of industrial and agricultural activities on the quality of groundwater in the Porsuk River Basin, Yuce (2006) analyzed the surface and groundwater quality with respect to organic and inorganic contaminants. According to this study, considerable amounts of NO_2, NO_3, NH_3, NH_4, phenol, adsorbable organic halogenes (AOX), phosphorus, free chlorine, sulfur, Fe, Al, Pb, Cr, Mn, Cd, and Zn were found in some parts of the basin, exceeding the limits specified for drinking and domestic usage in Turkish Drinking Water Standards and WHO. In addition to fertilizer and pesticide application, surface water and groundwater interaction was determined as the leading cause of the groundwater quality deterioration in the basin especially during dry period. It was also seen that although pesticide content did not exceed the limits determined by USEPA, it was over the European Union and WHO drinking water limits. (Yuce, 2006)

CHAPTER 4

METHODOLOGY

Soil Water Assessment Tool (SWAT) requires a variety of input parameters for simulation. Although there are databases integrated into SWAT used to calculate and/or set some of the input parameters as default, site specific input parameter values that represent the selected study area should be used as well. There is a strong relationship between the quality (prediction performance) of environmental models and underlying database (Bormann et al., 1999). In this chapter, detailed information about input parameters and modeling steps are presented.

The version of the model that was used in this study is ArcSWAT2009. The simulation framework follows a sequential order as depicted in Figure 4.1. A step cannot be started without completing the previous one. SWAT simulation starts with watershed delineation. "Watershed Delineator Menu" enables DEM setup and streams/outlets/inlets definitions. Under the title of "HRU Analysis Menu", land use/soils/slope can be defined. "Write Input Tables Menu" generates input parameters. It is necessary to incorporate several parameters related to weather, soils, ground water, channel, plant water use, plant growth, soil chemistry, and water quality characteristics, as well as data for sub-basin and HRU characterization for simulation of hydrologic and water quality processes. "Edit SWAT Input Menu" enables editing the input parameters. The final step is executing SWAT simulation which to apply sensitivity analysis and calibration of the model. Then, calibrated model is used for scenario development. Table 4.1 provides information regarding input source and frequency of data recording.

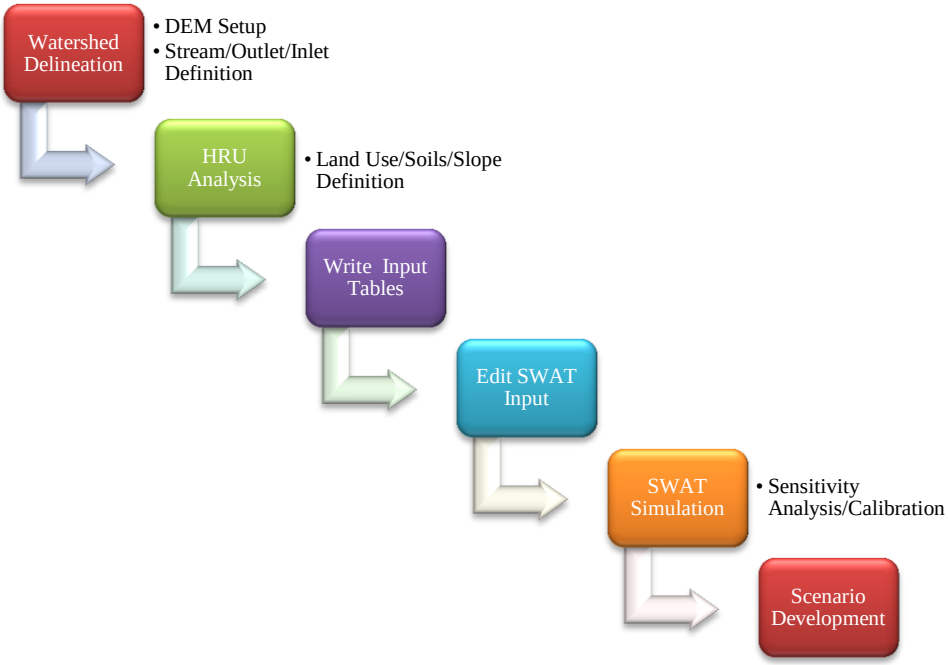


Figure 4.1 General framework of the methodology

Table 4.1 Summary table for input data

Input Data	**Source**	**Frequency of data recording**
DEM	AKS Consulting	-
Land Use Map	General Directorate of Agricultural Reform	-
Great Soil Groups	General Directorate of Agricultural Reform	-
Meteorological Data	General Directorate of Meteorological Service	Daily
Stream Flow Rates	SHW	Daily
Point Source Discharges	KWWTP	Monthly
Management Operations	Directorate of Eskişehir Soil and Water Resources Research Institute	-

4.1 Delineation of the Watershed of PDR

The very first step in a watershed simulation model is the configuration of the watershed. SWAT delineates sub-basins automatically by means of DEM. In environmental studies, simulations of the processes that occur in a watershed are carried out on the basis of DEM. The reason for this is mainly associated with the ability of a DEM to capture topographic properties of a watershed including its slope, field slope length, and channel network (Lin et al., 2013). Several studies

concentrating on the impacts of DEM resolutions on SWAT model outputs are available in literature (Cotter et al., 2003; Chaplot, 2005; Di Luzio et al., 2005; Dixon and Earls 2009). The most important conclusion that can be drawn from these studies is that there is a dependency between desired outputs, maximum acceptable errors, DEM accuracy and grid size (Lin et al., 2013). Figure 4.2 depicts the DEM of the study area which was obtained from AKS Consulting. Properties of the DEM of the area including the Watershed of the PDR are given in Table 4.2.

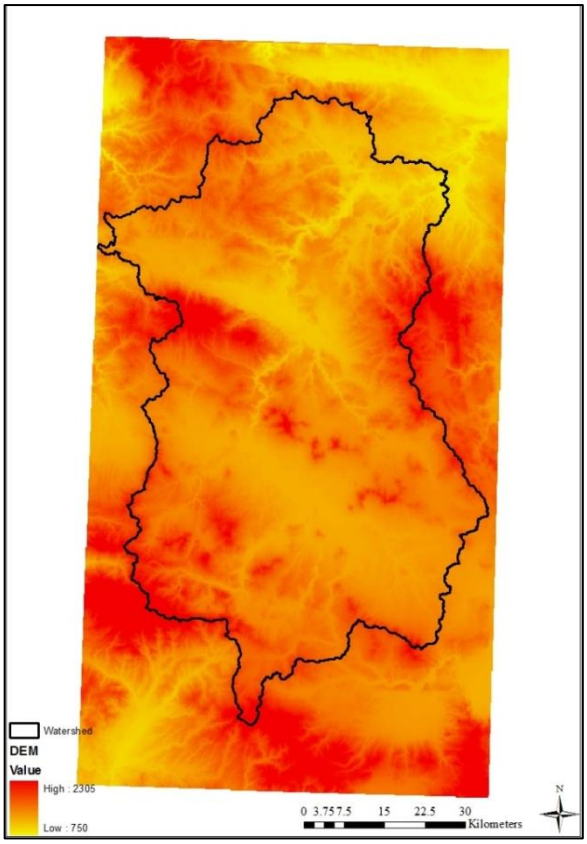


Figure 4.2 DEM of the area including the Watershed of the PDR

Table 4.2 Properties of the DEM of the area including the Watershed of the PDR

Property	**Value**
Projection	Universal Transverse Mercator (UTM)
False Northing	0
False Easting	500000
Central Meridian	33
Scale Factor	0.9996
Latitude of Origin	0
Geographic Coordination System	GCS_European_1950
Datum	D_European_1950
Zone	36
Scale	1/25,000
Pixel Size	20 m x 20 m

In addition to the automatic stream definition procedure, SWAT allows the users to determine the size and number of sub-basins by changing the drainage area required to generate the origin of a stream. The logic behind the subdivision is to generate homogenous areas in terms of climatic conditions, soil, and land use types, slope, and management characteristics (Daniel et al., 2011; Pisinaras et al., 2010; Tuppad et al., 2010; Wang et al., 2010). During sub-basin size determination, users should keep in mind that the smaller the drainage area, the more the real-like delineation can be achieved. However, representation of the actual distribution of the streams in the study area via the stream networks created by the model should be another consideration. In this study, the calculated minimum, maximum, and suggested drainage areas by the model were 2767, 553434, and 11068.676 ha, respectively. In this study, drainage area was selected as 11068.676 ha using a trial and error approach by considering the representation of the actual distribution of the streams in the study area.

After the configuration of the stream network and outlets, SWAT allows the users to add, delete, and redefine the sub-basin outlets, drainage inlets, and point source inputs. In this study, eleven sub-basin outlets were added manually to the locations of the monitoring stations of SHW and Electrical Power Resources Survey and Development Administration (Figure 4.3). Adding outlets at these locations enables the comparison of estimated and measured flows as well as pollution loads. Moreover, based on the location of the Kütahya Wastewater Treatment Plant (KWWTP) (Figure 4.3), one point source input was added because its contribution to both flow and phosphorus load is major when compared to other point sources. Then, the most downstream outlet of the watershed was selected as the main watershed outlet. After conducting watershed delineation, it was checked whether the boundary of the watershed and the stream network created by the model coincide with the actual ones. The reference was obtained from SHW. Following the delineation process, the topographic report describing the elevation distribution within the watershed and within each sub-basin unit was prepared. Furthermore, one reservoir was added. At the end of the delineation process, 29 sub-basins were created. Figure 4.4 demonstrates the delineation process output.

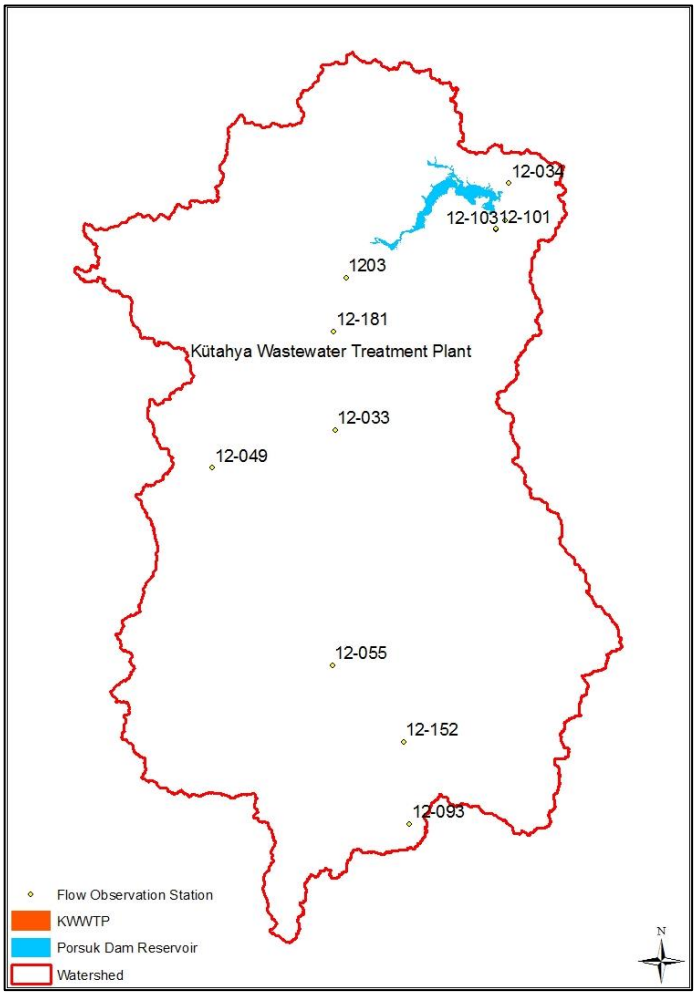


Figure 4.3 Locations of the stream flow observation stations and KWWTP

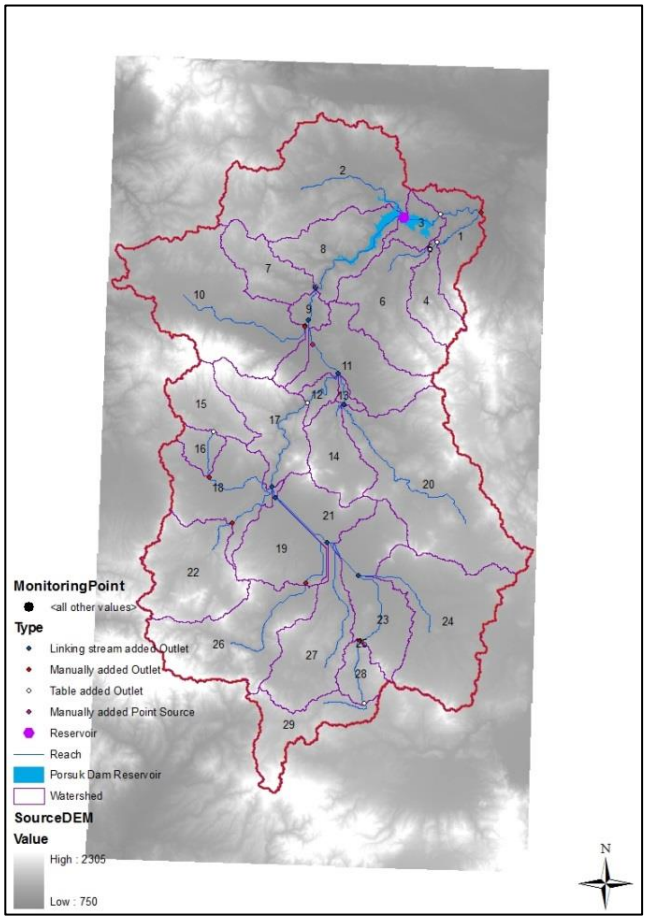


Figure 4.4 SWAT watershed delineation

4.2 HRU Analysis

"Watershed Delineator Menu" enables the division of the watershed into sub-basins which are then further divided into HRUs. Within an HRU, uniform land use, soil type, and slope prevail. This subdivision enables the model to represent the impacts of different land uses, soils, and slopes on hydrologic conditions. Therefore, land use, soil, and slope definitions are accomplished under the title of HRU Analysis Menu.

4.2.1 Land Use Definition

Land use is one of the most critical factors affecting watershed hydrology. In other words, the quality and quantity of both surface and sub-surface water that flow through the basin depend mostly on the land use and land cover. Therefore, they can be considered as the driving forces for the transport of non-point source pollution.

Land use map used in this study was obtained from General Directorate of Agricultural Reform. It was converted to ESRI grid from shape file. While converting the land use data, it should be kept in mind that the cell size and projection of the land use dataset must be same as for the DEM to achieve a proper overlay (Winchell et al., 2010). Moreover, it is necessary to represent at least 95% of the actual land use to proceed. In this study 99.37% overlap was achieved. In order to define the land uses of the study area, SWAT land cover database was used. Although SWAT allows the users to edit land use, plant growth, and urban database before land use map is loaded to add new types of land covers, there was no need to update land cover database in this study. Table 4.3 demonstrates the current land uses in the study area and the corresponding land use definitions in the SWAT databases. After reclassification of the land use, Figure 4.5 was obtained. As also revealed by the SWAT land use classification, the main land use categories of the catchment area are agricultural and forest.

Table 4.3 SWAT land use classification

Land Use Code (LUCODE)	**Area (%)**	**Current Land Use**	**Land Use Definition in SWAT Database**	
		Definition	**Definition**	**Symbol**
9	2.77	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	41.85	Agricultural Area	Agricultural Land-Generic	AGRL
4	0.60	Lake	Water	WATR

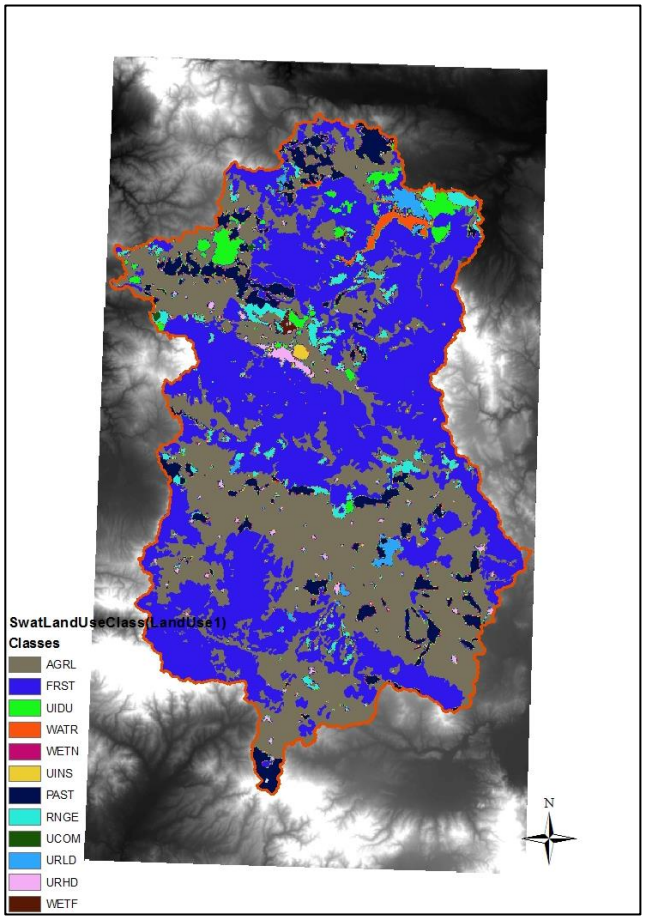


Figure 4.5 SWAT land use classification

4.2.2 Soils Definition

Information regarding the chemical and physical characteristics of the soil in the study area is essential for the evaluation of the effects of the current and alternative agricultural management practices on water. While the physical features of soil affect the water and air movement throughout the soil profile, chemical features may have an impact on the initial concentrations of the chemicals in the soil. Yet, SWAT requires only information regarding physical properties of the soil and there is no input data requirement concerning chemical properties. (Neitsch et al., 2010)

Soil types in the study area should be integrated into SWAT which includes the databases for US soils. Some of the soil input variables are given in Table 4.4. Unfortunately, there is no readily available data for all of the variables in Turkey. Therefore, soil data should be collected or calculated based on other relevant parameters. As a result, soil data collection can be required for the simulation of the catchments especially out of the US which can be an expensive and time-consuming step.

As mentioned before, soil data formats specified by SWAT are geodatabase feature class, ESRI grid, and shapefile. In order to accelerate the modeling process geodatabase feature class format was converted into ESRI grid format. Assumptions, cell size and projection characteristics used during the conversion of land use data were also valid for the conversion of soil data.

Table 4.4 Soil database variables required by SWAT (Neitsch et al., 2010)

Soil Component Parameters	
Variable Name	**Definition**
SNAM	Soil name (Optional)
NLAYERS	Number of layers in soil profile
HYDGRP	Soil hydrologic group (A, B, C, or D)
SOL_ZMX (mm)	Maximum rooting depth of soil profile
ANION_EXCL (fraction)	Fraction of porosity from which anions are excluded (Optional)
SOL_CRK (m^3/m^3)	Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume (Optional)
TEXTURE	Texture of soil layer (Optional)
Soil Layer Parameters	
Variable Name	**Definition**
SOL_Z (mm)	Depth from soil surface to bottom of layer
SOL_BD (g/cm^3)	Moist bulk density
SOL_AWC (mm/mm)	Available water capacity of the soil layer
SOL_CBN (% wt.)	Organic carbon content
SOL_K (mm/hr)	Saturated hydraulic conductivity
CLAY (% wt.)	Clay content
SILT (% wt.)	Silt content
SAND (% wt.)	Sand content
ROCK (% wt.)	Rock fragment content
SOL_ALB (fraction)	Moist soil albedo
USLE_K	USLE equation soil erodibility factor
SOL_EC (dS/m)	Electrical conductivity

There is no available field work that focuses on the soil properties of the study area in the variables required by SWAT. Therefore, soil input parameters for the study area were obtained based on the soil groups reported by General Directorate of Agricultural Reform which are referred to as “Great soil groups”. These groups are alluvial soils, brown earth soils, chestnut soils, reddish chestnut soils, hydromorphic soils, colluvial soils, brown forest soils, brown forest without lime, brown earth without lime, high mountain pasture soils, and bare rock and debris (AKS Consulting, 2010).

The soil types of the study area were input into SWAT databases via “Edit SWAT Input Menu”. These are provided in Table 4.4. First of all, soils names were determined based on the symbols specified in the National Soil Database (URL 1, 2012). Number of layers in a soil profile can

range between 1 and 10. In this study, one layer was used and depth from soil surface to bottom of layer (SOL_Z) was determined as 0.2 m. This is because the first 0.2 m represents snow and soil profile (Fiseha et al., 2012). Besides, fertilizers are applied to the first 15-20 cm of the soil layer (Bulut, 2005). Even though information concerning clay, silt, and sand contents of soil layers is required, texture data is not processed by the model, but there is a strong relationship between some of the soil input variables stated in Table 4.4 and clay, silt, and sand contents and texture of the soil layers. Some of the soil parameters such as saturated hydraulic conductivity, the water intake rate, erodibility, and the available water capacity that have a significant impact on soil mechanics and behavior and plant growth depend on soil texture (USDA Natural Resources Conservation Service, 2012a). Therefore, the very first step in the incorporation of the soil types of the study area should include the determination of the textures and clay, sand, and silt contents of the great soil groups. Table 4.5 indicates both the average values of clay, sand, and silt contents and textures of the great soil groups based on the study conducted by Aydınalp and Başar (2000).

Table 4.5 Clay, sand, and silt contents and textures of the great soil groups of the study area (Aydınalp and Başar, 2000)

Great Soil Groups	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Texture**
A*	54.30	31.67	14	L
M*	30	35.75	34.25	CL
U*	32.33	28	39.67	CL
N*	44.5	19.25	36.25	C
K*	55	28	17	SL

*Descriptions were given in Section 3.3

In addition to the aforementioned great soil groups, bare rock and debris was defined in the SWAT databases as rock outcrop; therefore, there is no need to determine soil database variables required by SWAT (Table 4.4) for bare rock and debris. Moreover, brown earth and chestnut soils resemble to each other. Reddish chestnut and chestnut soils have also several characteristics in common (Isparta Provincial Directorate of Culture and Tourism, 2012). Therefore, in this study the same values were used for some variables given in Table 4.4 of these great soil groups. Besides, the average value obtained from literature for the variables given in Table 4.4 was used for hydromorphic soils. Clay, sand, and silt contents and textures of the rest of the great soil groups of the study area are presented in Table 4.6.

Table 4.6 Clay, sand, and silt contents and textures of the great soil groups of the study area

Great Soil Groups	Sand (%)	Silt (%)	Clay (%)	Texture	Reference
Y*	59.0	25.0	15.0	SL	Aydınalp and FitzPATRICK, 2004
H*	27.0	43.0	30.0	SICL	Aydınalp, 2001; Dengiz and Bayramin, 2003
B*	31.3	33.6	35.1	CL	Dengiz and Bayramin, 2003; Aylar, n.d.
CE*	31.3	33.6	35.1	CL	Dengiz and Bayramin, 2003; Aylar, n.d.
D*	31.3	33.6	35.1	CL	Dengiz and Bayramin, 2003; Aylar, n.d.

*Descriptions were given in Section 3.3

The United States Natural Resource Conservation Service divides soils into four hydrologic groups which are A, B, C, and D according to their infiltration characteristics. A refers to the soils that have high infiltration rates and therefore, low runoff potential. Group B soils have moderate infiltration and moderate water transmission rate. Group C soils have slow infiltration rate and high runoff potential whereas group D soils have very slow infiltration and water transmission rate. United States Department of Agriculture (USDA) Natural Resources Conservation Service (2007) defines hydrologic groups of the soils based on their textures and clay and sand percentages. Therefore, considering textures and clay and sand percentages of the great soil groups of the study area, hydrologic soil groups were defined and pointed out in Table 4.7.

Table 4.7 Soil hydrologic groups (USDA Natural Resources Conservation Service, 2007)

Great Soil Groups	Soil Hydrologic Group
A	B
M	C
U	C
N	C
K	B
Y	B
B	C
H	C
D	C
CE	C

Maximum rooting depth of soil profile (Sol_ZMX) must be specified by the user. If not, the entire depth of the soil profile is taken as SOL_ZMX. In this study, no depth is specified. Moreover, entering data regarding fraction of porosity from which anions are excluded (ANION_EXCL) is optional; therefore, no data is entered. However, SWAT sets it as 0.5.

Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume (SOL_CRK) specification is also optional. Neitsch et al. (2010) recommended the quantification of the temporal change in soil volume in areas where vertisols are the dominant soil type in order to be able to estimate infiltration and surface runoff properly. However, the study area is not dominated by vertisols; therefore, no data is entered for SOL_CRK. The moist bulk density (SOL_BD) is defined as the ratio of the mass of solid particles to the total volume of the soil. Bulk densities' range values should vary between 1.1 and 1.9 g/cm^3. Bulk densities' ranges with respect to the textures are given in Table 4.8. In this study, the average values are used to set the bulk densities were used.

Table 4.8 Bulk densities with respect to textures (USDA Natural Resources Conservation Service, 2012b)

Soil Textural Class	**Bulk Density (g/cm^3)**	
	Range	**Average**
S	1.60-1.70	1.65
LS	1.55-1.65	1.60
SI	1.40-1.50	1.45
SL	1.50-1.60	1.55
SIL	1.45-1.55	1.50
C 35-50% 50-65%	 1.35-1.45 1.25-1.35	 1.40 1.30
SCL	1.45-1.55	1.50
L	1.45-1.55	1.50
SC	1.35-1.45	1.40
SICL	1.45-1.55	1.50
SIC	1.40-1.50	1.45
CL	1.40-1.50	1.45

Available water capacity of the soil layer (SOL_AWC) is also referred as the volume of the water being available to plant utilization provided that soil is at field capacity. It is a significant soil layer parameter especially during irrigation and drainage systems design and operation, droughtiness and yield predictions, water resource protections, and water budget developments. There is a direct proportion between organic matter content and available water capacity of soils as long as the other parameters remain the same. Moreover, organic matter has an important influence on porosity, bulk density, water infiltration, and cohesion. Table 4.9 prepared by USDA Natural Resources Conservation Service (2012b) indicates the available water capacity of the soil with respect to different textures based on different organic matter ranges.

Table 4.9 Available water capacities in centimeters per centimeter of soil (USDA Natural Resources Conservation Service, 2012b)

Soil Texture Class	**Greater than or equal to 3 percent organic matter**	**0.5 to 3 percent organic matter**	**Less than 0.5 percent organic matter**
S	0.07-0.09	0.06-0.08	0.05-0.07
LS	0.10-.012	0.09-0.11	0.08-0.10
SL	0.13-0.15	0.12-0.14	0.11-0.13
L and very fine SL	0.20-0.22	0.17-0.19	0.17-0.19
SIL	0.22-0.24	0.20-0.22	0.20-0.22
SICL	0.21-0.23	0.18-0.20	0.18-0.20
SCL	0.18-0.20	0.16-0.18	0.15-0.17
CL	0.17-0.19	0.15-0.19	0.14-0.16
SIC	0.12-0.14	0.11-0.13	0.10-0.12
C	0.11-0.13	0.09-0.11	0.08-0.10

It was realized that to be able to utilize the above table, organic matter content of the soil in the study area should be determined, but some of the studies used in preparation of the soil input variables for the study area included organic carbon content. Therefore, Equation 4.1 (Rosewell, 1993) was used to describe the relationship between organic carbon and organic matter contents. Table 4.10 shows the organic carbon and organic matter contents of the great soil groups in the study area. Moreover, Table 4.11 concentrates on both available water capacity and organic matter of the great soil groups based on given textures.

$$\text{Organic Matter} = \text{Organic Carbon} \times 1.72 \tag{4.1}$$

Table 4.10 Organic carbon and organic matter contents of the great soil groups

Great Soil Groups	Texture	Organic Carbon Content (%)	Organic Matter Content (%)	Reference
A	L	0.53	0.91	Aydınalp and Başar, 2000
M	CL	1.00	1.72	Aydınalp and Başar, 2000
U	CL	0.60	1.03	Aydınalp and Başar, 2000
N	C	0.89	1.53	Aydınalp and Başar, 2000
K	SL	0.55	0.95	Aydınalp and Başar, 2000
Y	SL	1.30	2.24	Aydınalp and FitzPATRICK, 2004
H	SICL	0.62	1.07	Aydınalp, 2001; Dengiz and Bayramin, 2003
B	CL	0.66	1.14	Dengiz and Bayramin, 2003; Aylar, n.d.
CE	CL	0.66	1.14	Dengiz and Bayramin, 2003; Aylar, n.d.
D	CL	0.66	1.14	Dengiz and Bayramin, 2003; Aylar, n.d.

Table 4.11 Available water capacities in the study area for different soil groups

Great Soil Groups	Texture	Organic Matter Content (%)	Available Water Capacity (mm H2O/mm soil)*
A	L	0.91	0.18
M	CL	1.72	0.17
U	CL	1.03	0.17
N	C	1.53	0.10
K	SL	0.95	0.13
Y	SL	2.24	0.13
H	SICL	1.07	0.19
B	CL	1.14	0.17
CE	CL	1.14	0.17
D	CL	1.14	0.17

*Average values given in Table 4.8 were used.

USDA Natural Resources Conservation Service defines saturated hydraulic conductivity as the quantitative measurement of the ability of a saturated soil to transmit water under a given hydraulic gradient. Although it can be stated by using different units, in SWAT it should be in mm/hr. Saturated hydraulic conductivity ranges with respect to different soil textures are shown in Table 4.12. Average values obtained using the given ranges in the table were used in simulations.

Table 4.12 Saturated hydraulic conductivity (SOL_K) values with respect to soil textures (USDA Natural Resources Conservation Service, 2012b)

Texture	Saturated hydraulic conductivity		
	Range (µm/sec)	**Range (mm/hr)**	**Average (mm/hr)**
S LS	42.34-141.14	152.42-508.10	330.26
SL	14.11-42.34	50.80-152.42	101.61
L SIL SI	4.23-14.11	15.23-50.80	33.01
CL SCL SICL	1.41-4.23	5.08-15.23	10.15
SC SIC C	0.42-1.41	1.51-5.08	3.29

Sediment and erosion yield are simulated within SWAT via MUSLE, which is the modified version of the Universal Soil Loss Equation (USLE). The main difference between two is the prediction of the average annual gross erosion. USLE bases it on rainfall energy while MUSLE predicts it by using a runoff factor. Based on the study conducted by Wischmeier and Smith (1978), soil erodibility factor is defined as the soil loss rate per erosion index unit for a particular soil as measured on a unit plot. Moreover, it was revealed that despite of the increase in sand and clay contents, reduction in silt content leads to decrease in erodibility for a given soil type. Table 4.13 shows USLE equation soil erodibility factor (USLE_K) values for different soil textures.

Table 4.13 USLE_K values based on soil textures (Rosewell, 1993)

Texture	USLE_K	Texture	USLE_K
S	0.15	SICL	0.40
LS	0.20	SC	0.17
SL	0.30	SIC	0.25
SCL	0.25	Light clay	0.25
L	0.40	Light medium clay	0.18
SIL	0.55	Medium clay	0.15
CL	0.30	Heavy clay	0.12

Moist soil albedo (SOL_ALB) is the ratio of the amount of solar radiation that is reflected from the soil surface. It is mostly related to the top layer of soils. It varies depending on the color of top layer as indicated in Table 4.14. In order to be able to find the albedo values for lighter and darker modifiers of the colors given in Table 4.14, it is recommended to add 0.01 to the albedo value for lighter modifiers and subtract 0.01 from the albedo value for darker modifiers of the colors given in Table 4.14 (Singh, n.d.). Although soil albedo values are used for the calculation

of potential evapotranspiration (PET) rates from the soil surface and estimations regarding soil water balance, it is not considered as a sensitive parameter for water balance predictions. Surface roughness and wetness have a significant impact on the soil albedo. For example, wet and rough surfaces lead to decrease in the albedo (Singh, n.d.). In addition, Dobos (2003) determined the approximated albedo ranges of natural surfaces. They are given in Table 4.15. As can be seen in Table 4.15, the upper and lower limits for albedo value are 1.0 and 0.0, respectively.

Table 4.14 Albedo values based on the color of the upper horizon (Singh, n.d.)

Color	**Albedo**
Brown	0.13
Red	0.14
Black	0.09
Gray	0.13
Yellow	0.17

Table 4.15 The approximated albedo ranges of natural surfaces (Dobos, 2003)

Natural surface types	**Approximated albedo**
Blackbody	0.0
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 of the 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	1.0

Based on Table 4.14 and Table 4.15, Table 4.16 is defined to present the albedo values of the great soil groups of the study area. For the determination of the albedo values of brown earth, chestnut, and reddish chestnut soils, color of the upper horizons were considered. On the other hand, alluvial and colluvial soils are the most suitable soil types for agricultural purposes (Türe and Böcük, 2007); therefore, average value given for cropland by Dobos (2003) was used. Moreover, approximated albedo range specified for grassland (Table 4.15) was used for high mountain pasture and hydromorphic soils. Dominant land use of the brown forest and brown forest without lime is forest (Eminağaoğlu et al., 2008); thus, average albedo value given for forest by Dobos (2003) was selected for these types of soils.

Table 4.16 Albedo values for the great soil groups of the study area

Great soil groups	Albedo
A	0.18
M	0.13
U	0.14
N	0.13
K	0.18
Y	0.15
H	0.15
B	0.13
CE	0.12
D	0.14

The ability of a material to conduct an electrical current is called electrical conductivity. The electrical conductivity of a soil is affected by the amount of moisture held by soil particles, soil texture and particle size. Sands, silts and clays are classified as less conductive, intermediate conductive and highly conductive, respectively. The unit of electrical conductivity should be dS/m to be executed by the SWAT (Grisso et al., 2009). Table 4.17 shows electrical conductivities for the great soil groups with respect to soil textures. Finally, after creating soil database representing the study area, the SWAT soil classification was generated as provided in Table 4.18. The required minimum percent overlap ratio for soil data is also 95%. In this study 98.83% overlap was achieved. The distribution of different soil classes following the reclassification of the soil into SWAT soil codes can be seen in Figure 4.6.

Table 4.17 Electrical conductivity (SOL_EC) values based on soil textures

Great Soil Groups	**Texture**	**Electrical Conductivity (dS/m)**	**Reference**
A	L	0.76	Aydınalp and Başar, 2000
M	CL	0.53	Aydınalp and Başar, 2000
U	CL	0.32	Aydınalp and Başar, 2000
N	C	0.20	Aydınalp and Başar, 2000
K	SL	0.69	Aydınalp and Başar, 2000
Y	SL	$41x10^{-5}$	Aydınalp and FitzPATRICK, 2004
H	SICL	4.4	Aydınalp, 2001; Dengiz and Bayramin, 2003
B	CL	0.72	Dengiz and Bayramin, 2003
CE	CL	0.72	Dengiz and Bayramin, 2003
D	CL	0.72	Dengiz and Bayramin, 2003

Table 4.18 SWAT soil classification

Soil Code (SCODE)	**Area (%)**	**Great soil groups**	**Soil definition in SWAT database**
1	3.54	Bare rock and debris	Rock Outcrop
2	8.53	Alluvial	A
3	11.29	Brown earth soils	B
4	0.97	Chestnut soils	CE
5	3.17	Reddish chestnut soils	D
6	0.09	Hydromorphic soils	H
7	1.16	Colluvial soils	K
8	59.14	Brown forest soils	M
9	8.38	Brown forest without lime	N
10	3.70	Brown earth without lime	U
11	0.03	High mountain pasture soils	Y

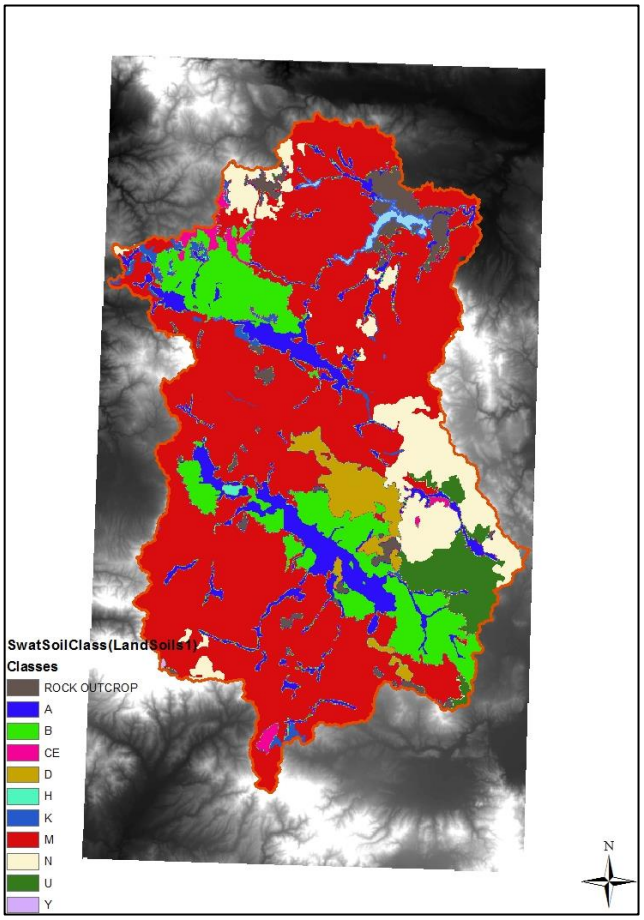


Figure 4.6 Soil classification based on SWAT soil classes

4.2.3 Slope Definition

For the accomplishment of HRU analysis, slope ranges of the study area should be defined as well. In order to achieve slope discretization, watershed slope statistics including minimum, maximum, median, and mean values can be utilized (Winchell et al., 2010). However, four slope classes were defined for the study area based on the study by AKS Consulting (2010). The slope classes and distribution of slope in the study area are provided in Table 4.19 and Figure 4.7.

Table 4.19 SWAT slope classification

Class	Lower Limit (%)	Upper Limit (%)
1	0	10
2	10	20
3	20	30
4	30	>30

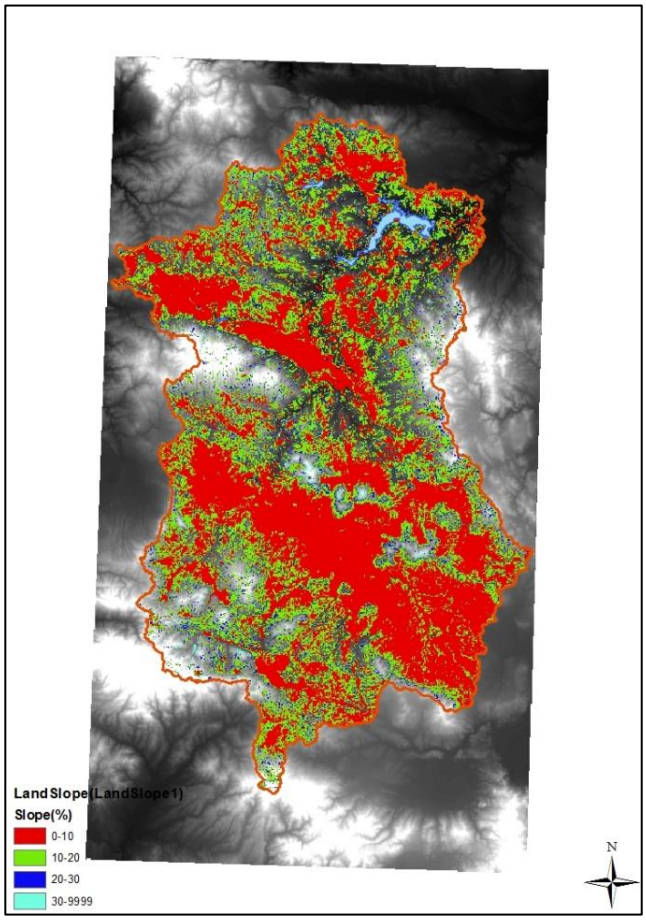


Figure 4.7 Slope distribution in the study area

Once the classification of land use, soils, and slope were completed, overlay process were carried out and Land Use, Soils, and Slope Distribution Report describing the distribution of the land use, soil, and slope classes within the watershed and sub-basins was created. The next step was the determination of the HRU distribution. For the accomplishment of HRU distribution, there are three options including dominant land use, soils, and slope, dominant HRU, and multiple HRUs. In this study, multiple HRUs option was selected to be able to create multiple HRUs within each sub-basin instead of focusing on the dominant land use and soil type and slope class. The final step was the identification of the threshold level for land use, soil and slope classes. This is used for the elimination of minor land use categories, soil types, and slope classes. Although the relevant values are set as 20%, 10%, and 20% for land use, soil, and slope, respectively, as default, they should be determined according to the project goal and the desired level of detail in the output. In this study all were set as 0% not to eliminate minor land uses, soils, and slopes. As can be seen in Table 4.3 and Table 4.18, the areas covered by the most of the land uses and soil types, respectively, are very small in the area. Finally, the Final HRU Distribution Report was created. This report included the distribution of the land use, soil, and slope classes within the watershed as well as the sub-basins generated based on the threshold

values. 1772 HRUs were created for 29 sub-basins. Figure 4.8 summarizes the distribution for different parameters following the HRU analysis.

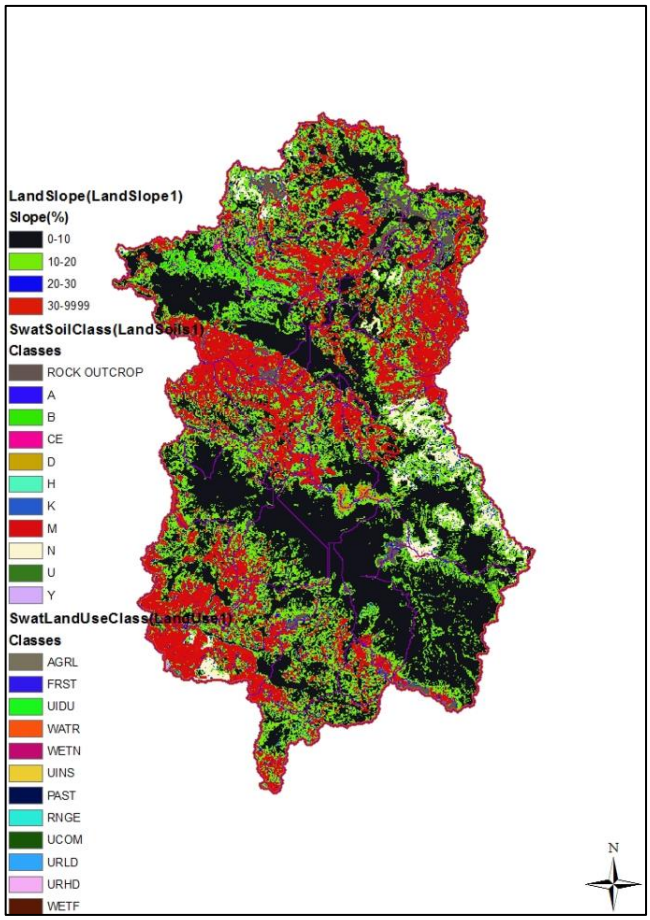


Figure 4.8 HRU definition

4.3 Weather Stations

Weather related parameters that are essential for the simulations are precipitation, maximum and minimum air temperatures, solar radiation, wind speed, and relative humidity. Although daily weather data for the simulation of most hydrologic models are essential, reaching these data is not easy because in most parts of the world either daily weather data is not available or not accurate. However, SWAT is able to superimpose missing data using monthly statistics by means of a weather generator model that uses monthly statistics calculated according to the available daily data via some software, WGN Excel Macro and pcpSTAT, which are available on the webpage of the model (URL 2, 2011). In cases where the users want to use simulated weather and there is missing data, this feature is quite useful.

Weather stations in the study area should be integrated into the SWAT databases which only contain weather stations across the United States. Therefore, prior to the SWAT simulation, weather stations should be input by the user. In order to do that, SWAT requires information regarding weather station and monthly weather parameters which are listed in Table 4.20.

Table 4.20 Weather generator database variables required by SWAT (Neitsch et al., 2010)

Weather Station Parameters	
Variable Name	**Definition**
Station Name	Weather station name (optional)
WLATITUDE (degree)	Latitude of weather station
WLONGITUDE (degree)	Longitude of weather station
WELEV (m)	Elevation of weather station
RAIN_YRS (yrs)	The number of years of maximum monthly 0.5 h rainfall data used to define values for RAIN_HHMX(1)–RAIN_HHMX(12). SWAT will set it as 10 if no value is entered.
Monthly Weather Parameters	
Variable Name	**Definition**
TMPMX (°C)	Average or mean daily maximum air temperature for month
TMPMN (°C)	Average or mean daily minimum air temperature for month
TMPSTDMX (°C)	Standard deviation for daily maximum air temperature in month
TMPSTDMN (°C)	Standard deviation for daily minimum air temperature in month
PCPMM (mm H_2O)	Average or mean total monthly precipitation
PCPSTD (mm H_2O/day)	Standard deviation for daily precipitation in month
PCPSKW	Skew coefficient for daily precipitation in month
PR_W1	Probability of a wet day that follows a dry day in the month
PR_W2	Probability of a wet day that follows a wet day in the month
PCPD	Average number of days of precipitation in month
RAINHHMX (mm H_2O)	Maximum 0.5 hour rainfall in entire period of record for month
SOLARAV (MJ/m^2/day)	Average daily solar radiation for month
DEWPT	Average daily dew point temperature for each month or relative humidity. If all twelve months are less than one, then the model assumes that relative humidity is input. Otherwise, dew point temperature becomes input. It is necessary if Penman-Monteith potential evaporation equation is used.
WNDAV (m/s)	Average daily wind speed in month

As it is well known, temperature plays an important role in a number of physical, chemical, and biological processes such as plant production, organic matter decomposition, and mineralization. Therefore, soil and water temperatures which can be derived from air temperature should be available. Furthermore, main mechanism that has a significant control on the water balance is precipitation. It can affect temperature, solar radiation, and relative humidity. SWAT offers two options, daily precipitation and sub-daily precipitation, to the users. If the SCS curve number method is used for the simulation of surface runoff, then daily precipitation option should be selected. On the other hand, the latter is used if the simulation bases on the Green &Ampt infiltration method. In this study, SCS curve number method was adopted because of the reasons

stated in Section 2.1.1.1; therefore, daily precipitation option was chosen. Solar radiation becomes an important energy input for keeping an accurate water balance because it has a major influence on the water movement in the land phase by altering snow fall, snow melt, and evaporation. The requirement of wind speed and relative humidity data depend on the method that is used for the prediction of PET and transpiration processes. Heuvelmans (2005) recommended using Penman-Monteith method provided that data required by the method are available as stated in Section 2.1.1.1. Therefore, the Penman-Monteith method was used in this study because wind speed and relative humidity data were available.

Meteorological data required by SWAT was obtained from the General Directorate of Meteorological Service for four meteorological stations; Kütahya, Afyonkarahisar Region, Bozüyük and Eskişehir Anatolia. The most appropriate station is determined by the SWAT by considering the relative distance. The information regarding these four meteorological stations was given in Table 3.1 in Section 3.1. Locations were depicted in Figure 3.4 in Section 3.1.

Meteorological data cover daily maximum and minimum temperature, daily total precipitation and solar radiation, daily average wind speed and relative humidity in a period of 17 years (1995-2011) for Kütahya and Eskişehir Anatolia stations. However, meteorological data regarding Bozüyük and Afyonkarahisar Region stations spans over 15 years (1997-2011). The missing two years of data were generated via weather generator. Latitude, longitude and elevation of these four meteorological stations were taken from the station information database which is available on the webpage of General Directorate of Meteorological Service (URL 3, 2012). Other variables given in Table 4.20, except maximum 0.5 hour rainfall in entire period of record for month (RAINHHMX), were calculated via WGN Excel Macro and pcpSTAT software. RAINHHMX values which are necessary to determine the peak runoff rate were calculated by looking at the daily precipitation data distribution and assuming that maximum daily precipitation falls in 0.5 hour in a month. In order to validate this assumption, average RAINHHMX values occurring for many years calculated on the basis of daily precipitation data were compared with the RAINHHMX values obtained from General Directorate of Meteorological Service. For Kütahya station which is the only station that has made observations for many years within the boundaries of the watershed, the RAINHHMX value obtained from General Directorate of Meteorological Service is 37.6 mm while calculated average RAINHHMX value is 39.3 mm. This comparison proved the validity of the assumption that was made.

After inputting the information about the weather stations within and vicinity of the study area, gage location tables for weather generator, precipitation, temperature, solar radiation, wind speed, and relative humidity were generated in dbase format. Formats of precipitation and temperature gage location tables are almost same. Only corresponding table names are different. Therefore, only temperature gage location table is given as an example. Table 4.21 shows the temperature gage location dbase table format. On the other hand, formats of weather generator, solar radiation, wind speed, and relative humidity gage location tables are the same except the

corresponding table name column. The only difference between these two groups is that precipitation and temperature gage location tables include elevation of rain gage (ELEVATION) as well as gage identification number (ID), gage name (NAME), x coordinate in the defined projection (XPR), and y coordinate in the defined projection (YPR). An example table to the second group is shown in Table 4.22.

Table 4.21 Temperature gage location table

ID	NAME	XPR	YPR	ELEVATION (m)
1	tmpa190	287960	4290529	1034
2	tmpe123	288461	4409802	787
3	tmpb702	248030	4421251	754
4	tmpk155	238863	4367410	969

Table 4.22 Weather generator gage location table

ID	NAME	XPR	YPR
1	a190	287960	4290529
2	e123	288461	4409802
3	b702	248030	4421251
4	k155	238863	4367410

In addition to the gage location tables, daily precipitation, temperature, solar radiation, wind speed, and relative humidity data tables were prepared for every location listed in the gage location table in a format specified by Winchell et al. (2010). The value of "-99.0" should be replaced with the missing data so that weather generator can generate a value in place of the missing data during simulation (Winchell et al., 2010). Furthermore, it is necessary to obtain records that have the same starting and ending date. Moreover, gage location tables and gage data tables should be located in the same folder. As an example, the maximum and minimum temperature data table of Kütahya Station (k155) is given in Table 4.23 for a selected time period. Following the weather database setup process, the weather gages determined by SWAT were added to the monitoring point layer. These are shown in Figure 4.9.

Table 4.23 Maximum and minimum temperature data table of Kütahya Station (k155) for a selected time period

DATE	MAX (°C)	MIN (°C)
1/1/1995	11.6	7.7
1/2/1995	15.2	11.0
1/3/1995	13.4	7.6
1/4/1995	12.0	4.2
1/5/1995	10.0	2.0
1/6/1995	12.0	3.8

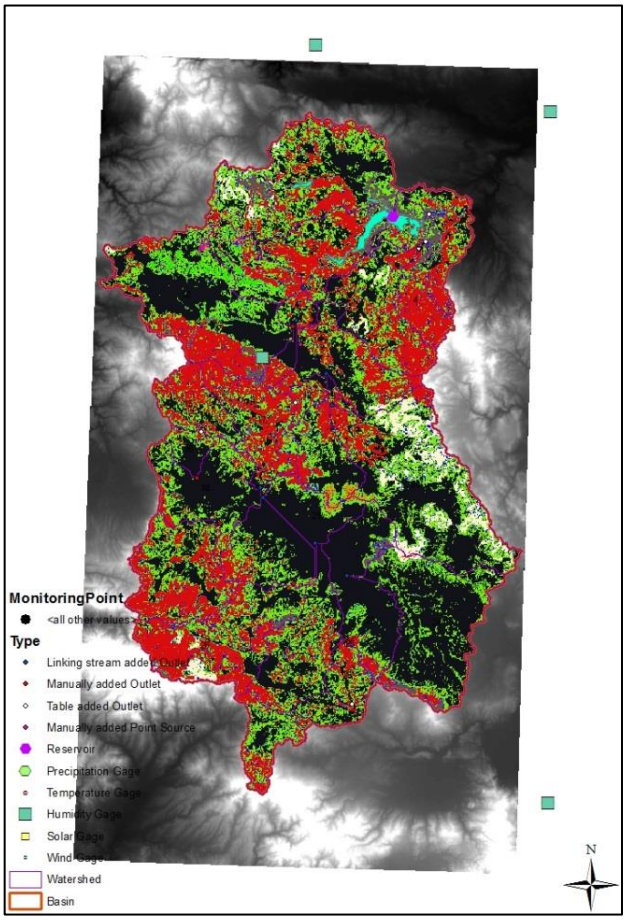


Figure 4.9 Weather gages used by SWAT

4.4 Identification of the Initial Watershed Inputs

Before conducting SWAT simulation, there is one more step, identification of the initial conditions for the watershed input parameters. SWAT is able to assign them by using default values or evaluation of the watershed delineation, land use/soil/slope characterization. Moreover, SWAT allows users to modify these input values via "Edit SWAT Input Menu" during initial run as well as during the calibration process. "Edit SWAT Input Menu" also allows to edit eight SWAT databases including soils, land cover, fertilizers, pesticides, tillage, urban, weather stations, and septic water quality because these databases contain information for US. Before writing the SWAT input tables, these databases must be edited in accordance with the properties for the study area. Soils, land cover, and weather stations databases were determined by considering the user defined soil groups, land cover, and weather station information as mentioned before. Fertilizers that are used in the study area were considered during the preparation of the fertilizer database. Modifications made for this database will be mentioned in Section 4.7.3. Tillage, urban, pesticide and septic water quality databases were accepted as the default ones.

4.5 Point Source Discharges

As stated in Section 4.1, one point source was introduced into the sub-basin 11 where KWWTP is located. Monthly records of input data regarding point source were obtained from KWWTP and entered into the model. The user defined point source data file should include loads regarding water, sediment, nutrients, carbonaceous biochemical oxygen demand (CBOD), DO, pesticide, metal, bacteria, and chlorophyll-a.

4.6 Reservoirs

Impoundments are significant components of water supply and flood control. One of the four types of impoundments that are modeled by SWAT is reservoirs. They are located on the main channel network of the watershed. They are subjected to the loadings from all sub-basins located in the upstream of the water body. As stated in Section 4.1, one reservoir was added into sub-basin 8. Its specifications are given in Table 4.24.

Table 4.24 Properties of the reservoir in the sub-basin 8

Reservoir specifications	**Value**	**Reference**
Reservoir surface area when the reservoir is filled to the emergency spillway	27.7 km^2	AKS Consulting, 2010
Reservoir surface area when the reservoir is filled to the principal spillway	23 km^2	URL 4, 2013
Volume of water needed to fill the reservoir to the emergency spillway	525 hm^3	AKS Consulting, 2010
Volume of water needed to fill the reservoir to the principal spillway	431 hm^3	URL 4, 2013

4.7 Management Operations

As stated previously, the objective of this study is to conduct a hypothetical assessment for agricultural non-point source pollution by applying different land use and water management practices. These practices are input in the HRU management file (.mgt) in which input data regarding planting, harvest, irrigation, fertilizer, and pesticide applications, and tillage operations as well as tile drains and urban areas are stored. This file consists of two parts which are general management variables and scheduled management operations. The former includes inputs that remain constant during the simulation whereas the latter organizes the schedule of management operations as the name implies. Table 4.25 shows the general management variables and scheduled management operations.

Table 4.25 General management variables and scheduled management operations (Neitsch et al., 2010)

General Management Variables	Initial Plant Growth Parameters General Management Parameters Urban Management Parameters Irrigation Management Parameters Tile Drain Management Parameters Management Operations
Scheduled Management Operations	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 Grazing Operation Auto Irrigation Initialization Auto Fertilization Initialization Street Sweeping Operation Release/Impound Continuous Fertilization Continuous Pesticide End of Year Rotation Flag

In the land use definition section (Section 4.2.1), agricultural areas within the boundary of the watershed were classified as Agricultural Land-Generic (AGRL) for simulation conducted using default values. Default management operations set by SWAT for AGRL was used for this simulation. It includes planting/beginning of growing season, auto fertilization initialization and harvest and kill operation.

As seen in Table 4.25, several management operations can be simulated in SWAT. In this study, only planting/beginning of growing season, irrigation operation, fertilizer application, tillage operation, harvest and kill operation were considered based on availability of information. Moreover, different management scenarios can be developed by changing the parameters regarding scheduled management operations. These operations will be explained here in detail.

4.7.1 Planting/Beginning of Growing Season

SWAT has two options for initiation of plant growth which are date and heat unit scheduling, but Nietsch et al. (2011) suggested using date scheduling if the information regarding the date of the planting/beginning of growing season is available. In this study, date scheduling was applied. For date scheduling, month and day of the operation are required and this information was obtained from Directorate of Eskişehir Soil and Water Resources Research Institute. However, the exact day of the operation is not available. According to the study conducted by Süzer (2004) and the given information in the websites of Provincial Directorates of Food, Agriculture, and

Livestock, the first day or the mid of the relevant month were used for planting of a given crop (Table 4.30).

4.7.2 Irrigation Operation

Irrigation operation is the most critical input among other management operations because it has direct impact on water balance. There are two options for irrigation, manual application of irrigation and auto-application of irrigation. The required information regarding irrigation operation is timing of the operation, application amount, source of irrigation water, and location of the source. In this study, only for one scenario, auto-application of irrigation was carried out whereas manual application of irrigation which is currently applied type of irrigation in the basin was selected for the rest of the scenarios. The application amount of the irrigation water was determined based on the information given in Table 3.6. Table 4.30 also includes irrigation amount (mm).

4.7.3 Fertilizer Application

SWAT allows applying fertilizer via the user defined schedule or auto-application schedule assigned by SWAT. In this study, user defined schedule for fertilizer application was applied. The necessary information for practicing fertilizer application is the timing of the operation, the type and amount of fertilizer, and the depth distribution of fertilizer application and they are given in Table 4.30. Some of the fertilizers that are applied in the study area are not available in the SWAT database. The fertilizer database contains information regarding the fraction of different forms of nitrogen and phosphorus as well as the concentration of bacteria that manure includes. Table 4.26 gives a brief description of the variables in the database.

Table 4.26 Data requirement for the fertilizer database in SWAT

Variable Name	Definition
IFNUM	Fertilizer identification number
FERTNM	Fertilizer name
FMINN	Mineral nitrogen (NO_3 and NH_4) fraction in fertilizer (kg min-N/kg fertilizer)
FMINP	Mineral phosphorus fraction in fertilizer (kg min-P/kg fertilizer)
FORGN	Organic nitrogen fraction in fertilizer (kg org-N/kg fertilizer)
FORGP	Organic phosphorus fraction in fertilizer (kg org-P/kg fertilizer)
FNH3N	Mineral nitrogen fraction in fertilizer applied as ammonia (kg NH_3-N/kg min-N)
BACTPDB	Persistent bacteria concentration in manure/fertilizer (# cfu/g manure) (optional)
BACTLPDB	Less-persistent bacteria concentration in manure/fertilizer (# cfu/g manure) (optional)
BACTKDDB	Bacteria partition coefficient (optional)

Fertilizer name and identification number were determined based on the ratio of N %, P_2O_5%, and K_2O %. According to Table 3.9, commonly applied fertilizer types in the study area are 21% $(NH_4)_2SO_4$, 26% and 33% $(NH_4)NO_3$, urea, TSP, DAP, 20.20.0, 20.20.0 + Zn, 15.15.15, 15.15.15 + Zn, 12.30.12, KNO_3, and 20% P_2O_5. 21% $(NH_4)_2SO_4$, 26% $(NH_4)NO_3$, TSP,

12.30.12, KNO_3, and 20% P_2O_5 are not available in the database. Therefore, they were added by calculating the equivalent fertilizer amounts given in Table 4.26. Table 4.27 indicates fertilizer types that are applied in the study area and their mineral and organic nitrogen and phosphorus contents.

Table 4.27 Fertilizer types and their mineral and organic nitrogen and phosphorus contents

Fertilizer Name	**FMINN (kg min-N/kg fertilizer)**	**FMINP (kg min-P/kg fertilizer)**	**FORGN (kg org-N/kg fertilizer)**	**FORGP (kg org-P/kg fertilizer)**	**FNH_3N (kg NH_3-N/kg min-N)**
21% $(NH_4)_2SO_4$ (21-00-00)	0.210	0.000	0.000	0.000	0.000
26% $(NH_4)NO_3$ (26-00-00)	0.260	0.000	0.000	0.000	0.000
33% $(NH_4)NO_3$ (33-00-00)	0.330	0.000	0.000	0.000	0.000
Urea	0.460	0.000	0.000	0.000	0.000
TSP (00-45-00)	0.000	0.198	0.000	0.000	0.000
DAP (18-46-00)	0.180	0.202	0.000	0.000	0.000
20.20.0 (20-20-00)	0.200	0.088	0.000	0.000	0.000
15.15.15 (15-15-15)	0.150	0.066	0.000	0.000	0.000
12.30.12 (12-30-12)	0.120	0.132	0.000	0.000	0.000
KNO_3 (13-00-46)	0.130	0	0.000	0.000	0.000
20% P_2O_5 (00-20 00)	0.000	0.088	0.000	0.000	0.000

4.7.4 Tillage Operation

Tillage operation provides mixing of the upper soil layers in terms of residue, nutrients, bacteria and pesticides if applied. Type and timing of the operation should be set. SWAT has a database for tillage and applied tillage operations in the study area are available in this database. Therefore, default values for the given tillage operations in Table 4.30 were used.

4.7.5 Harvest and Kill Operation

SWAT offers two alternatives to cease plant growth in HRU. The first alternative is harvest only operation. Plant biomass is removed from the HRU without killing the plant. It is applicable for tree, hay or grass. On the other hand, as the name implies, harvest and kill operation removes the fraction of plant biomass set by plant harvest index while killing the remaining fraction and converting it into residue. For wheat and sugar beet the second alternative is preferable. As in the case of planting/beginning of growing season, timing of the operation is the only information

that is essential for the application of the operation and it was obtained from Directorate of Eskişehir Soil and Water Resources Research Institute and is presented in Table 4.30.

In order to be able to write input values, Manning's roughness coefficient and heat unit values should be defined. Manning's roughness coefficient plays an important role in the determination of runoff velocity and flow rate because velocity calculation in SWAT bases on Manning's equation. On the other hand, heat unit is expressed as the accumulation of the difference between daily mean air temperature and plant's base temperature recorded throughout the plant's growth. It is also used to determine harvest dates of all types of crops (Neitsch et al., 2011).

4.8 SWAT Simulation

SWAT simulations were performed on yearly average data due to discontinuity in observation data. In such cases, Benaman et al. (2005) and Sudheer et al. (2007) suggested performing simulations on long term average basis. Before calibration, a SWAT run was conducted using default values. The simulation period was from January 1995 to September 2010 in which the first four years were used as the warm up period for average annual conditions. The intended use of the warm up period is to generate initial values of parameters that are not available (Bekiaris et al., 2005). Following the warm up period, the model is considered as ready to represent the conditions in the watershed. Although it is highly recommended to use at least 1 year of warm up period, it was stated that 2-5 years is preferable as stated in the model. On the other hand, Srinivasan (2012) stated that the duration of warm up period depends on the available data and types of simulation. For example, 2-3 years is suggested for hydrology whereas for water quality simulations it should be increased.

To be able to evaluate model performance in simulating flow rates, some measures should be used. Although there are numerous evaluation techniques as stated in Section 2.1.1.1, in this study the most commonly used ones, NSE and percent deviation between the simulated and observed yearly average flow rate values, are considered. Equation 4.2 (Nash and Sutcliffe, 1970) and 4.3 are used for the determination of NSE and percent deviation, respectively.

$$NSE=1-\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{mean}\right)^2}\right] \tag{4.2}$$

$$\text{Absolute Percent Deviation}_i=\frac{|Y_i^{obs}-Y_i^{sim}|}{Y_i^{obs}}\times 100 \tag{4.3}$$

where,

Y_i^{obs} : ith observation value for the constituent being evaluated
Y_i^{sim} : ith simulated value for the constituent being evaluated
Y^{mean} : mean of observed data for the constituent being evaluated
n : total number of observations

In literature, there are some predetermined criteria for these model performance evaluation measures. When these criteria are met, model can be considered successful and calibration process can be terminated as well. Although the range for NSE is in between $-\infty$ and 1.0, positive values (values between 0.0 and 1.0) are considered as acceptable (Moriasi et al., 2007). Santhi et al. (2001), Ramanarayanan et al. (1997) and Moriasi et al. (2007) considered simulation results as satisfactory when NSE was greater than 0.5. On the other hand, Green et al. (2006) and Green and Griensven (2008) terminated calibration process when a value greater than 0.4 for NSE was achieved. Even greater than 0.36 was considered to be satisfactory by Van Liew and Garbrecht (2003), Motovilov et al. (1999) and Geza and McCray (2008). Moreover, the agreed value of percent deviation is within ±15% by Abraham et al. (2007) and Santhi et al. (2001).

Water balance is considered as the driving force behind all the processes taking place in the watershed and it plays a fundamental role in all SWAT applications independent of the focus of the studies (Gassman et al., 2007). Besides, flow is the most commonly used watershed response variable in SWAT (White and Chaubey, 2005). The abovementioned criteria were used for the evaluation of model performance in terms of stream flow rate at the most downstream observation station prior to the PDR (sub-basin 8) and the most upstream observation station within the watershed (sub-basin 28). Stream flow observation station corresponding to the most downstream location prior to the PDR is operated by Electrical Power Resources Survey and Development Administration and it is numbered as 12-03 (Figure 4.10) . On the other hand, the most upstream observation station within the watershed belongs to SHW. This station is numbered as 12-093 (Figure 4.10). Stream flow observation stations located in between these two stations were ignored in this study because they do not have sufficient stream flow data.

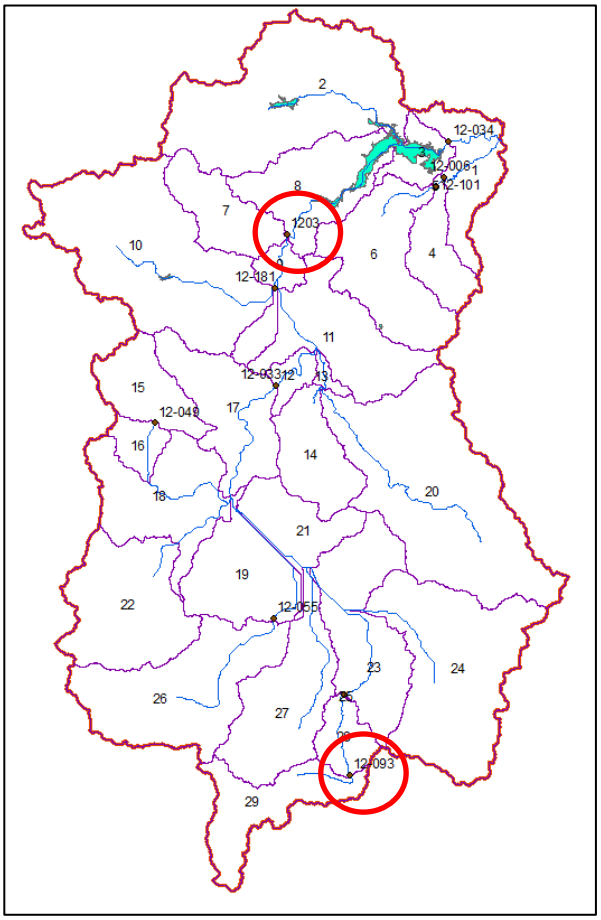


Figure 4.10 Locations of the most downstream observation station prior to the PDR and the most upstream observation station

4.9 Scenario Development

The major problem that has an impact on the water quality in the Watershed of the PDR is associated with phosphorus transport from agricultural areas (AKS Consulting, 2011). Therefore, different management scenarios were developed to determine the relative SOLP input arising from different agricultural practices and land use. SOLP is the only phosphorus form readily available for plant uptake.

Besides two base-case scenarios (Base-Case Scenario I and Base-Case Scenario II), nine scenarios were developed and will be explained in the following sections. A summary table is provided to summarize the differences between the scenarios considered in this study (Table 4.28). Base-Case Scenario I represents the simulation carried out using default management operations set by SWAT for AGRL whereas agricultural management practices applied in the study area for AGRC and SGBT (i.e. planting/beginning of growing season, fertilizer application, irrigation application, tillage operation and harvest and kill operation) were included

in Base-Case Scenario II. Also an additional scenario (Scenario X) was tested which included the combination of the two of the best nine scenarios in terms of reduction in SOLP loads.

Table 4.28 Representation of the scenarios

Scenarios	**Content**
Base-Case Scenario I	Agricultural areas were defined as AGRL and default management operations were used.
Base-Case Scenario II	Agricultural areas were split into AGRC, SGBT and AGRL and currently applied management operations in the study area were used.
Scenario I-a I-b I-c	Fertilizer application rates were increased by; two times three times four times
Scenario II-a II-b II-c II-d	Fertilizer application rates were reduced by; 20% 30% 40% 50%
Scenario III-a III-b III-c III-d	Irrigation rates were reduced by; 20% 30% 40% 50%
Scenario IV-a IV-b	Irrigated wheat production was considered and irrigation rates applied for SGBT were increased by; two times four times
Scenario V	Auto-irrigation was applied for SGBT and AGRC.
Scenario VI-a VI-b VI-c VI-d	SOLP loads resulting from KWWTP were decreased by; 20% 30% 40% 50% 67%
Scenario VII	AGRL was converted into RNGE for all sub-basins.
Scenario VIII-a VIII-b	 AGRL was replaced with RNGE in sub-basins 2, 3, 6 and 8. AGRC was replaced with RNGE in sub-basins 2, 3, 6 and 8.
Scenario IX-a IX-b	 AGRL was replaced with RNGE in sub-basins 8, 9, 11, 17, 21, 23 and 28. AGRC was replaced with RNGE in sub-basins 8, 9, 11, 17, 21, 23 and 28.
Scenario X	Fertilizer application and irrigation rates were reduced by 50% and 20%, respectively.

4.9.1 Base-Case Scenario I

In order to evaluate the relative impacts of different management practices applied in the study area, a Base-Case Scenario I was established. In this scenario, agricultural practices were defined as generic. In Base-Case Scenario I, all agricultural areas were defined as AGRL as stated in Section 4.2.1 and default management operations (planting/beginning of growing season, auto fertilization initialization and harvest and kill operation) defined by SWAT were used.

4.9.2 Base-Case Scenario II

As stated in Section 3.2, the most widely grown crops in the study area are wheat and sugar beet. In the basin, both irrigated and non-irrigated wheat productions are carried out. For the first scenario, only non-irrigated wheat production was considered. According to the USDA terminology, wheat is classified as close-grown crops and there is a predefined land use type for wheat in SWAT database which is Agricultural Land-Close-Grown (AGRC). Sugar beet is also defined in SWAT database as SGBT. To prepare the input for this scenario, AGRL was split into three for production of non-irrigated wheat, sugar beet and generic plants. SWAT land use classification developed for Base-Case Scenario II is given in Table 4.29. Different crops may require different fertilization, irrigation, tillage and harvesting practices which may impact overall SOLP loads from agricultural lands. Practices applied for wheat and sugar beet are listed in Table 4.30. All input variables, except land use and land management variables, were kept constant for Base-Case Scenario II.

Table 4.29 Land use classification developed for Base-Case Scenario II

Land Use Code (LUCODE)	**Area (%)**	**Current Land Use**	**Land Use Definition in SWAT Database**	
		Definition	**Definition**	**Symbol**
9	2.77	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	7.53	Agricultural Area	Agricultural Land-Generic	AGRL
1	33.06	Agricultural Area	Agricultural Land-Close-Grown	AGRC
1	1.26	Agricultural Area	Sugar Beet	SGBT
4	0.60	Lake	Water	WATR

Table 4.30 Agricultural management practices applied for wheat (AGRC) and sugar beet (SGBT)

Wheat (AGRC)	
Non-irrigated Agriculture	
Management practices	**Date and amount of the practices**
Tillage by paraplow	September 15
Tillage by finishing harrow	October 1
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	October 15 - 150 kg/ha
Planting/beginning of growing season	October 15
Fertilizer application (Urea)	February 15 - 60 kg/ha
Fertilizer application (Ammonium Nitrate, 26-00-00)	March 15 - 150 kg/ha
Harvest and kill operation	July 1
Sugar Beet (SGBT)	
Irrigated Agriculture	
Management practices	**Date and amount of the practices**
Tillage by paraplow	September 15
Tillage by finishing harrow	October 1
Fertilizer Application (20-20-00 Composite)	October 15 - 300 kg/ha
Fertilizer application (Ammonium Sulfate, 21-00-00)	October 15 - 200 kg/ha
Planting/beginning of growing season	November 1
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	March 15 - 200 kg/ha
Fertilizer application (Ammonium Nitrate, 33-00-00)	March 15 - 200 kg/ha
Irrigation	May 15 – 323.75 mm
Irrigation	June 15 – 323.75 mm
Irrigation	July 15 – 323.75 mm
Irrigation	August 15 – 323.75 mm
Harvest and kill operation	December15

4.9.3 Scenario I

In Scenario I, to assess the impact of fertilizer on SOLP, amount of fertilizer applied for wheat and sugar beet were doubled (Scenario I-a) and increased by three (Scenario I-b) and four times (Scenario I-c). Apart from these, there was no modification. Therefore, only changes in fertilizer application rates are given in Table 4.31. The rest of the management practices were the same as stated in Table 4.30.

Table 4.31 Management practices developed for Scenario I

Wheat (AGRC)				
Non-irrigated Agriculture				
Management practices	**Base-Case Scenario II**	**Scenario I-a**	**Scenario I-b**	**Scenario I-c**
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	October 15 - 150 kg/ha	October 15 - 300 kg/ha	October 15 - 450 kg/ha	October 15 - 600 kg/ha
Fertilizer application (Urea)	February 15 - 60 kg/ha	February 15 - 120 kg/ha	February 15 - 180 kg/ha	February 15 - 240 kg/ha
Fertilizer application (Ammonium Nitrate, 26-00-00)	March 15 - 150 kg/ha	March 15 - 300 kg/ha	March 15 - 450 kg/ha	March 15 - 600 kg/ha
Sugar Beet (SGBT)				
Irrigated Agriculture				
Management practices	**Base-Case Scenario II**	**Scenario I-a**	**Scenario I-b**	**Scenario I-c**
Fertilizer Application (20-20-00 Composite)	October 15 - 300 kg/ha	October 15 - 600 kg/ha	October 15 - 900 kg/ha	October 15 - 1200 kg/ha
Fertilizer application (Ammonium Sulfate, 21-00-00)	October 15 - 200 kg/ha	October 15 - 400 kg/ha	October 15 - 600 kg/ha	October 15 - 800 kg/ha
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	March 15 - 200 kg/ha	March 15 - 400 kg/ha	March 15 - 600 kg/ha	March 15 - 800 kg/ha
Fertilizer application (Ammonium Nitrate, 33-00-00)	March 15 - 200 kg/ha	March 15 - 400 kg/ha	March 15 - 600 kg/ha	March 15 - 800 kg/ha

4.9.4 Scenario II

In addition to the increase in fertilizer application rates, Scenario II was built to see the effect of decrease in fertilizer application rates on SOLP. Therefore, fertilizer application rates were reduced by 20% (Scenario II-a), 30% (Scenario II-b), 40% (Scenario II-c) and 50% (Scenario II-d) in this scenario. These percentages were determined to assess the impact of fertilizer consumption on SOLP loads arising from different sub-basins. Proposed fertilizer types and amounts are site specific. Before the determination of fertilizer types and amounts that are appropriate for a given crop, a detailed survey for a given soil and crop has to be carried out. Management practices modified in Scenario II are provided in Table 4.32.

Table 4.32 Management operations developed for wheat and sugar beet in Scenario II

Wheat (AGRC)					
Non-irrigated Agriculture					
Management practices	**Base-Case Scenario II**	**Scenario II-a**	**Scenario II-b**	**Scenario II-c**	**Scenario II-d**
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	October 15 - 150 kg/ha	October 15 - 120 kg/ha	October 15 - 105 kg/ha	October 15 - 90 kg/ha	October 15 - 75 kg/ha
Fertilizer application (Urea)	February 15 - 60 kg/ha	February 15 - 48 kg/ha	February 15 - 42 kg/ha	February 15 - 36 kg/ha	February 15 - 30 kg/ha
Fertilizer application (Ammonium Nitrate, 26-00-00)	March 15 - 150 kg/ha	March 15 - 120 kg/ha	March 15 - 105 kg/ha	March 15 - 90 kg/ha	March 15 - 75 kg/ha
Sugar Beet (SGBT)					
Irrigated Agriculture					
Management practices	**Base-Case Scenario II**	**Scenario II-a**	**Scenario II-b**	**Scenario II-c**	**Scenario II-d**
Fertilizer Application (20-20-00 Composite)	October 15 - 300 kg/ha	October 15 - 240 kg/ha	October 15 - 210 kg/ha	October 15 - 180 kg/ha	October 15 - 150 kg/ha
Fertilizer application (Ammonium Sulfate, 21-00-00)	October 15 - 200 kg/ha	October 15 - 160 kg/ha	October 15 - 140 kg/ha	October 15 - 120 kg/ha	October 15 - 100 kg/ha
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)	March 15 - 200 kg/ha	March 15 - 160 kg/ha	March 15 - 140 kg/ha	March 15 - 120 kg/ha	March 15 - 100 kg/ha
Fertilizer application (Ammonium Nitrate, 33-00-00)	March 15 - 200 kg/ha	March 15 - 160 kg/ha	March 15 - 140 kg/ha	March 15 - 120 kg/ha	March 15 - 100 kg/ha

4.9.5 Scenario III

The effect of using different irrigation application amounts on SOLP was investigated in Scenario III. Therefore, application amounts of the irrigation for sugar beet were reduced by 20% (Scenario III-a), 30% (Scenario III-b), 40% (Scenario III-c) and 50% (Scenario III-d) while all other parameters were the same as those used in Base-Case Scenario II. These percentages, except 50% decrease, can be achieved using irrigation methods other than surface type irrigation (e.g. sprinkling, drip irrigation, etc.). 50% decrease in irrigation rate was also considered to evaluate the impact of irrigation on SOLP transport. Table 4.33 focuses on the changes in irrigation application amounts.

Table 4.33 Management practices developed for sugar beet in Scenario III

Sugar Beet (SGBT)					
Irrigated Agriculture					
Management practices	**Base-Case Scenario II**	**Scenario III-a**	**Scenario III-b**	**Scenario III-c**	**Scenario III-d**
Irrigation	May 15 – 323.75 mm	May 15 – 259 mm	May 15 – 226.63 mm	May 15 – 194.25 mm	May 15 – 161.88 mm
Irrigation	June 15 – 323.75 mm	June 15 – 259 mm	June 15 – 226.63 mm	June 15 – 194.25mm	June 15 – 161.88mm
Irrigation	July 15 – 323.75 mm	July 15 – 259 mm	July 15 – 226.63 mm	July 15 – 194.25mm	July 15 – 161.88mm
Irrigation	August 15 – 323.75 mm	August 15 – 259 mm	August 15 – 226.63 mm	August 15 – 194.25mm	August 15 – 161.88mm

4.9.6 Scenario IV

In Scenario IV, application amounts of the irrigation for sugar beet were doubled (Scenario IV-a) and increased by four times (Scenario IV-b) to assess the impact of irrigation amount on SOLP because irrigation plays an important role in water balance as stated in Section 4.7.2. Moreover, irrigated wheat production was applied for this scenario. For other practices, values given for Base-Case Scenario II were valid. Table 4.34 defines the management operations modified in Scenario IV.

Table 4.34 Management operations developed for wheat and sugar beet in Scenario IV

Wheat (AGRC)			
Irrigated Agriculture			
Management practices		**Date and amount of the practices**	
Fertilizer application (Diammonium Phosphate (DAP), 18-46-00)		October 15 - 200 kg/ha	
Irrigation		May 15 – 392.5 mm	
Irrigation		August 1 – 392.5 mm	
Sugar Beet (SGBT)			
Irrigated Agriculture			
Management practices	**Base-Case Scenario II**	**Scenario IV-a**	**Scenario IV-b**
Irrigation	May 15 – 323.75 mm	May 15 – 647.5 mm	May 15 – 1295 mm
Irrigation	June 15 – 323.75 mm	June 15 – 647.5 mm	June 15 – 1295 mm
Irrigation	July 15 – 323.75 mm	July 15 – 647.5 mm	July 15 – 1295 mm
Irrigation	August 15 – 323.75 mm	August 15 – 647.5 mm	August 15 – 1295 mm

4.9.7 Scenario V

As a last irrigation application modification, Scenario V was built. Up to now, manual application of irrigation was applied based on the values given in Table 3.6. In this scenario, auto-application of irrigation in which irrigation is automatically applied depending on water stress threshold or soil water deficit threshold was selected. With this type of irrigation whenever user defined water stress is experienced irrigation is introduced to the system. Therefore, only irrigation dates specified in Table 4.34 for both wheat and sugar beet were input.

4.9.8 Scenario VI

In Scenario VI, 20% (Scenario VI-a), 30% (Scenario VI-b), 40% (Scenario VI-c), 50% (Scenario VI-d) and 67% (Scenario VI-e) decrease in SOLP loads resulting from KWWTP which is the only point source introduced into the model were considered. Current phosphorus treatment efficiency of KWWTP is about 70% (AKS Consulting, 2011) and 67% decrease in SOLP corresponds to 90% phosphorus treatment efficiency. With the application of this scenario, whether wastewater treatment plant process modification regarding phosphorus treatment is required or not will be understood. For all management operations, values given for Base-Case Scenario II were valid. The same changes in SOLP loads resulting from KWWTP were applied to the Base-Case Scenario I as well.

4.9.9 Scenario VII

In order to determine the degree of influence of the agricultural land use on the study area, agricultural land use defined in Base-Case Scenario I (AGRL) was replaced with Range-Grasses (RNGE) in Scenario VII. Land use classification developed for Scenario VII is given in Table

4.35. As can be seen in Table 4.35, RNGE increased by 42% with respect to land use developed for Base-Case Scenario I.

Table 4.35 Land use classification developed for Scenario VII

Land Use Code (LUCODE)	**Area (%)**	**Current Land Use**	**Land Use Definition in SWAT Database**	
		Definition	**Definition**	**Symbol**
9	44.62	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
4	0.60	Lake	Water	WATR

4.9.10 Scenario VIII

To create a buffer zone around the PDR, agricultural land use defined in Base-Case Scenario I (AGRL) was replaced with RNGE in sub-basins 2, 3, 6 and 8. Therefore, AGRL decreased by 4.8% while RNGE increased by 4.8%. Table 4.36 shows land use classification developed for Scenario VIII-a. On the other hand, Scenario VIII-b was built to determine the relative effect of land use modification with respect to the Base-Case Scenario II. Thus, agricultural land uses on the sub-basins (2, 3, 6 and 8) located around the PDR were replaced with RNGE. AGRC is the dominant agricultural crop grown in these sub-basins. As a result, AGRC decreased by 3.8% in total in sub-basins 2, 3, 6 and 8 while RNGE increased by 3.8%. Result of the land use update is presented in Table 4.37.

Table 4.36 Land use classification developed for Scenario VIII-a

Land Use Code (LUCODE)	Area (%)	Current Land Use	Land Use Definition in SWAT Database	
		Definition	**Definition**	**Symbol**
9	7.57	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	37.05	Agricultural Area	Agricultural Land-Generic	AGRL
4	0.60	Lake	Water	WATR

Table 4.37 Land use update applied for Scenario VIII-b

Land Use Code (LUCODE)	Area (%)	Current Land Use	Land Use Definition in SWAT Database	
		Definition	**Definition**	**Symbol**
9	6.57	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	7.53	Agricultural Area	Agricultural Land-Generic	AGRL
1	29.26	Agricultural Area	Agricultural Land-Close-Grown	AGRC
1	1.26	Agricultural Area	Sugar Beet	SGBT
4	0.60	Lake	Water	WATR

4.9.11 Scenario IX

In addition to the sub-basins surrounding the PDR, the influence of land uses in sub-basins around the tributaries on SOLP loads transported to the PDR was also tried to identify. For this purpose, buffer zones were created around the tributaries in Scenario IX-a. Therefore, RNGE

type land use was set for the tributaries in sub-basins 8, 9, 11, 17, 21, 23 and 28 instead of agricultural land use which was defined in Base-Case Scenario I as AGRL. As a result of land use update, RNGE increased by 8.1% whereas AGRL decreased by the same amount. Land use classification developed for Scenario IX-a is given in Table 4.38. In Scenario IX-b, agricultural land use on the sub-basins around the main tributaries (8, 9, 11, 17, 21, 23 and 28) was replaced with RNGE. These sub-basins were dominated by AGRC. Therefore, AGRC (6.4% decrease) was replaced with RNGE (6.4% increase) in these sub-basins. As a result of this modification, generated land use distributions are provided in Table 4.39.

Table 4.38 Land use classification developed for Scenario IX-a

Land Use Code (LUCODE)	**Area (%)**	**Current Land Use**	**Land Use Definition in SWAT Database**	
		Definition	**Definition**	**Symbol**
9	10.85	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	33.77	Agricultural Area	Agricultural Land-Generic	AGRL
4	0.60	Lake	Water	WATR

Table 4.39 Land use distributions generated for Scenario IX-b

Land Use Code (LUCODE)	**Area (%)**	**Current Land Use**	**Land Use Definition in SWAT Database**	
		Definition	**Definition**	**Symbol**
9	9.16	Range + Rural Land Use + Shrubbery	Range-Grasses	RNGE
2	44.14	Forest	Forest Mixed	FRST
16	0.12	Wetland	Wetlands-Forested	WETF
6	0.13	Military Site	Institutional	UINS
5	0.00	Marshy Place	Wetlands-Non-Forested	WETN
8	6.08	Pasture	Pasture	PAST
11	0.05	Storage Area	Commercial	UCOM
12	1.02	Stony Area	Residential-Low Density	URLD
15	1.41	Urban Land Use + Residential Area	Residential-High Density	URHD
3	1.82	Mining Site + Industrial Area	Industrial	UIDU
1	7.53	Agricultural Area	Agricultural Land-Generic	AGRL
1	26.67	Agricultural Area	Agricultural Land-Close-Grown	AGRC
1	1.26	Agricultural Area	Sugar Beet	SGBT
4	0.60	Lake	Water	WATR

CHAPTER 5

RESULTS AND DISCUSSION

This chapter includes information regarding simulation results, sensitivity analysis output, manual calibration results and scenario simulation results. SWAT simulations were carried out between January 1995 and September 2010 with 4 years of warm up period for average annual conditions. Details of the initial stage in SWAT simulation were explained in Section 4.8. Results of the SWAT run conducted using default values in terms of flow rates for the sub-basin 8 (the most downstream observation station prior to the PDR) and sub-basin 28 (the most upstream observation station within the watershed) are given in Table 5.1. Figure 5.1 and Figure 5.2 provide simulated versus observed flow rates for sub-basins 8 and 28, respectively. As stated before, the dominant land use in the study area is agricultural land use and irrigated agricultural productions are carried out. However, information regarding the irrigation amounts and the water amount withdrawn from the river for irrigation are not available. Therefore, flow rates that belong to the months at which irrigation is applied were disregarded for observation station 12-03 during calibration. On the other hand, all observed flow rates for observation station 12-093 were used because there is no irrigation area located around it. When Table 5.1 was examined, it can be clearly seen that default values were not sufficient to obtain acceptable results which also indicates the need for calibration. If Figure 5.1 and Figure 5.2 are examined separately, it can be seen that in general simulated flow rates are higher than observed flow rates in both stations.

Table 5.1 Simulated and observed flow rates for both sub-basin 8 (the most downstream prior to the PDR) and sub-basin 28 (the most upstream) on average annual basis for default model parameters

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation* (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation* (%)	
1999	32.81	9.46	246.98	-93.92	1.36	-	-	-3.45
2000	37.20	6.02	518.45		1.12	-	-	
2001	41.75	4.28	876.61		0.92	0.23	304.56	
2002	45.82	10.64	330.56		1.59	0.92	72.45	
2003	32.07	9.03	255.35		1.18	0.70	67.19	
2004	22.45	7.43	202.32		0.57	0.64	10.09	
2005	23.84	5.79	311.89		0.61	-	-	
2006	31.17	7.80	299.72		1.24	-	-	
2007	21.90	3.56	515.00		0.80	-	-	
2008	15.43	3.05	406.73		0.72	-	-	
2009	40.76	8.50	379.30		1.52	-	-	
2010	29.65	11.19	164.97		1.34	0.89	51.69	
Average	**31.24**	**7.23**	**332.23**		**1.08**	**0.68**	**60.10**	

*Absolute Percent Deviation

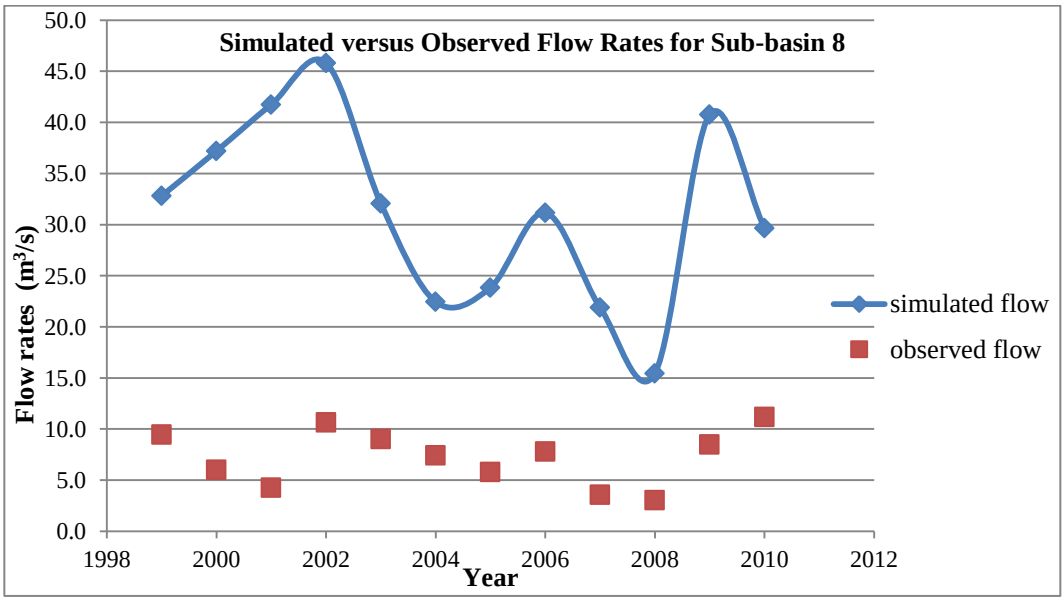


Figure 5.1 Simulated and observed flow rates for average annual conditions for default model parameters: sub-basin 8

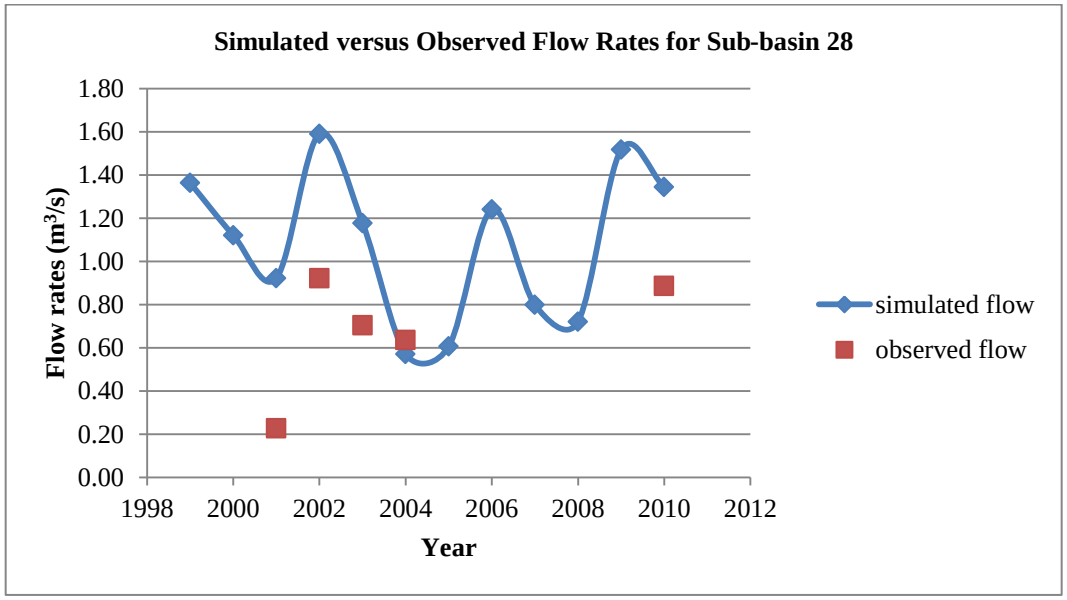


Figure 5.2 Simulated and observed flow rates for average annual conditions for default parameters: sub-basin 28

Madsen (2003) stated that hydrology related parameters should be modified at the first place to reduce the impacts of correlation between model parameters and predicted outputs and uncertainty resulting from measurements. Neitsch et al. (2002a) also specified an order to be followed during model calibration. According to this, firstly water balance and stream flow which is followed by sediment and nutrients should be calibrated. In this study, only flow calibration was carried out due to lack of water quality data. Firstly, a sensitivity analysis was performed. This analysis was also limited to the sensitivity of simulated flow rates to flow related parameters.

5.1 Sensitivity Analysis

State variables in SWAT are controlled by numerous parameters. This makes the calibration process complex, time consuming and computationally extensive. In order to reduce the number of parameters involved in the calibration process, sensitivity analysis can be performed. There are two options for conducting a sensitivity analysis in SWAT which are running sensitivity analysis with or without observed data. In this study, observed flow rates data obtained from Electrical Power Resources Survey and Development Administration's observation station (12-03) was used. Station 12-03 is the closest station to the main watershed outlet and has sufficient stream flow data.

There are 27 flow related parameters assigned by SWAT for sensitivity analysis. Sensitivity for these 27 flow parameters was determined and given in Table 5.2. During sensitivity analysis, the parameter values were changed within the ranges given as the lower and upper bounds in Table

5.2. The number of intervals within LH and the percentage of change were set as 10 and 5% by default, respectively. A total of 280 runs were executed for sensitivity analysis. The sensitivity of the parameters is determined via sensitivity index defined by the Equation 5.1 (Srinivasan and van Griensven, 2007). The greater the sensitivity index, the more is the output influenced by the variations in the inputs.

$$I=\frac{x}{y}\frac{(y_2-y_1)}{(x_2-x_1)} \tag{5.1}$$

where,

I : sensitivity index
x : parameter
y : predicted output
x_1, x_2 : correspond to predetermined percent change of the initial parameter
y_1, y_2 : correspond to predetermined percent change of the predicted output

Table 5.2 Parameters in the sensitivity analysis, their rankings, ranges and units, and processes that are represented by these parameters

Parameter	**Description**	**Process**	**Unit**	**Ranking Based on Sensitivity Level**	**Lower Bound**	**Upper Bound**
Alpha_bf	Base-flow Alpha Factor	Groundwater	days	1	0	1
Cn2	Initial SCS runoff curve number for moisture condition II	Surface runoff	%	2	-25	25
Rchrg_dp	Deep aquifer percolation fraction	Groundwater	-	3	0	1
Surlag	Surface runoff lag coefficient	Surface runoff	days	4	0	10
Ch_K2	Channel effective hydraulic conductivity	Channel	mm/h	5	0	150
Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur	Groundwater	mm	6	0	1000
Esco	Soil evaporation compensation factor	Evapotranspiration	-	7	0	1
Ch_N2	Manning's n value for main channel	Channel	-	8	0	1
Blai	Maximum potential leaf area index	Crop	-	9	0	1
Canmx	Maximum canopy storage	Runoff	mm	10	0	10
Sol_Z	Depth from soil surface to bottom of layer	Soil	mm	11	-25	25
Sol_Awc	Available water capacity of the soil layer	Soil	mmH_2O/mm soil	12	-25	25
Gw_Revap	Groundwater revap coefficient	Groundwater	-	13	0	0.036
Slope	Average slope steepness	Geomorphology	m/m	14	-25	25
Sol_K	Saturated hydraulic conductivity	Soil	mm/h	15	-25	25
Epco	Plant uptake compensation factor	Evapotranspiration	-	16	0	1
Revapmn	Threshold depth of water in the shallow aquifer required for revap or percolation to the deep aquifer to occur	Groundwater	mm	17	0	100
Gw_Delay	Groundwater delay time	Groundwater	days	18	0	10
Biomix	Biological mixing efficiency	Soil	-	19	0	1
Slsubbsn	Average slope length	Geomorphology	m	20	-25	25
Sol_Alb	Moist soil albedo	Evapotranspiration	-	21	-25	25
Sftmp	Snowfall temperature	Snow	^{o}C	27	0	5
Smfmx	Melt factor for snow on June 21	Snow	mm $H_2O/^{o}$C-day	27	0	10
Smfmn	Melt factor for snow on December 21	Snow	mm $H_2O/^{o}$C-day	27	0	10
Smtmp	Snow melt base temperature	Snow	^{o}C	27	-25	25
Timp	Snow pack temperature lag factor	Snow	-	27	0	1
Tlaps	Temperature lapse rate	Geomorphology	^{o}C/km	27	0	50

5.2 Manual Calibration

SWAT manual calibration for flow involves modification of flow related parameters by using predetermined variation methods to achieve performance evaluation criteria given in Section 4.8. In manual calibration, it is user's responsibility to control whether the modified parameters are in the predefined range or not. It is not necessary to modify all the parameters determined by sensitivity analysis. Therefore, based on the studies conducted by Güngör and Göncü (2012), Sudheer et al. (2007), Santhi et al. (2001), White and Chaubey (2005), Abraham et al. (2007), Beneman et al. (2005) and Van Liew et al. (2005) and results of the sensitivity analysis conducted in this study, some parameters were selected for calibration. These parameters were categorized into three groups. This categorization makes decision making process regarding the selection of the priority parameters for calibration easier. Modified parameters and processes that are controlled by these parameters are given in Table 5.3 and modifications made during calibration were applied for all HRUs.

Table 5.3 Parameters and processes governed by these parameters

Process	**Parameter**
Surface Response	CN2
	SOL_AWC
	ESCO
	EPCO
	SLOPE
	CANMX
Sub-surface Response	GW_REVAP
	REVAPMN
	GW_DELAY
	GWQMN
	RCHRG_DP
	ALPHA_BF
Basin Response	CH_K2
	CH_N2
	SURLAG

The parameters given in Table 5.3 were modified one by one and in combinations to determine their effects on the flow rates and it was realized that the changes in ET method, base-flow alpha factor (ALPHA_BF) and deep aquifer percolation fraction (RCHRG_DP) provide a considerable improvement in flow rate values. These parameters are also among the most common ones used in calibration of SWAT in literature (White and Chaubey, 2005; Van Liew and Garbrecht, 2003; Abraham et al., 2007; Güngör and Göncü, 2012). Default values were used for the rest of the parameters. In the case of overestimation of flow rates, it is recommended that the very first thing to do is to change ET method (Srinivasan, 2012). Therefore, instead of Penman-Monteith method, Hargreaves method was used for the estimation of ET because it is robust and requires less data as mentioned in Section 2.1.1.1. The results of the simulation after the modification of

ET method are given in Table 5.4. Simulated versus observed flow rates for sub-basins 8 and 28 are provided in Figure 5.3 and Figure 5.4, respectively. As can be seen in Table 5.4, even if ET method was changed, model overestimated flow rates in both upstream and downstream of the watershed. To overcome this problem, surface runoff was reduced by increasing groundwater flow. Therefore, the primary aim was here to modify parameters leading to decrease in surface runoff by increasing groundwater flow because their impact on surface runoff is considerable. When Table 5.1 and Table 5.4 were compared, it was seen that there is a decrease in both NSE and average absolute percent deviation between the simulated and observed yearly average flow rate values. For sub-basin 8, 27% and 15% decrease in NSE and average absolute percent deviation were achieved. For sub-basin 28, 15% and 17% decrease in NSE and average absolute percent deviation were achieved as well. However, predetermined criteria in literature for these measures were not met. As mentioned above, ALPHA_BF is one of the groundwater related parameters that were modified during manual calibration process. It represents the reaction of groundwater flow to varying recharges (Neitsch et al., 2010). Its default value is 0.048 days. It was reduced to 0.01 days. Results of this modification are presented in Table 5.5. Simulated versus observed flow rates for sub-basins 8 and 28 are presented in Figure 5.5 and Figure 5.6. As can be seen in Table 5.5, there is a decrease in NSE and average absolute percent deviation when compared to Table 5.1, but the extent of decrease was less than that was achieved by ET modification.

Table 5.4 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis after changing ET method

Year	**Sub-basin 8 (12-03)**			**NSE**	**Sub-basin 28 (12-093)**			**NSE**
	Simulated (m^3/s)	**Observed (m^3/s)**	**Deviation (%)**		**Simulated (m^3/s)**	**Observed (m^3/s)**	**Deviation (%)**	
1999	30.31	9.46	220.54	-68.98	1.31	-	-	-2.92
2000	32.51	6.02	440.48		1.00	-	-	
2001	39.26	4.28	818.36		0.89	0.23	289.39	
2002	41.01	10.64	285.36		1.55	0.92	67.90	
2003	28.99	9.03	221.22		1.12	0.70	58.38	
2004	19.31	7.43	160.03		0.49	0.64	22.81	
2005	21.29	5.79	267.83		0.53	-	-	
2006	27.68	7.80	254.96		1.12	-	-	
2007	17.22	3.56	383.57		0.68	-	-	
2008	13.56	3.05	345.32		0.71	-	-	
2009	34.51	8.50	305.81		1.47	-	-	
2010	25.87	11.19	131.19		1.30	0.89	46.95	
Average	**27.63**	**7.23**	**282.27**		**1.01**	**0.68**	**50.05**	

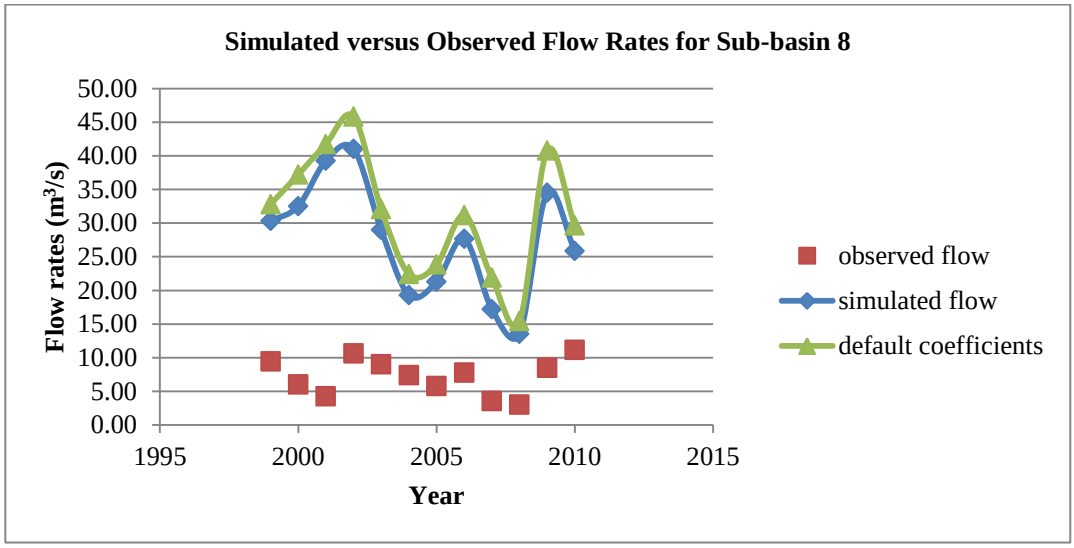


Figure 5.3 Simulated and observed flow rates for average annual conditions after the modification of the ET method: sub-basin 8

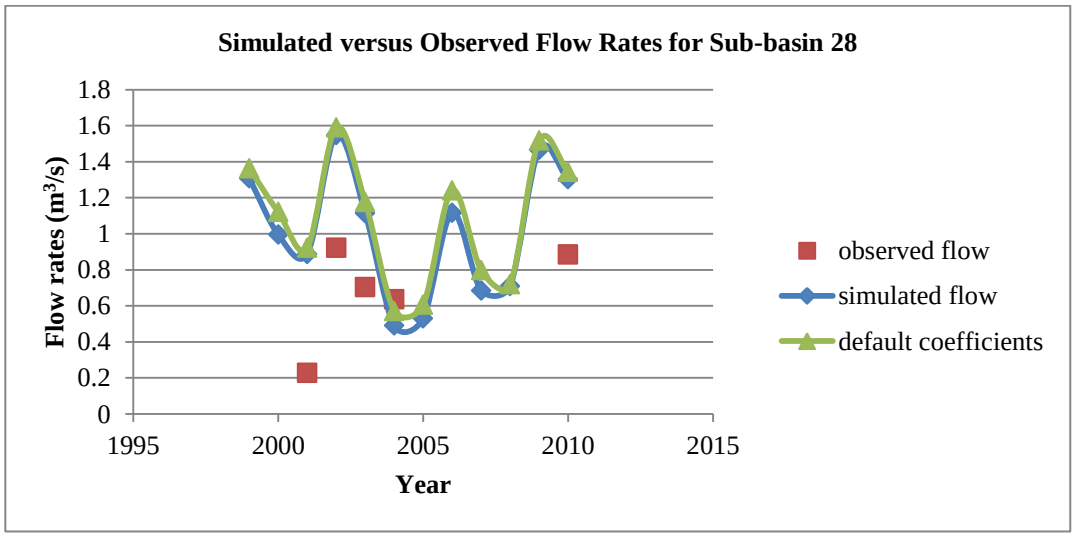


Figure 5.4 Simulated and observed flow rates for average annual conditions after modification of the ET method: sub-basin 28

Table 5.5 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis when ALPHA_BF = 0.01 days

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)	
1999	32.89	9.46	247.82	-85.22	1.32	-	-	-2.47
2000	36.18	6.02	501.50		1.06	-	-	
2001	37.96	4.28	787.95		0.77	0.23	238.03	
2002	45.12	10.64	323.98		1.61	0.92	74.84	
2003	32.62	9.03	261.44		1.05	0.70	49.72	
2004	21.60	7.43	190.87		0.57	0.64	9.80	
2005	22.65	5.79	291.33		0.49	-	-	
2006	27.25	7.80	249.45		1.08	-	-	
2007	20.70	3.56	481.30		0.80	-	-	
2008	16.69	3.05	448.11		0.67	-	-	
2009	39.33	8.50	362.49		1.48	-	-	
2010	29.21	11.19	161.04		1.30	0.89	46.39	
Average	**30.18**	**7.23**	**317.64**		**1.02**	**0.68**	**50.67**	

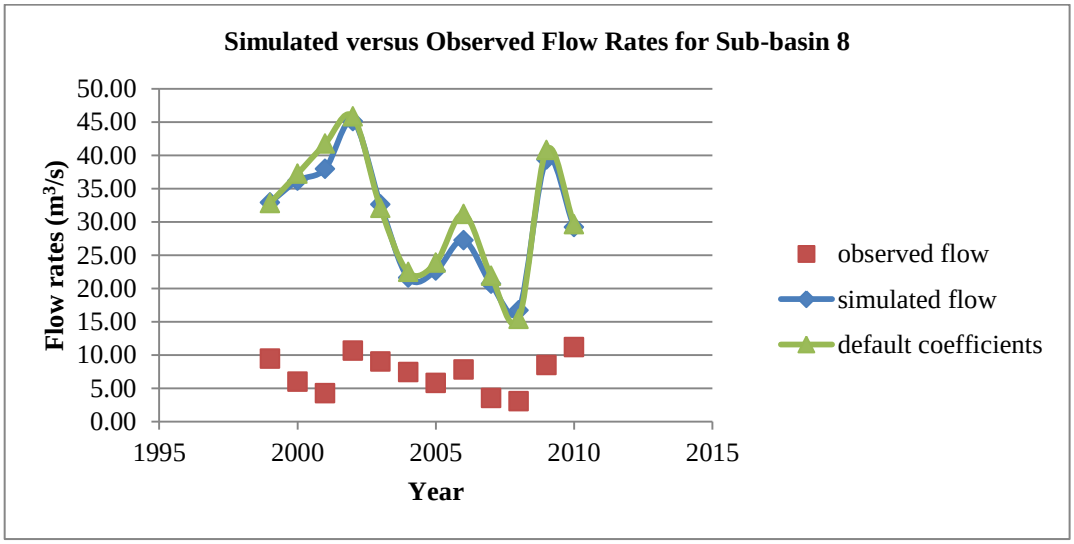


Figure 5.5 Simulated and observed flow rates for average annual conditions when ALPHA_BF = 0.01 days: sub-basin 8

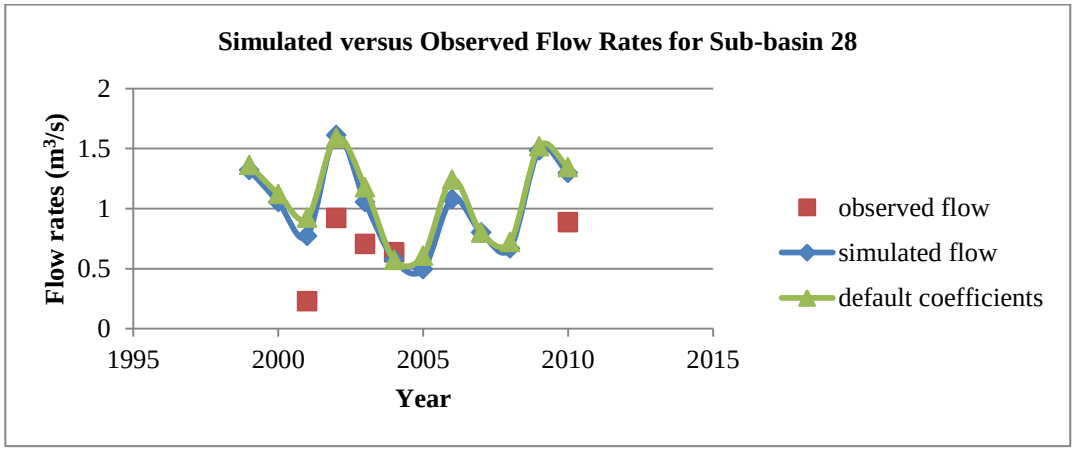


Figure 5.6 Simulated and observed flow rates for average annual conditions sub-basin 28 when ALPHA_BF = 0.01 days: sub-basin 28

The second modification regarding ALPHA_BF is to reduce it to its minimum value (ALPHA_BF = 0.0 days) to satisfy further improvement in flow rate simulation. Although it seems that it did not achieve a considerable decrease by itself, it is a quite significant parameter when it is used in combination with RCHRG_DP based on other trials that will be shown later on. The results of the second modification of ALPHA_BF are given in Table 5.6. Simulated versus observed flow rates for sub-basins 8 and 28 are shown in Figure 5.7 and Figure 5.8, respectively. As can be seen in Table 5.6, relatively low percent deviation was achieved in 1999 for sub-basin 8 and in 2003 for sub-basin 28. In overall, although there is room for improvement, 84% and 72% decrease in NSE and average absolute percent deviation for sub-basin 8 were achieved. For sub-basin 28, 81% and 55% reduction in NSE and average absolute percent deviation were obtained.

Table 5.6 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis when ALPHA_BF = 0.0 days

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)	
1999	9.20	9.46	2.66	-15.11	0.38	-	-	-0.65
2000	21.07	6.02	250.29		0.69	-	-	
2001	31.64	4.28	640.12		0.52	0.23	128.86	
2002	17.93	10.64	68.48		0.73	0.92	21.33	
2003	15.49	9.03	71.63		0.71	0.70	0.23	
2004	8.98	7.43	20.86		0.30	0.64	52.31	
2005	8.45	5.79	45.91		0.21	-	-	
2006	17.83	7.80	128.65		0.69	-	-	
2007	9.62	3.56	170.04		0.44	-	-	
2008	4.00	3.05	31.30		0.21	-	-	
2009	16.63	8.50	95.56		0.67	-	-	
2010	7.24	11.19	35.27		0.37	0.89	57.70	
Average	**14.01**	**7.23**	**93.80**		**0.49**	**0.68**	**26.78**	

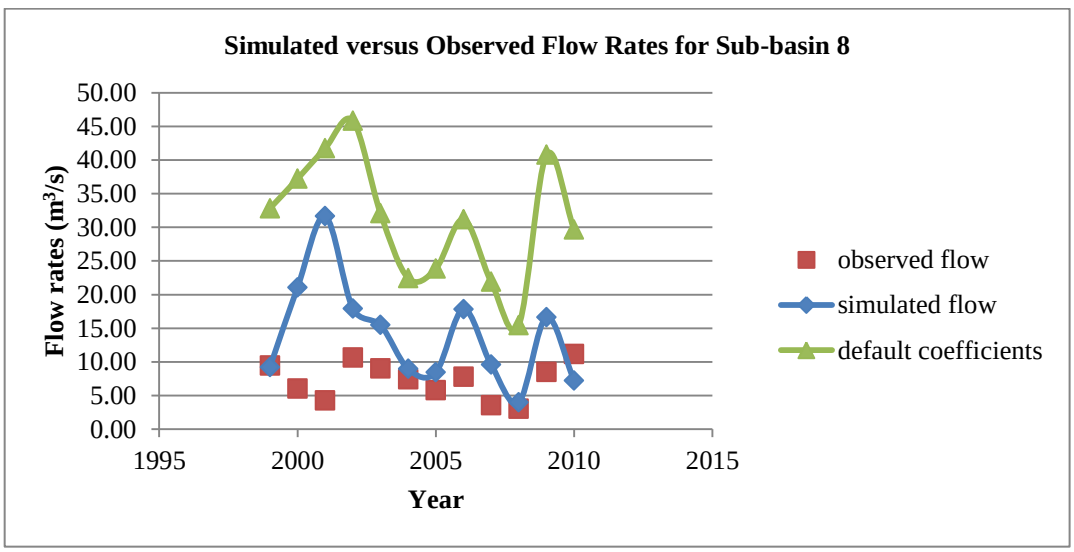


Figure 5.7 Simulated and observed flow rates for average annual conditions when ALPHA_BF = 0.0 days: sub-basin 8

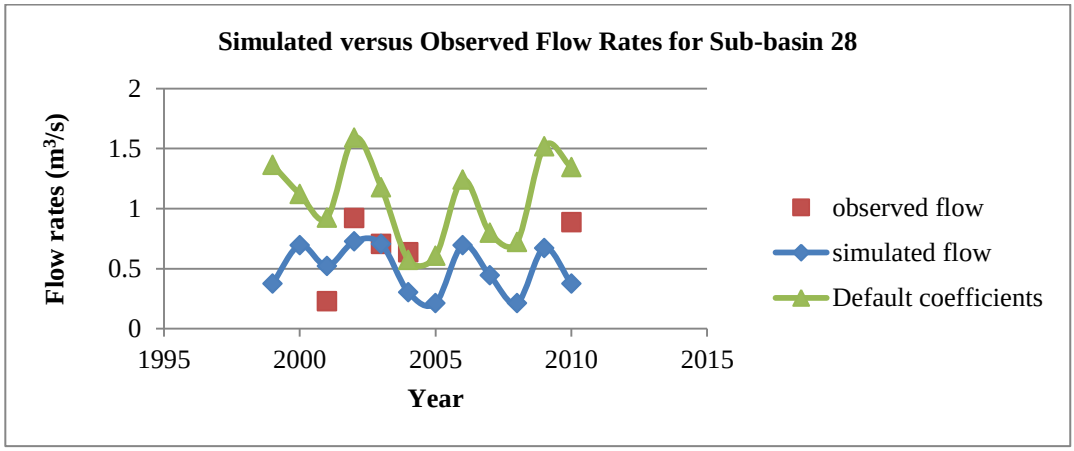


Figure 5.8 Simulated and observed flow rates for average annual conditions when ALPHA_BF = 0.0 days: sub-basin 28

The second aforementioned groundwater related parameter is RCHRG_DP. In order to decrease surface runoff, RCHRG_DP should be increased because it represents the percolation fraction from root zone to the deep aquifer. It was changed from its initial value (0.05) to 0.75 by keeping other parameters at their default values to understand the influence of RCHRG_DP on flow rates. Table 5.7 gives the results of the first modification of RCHRG_DP (RCHRG_DP = 0.75). Simulated versus observed flow rates for sub-basins 8 and 28 are given in Figure 5.9 and Figure 5.10, respectively. Although increasing RCHRG_DP to 0.75 resulted in a significant decrease in flow rates, it is apparent that further improvement is required. Therefore, increasing RCHRG_DP to its maximum value (1.0) was also tried and the results of this trial are given in Table 5.8. Figure 5.11 and Figure 5.12 present simulated versus observed flow rates for sub-basins 8 and 28, respectively. ALPHA_BF = 0.0 days and RCHRG_DP = 1.0 cases ended up with the same simulation results. As a result, the same NSE and average absolute percent deviation were obtained as well.

Table 5.7 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis when RCHRG_DP = 0.75

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)	
1999	15.12	9.46	59.90	-25.86	0.62	-	-	-0.04
2000	25.05	6.02	316.46		0.81	-	-	
2001	34.29	4.28	702.11		0.63	0.23	176.45	
2002	25.01	10.64	135.01		0.95	0.92	2.65	
2003	19.66	9.03	117.84		0.83	0.70	17.70	
2004	12.42	7.43	67.25		0.37	0.64	41.08	
2005	12.28	5.79	112.16		0.32	-	-	
2006	21.27	7.80	172.76		0.84	-	-	
2007	12.78	3.56	258.89		0.53	-	-	
2008	6.891	3.05	126.31		0.34	-	-	
2009	22.71	8.50	167.05		0.88	-	-	
2010	12.89	11.19	15.19		0.63	0.89	29.39	
Average	**18.36**	**7.23**	**154.10**		**0.65**	**0.68**	**4.36**	

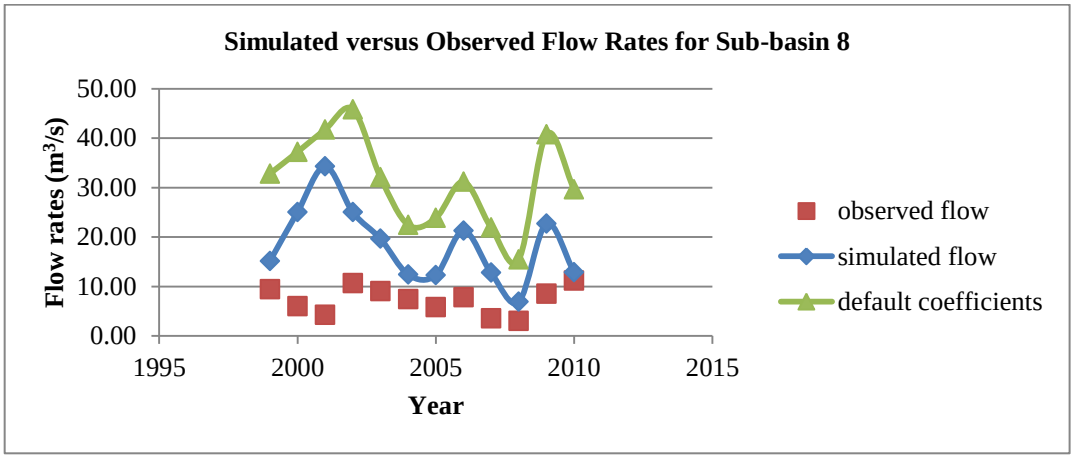


Figure 5.9 Simulated and observed flow rates for average annual conditions when RCHRG_DP = 0.75: sub-basin 8

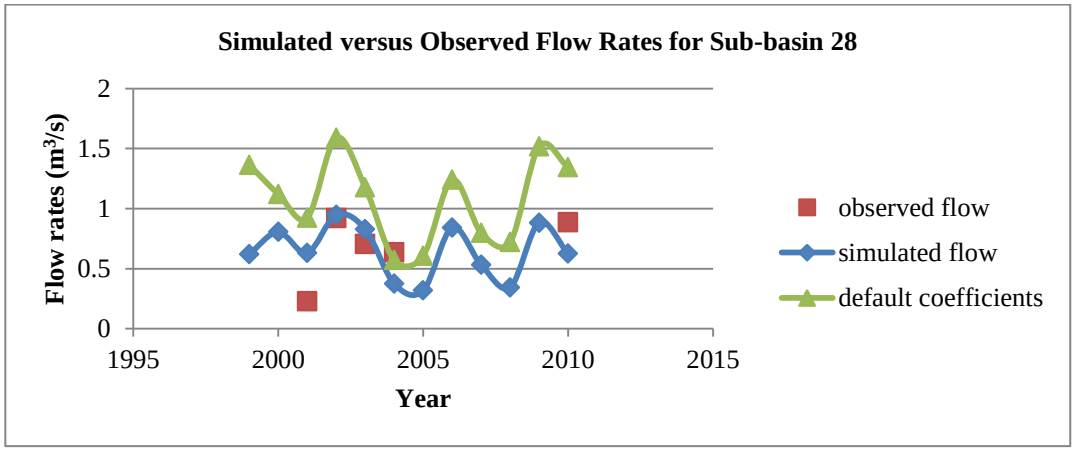


Figure 5.10 Simulated and observed flow rates for average annual conditions when RCHRG_DP = 0.75: sub-basin 28

Table 5.8 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis when RCHRG_DP = 1.0

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)	
1999	9.20	9.46	2.66	-15.11	0.38	-	-	-0.65
2000	21.07	6.02	250.29		0.69	-	-	
2001	31.64	4.28	640.12		0.52	0.23	128.86	
2002	17.93	10.64	68.48		0.73	0.92	21.33	
2003	15.49	9.03	71.63		0.71	0.70	0.23	
2004	8.98	7.43	20.86		0.30	0.64	52.31	
2005	8.45	5.79	45.91		0.21	-	-	
2006	17.83	7.80	128.65		0.69	-	-	
2007	9.62	3.56	170.04		0.44	-	-	
2008	4.00	3.05	31.30		0.21	-	-	
2009	16.63	8.50	95.56		0.67	-	-	
2010	7.24	11.19	35.27		0.37	0.89	57.70	
Average	**14.01**	**7.23**	**93.80**		**0.49**	**0.68**	**26.78**	

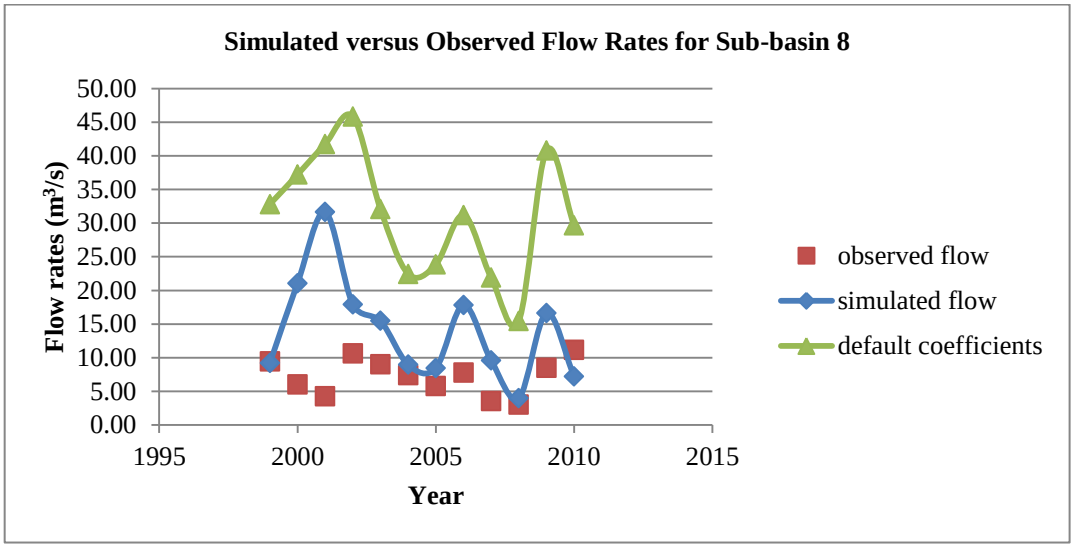


Figure 5.11 Simulated and observed flow rates for average annual conditions when RCHRG_DP = 1.0: sub-basin 8

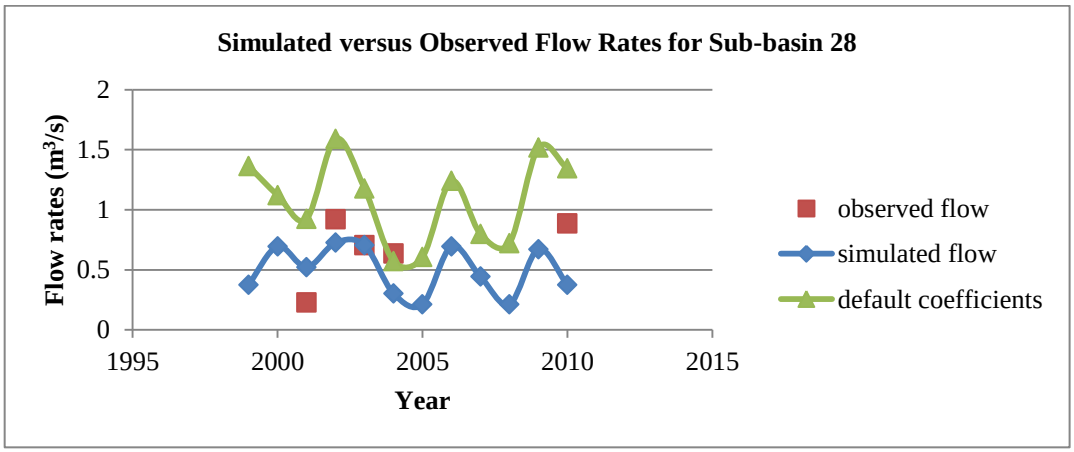


Figure 5.12 Simulated and observed flow rates for average annual conditions when RCHRG_DP = 1.0: sub-basin 28

After carrying out individual modifications, combinations of the changes made before were tried. Which parameters were included in the combinations are given in Table 5.9. The results of the first (CC1) and second (CC2) combinations are given in the following tables and figures. On the other hand, the results of the third (CC3) and fourth (CC4) combinations are not shown here because they gave the same result as those in the second combination.

Table 5.9 Modified parameters in the combinations

Combination Title	Parameters		
	ET Method	**ALPHA_BF**	**RCHRG_DP**
CC1	Hargreaves	0.01	0.75
CC2	Hargreaves	0.0	0.75
CC3	Hargreaves	0.01	1.0
CC4	Hargreaves	0.0	1.0

Table 5.10 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis after CC1

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	**Observed (m^3/s)**	**Deviation (%)**		**Simulated (m^3/s)**	**Observed (m^3/s)**	**Deviation (%)**	
1999	13.35	9.46	41.18	-17.65	0.55	-	-	-0.05
2000	21.54	6.02	258.10		0.71	-	-	
2001	31.98	4.28	648.07		0.57	0.23	148.38	
2002	21.83	10.64	105.13		0.90	0.92	2.40	
2003	17.47	9.03	93.57		0.74	0.70	5.71	
2004	10.31	7.43	38.84		0.33	0.64	47.63	
2005	10.40	5.79	79.68		0.25	-	-	
2006	18.29	7.80	134.55		0.73	-	-	
2007	9.73	3.56	173.35		0.45	-	-	
2008	6.00	3.05	96.88		0.31	-	-	
2009	18.40	8.50	116.37		0.82	-	-	
2010	10.62	11.19	5.09		0.56	0.89	36.86	
Average	**15.83**	**7.23**	**118.99**		**0.58**	**0.68**	**14.52**	

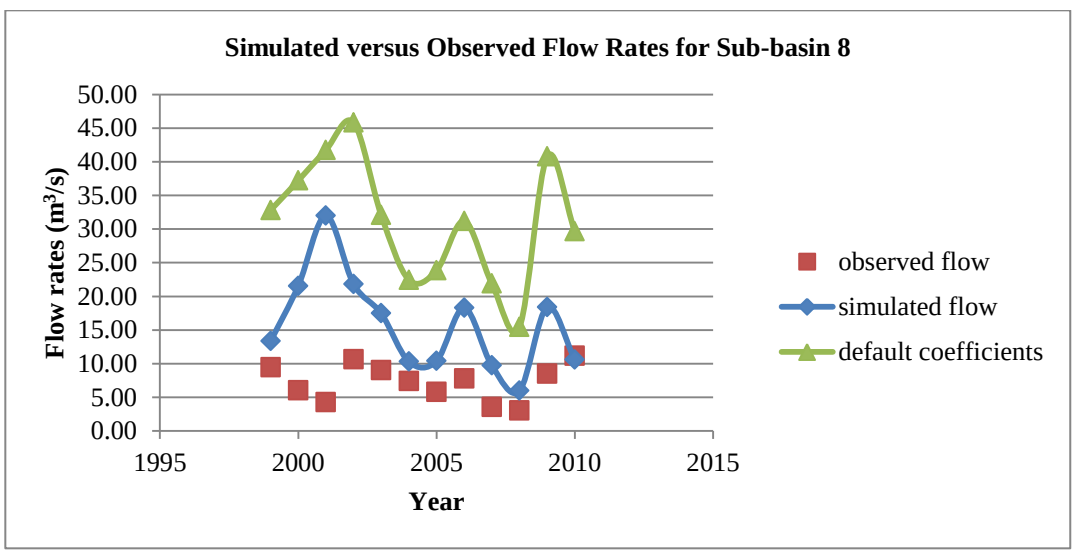


Figure 5.13 Simulated and observed flow rates for average annual conditions after CC1: sub-basin 8

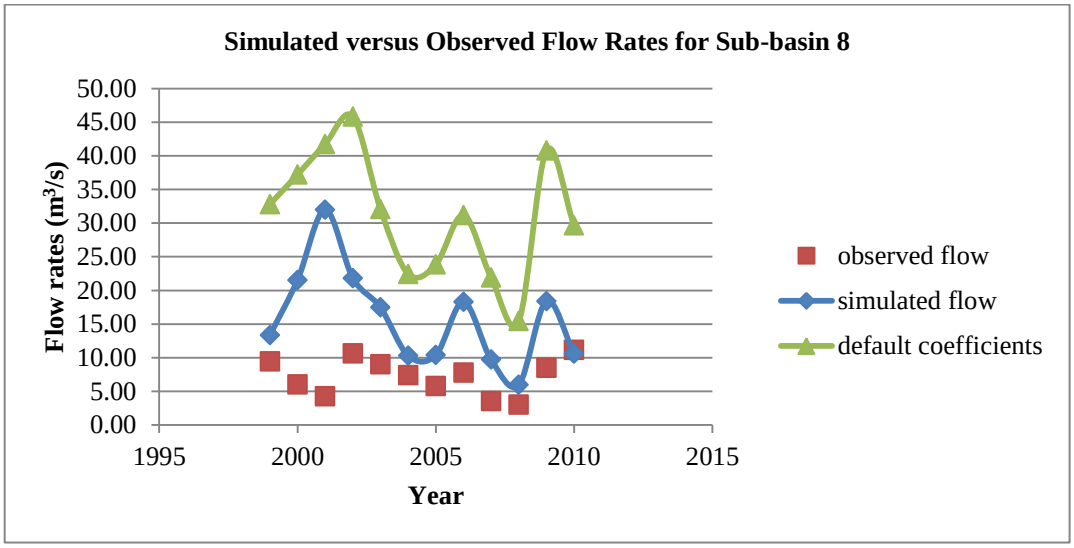


Figure 5.14 Simulated and observed flow rates for average annual conditions after CC1: sub-basin 28

Table 5.11 Simulated and observed flow rates for both sub-basin 8 and sub-basin 28 on average annual basis after CC2

Year	Sub-basin 8 (12-03)			NSE	Sub-basin 28 (12-093)			NSE
	Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)		Simulated (m^3/s)	Observed (m^3/s)	Deviation (%)	
1999	8.55	9.46	9.56	-12.64	0.35	-	-	-0.74
2000	19.19	6.02	219.04		0.65	-	-	
2001	30.90	4.28	622.81		0.51	0.23	123.42	
2002	16.20	10.64	52.23		0.71	0.92	22.65	
2003	14.59	9.03	61.66		0.67	0.70	4.56	
2004	8.05	7.43	8.39		0.28	0.64	55.68	
2005	7.83	5.79	35.28		0.20	-	-	
2006	16.46	7.80	111.08		0.64	-	-	
2007	7.88	3.56	121.40		0.38	-	-	
2008	3.52	3.05	15.47		0.20	-	-	
2009	14.54	8.50	70.98		0.66	-	-	
2010	6.64	11.19	40.71		0.36	0.89	59.06	
Average	**12.86**	**7.23**	**77.97**		**0.47**	**0.68**	**30.58**	

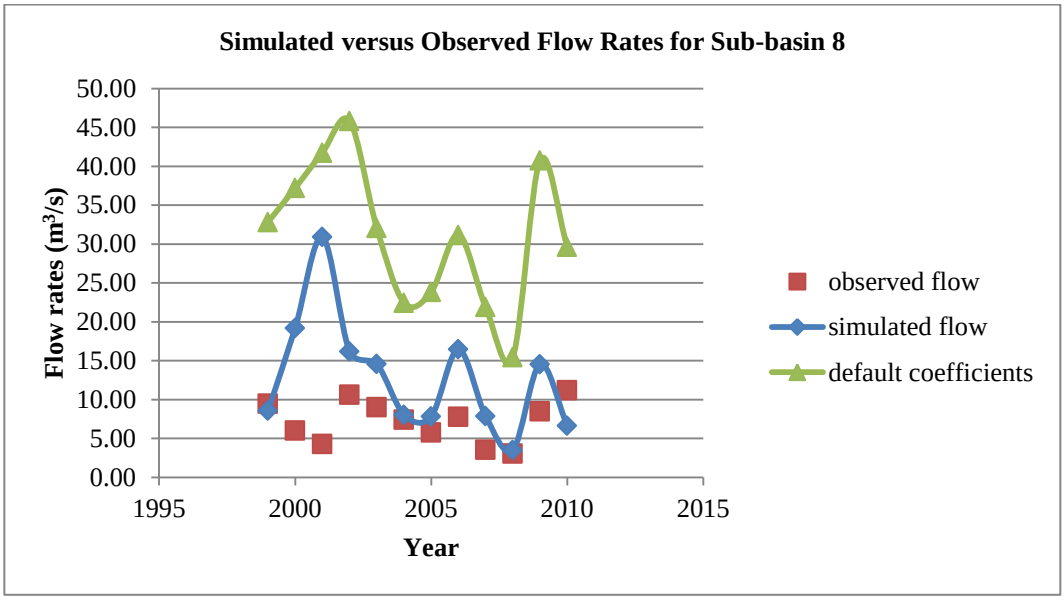


Figure 5.15 Simulated and observed flow rates for average annual conditions after CC2: sub-basin 8

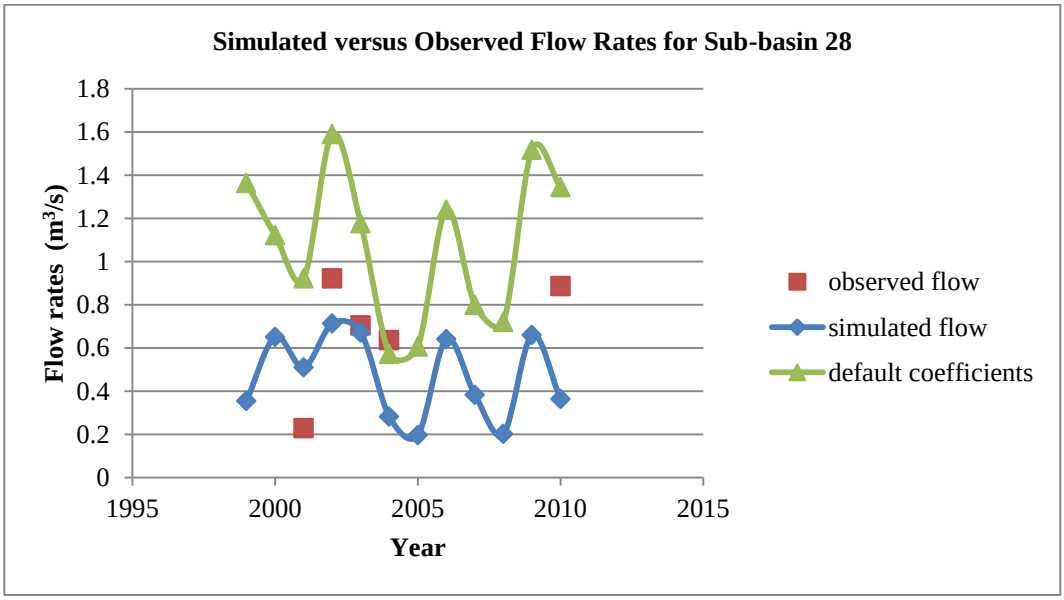


Figure 5.16 Simulated and observed flow rates for average annual conditions after CC2: sub-basin 28

When NSE and average absolute percent deviation between the simulated and observed yearly average flow rate values obtained in the abovementioned trials were examined, it was seen that CC2 provides the best possible calibration result for both the most downstream sub-basin prior

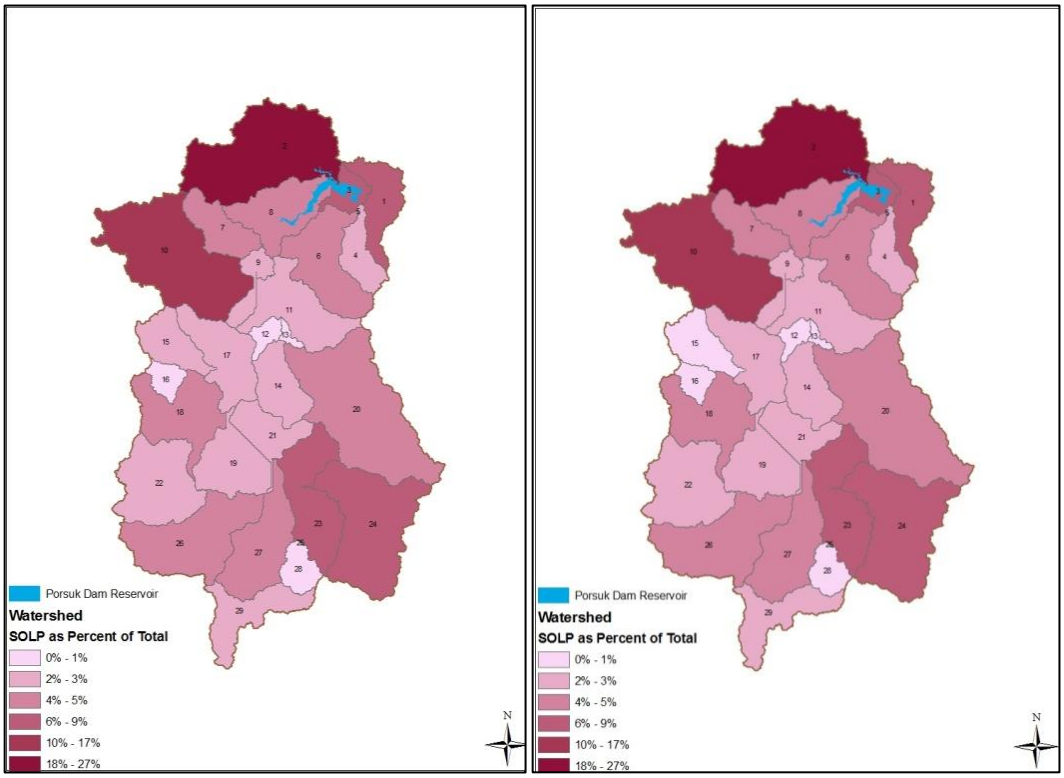
to the PDR (sub-basin 8) and the upstream sub-basin (sub-basin 28). Table 5.12 summarizes NSE and average absolute percent deviation values obtained in these calibration trials for sub-basins 8 and 28. Although the fourth calibration trial (RCHRG_DP = 0.75) seems as the best for sub-basin 28 based on both NSE and average absolute percent deviation values, the aim here is to proceed with the most representative calibration trial. Before giving the results of scenario simulations, the effects of abovementioned calibration trials on SOLP loads arising from different sub-basins were presented (Table 5.13). Change in ET method, CC1 and CC2 resulted in the same SOLP loads from each sub-basin (Figure 5.17a). Moreover, ALPHA_BF=0.01 days, ALPHA_BF = 0.0 days, RCHRG_DP = 0.75 and RCHRG_DP =1.0 modifications ended up with similar SOLP loads from each sub-basin as well (Figure 5.17b). Therefore, different calibration parameter values mapped to two different outcomes in overall SOLP loads. However, there was only 3.3% decrease in overall SOLP load to the PDR within these two different outcomes. This indicated that there is not a strong relationship between flow rates and SOLP loads arising from different sub-basins for the calibration trials considered. Moreover, accuracy of the stream flow data obtained from stream flow observation stations of both Electrical Power Resources Survey and Development Administration and SHW are questionable. Although it was clearly seen that predetermined criteria in literature for NSE and percent deviation were not achieved, this study will continue with the assumption that the model is calibrated. Among given flow rate values in Table 5.11, it was realized that the most satisfactory results were obtained in 2003 and 2004 for both sub-basins. Thus, scenarios given in Section 4.9 were developed only for these two years.

Table 5.12 NSE and average absolute percent deviation values with respect to the calibration trials

Calibration trials	**Sub-basin 8**		**Sub-basin 28**	
	NSE	**Average absolute percent deviation**	**NSE**	**Average absolute percent deviation**
Initial run (default values)	-93.92	332.23	-3.45	60.10
Change in ET method	-68.98	282.27	-2.92	50.05
ALPHA_BF = 0.01 days	-85.22	317.64	-2.74	50.67
ALPHA_BF = 0.0 days	-15.11	93.80	-0.65	26.78
RCHRG_DP = 0.75	-25.86	154.10	-0.04	4.36
RCHRG_DP = 1.0	-15.11	93.80	-0.65	26.78
CC1	-17.65	118.99	-0.05	14.52
CC2	-12.64	77.97	-0.74	30.58

Table 5.13 SOLP loads from sub-basins with respect to the given calibration trials

	Change in ET method	**ALPHA_BF = 0.01 days**	**ALPHA_BF = 0.0 days**	**RCHRG_DP = 0.75**	**RCHRG_DP = 1.0**	**CC1**	**CC2**
Sub-basin number	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**
1	399.92	394.74	394.74	394.74	394.74	399.92	399.92
2	1177.03	1165.9	1165.9	1165.9	1165.9	1177.03	1177.03
3	353.95	346.52	346.52	346.52	346.52	353.95	353.95
4	86.52	82.88	82.88	82.88	82.88	86.52	86.52
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	172.57	170.65	170.65	170.65	170.65	172.57	172.57
7	197.54	183.02	183.02	183.02	183.02	197.54	197.54
8	273.13	274.69	274.69	274.69	274.69	273.13	273.13
9	149.68	141.97	141.97	141.97	141.97	149.68	149.68
10	536.53	521.42	521.42	521.42	521.42	536.53	536.53
11	143.75	131.48	131.48	131.48	131.48	143.75	143.75
12	18.07	15.95	15.95	15.95	15.95	18.07	18.07
13	4.41	4.31	4.31	4.31	4.31	4.41	4.41
14	63.05	57.71	57.71	57.71	57.71	63.05	63.05
15	55.78	42.55	42.55	42.55	42.55	55.78	55.78
16	19.58	18.49	18.49	18.49	18.49	19.58	19.58
17	105.26	92.87	92.87	92.87	92.87	105.26	105.26
18	255.73	259.31	259.31	259.31	259.31	255.73	255.73
19	91.26	86.98	86.98	86.98	86.98	91.26	91.26
20	250.31	229.1	229.1	229.1	229.1	250.31	250.31
21	90.62	96.23	96.23	96.23	96.23	90.62	90.62
22	129.63	98.27	98.27	98.27	98.27	129.63	129.63
23	444.93	429.11	429.11	429.11	429.11	444.93	444.93
24	391.33	388.18	388.18	388.18	388.18	391.33	391.33
25	0.06	0.06	0.06	0.06	0.06	0.06	0.06
26	189.67	171.97	171.97	171.97	171.97	189.67	189.67
27	214.94	213.09	213.09	213.09	213.09	214.94	214.94
28	32.70	34.25	34.25	34.25	34.25	32.7	32.70
29	72.26	72.26	72.26	72.26	72.26	72.26	72.26
Total	**5920.23**	**5723.94**	**5723.94**	**5723.94**	**5723.94**	**5920.23**	**5920.23**



(a) (b)

Figure 5.17 SOLP as percent of total from sub-basins for two different outcomes (a) SOLP after changing ET method, CC1 and CC2, (b) SOLP when ALPHA_BF=0.01 days, ALPHA_BF = 0.0 days, RCHRG_DP = 0.75 and RCHRG_DP =1.0

5.3 Scenario Simulations Results

As given in Section 4.9, nine scenarios were developed to determine SOLP loads to the PDR as well as two base case scenarios. Also an additional scenario was tested which included the combination of the two of the best nine scenarios in terms of reduction in SOLP loads. In this section, results of these scenarios are provided.

5.3.1 Base-Case Scenario I

Base-Case Scenario I was developed by using mainly default values. All agricultural areas were defined as AGRL and default management operations defined for AGRL in SWAT were used to provide a basis for the comparison made between scenarios. Results of the first base-case simulation are given in Table 5.14. As can be seen in Table 5.14, overall SOLP loads arising from different sub-basins were determined as 5033.78 kg/year. Moreover, transported SOLP loads varied with respect to sub-basins proportionally with their areas.

Table 5.14 SOLP loads from sub-basins: Base-Case Scenario I

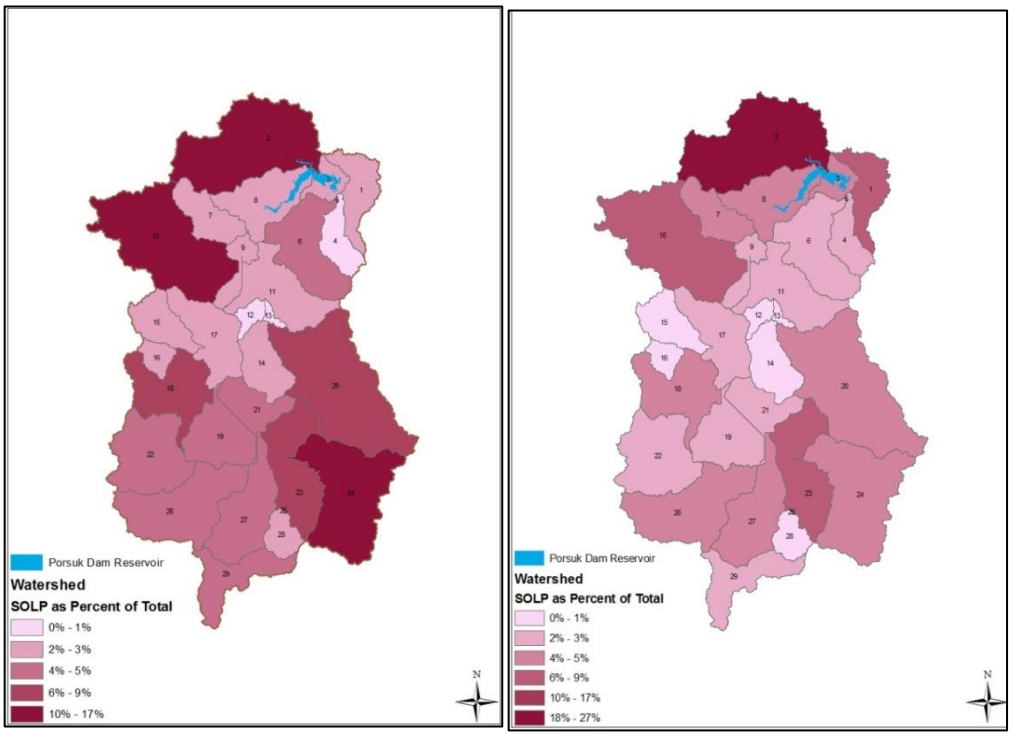
Sub-basin Number	**SOLP (kg/year)**	**Sub-basin Number**	**SOLP (kg/year)**
1	323.25	16	10.88
2	1336.70	17	83.59
3	247.72	18	182.41
4	65.43	19	59.89
5	0.00	20	178.19
6	126.55	21	67.27
7	180.11	22	100.36
8	215.38	23	344.08
9	138.88	24	265.10
10	453.40	25	0.05
11	115.70	26	151.74
12	14.35	27	177.88
13	3.08	28	31.14
14	44.88	29	76.07
15	39.71	**Total**	**5033.78**

5.3.2 Base-Case Scenario II

Within Base-Case Scenario II, agricultural areas which were defined as AGRL for the previous scenario were split into AGRC, SGBT and AGRL. Therefore, this scenario represents current situation observed in the study area better. Moreover, the impact of currently applied agricultural management practices in the study area on SOLP loads was determined via this scenario. Table 5.15 shows the SOLP loads resulting from different sub-basins after the development of Base-Case Scenario II. In all sub-basins, except sub-basin 5, SOLP loads increased as expected when compared to Base-Case Scenario I. SOLP loads remained the same in sub-basin 5. The reason is that its area is very small compared to other sub-basins. Default management operations set for AGRL in Base-Case Scenario I include only the automatic application of elemental nitrogen as fertilizer. On the other hand, fertilizers applied in Base-Case Scenario II have phosphorus fraction as well. Therefore, increase in overall SOLP loads was expected. SOLP as percent of total from different sub-basins is presented in Figure 5.18a. In order to make the comparison easier, SOLP distribution map of Base-Case Scenario I (Figure 5.18b) was also included into Figure 5.18.

Table 5.15 SOLP loads from sub-basins: Base-Case Scenario II

Sub-basin Number	Base-Case Scenario I SOLP (kg/year)	Base-Case Scenario II SOLP (kg/year)	Sub-basin Number	Base-Case Scenario I SOLP (kg/year)	Base-Case Scenario II SOLP (kg/year)
1	323.25	441.36	16	10.88	230.59
2	1336.70	4076.92	17	83.59	232.18
3	247.72	250.50	18	182.41	1255.40
4	65.43	139.59	19	59.89	872.67
5	0.00	0.00	20	178.19	2061.90
6	126.55	678.78	21	67.27	801.58
7	180.11	342.79	22	100.36	890.71
8	215.38	393.31	23	344.08	1839.03
9	138.88	249.98	24	265.10	2196.52
10	453.40	2131.00	25	0.05	0.26
11	115.70	599.54	26	151.74	682.83
12	14.35	57.40	27	177.88	1111.77
13	3.08	33.24	28	31.14	242.89
14	44.88	378.32	29	76.07	806.29
15	39.71	368.73	**Total**	**5033.78**	**23366.09**
Overall Percent Change in SOLP Load (%)				**364.2**	



(a) (b)

Figure 5.18 SOLP as percent of total arising from different sub-basins (a) Base-Case Scenario II, (b) Base-Case Scenario I

5.3.3 Scenario I

Scenario I covers increase in fertilizer application rates for AGRC and SGBT. Within this scenario, fertilizer application rates were increased by two, three and four times compared to Base Case Scenario II. The results are given in Table 5.16. Unsurprisingly, increase in the fertilizer application rates led to increase in SOLP loads, except in sub-basin 5. Moreover, a linear relationship was found between SOLP loads transported to the PDR and fertilizer application rates as depicted in Figure 5.19. Figure 5.19 revealed that care should be taken regarding fertilizer application to minimize phosphorus transport since it linearly increases the transported SOLP in the watershed. Increase by two, three and four times in fertilizer application rates corresponded to 77%, 158% and 236.5% increase in overall SOLP loads transported to the PDR, respectively. Figure 5.20 provides SOLP as percent of total from different sub-basins for Scenario I-a, Scenario I-b and Scenario I-c, respectively.

Table 5.16 SOLP loads from sub-basins: Scenario I-a, Scenario I-b and Scenario I-c

Sub-basin Number	**Base-Case Scenario II SOLP (kg/year)**	**Scenario I-a SOLP (kg/year)**	**Scenario I-b SOLP (kg/year)**	**Scenario I-c SOLP (kg/year)**
1	441.36	491.09	547.04	596.77
2	4076.92	6728.03	9668.76	12698.61
3	250.50	250.50	250.5	250.5
4	139.59	196.30	257.37	309.72
5	0.00	0.00	0.00	0.00
6	678.78	1138.97	1610.67	2070.86
7	342.79	528.72	708.83	894.75
8	393.31	561.87	730.42	898.98
9	249.98	342.57	438.24	537
10	2131.00	3717.92	5395.52	7073.11
11	599.54	1041.31	1514.64	1987.96
12	57.40	98.86	143.51	186.56
13	33.24	62.79	94.19	124.97
14	378.32	705.33	1038.76	1372.19
15	368.73	720.45	1077.84	1423.88
16	230.59	439.43	659.14	870.15
17	232.18	380.78	529.37	677.97
18	1255.40	2264.00	3304.8	4324.14
19	872.67	1694.00	2541	3387.99
20	2061.90	3894.69	5829.31	7713.02
21	801.58	1423.78	2085.22	2729.84
22	890.71	1743.78	2609.4	3449.93
23	1839.03	3298.39	4817.07	6312.02
24	2196.52	4222.63	6324.48	8255.9
25	0.26	0.43	0.59	0.74
26	682.83	1244.26	1820.87	2397.48
27	1111.77	2090.14	3068.5	3969.03
28	242.89	460.86	681.95	887.47
29	806.29	1635.40	2464.51	3232.76
Total	**23366.09**	**41377.28**	**60212.49**	**78634.33**
Overall Percent Change in SOLP Load (%)		**77**	**158**	**236.5**

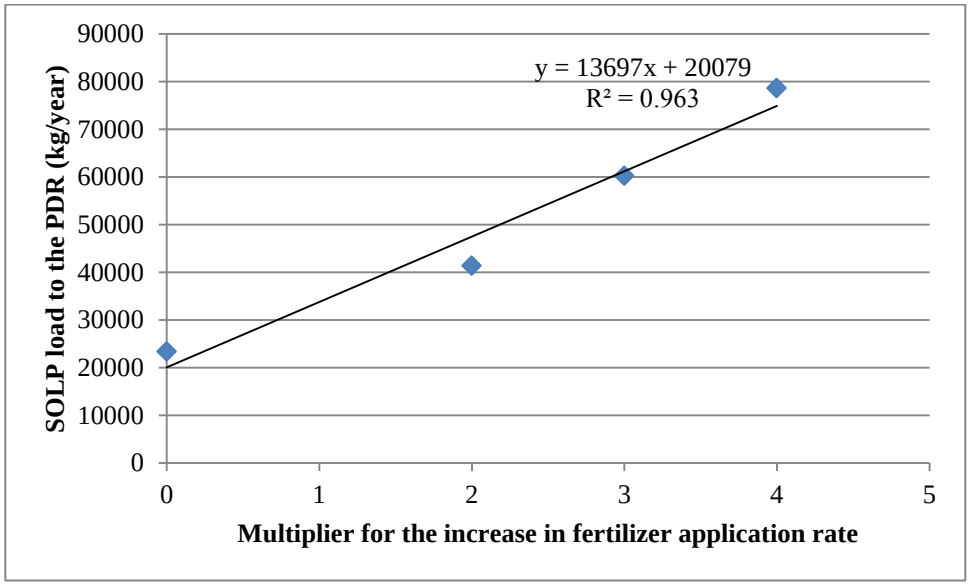
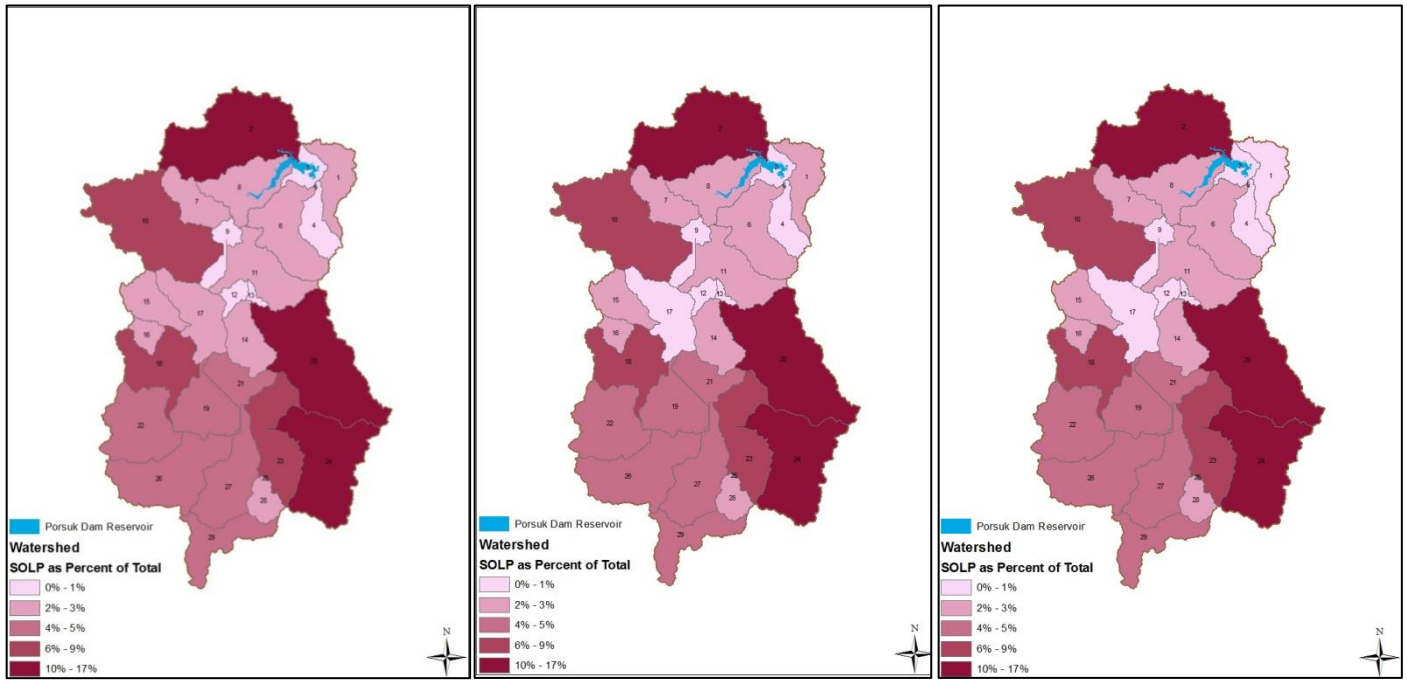


Figure 5.19 SOLP load to the PDR with respect to increase in fertilizer application rates



(a) (b) (c)

Figure 5.20 SOLP as percent of total from different sub-basins (a) Scenario I-a, (b) Scenario I-b, (c) Scenario I-c

5.3.4 Scenario II

Increase in fertilizer application rates was examined in Scenario I. A linear relationship was observed between SOLP loads transported to the PDR and fertilizer application rates. Therefore, it can be claimed that fertilizer application is a crucial management operation for investigation of non-point source pollution in the study area. Thus, Scenario II was developed to further investigate the effect of fertilizer application rates on SOLP loads. This time fertilizer application rates were reduced by 20% (Scenario II-a), 30% (Scenario II-b), 40% (Scenario II-c) and 50% (Scenario II-d). Linear relationship still exists between SOLP loads transported to the PDR and fertilizer application rates as shown in Figure 5.21. Although SOLP loads remained unchanged in sub-basins 3 and 5, a decrease was observed in overall SOLP load transported to the PDR (Table 5.17). This is because there is no agricultural land in sub-basin 3. 20%, 30%, 40% and 50% decrease in fertilizer application rates corresponded to 18%, 26%, 33% and 40% decrease in overall SOLP loads transported to the PDR, respectively. Figure 5.22 provides SOLP as percent of total from different sub-basins for Scenario II-a, Scenario II-b, Scenario II-c and Scenario II-d, respectively.

Table 5.17 SOLP loads from sub-basins: Scenario II-a, Scenario II-b, Scenario II-c, Scenario II-d

Sub-basin Number	**Base-Case Scenario II**	**Scenario II-a**	**Scenario II-b**	**Scenario II-c**	**Scenario II-d**
	SOLP (kg/year)	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**
1	441.36	435.15	422.71	422.71	416.50
2	4076.92	3408.57	3141.23	2873.90	2628.83
3	250.50	250.50	250.50	250.50	250.50
4	139.59	126.50	122.14	122.14	113.42
5	0.00	0.00	0.00	0.00	0.00
6	678.78	575.24	540.72	494.71	448.69
7	342.79	307.93	290.50	273.07	255.64
8	393.31	346.48	337.12	318.39	309.03
9	249.98	225.29	216.03	209.86	200.60
10	2131.00	1722.94	1564.25	1428.23	1292.20
11	599.54	483.84	441.77	399.70	357.62
12	57.40	46.24	43.05	39.86	35.08
13	33.24	25.86	22.78	21.55	18.47
14	378.32	301.37	269.31	237.25	211.60
15	368.73	294.99	260.95	232.59	198.55
16	230.59	180.56	160.98	145.75	126.17
17	232.18	204.32	195.03	176.46	167.17
18	1255.40	1019.34	912.04	826.20	729.63
19	872.67	675.89	590.33	530.44	453.44
20	2061.90	1629.15	1450.96	1272.78	1120.04
21	801.58	644.62	577.36	526.91	470.86
22	890.71	702.53	614.71	551.99	476.72
23	1839.03	1471.22	1328.85	1210.20	1067.82
24	2196.52	1723.14	1514.84	1325.49	1155.07
25	0.26	0.23	0.21	0.19	0.19
26	682.83	546.26	500.74	440.04	394.52
27	1111.77	900.54	811.60	722.65	633.71
28	242.89	196.18	174.38	158.81	137.01
29	806.29	623.73	547.67	471.60	395.54
Total	**23366.09**	**19068.61**	**17302.78**	**15683.96**	**14064.63**
Overall Percent Change in SOLP Load (%)		**18**	**26**	**33**	**40**

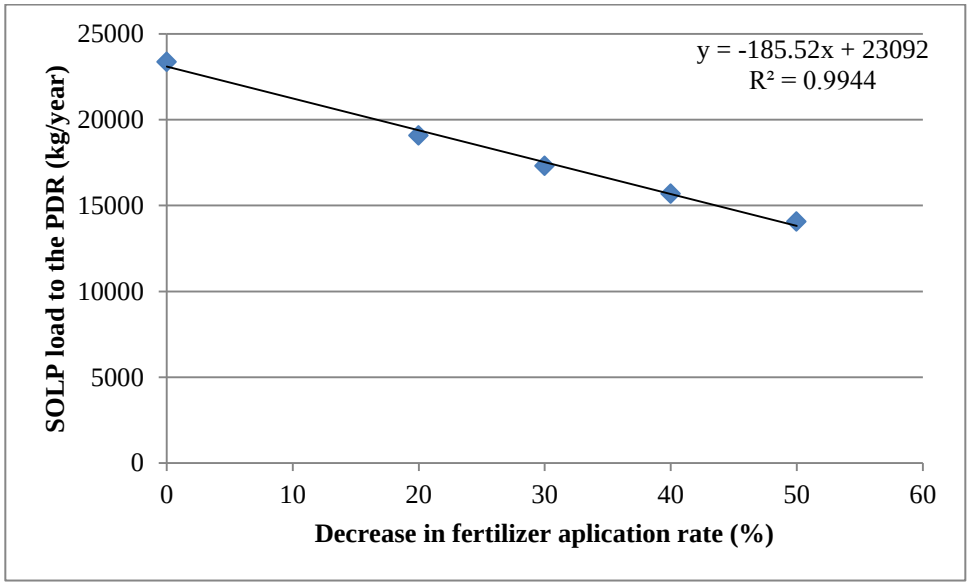
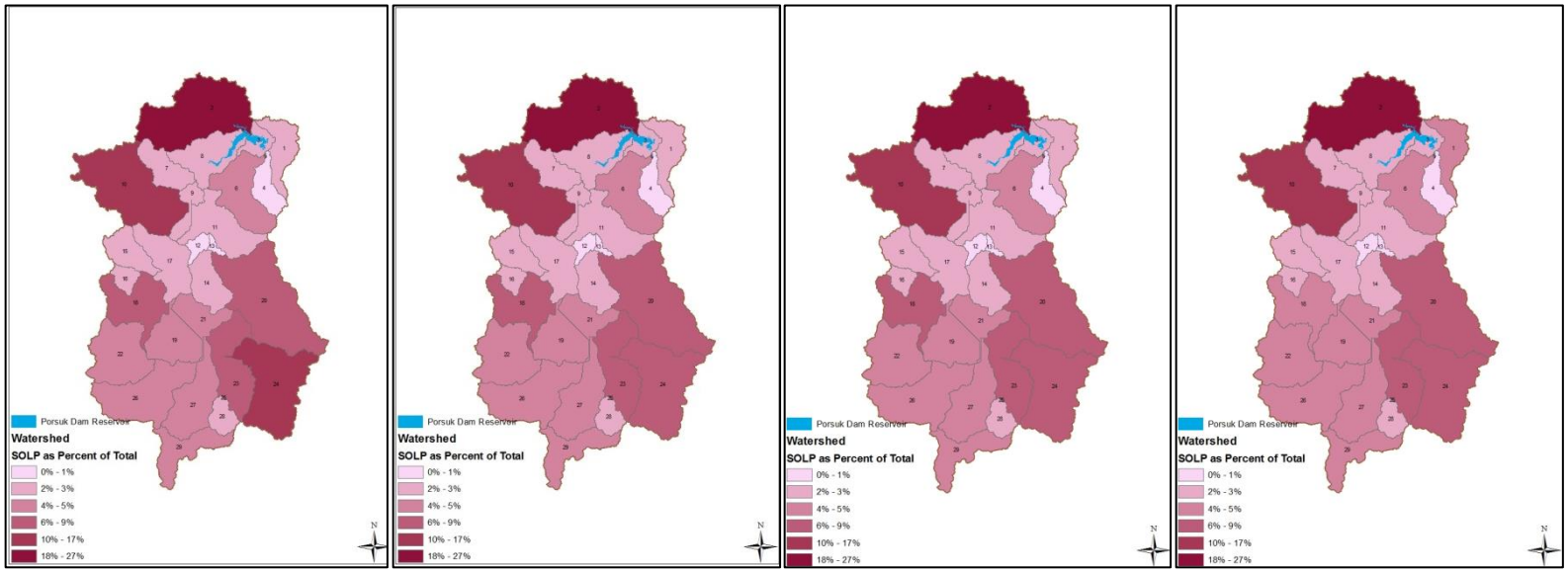


Figure 5.21 SOLP load to the PDR with respect to decrease in fertilizer application rates



(a) (b) (c) (d)

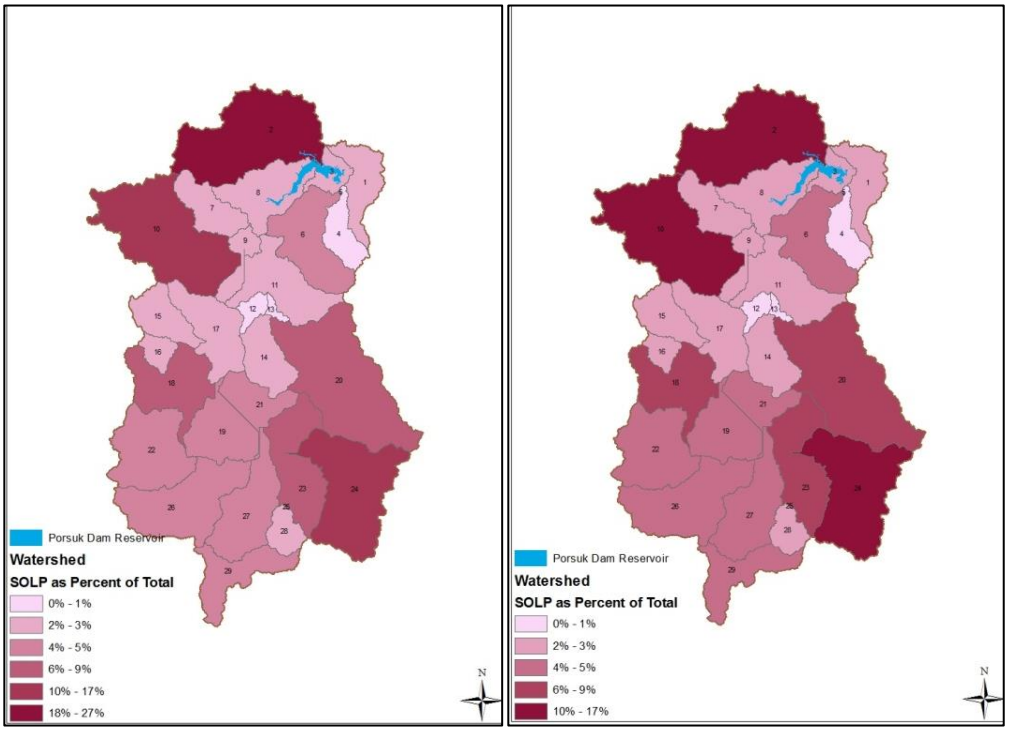
Figure 5.22 SOLP as percent of total from different sub-basins (a) Scenario II-a, (b) Scenario II-b, (c) Scenario II-c, (d) Scenario II-d

5.3.5 Scenario III

In Scenario III, the impact of decrease in irrigation amount applied for sugar beet on SOLP transported from sub-basins was investigated. As can be seen in Table 5.18, SOLP load decreased 2.7% in overall. Reductions in irrigation amounts by 20% (Scenario III-a), 30% (Scenario III-b), 40% (Scenario III-c) and 50% (Scenario III-d) ended up with the same overall SOLP. There may be more effective mechanisms that are responsible for SOLP transport (e.g. rainfall) compared to irrigation water. Moreover, once irrigation is applied, sugar beet uses all irrigation water. As a result, there may be no available irrigation water contributing to surface runoff when irrigation amounts are decreased. Distribution of SOLP as percent of total with respect to different sub-basins for Base-Case Scenario II (Figure 5.23b) and Scenario III (Figure 5.23a) are provided in Figure 5.23.

Table 5.18 SOLP loads from sub-basins: Scenario III-a, Scenario III-b, Scenario III-c and Scenario III-d

Sub-basin Number	**Base-Case Scenario II**	**Scenario III-a**	**Scenario III-b**	**Scenario III-c**	**Scenario III-d**
	SOLP (kg/year)	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**
1	441.36	441.36	441.36	441.36	441.36
2	4076.92	3987.81	3987.81	3987.81	3987.81
3	250.50	250.50	250.50	250.50	250.50
4	139.59	139.59	139.59	139.59	139.59
5	0.00	0.00	0.00	0.00	0.00
6	678.78	667.28	667.28	667.28	667.28
7	342.79	342.79	342.79	342.79	342.79
8	393.31	393.31	393.31	393.31	393.31
9	249.98	243.81	243.81	243.81	243.81
10	2131.00	2062.99	2062.99	2062.99	2062.99
11	599.54	578.51	578.51	578.51	578.51
12	57.40	55.81	55.81	55.81	55.81
13	33.24	31.40	31.40	31.40	31.40
14	378.32	365.49	365.49	365.49	365.49
15	368.73	363.06	363.06	363.06	363.06
16	230.59	224.06	224.06	224.06	224.06
17	232.18	232.18	232.18	232.18	232.18
18	1255.40	1212.48	1212.48	1212.48	1212.48
19	872.67	847	847	847	847
20	2061.90	1985.53	1985.53	1985.53	1985.53
21	801.58	773.55	773.55	773.55	773.55
22	890.71	878.16	878.16	878.16	878.16
23	1839.03	1767.84	1767.84	1767.84	1767.84
24	2196.52	2120.78	2120.78	2120.78	2120.78
25	0.26	0.26	0.26	0.26	0.26
26	682.83	652.48	652.48	652.48	652.48
27	1111.77	1100.66	1100.66	1100.66	1100.66
28	242.89	239.77	239.77	239.77	239.77
29	806.29	783.47	783.47	783.47	783.47
Total	**23366.09**	**22741.93**	**22741.93**	**22741.93**	**22741.93**
Overall Percent Change in SOLP Load (%)		**2.7**			



(a) (b)

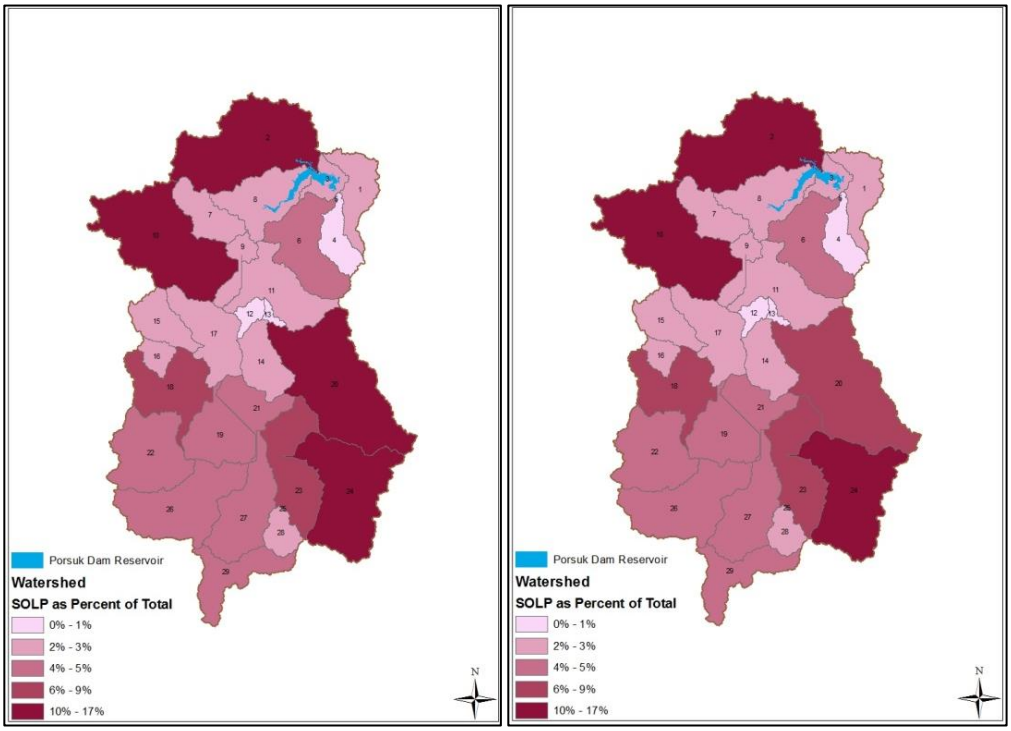
Figure 5.23 SOLP as percent of total from different sub-basins (a) Scenario III, (b) Base-Case Scenario II

5.3.6 Scenario IV

In Scenario IV, irrigated wheat production was considered and irrigation rates applied for SGBT were increased by two (Scenario IV-a) and four times (Scenario IV-b). Overall SOLP loads increased (19%) when irrigation amounts were increased by two times. However, beyond two folds of increase in irrigation amount does not cause additional increase in SOLP loads (Table 5.19), although concentrations may change. There was a limit in increase in SOLP with the increase in irrigation rates. As given in Figure 2.4 in Section 2.1.1.1, there is a two-way relationship between stable, active and soluble mineral forms of phosphorus. Therefore, if the amount of irrigation water applied is more than required, then it may be claimed that some portions of SOLP are converted into active and eventually stable phosphorus forms. Figure 5.24 indicates SOLP as percent of total arising from different sub-basins for two folds of increase in the irrigation rate (Figure 5.24a) and Base-Case Scenario II (Figure 5.24b).

Table 5.19 SOLP loads from sub-basins: Scenario IV-a, Scenario IV-b

Sub-basin Number	**Base-Case Scenario II SOLP (kg/year)**	**Scenario IV-a SOLP (kg/year)**	**Scenario IV-b SOLP (kg/year)**
1	441.36	460.01	460.01
2	4076.92	4789.83	4789.83
3	250.50	250.50	250.50
4	139.59	152.68	152.68
5	0.00	0.00	0.00
6	678.78	793.83	*793.83*
7	342.79	395.09	395.09
8	393.31	430.76	430.76
9	249.98	271.59	271.59
10	2131.00	2516.40	2516.40
11	599.54	704.73	704.73
12	57.40	66.97	66.97
13	33.24	39.40	39.40
14	378.32	455.26	455.26
15	368.73	465.17	465.17
16	230.59	282.80	282.80
17	232.18	278.62	278.62
18	1255.40	1502.18	1502.18
19	872.67	1069.44	1069.44
20	2061.90	2520.09	2520.09
21	801.58	947.32	947.32
22	890.71	1103.98	1103.98
23	1839.03	2159.38	2159.38
24	2196.52	2688.85	2688.85
25	0.26	0.31	0.31
26	682.83	819.39	819.39
27	1111.77	1367.48	1367.48
28	242.89	302.05	302.05
29	806.29	1026.88	1026.88
Total	**23366.09**	**27860.98**	**27860.98**
Overall Percent Change in SOLP Load (%)		**19**	



(a) (b)

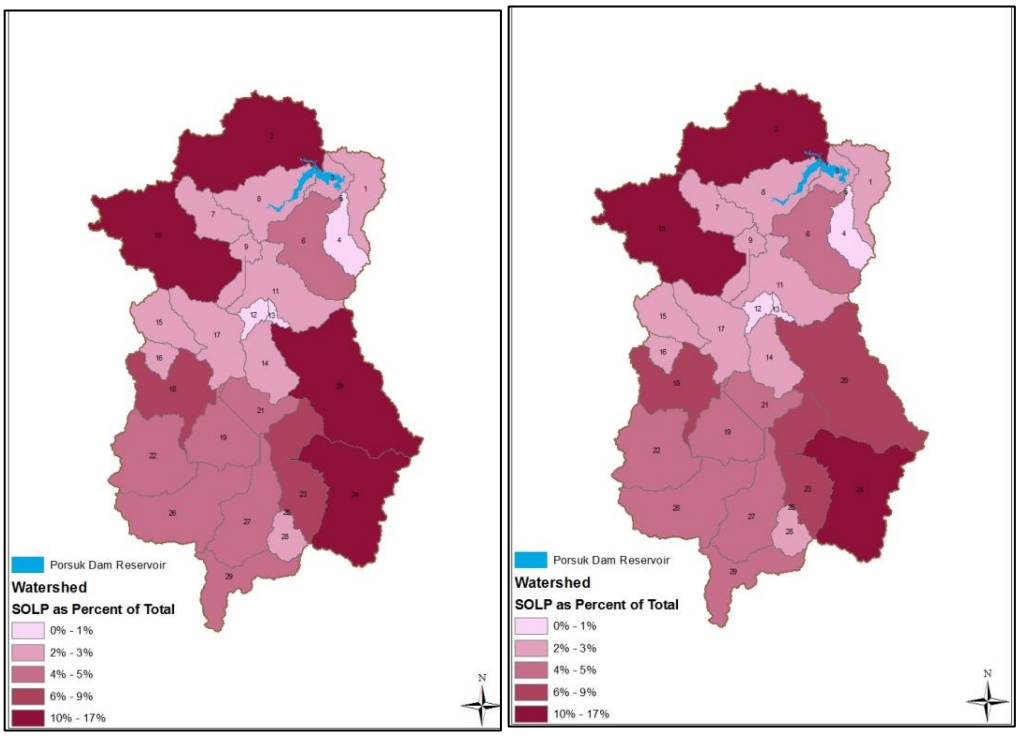
Figure 5.24 SOLP as percent of total from different sub-basins (a) Scenario IV, (b) Base-Case Scenario II

5.3.7 Scenario V

In Scenario V, auto-irrigation was applied for both SGBT and AGRC. For this scenario, only the dates of irrigation applications were specified. Default values were used for other input parameters. Irrigation was automatically applied depending on soil water deficit threshold. As can be seen in Table 5.20, auto-irrigation application resulted in increase in SOLP loads transported to the PDR. The main reason is that auto-irrigated wheat production was considered in this scenario while non-irrigated wheat production was applied in Base-Case Scenario II. Moreover, average value of the water stress threshold that triggers irrigation over the given interval in SWAT was used. This average value may lead to higher irrigation water use. The increase in overall SOLP loads was 20%. Figure 5.25 provides a visual representation for SOLP as percent of total from different sub-basins for Scenario V (Figure 5.25a) and Base-Case Scenario II (Figure 5.25b).

Table 5.20 SOLP loads from sub-basins: Scenario V

Sub-basin Number	Base-Case Scenario II	Scenario V	Sub-basin Number	Base-Case Scenario II	Scenario V
	SOLP (kg/year)	SOLP (kg/year)		SOLP (kg/year)	SOLP (kg/year)
1	441.36	453.79	16	230.59	282.80
2	4076.92	4767.55	17	232.18	278.62
3	250.50	256.07	18	1255.40	1502.18
4	139.59	152.68	19	872.67	1069.44
5	0.00	0.00	20	2061.90	2520.09
6	678.78	839.85	21	801.58	947.32
7	342.79	395.09	22	890.71	1103.98
8	393.31	449.49	23	1839.03	2159.38
9	249.98	283.93	24	2196.52	2688.85
10	2131.00	2539.07	25	0.26	0.31
11	599.54	704.73	26	682.83	819.39
12	57.40	66.97	27	1111.77	1367.48
13	33.24	39.40	28	242.89	302.05
14	378.32	468.08	29	806.29	1026.88
15	368.73	465.17	**Total**	**23366.09**	**27950.64**
Overall Percent Change in SOLP Load (%)					**20**



(a) (b)

Figure 5.25 SOLP as percent of total from different sub-basins (a) Scenario V, (b) Base-Case Scenario II

5.3.8 Scenario VI

In Scenario VI, SOLP loads resulting from KWWTP were decreased by 20% (Scenario VI-a), 30% (Scenario VI-b), 40% (Scenario VI-c), 50% (Scenario VI-d) and 67% (Scenario VI-e) while all management operations were the same as those in Base-Case Scenario II. It was clearly seen that SOLP load arising from sub-basin 11 were not affected by the point source (Table 5.21). Hence, annual average SOLP loads from sub-basins were the same as Base-Case Scenario II. Within this scenario, before mentioned percent decreases in SOLP loads resulting from KWWTP with respect to Base-Case Scenario I was also examined. It was realized that point source does not have a direct effect on SOLP load resulting from sub-basin 11 (Table 5.22).

Table 5.21 SOLP loads from sub-basins: Scenario VI-a, Scenario VI-b, Scenario VI-c, Scenario VI-d, Scenario VI-e

Sub-basin Number	**Base-Case Scenario II**	**Scenario VI-a**	**Scenario VI-b**	**Scenario VI-c**	**Scenario VI-d**	**Scenario VI-e**
	SOLP (kg/year)	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**
1	441.36	441.36	441.36	441.36	441.36	441.36
2	4076.92	4076.92	4076.92	4076.92	4076.92	4076.92
3	250.50	250.50	250.50	250.50	250.50	250.50
4	139.59	139.59	139.59	139.59	139.59	139.59
5	0.00	0.00	0.00	0.00	0.00	0.00
6	678.78	678.78	678.78	678.78	678.78	678.78
7	342.79	342.79	342.79	342.79	342.79	342.79
8	393.31	393.31	393.31	393.31	393.31	393.31
9	249.98	249.98	249.98	249.98	249.98	249.98
10	2131.00	2131.00	2131.00	2131.00	2131.00	2131.00
11	**599.54**	**599.54**	**599.54**	**599.54**	**599.54**	**599.54**
12	57.40	57.40	57.40	57.40	57.40	57.40
13	33.24	33.24	33.24	33.24	33.24	33.24
14	378.32	378.32	378.32	378.32	378.32	378.32
15	368.73	368.73	368.73	368.73	368.73	368.73
16	230.59	230.59	230.59	230.59	230.59	230.59
17	232.18	232.18	232.18	232.18	232.18	232.18
18	1255.40	1255.40	1255.40	1255.40	1255.40	1255.40
19	872.67	872.67	872.67	872.67	872.67	872.67
20	2061.90	2061.90	2061.90	2061.90	2061.90	2061.90
21	801.58	801.58	801.58	801.58	801.58	801.58
22	890.71	890.71	890.71	890.71	890.71	890.71
23	1839.03	1839.03	1839.03	1839.03	1839.03	1839.03
24	2196.52	2196.52	2196.52	2196.52	2196.52	2196.52
25	0.26	0.26	0.26	0.26	0.26	0.26
26	682.83	682.83	682.83	682.83	682.83	682.83
27	1111.77	1111.77	1111.77	1111.77	1111.77	1111.77
28	242.89	242.89	242.89	242.89	242.89	242.89
29	806.29	806.29	806.29	806.29	806.29	806.29
Total	**23366.09**	**23366.09**	**23366.09**	**23366.09**	**23366.09**	**23366.09**
Overall Percent Change in SOLP Load (%)		**-**	**-**	**-**	**-**	**-**

Table 5.22 SOLP loads from sub-basins: Scenario VII-a, Scenario VII-b, Scenario VII-c, Scenario VII-d, Scenario VII-e

Sub-basin Number	**Base-Case Scenario I**	**Scenario VII-a**	**Scenario VII-b**	**Scenario VII-c**	**Scenario VII-d**	**Scenario VII-e**
	SOLP (kg/year)	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**	**SOLP (kg/year)**
1	323.25	323.25	323.25	323.25	323.25	323.25
2	1336.70	1336.70	1336.70	1336.70	1336.70	1336.70
3	247.72	247.72	247.72	247.72	247.72	247.72
4	65.43	65.43	65.43	65.43	65.43	65.43
5	0.00	0.00	0.00	0.00	0.00	0.00
6	126.55	126.55	126.55	126.55	126.55	126.55
7	180.11	180.11	180.11	180.11	180.11	180.11
8	215.38	215.38	215.38	215.38	215.38	215.38
9	138.88	138.88	138.88	138.88	138.88	138.88
10	453.40	453.40	453.40	453.40	453.40	453.40
11	**115.70**	**115.70**	**115.70**	**115.70**	**115.70**	**115.70**
12	14.35	14.35	14.35	14.35	14.35	14.35
13	3.08	3.08	3.08	3.08	3.08	3.08
14	44.88	44.88	44.88	44.88	44.88	44.88
15	39.71	39.71	39.71	39.71	39.71	39.71
16	10.88	10.88	10.88	10.88	10.88	10.88
17	83.59	83.59	83.59	83.59	83.59	83.59
18	182.41	182.41	182.41	182.41	182.41	182.41
19	59.89	59.89	59.89	59.89	59.89	59.89
20	178.19	178.19	178.19	178.19	178.19	178.19
21	67.27	67.27	67.27	67.27	67.27	67.27
22	100.36	100.36	100.36	100.36	100.36	100.36
23	344.08	344.08	344.08	344.08	344.08	344.08
24	265.10	265.1	265.1	265.1	265.1	265.1
25	0.05	0.05	0.05	0.05	0.05	0.05
26	151.74	151.74	151.74	151.74	151.74	151.74
27	177.88	177.88	177.88	177.88	177.88	177.88
28	31.14	31.14	31.14	31.14	31.14	31.14
29	76.07	76.07	76.07	76.07	76.07	76.07
Total	**5033.78**	**5033.78**	**5033.78**	**5033.78**	**5033.78**	**5033.78**
Overall Percent Change in SOLP Load (%)		-	-	-	-	-

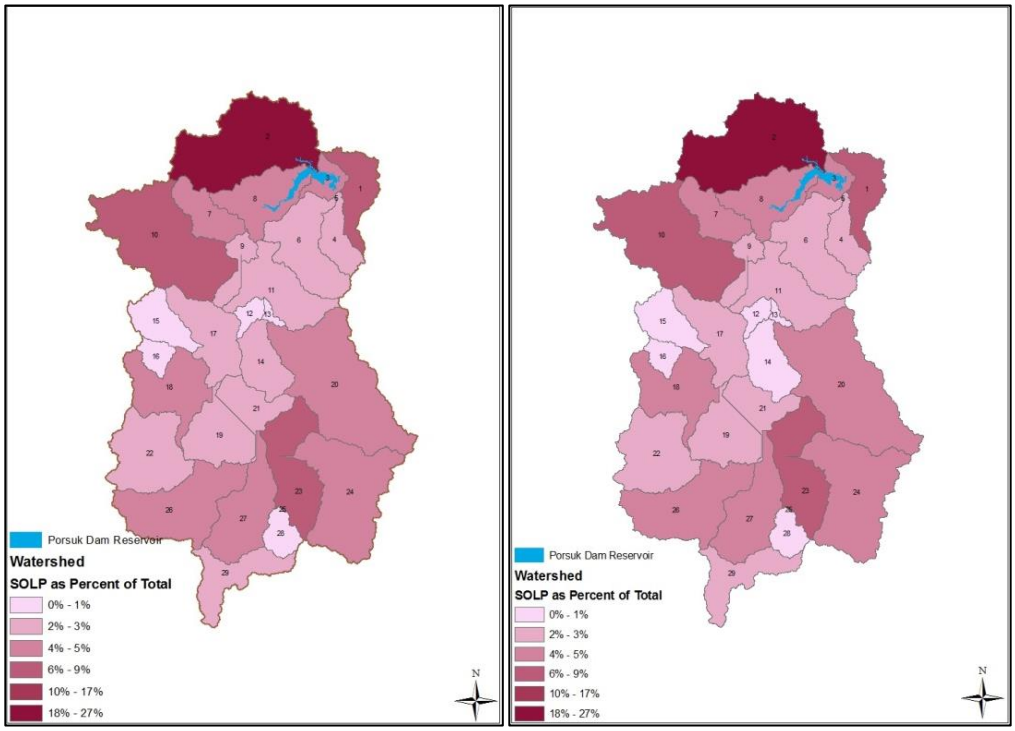
5.3.9 Scenario VII

In Scenario VII, AGRL was converted into RNGE for all sub-basins. This land use update resulted in 2.4% increase in overall SOLP load to the PDR (Table 5.23). This increase may be attributed to the default harvest index value set for RNGE and AGRL in SWAT. Harvest index represents the fraction of the aboveground biomass removed in a harvest operation (Neitsch et al., 2010). In other words, the fraction of plant biomass defined by harvest index becomes unavailable for decay and conversion to residue. Default value of this fraction for AGRL is higher than that for RNGE. Therefore, more plant biomass becomes available for decomposition

and conversion to residue in the case of RNGE. Figure 5.26 depicts the distribution of SOLP as percent of total from different sub-basins for Scenario VII (Figure 5.26a) and Base-Case Scenario I (Figure 5.26b).

Table 5.23 SOLP loads from sub-basins: Scenario VII

Sub-basin Number	**Base-Case Scenario I**	**Scenario VII**	**Sub-basin Number**	**Base-Case Scenario I**	**Scenario VII**
	SOLP (kg/year)	**SOLP (kg/year)**		**SOLP (kg/year)**	**SOLP (kg/year)**
1	323.25	323.25	16	10.88	17.40
2	1336.70	1358.97	17	83.59	83.59
3	247.72	247.72	18	182.41	214.60
4	65.43	65.43	19	59.89	59.89
5	0.00	0.00	20	178.19	203.64
6	126.55	138.06	21	67.27	78.48
7	180.11	180.11	22	100.36	100.36
8	215.38	215.38	23	344.08	344.08
9	138.88	141.97	24	265.10	265.10
10	453.40	453.40	25	0.05	0.06
11	115.70	126.22	26	151.74	151.74
12	14.35	14.35	27	177.88	166.77
13	3.08	3.08	28	31.14	28.03
14	44.88	51.30	29	76.07	76.07
15	39.71	45.38	**Total**	**5033.78**	**5154.41**
Overall Percent Change in SOLP Load (%)					**2.4**



(a) (b)

Figure 5.26 SOLP as percent of total from sub-basins (a) Scenario VII, (b) Base-Case Scenario I

5.3.10 Scenario VIII

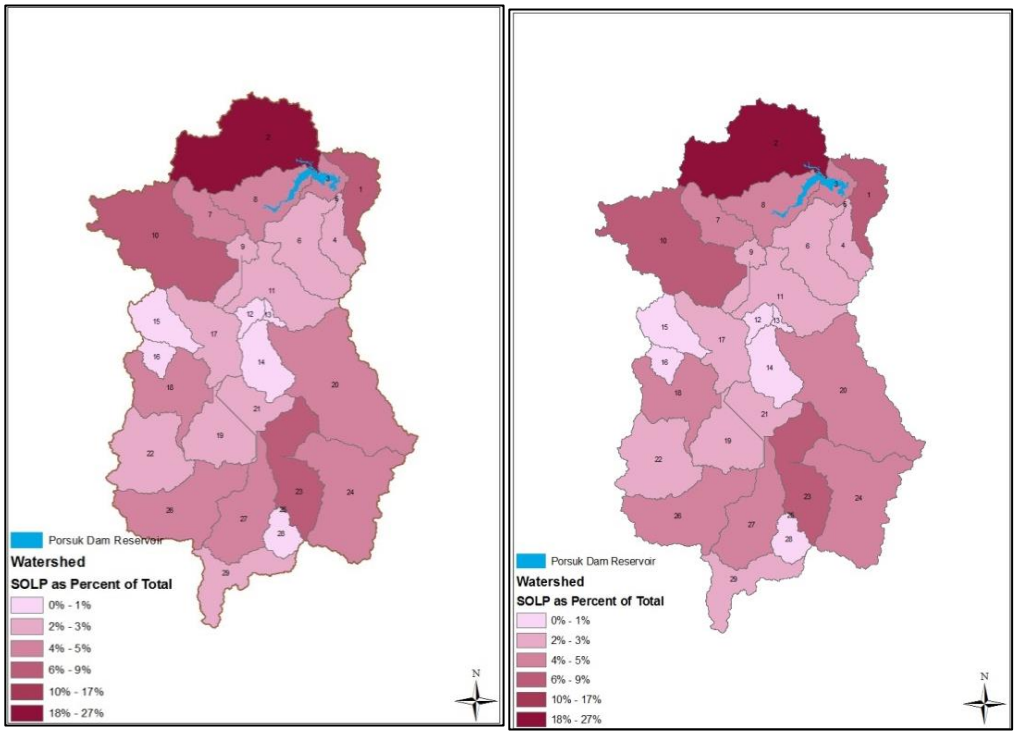
In Scenario VIII-a, AGRL was replaced with RNGE in sub-basins 2, 3, 6 and 8 to create a buffer zone around the PDR. Results of Scenario VIII-a were compared with the Base-Case Scenario I. On the other hand, AGRC in abovementioned sub-basins was converted into RNGE in Scenario VIII-b since AGRC is the dominant agricultural crop grown in these sub-basins. Results of Scenario VIII-b were compared with the Base-Case Scenario II. As can be seen in Table 5.24, there was 0.7% increase in overall SOLP load transported to the PDR when AGRL was replaced with RNGE and its reason was explained in Scenario VII. As a result of AGRC to RNGE conversion, 8.7% increase in overall SOLP load transported to the PDR was observed (Table 5.25). The reason why increase in overall SOLP load with respect to Base-Case Scenario II was higher than that with respect to Base-Case Scenario I may be that harvest index set for AGRC is higher than that set for AGRL. Figure 5.27 shows SOLP as percent of total from sub-basins for Scenario VIII-a (Figure 5.27a) and Base-Case Scenario I (Figure 5.27b). Figure 5.28 compares the distribution of SOLP as a percent of total throughout the watershed between Scenario VIII-b (Figure 5.28a) and Base-Case Scenario II (Figure 5.28b).

Table 5.24 SOLP loads from sub-basins: Scenario VIII-a

Sub-basin Number	Base-Case Scenario I	Scenario VIII-a	Sub-basin Number	Base-Case Scenario I	Scenario VIII-a
	SOLP (kg/year)	**SOLP (kg/year)**		**SOLP (kg/year)**	**SOLP (kg/year)**
1	323.25	323.25	16	10.88	10.88
2	1336.70	1358.97	17	83.59	83.59
3	247.72	247.72	18	182.41	182.41
4	65.43	65.43	19	59.89	59.89
5	0.00	0.00	20	178.19	178.19
6	126.55	138.06	21	67.27	67.27
7	180.11	180.11	22	100.36	100.36
8	215.38	215.38	23	344.08	344.08
9	138.88	138.88	24	265.10	265.1
10	453.40	453.4	25	0.05	0.05
11	115.70	115.7	26	151.74	151.74
12	14.35	14.35	27	177.88	177.88
13	3.08	3.08	28	31.14	31.14
14	44.88	44.88	29	76.07	76.07
15	39.71	39.71	**Total**	**5033.78**	**5067.56**
Overall Percent Change in SOLP Load (%)					**0.7**

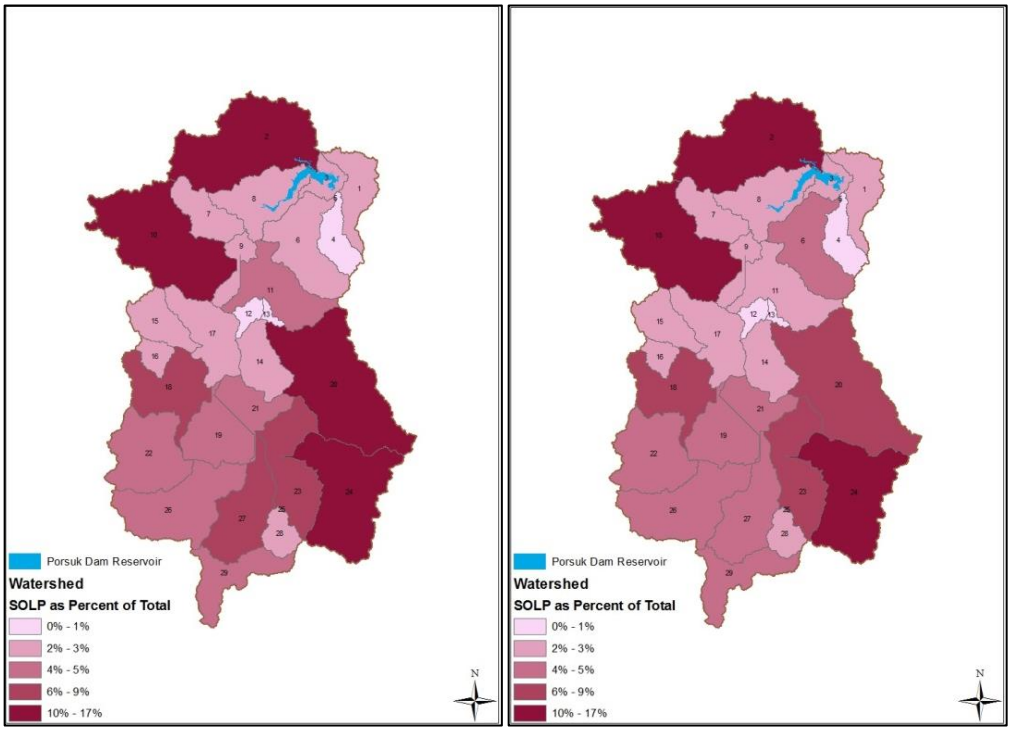
Table 5.25 SOLP loads from sub-basins: Scenario VIII-b

Sub-basin Number	Base-Case Scenario II	Scenario VIII-b	Sub-basin Number	Base-Case Scenario II	Scenario VIII-b
	SOLP (kg/year)	**SOLP (kg/year)**		**SOLP (kg/year)**	**SOLP (kg/year)**
1	441.36	453.79	16	230.59	289.33
2	4076.92	2428.33	17	232.18	278.62
3	250.50	250.5	18	1255.40	1534.37
4	139.59	152.68	19	872.67	1095.11
5	0.00	0.00	20	2061.90	2571.01
6	678.78	379.66	21	801.58	969.74
7	342.79	395.09	22	890.71	1141.61
8	393.31	252.84	23	1839.03	2230.56
9	249.98	271.59	24	2196.52	2764.59
10	2131.00	2584.41	25	0.26	0.31
11	599.54	725.76	26	682.83	834.57
12	57.40	66.97	27	1111.77	1400.84
13	33.24	41.25	28	242.89	308.28
14	378.32	468.08	29	806.29	1042.09
15	368.73	470.84	**Total**	**23366.09**	**25402.81**
Overall Percent Change in SOLP Load (%)					**8.7**



(a) (b)

Figure 5.27 SOLP as percent of total from sub-basins (a) Scenario VIII-a, (b) Base Case Scenario I



(a) (b)

Figure 5.28 SOLP as percent of total from different sub-basins (a) Scenario VIII-b, (b) Base-Case Scenario II

5.3.11 Scenario IX

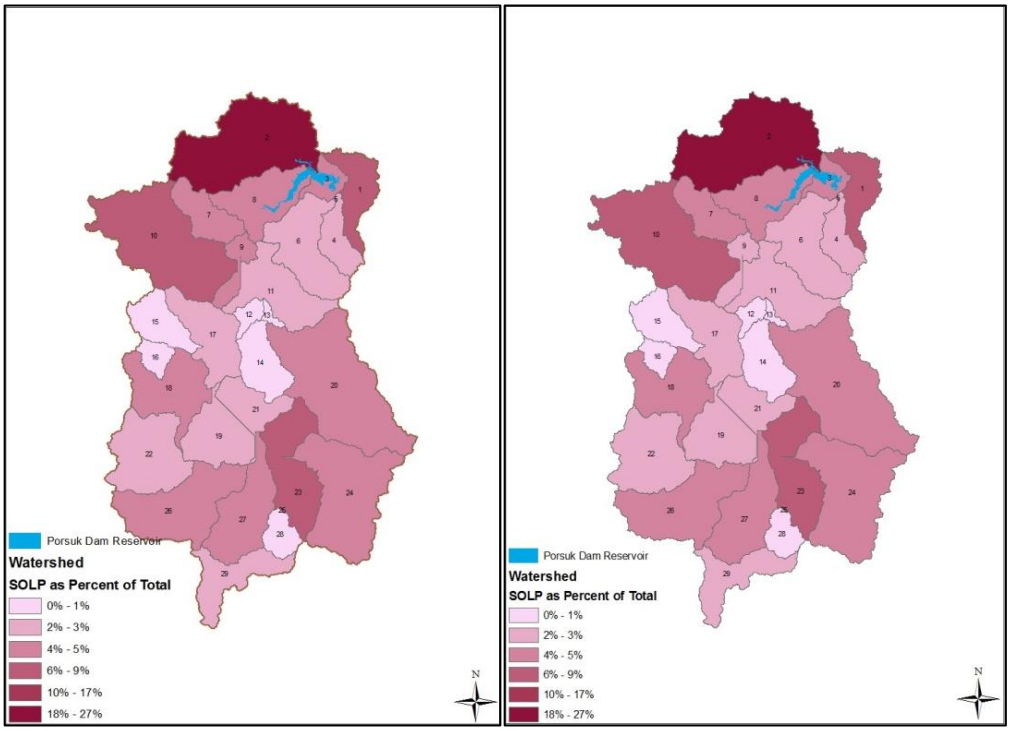
In Scenario IX-a, the aim was to create buffer zones around the tributaries. Therefore, AGRL for the tributaries located in sub-basins 8, 9, 11, 17, 21, 23 and 28 were replaced with RNGE. Results of Scenario IX-a were compared with the Base-Case Scenario I. This land use refinement resulted in 0.4% increase (this increase was 0.7% in the previous scenario) in overall SOLP load transported to the PDR because different sub-basins were considered in these two scenarios (Table 5.26). Besides, land use distributions in these sub-basins were not uniform. Figure 5.29 provides SOLP distribution as percent of total with respect to different sub-basins for Scenario IX-a (Figure 5.29a) and Base-Case Scenario I (Figure 5.29b). On the other hand, AGRC in abovementioned sub-basins was converted into RNGE in Scenario IX-b since these sub-basins are dominated by AGRC as stated in Section 4.9.11. Results of Scenario IX-b were compared with the Base-Case Scenario II. Replacing AGRC with RNGE resulted in 13.5% increase (this increase was 8.7% in the previous scenario) in overall SOLP load to the PDR (Table 5.27). The reason for this difference can be associated with the same reason found in Scenario IX-a. Figure 5.30 provides the distribution of SOLP as a percent of total throughout the watershed for Scenario IX-b (Figure 5.30a) and Base-Case Scenario II (Figure 5.30b).

Table 5.26 SOLP loads from sub-basins: Scenario IX-a

Sub-basin Number	Base-Case Scenario I	Scenario IX-a	Sub-basin Number	Base-Case Scenario I	Scenario IX-a
	SOLP (kg/year)	SOLP (kg/year)		SOLP (kg/year)	SOLP (kg/year)
1	323.25	323.25	16	10.88	10.88
2	1336.70	1336.7	17	83.59	83.59
3	247.72	247.72	18	182.41	182.41
4	65.43	65.43	19	59.89	59.89
5	0.00	0.00	20	178.19	178.19
6	126.55	126.55	21	67.27	78.48
7	180.11	180.11	22	100.36	100.36
8	215.38	215.38	23	344.08	344.08
9	138.88	141.97	24	265.10	265.1
10	453.40	453.4	25	0.05	0.05
11	115.70	126.22	26	151.74	151.74
12	14.35	14.35	27	177.88	177.88
13	3.08	3.08	28	31.14	28.03
14	44.88	44.88	29	76.07	76.07
15	39.71	39.71	**Total**	**5033.78**	**5055.48**
Overall Percent Change in SOLP Load (%)					**0.4**

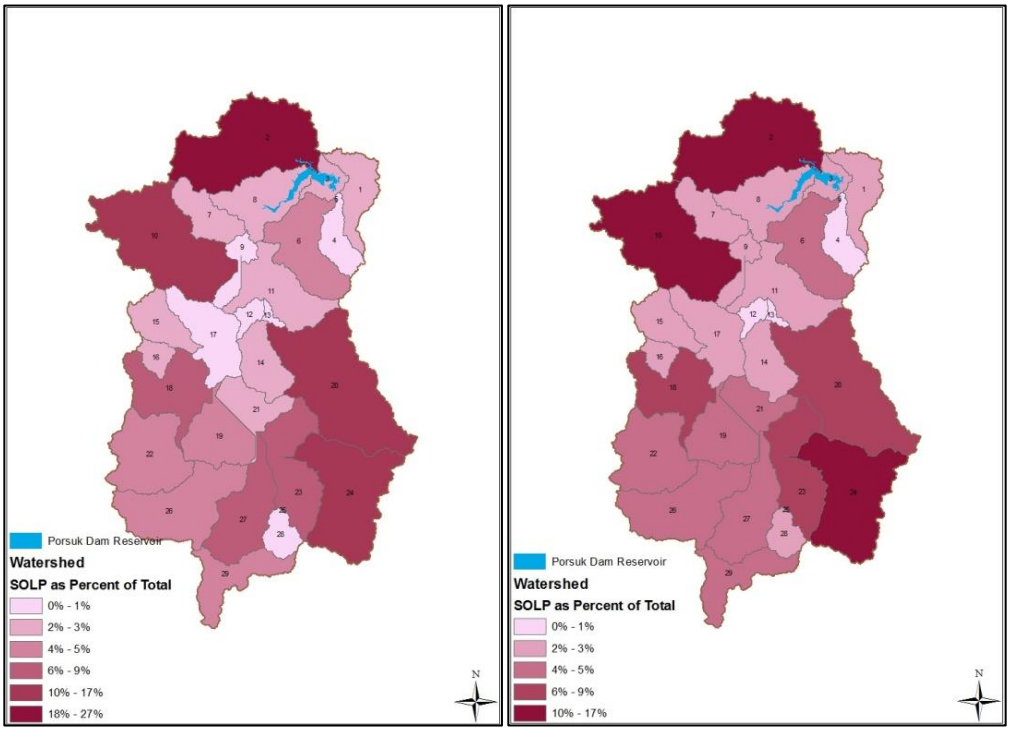
Table 5.27 SOLP loads from sub-basins: Scenario IX-b

Sub-basin Number	Base-Case Scenario II	Scenario IX-b	Sub-basin Number	Base-Case Scenario II	Scenario IX-b
	SOLP (kg/year)	SOLP (kg/year)		SOLP (kg/year)	SOLP (kg/year)
1	441.36	453.79	16	230.59	289.33
2	4076.92	4856.66	17	232.18	176.46
3	250.50	250.5	18	1255.40	1534.37
4	139.59	157.04	19	872.67	1095.11
5	0.00	0.00	20	2061.90	2571.01
6	678.78	816.84	21	801.58	369.96
7	342.79	395.09	22	890.71	1141.61
8	393.31	252.84	23	1839.03	1969.54
9	249.98	172.83	24	2196.52	2764.59
10	2131.00	2584.41	25	0.26	0.31
11	599.54	252.44	26	682.83	834.57
12	57.40	66.97	27	1111.77	1400.84
13	33.24	41.25	28	242.89	99.65
14	378.32	468.08	29	806.29	1042.09
15	368.73	470.84	**Total**	**23366.09**	**26529.01**
Overall Percent Change in SOLP Load (%)					**13.5**



(a) (b)

Figure 5.29 SOLP as percent of total from different sub-basins (a) Scenario IX-a, (b) Base-Case Scenario I



(a) (b)

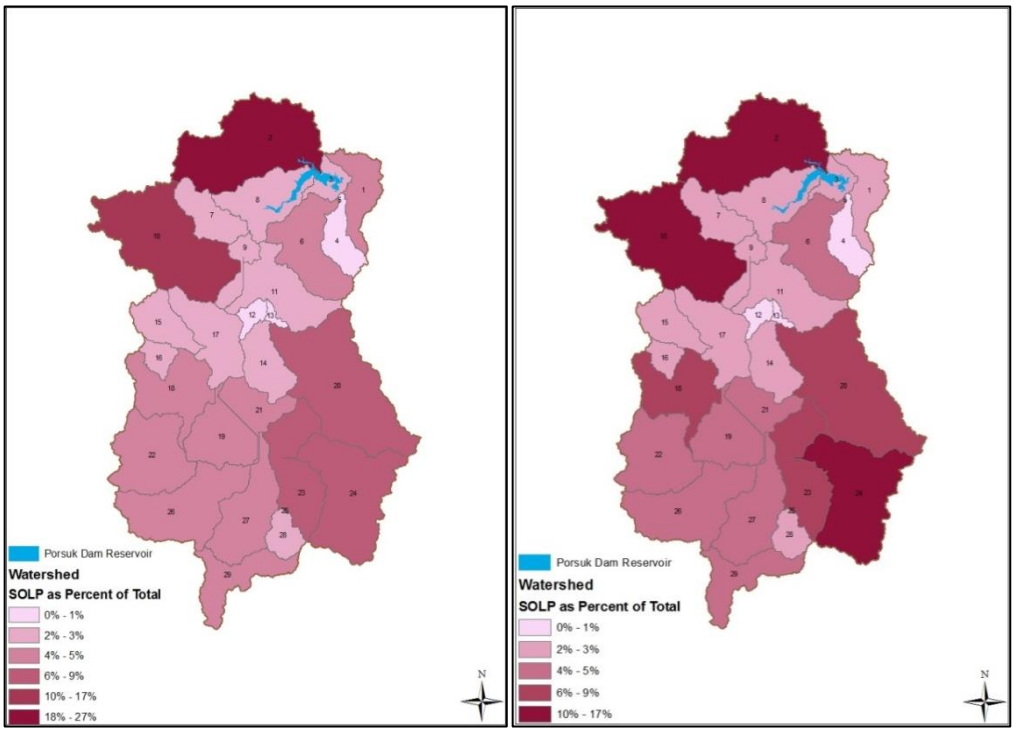
Figure 5.30 SOLP as percent of total from different sub-basins (a) Scenario IX-b, (b) Base-Case Scenario II

5.3.12 Scenario X

As stated before, an additional scenario (Scenario X) was tested which included the most promising two scenarios (Scenario II-d and Scenario III-a) in terms of reduction in SOLP loads. Results are given in Table 5.28. 40% decrease in overall SOLP load transported to the PDR was achieved by decreasing fertilizer application rate by 50% and irrigation rate by 20%. When Table 5.17 and Table 5.18 were examined, it was understood that 40% decrease in overall SOLP load can be attributed to only 50% decrease in fertilizer application rate. Therefore, an additive impact cannot be observed here. Figure 5.31 describes the distribution of SOLP as percent of total throughout the watershed for Scenario X (Figure 5.31a) and Base-Case Scenario II (Figure 5.31b).

Table 5.28 SOLP loads from sub-basins: Scenario II-d + Scenario III-a

Sub-basin Number	Base-Case Scenario II	Scenario X	Sub-basin Number	Base-Case Scenario II	Scenario X
	SOLP (kg/year)	SOLP (kg/year)		SOLP (kg/year)	SOLP (kg/year)
1	441.36	416.50	16	230.59	126.17
2	4076.92	2628.83	17	232.18	167.17
3	250.50	250.50	18	1255.40	729.63
4	139.59	113.42	19	872.67	453.44
5	0.00	0.00	20	2061.90	1120.04
6	678.78	448.69	21	801.58	470.86
7	342.79	255.64	22	890.71	476.72
8	393.31	309.03	23	1839.03	1067.82
9	249.98	200.60	24	2196.52	1155.07
10	2131.00	1292.20	25	0.26	0.19
11	599.54	357.62	26	682.83	394.52
12	57.40	35.08	27	1111.77	633.71
13	33.24	18.47	28	242.89	137.01
14	378.32	211.60	29	806.29	395.54
15	368.73	198.55	**Total**	**23366.09**	**14064.63**
Overall Percent Change in SOLP Load (%)					**40**



(a) (b)

Figure 5.31 SOLP as percent of total from different sub-basins (a) Scenario X, (b) Base-Case Scenario II

5.4 Calculation of SOLP Export Coefficients

The quantities of nutrients transported with respect to unit drainage area are called as nutrient export coefficients (Carrigan and Sorensen, 2012). These coefficients represent mass of nutrient per unit drainage area and time. Since phosphorus is the pollutant of concern in this study, export coefficients were calculated only for SOLP. SOLP export coefficients for different sub-basins with respect to Base-Case Scenario I, Base-Case Scenario II and Scenario X are provided in Table 5.29. SOLP export coefficients for scenarios other than these three are given in Table C.1 in Appendix C. As can be seen in Table 5.29, the overall SOLP export coefficients from the whole basin for Base-Case Scenario I, Base-Case Scenario II and Scenario X are 0.01, 0.046 and 0.028 kg/ha/year, respectively. Figure 5.32 and Figure 5.33 show the relationship between SOLP export coefficients and land uses. When these two figures were compared, it was seen that there is a weak relationship between SOLP export coefficients for different sub-basins and agricultural area and range grass percentages. However, it can be claimed that the relationship depicted in Figure 5.33 is more distinguishable compared to Figure 5.32. For watersheds whose land uses are dominated by agriculture and forest (as in the case of Watershed of the PDR), typical value of SOLP export coefficient given in literature is about 0.1 kg/ha/year (Clesceri et al., 1986). Typical value of this coefficient becomes 0.15 kg/ha/year for agricultural watersheds (Clesceri et al., 1986). The overall SOLP export coefficients determined for the given three scenarios vary from the typical values given in literature. If SOLP export coefficients are calculated based on the areas where actually agriculture is practiced, then the overall SOLP export coefficient of 0.1 kg/ha/year could be reached only for Base-Case Scenario II, while for Base-Case Scenario I and Scenario X overall export coefficients are 0.02 and 0.07 kg/ha/year, respectively. Although representation of a watershed by nutrient export coefficient is one way for pollutant loads simulation, this coefficient depends on various factors (i.e. climate, topography, agricultural practices) that have a control on the phosphorus yield characteristics. It was seen that the Watershed of the PDR cannot be represented by SOLP export coefficient obtained directly from literature. A detailed study for the determination of SOLP export coefficient for the study area should be carried out.

Table 5.29 SOLP export coefficients for different sub-basins with respect to Base-Case Scenario I, Base-Case Scenario II and Scenario X

Sub-basin Number	**Drainage Area (ha)**	**Base-Case Scenario I**	**Base-Case Scenario II**	**Scenario X**
		SOLP (kg/ha/year)	**SOLP (kg/ha/year)**	**SOLP (kg/ha/year)**
1	12432.72	0.026	0.035	0.034
2	44556.52	0.030	0.091	0.059
3	5566.64	0.045	0.045	0.045
4	8724.44	0.007	0.016	0.013
5	1.00	0.000	0.000	0.000
6	23009.56	0.005	0.029	0.020
7	11620.16	0.015	0.029	0.022
8	18728.84	0.011	0.021	0.017
9	6172.40	0.023	0.040	0.032
10	45340.48	0.010	0.047	0.028
11	21036.64	0.005	0.028	0.017
12	3189.08	0.004	0.018	0.011
13	1231.20	0.003	0.027	0.015
14	12824.24	0.003	0.030	0.017
15	11345.64	0.004	0.032	0.018
16	4350.76	0.003	0.053	0.029
17	18574.56	0.005	0.012	0.009
18	21459.76	0.009	0.059	0.034
19	17111.08	0.004	0.051	0.026
20	50911.00	0.004	0.041	0.022
21	11210.84	0.006	0.072	0.042
22	25090.40	0.004	0.036	0.019
23	23729.40	0.015	0.078	0.045
24	37871.12	0.007	0.058	0.031
25	25.12	0.002	0.010	0.008
26	30347.88	0.005	0.023	0.013
27	22235.48	0.008	0.050	0.028
28	6227.88	0.005	0.039	0.022
29	15213.00	0.005	0.053	0.026
Overall	**510137.84**	**0.010**	**0.046**	**0.028**

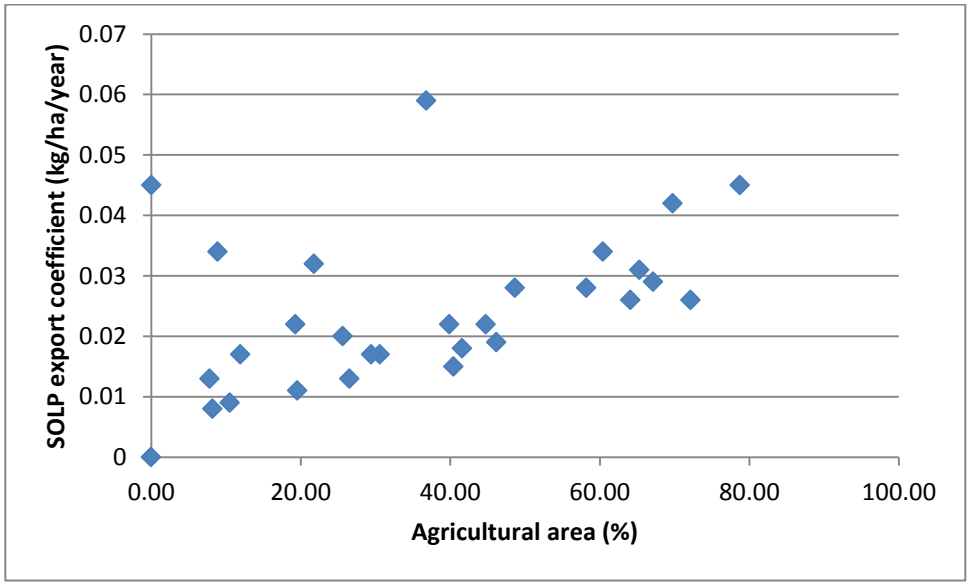


Figure 5.32 SOLP export coefficients for different sub-basins with respect to agricultural area

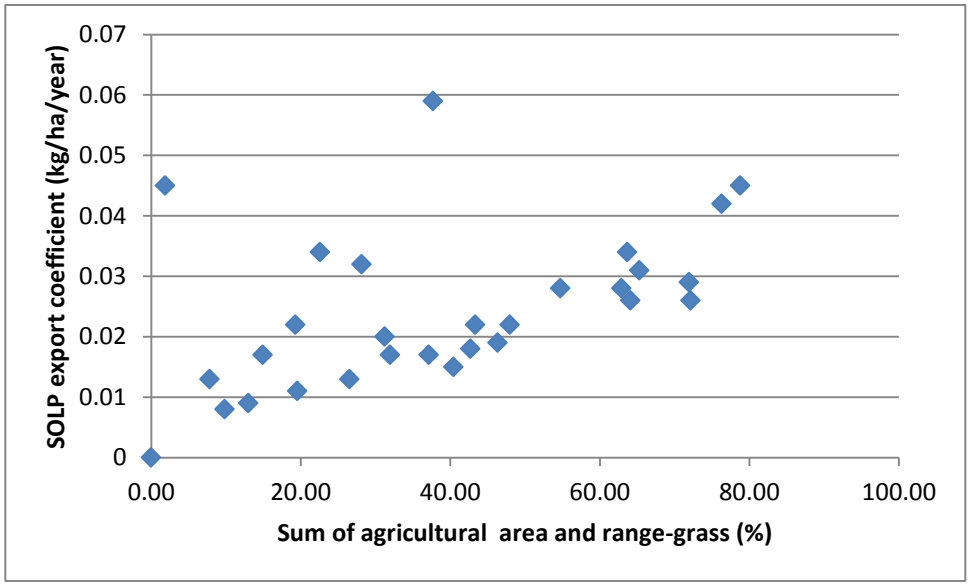


Figure 5.33 SOLP export coefficients for different sub-basins with respect to sum of agricultural area and range grass

5.5 Overall Assessment of Scenario Simulations

According to the results of the scenarios, it can be deduced that changes in only fertilizer application rates have a strong impact on SOLP loads arising from different sub-basins (Table 5.28). Indeed, a linear relationship was found between overall SOLP loads transported to the

PDR and fertilizer application rates. Moreover, SOLP loads from different sub-basins were affected by varying irrigation rates and types and land use changes although to a lesser extent than that was seen in the case of changes in fertilizer application rates.

When the results of all scenarios were examined, it was seen that maximum SOLP load arose from sub-basin 2. The main reasons are that sub-basin 2 has the maximum drainage area and SOLP export coefficient among other sub-basins. Following sub-basin 2, sub-basins 10, 20, 23 and 24 were also responsible for the transport of the considerable amount of SOLP load due to mainly their large drainage areas, land uses and high SOLP export coefficients. Therefore, precautions should be taken in these sub-basins.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

As mentioned throughout the thesis, the overall objectives of this study are to carry out a hypothetical assessment for non-point source pollution resulting from agricultural activities in the Watershed of the PDR and to determine the relative impacts of different agricultural operations and land use changes on SOLP resulting from different sub-basins.

The major water quality problem in the Watershed of the PDR is associated with phosphorus transport from agricultural areas. To identify the degree of SOLP pollution throughout the watershed especially in the PDR, nine scenarios were developed. These scenarios generally consist of varying fertilizer and irrigation rates, decreasing SOLP loads resulting from KWWTP and land use changes throughout the watershed and around the PDR and around the main tributaries. After assessing the results of these nine scenarios, an additional scenario (Scenario X) was also tested which included the combination of the two of the best nine scenarios (Scenario II-d and Scenario III-a) in terms of reduction in SOLP loads. In conclusion, decreasing fertilizer application rate by 50% (Scenario II-d) and irrigation rate by 20% (Scenario III-a) lead to 40% decrease in overall SOLP load transported to the PDR. 40% decrease in overall SOLP load can be attributed to only 50% decrease in fertilizer application rate. Therefore, an additive impact cannot be observed. Moreover, SOLP export coefficients were calculated for different sub-basins. It was seen there is a difference between the export coefficients obtained from literature and calculated ones. According to the results of all the aforementioned scenarios, the most critical sub-basin that is responsible for the considerable and non-proportional SOLP load was determined as sub-basin 2. Following sub-basin 2, sub-basins 10, 20, 23 and 24 can be considered as the high concern areas within the watershed to control SOLP loads. Therefore, it can be recommended that fertilizer should be applied in a controlled manner to achieve a considerable decrease in overall SOLP load to the PDR. Moreover, although it is highly recommended that care should be taken in agricultural land use planning in order to better protect the water quality in the Watershed of the PDR, all sources of pollution should be considered to achieve sustainable watershed management. It must be emphasized that the results of this study are valid for the conditions considered.

While carrying out such a study, the methodological limitations of the study should be pointed out. The main difficulty encountered during this study was related to the identification of input parameters since state variables in SWAT are controlled by numerous parameters. Limited data was a drawback. Models other than SWAT which may require less input parameters and data can be used as well in future studies. Some recommendations for future studies are as follows;

- Pesticide simulation was not considered within the scope of this study because pesticide application rates in the study area were not available. Therefore, it is recommended to perform pesticide transport simulation once pesticide application rates become available.
- Although agriculture has been considered as the primary activity responsible for the impairment in the quality of water resources and reduction in water availability and it is the dominant land use in the study area, a study should be conducted to evaluate the effects of other point and non-point sources.
- Information regarding the chemical and physical characteristics of the soil in the study area is essential for the accomplishment of the purpose of the SWAT. However, there is no available field work that focuses on the soil properties of the study area. Therefore, soil input parameters were obtained from the literature. It is highly recommended to conduct a detailed soil survey in the study area to improve the accuracy of the results.
- In this study, only flow calibration was performed due to lack of data regarding sediment and various pollutants. Once water quality data become available, their calibration should also be conducted.
- Another limitation of this study is related to data accuracy. Accuracy of the stream flow data obtained from stream flow observation stations of both Electrical Power Resources Survey and Development Administration and SHW are questionable. This situation directly affects calibration process. Therefore, site measurements should be carried out to obtain more reliable data. Once the more reliable data become available, daily or monthly calibration should also be performed.
- Information regarding management operations applied in the study area was derived from the literature. It is recommended that a detailed study should be performed for the determination of the timing of the planting/beginning of growing season and harvest and kill operation, timing of the irrigation operation, application amount, source of irrigation water, and location of the source, timing of the fertilizer operation, the type and amount of fertilizer, and the depth distribution of fertilizer and type and timing of the tillage operation.
- For scenario development only the most commonly applied agricultural productions (wheat and sugar beet) were taken into account in this study. However, change in crop pattern has a significant impact on both hydrological and nutrient related processes because agricultural crops react differently to the varying fertilizer and irrigation rates. Once the crop pattern in the study area is specified in detail, an additional scenario should be established for the evaluation of the effects of crop pattern change on the pollutant of concern.
- The same tillage operations obtained from literature were used for all scenarios developed in this study. Residue, nutrients, pesticides and bacteria are redistributed throughout the soil profile by means of the tillage operation. Moreover, redistribution ratio depends on the type of tillage operation. Thus, it is suggestible to try different types of tillage operation as an additional scenario.

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URL 1 National Soil Database http://aris.cob.gov.tr/sites/default/files/lejant.pdf (access May 2012)

URL 2 Soil Water Assessment Tool http://swat.tamu.edu/ (access Jan. 2011)

URL 3 Meteoroloji Genel Müdürlüğü İstasyon Bilgileri Veritabanı http://dmi.gov.tr/kurumsal/istasyonlarimiz.aspx (access Jan. 2012)

URL 4 State Hydraulic Works http://www2.dsi.gov.tr/baraj/detay.cfm?BarajID=42 (access May 2013)

APPENDIX A

SUMMARY OF WATERSHED SCALE HYDROLOGIC AND NON-POINT SOURCE POLLUTION MODELS

Table A.1 Summary of watershed-scale hydrologic and non-point source pollution models: continuous models (Borah and Bera, 2003)

Description/ Criteria	AnnAGNPS	ANSWERS-Continuous	HSPF	MIKE SHE	SWAT
Model components/ capabilities	Hydrology, transport of sediment, nutrients, and pesticides resulting from snowmelt, precipitation and irrigation, source accounting capability, and user interactive programs including TOPAGNPS generating cells and stream network from DEM.	Daily water balance, infiltration, runoff and surface water routing, drainage, river routing, ET, sediment detachment, sediment transport, nitrogen and phosphorous transformations, nutrient losses through uptake, runoff, and sediment.	Runoff and water quality constituents on pervious and impervious land areas, movement of water and constituents in stream channels and mixed reservoirs, and part of the USEPA BASINS modeling system with user interface and ArcViewGIS platform.	Interception-ET, overland and channel flow, unsaturated zone, saturated zone, snowmelt, exchange between aquifer and rivers, advection and dispersion of solutes, geochemical processes, crop growth and nitrogen processes in the root zone, soil erosion, dual porosity, irrigation, and user interface with pre- and post-processing, GIS, and UNIRAS for graphical presentation.	Hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, agricultural management, channel and reservoir routing, water transfer, and part of the USEPA BASINS modeling system with user interface and ArcViewGIS platform.
Temporal scale	Long term; daily or sub-daily steps.	Long term; dual time steps: daily for dry days and 30 seconds for days with precipitation.	Long term; variable constant steps (hourly).	Long term and storm event; variable steps depending numerical stability.	Long term; daily steps.
Watershed representation	Homogeneous land areas (cells), reaches, and impoundments.	Square grids with uniform hydrologic characteristics, some having companion channel elements; 1-D simulations.	Pervious and impervious land areas, stream channels, and mixed reservoirs; 1-D simulations.	2-D rectangular/square overland grids, 1-D channels, 1-D unsaturated and 3-D saturated flow layers.	Sub-basins grouped based on climate, hydrologic response units (lumped areas with same cover, soil, and management), ponds, groundwater, and main channel.
Rainfall excess on overland/ water balance	Water balance for constant sub-daily time steps and two soil layers (8-in. tillage depth and user-supplied second layer).	Daily water balance, rainfall excess using interception, Green-Ampt infiltration equation, and surface storage coefficients.	Water budget considering interception, ET, and infiltration with empirically based areal distribution.	Interception and ET loss and vertical flow solving Richards equation using implicit numerical method.	Daily water budget; precipitation, runoff, ET, percolation, and return flow from subsurface and groundwater flow.
Runoff on overland	Runoff curve number generating daily runoff following SWRRB and EPIC procedures and SCS TR-55 method for peak flow.	Manning and continuity equations (temporarily variable and spatially uniform) solved by explicit numerical scheme.	Empirical outflow depth to detention storage relation and flow using Chezy-Manning equation.	2-D diffusive wave equations solved by an implicit finite-difference scheme.	Runoff volume using curve number and flow peak using modified Rational formula or SCS TR-55 method.
Subsurface flow	Lateral subsurface flow using Darcy's equation or tile drain flow using Hooghoudt's equation and parallel drain approximation.	Subsurface flow defined by tile drainage coefficient and groundwater or interflow release fraction; unsaturated zone drainage determined using Darcy's gravity flow.	Interflow outflow, percolation, and groundwater outflow using empirical relations.	3-D groundwater flow equations solved using a numerical finite-difference scheme and simulated river-groundwater exchange.	Lateral subsurface flow using kinematic storage model (Sloan et al., 1983), and groundwater flow using empirical relations.
Runoff in channel	Assuming trapezoidal and compound cross-sections, Manning's equation is numerically solved for hydraulic parameters and TR-55 for peak flow.	Manning and continuity equations (temporarily variable and spatially uniform) solved by explicit numerical scheme.	All inflows assumed to enter one upstream point, and outflow is a function of reach volume or user-supplied demand.	1-D diffusive wave equations solved by an implicit finite-difference scheme.	Routing based on variable storage coefficient method and flow using Manning's equation adjusted for transmission losses, evaporation, diversions, and return flow.

Table A.1 Summary of watershed-scale hydrologic and non-point source pollution models: continuous models (continued)

Description/ Criteria	AnnAGNPS	ANSWERS-Continuous	HSPF	MIKE SHE	SWAT
Flow in reservoir	Average outflow during runoff event is calculated based on permanent pool storage and stage, runoff volume, and coefficients derived from elevation-storage relation.	Not simulated.	Same as channel.	No information.	Water balance and user-provided outflow (measured or targeted).
Overland sediment	Uses RUSLE to generate sheet and rill erosion daily or user-defined runoff event, HUSLE for delivery ratio, and sediment deposition based on size distribution and particle fall velocity.	Raindrop detachment using rainfall intensity and USLE factors, flow erosion using unit-width flow and USLE factors, and transport and deposition of sediment sizes using modified Yalin's equation.	Rainfall splash detachment and wash off of the detached sediment based on transport capacity as function of water storage and outflow plus scour from flow using power relation with water storage and flow.	No information.	Sediment yield based on Modified Universal Soil Loss Equation (MUSLE) expressed in terms of runoff volume, peak flow, and USLE factors.
Channel sediment	Modified Einstein equation for sediment transport and Bagnold equation to determine transport capacity of flow.	Not simulated.	Non-cohesive (sand) sediment transport using user-defined relation with flow velocity or Toffaleti or Colby method, and cohesive (silt, clay) sediment transport based on critical shear stress and settling velocity.	No information.	Bagnold's stream power concept for bed degradation and sediment transport, degradation adjusted with USLE soil erodibility and cover factors, and deposition based on particle fall velocity.
Reservoir sediment	Sediment deposition based on constant detention discharge, zero transport capacity, and dilution with pool water.	Not simulated.	Same as channel.	No information.	Outflow using simple continuity based on volumes and concentrations of inflow, outflow, and storage.
Chemical simulation	Soil moisture, nutrients, and pesticides in each cell are tracked using NRCS soil databases and crop information, and reach routing includes fate and transport of nitrogen, phosphorous, and individual pesticides, and organic carbon.	Nitrogen and phosphorous transport and transformations through mineralization, ammonification, nitrification, and denitrification, and losses through uptake, runoff, and sediment.	Soil and water temperatures, dissolved oxygen, carbon dioxide, nitrate, ammonia, organic N, phosphate, organic P, pesticides in dissolved, adsorbed, and crystallized forms, and tracer chemicals chloride or bromide to calibrate solute movement through soil profiles.	Dissolved conservative solutes in surface, soil, and ground waters by solving numerically the advection-dispersion equation for the respective regimes.	Nitrate-N based on water volume and average concentration, runoff P based on partitioning factor, daily organic N and sediment adsorbed P losses using loading functions, crop N and P use from supply and demand, and pesticides based on plant leaf-area-index, application efficiency, wash off fraction, organic carbon adsorption coefficient, and exponential decay according to half lives.
BMP evaluation	Agricultural management.	Impact of watershed management practices on runoff and sediment losses.	Nutrient and pesticide management.	No information.	Agricultural management: tillage, irrigation, fertilization, pesticide applications, and grazing.

Table A.2 Summary of watershed-scale hydrologic and non-point source pollution models: single-event models (Borah and Bera, 2003)

Description/ Criteria	AGNPS	ANSWERS	CASC2D	DWSM	KINEROS	PRMS Storm Mode
Model components/ capabilities	Hydrology, soil erosion, and transport of sediment, nitrogen, phosphorous, and chemical oxygen demand from nonpoint and point sources, and user interface for data input and analysis of results.	Runoff, infiltration, subsurface drainage, soil erosion, and overland sediment transport.	Spatially varying rainfall inputs including radar estimates, rainfall excess and 2-D flow routing on cascading overland grids, continuous soil moisture accounting, diffusive wave or full-dynamic channel routing, upland erosion, sediment transport in channels, and part of U.S. Army Corps of Engineers' Watershed Modeling System with graphical user interface and GIS data processing.	Spatially varying rainfall inputs; individual hyetograph for each overland, rainfall excess, surface and subsurface overland flow, surface erosion and sediment transport, agrochemical mixing and transport, channel erosion and deposition and routing of flow, sediment, and agrochemical and flow routing through reservoirs.	Distributed rainfall inputs; each catchment element assigned to a rain gauge from a maximum of 20, rainfall excess, overland flow, channel routing, surface erosion and sediment transport, channel erosion and sediment transport, flow and sediment routing through detention structures.	Hydrology and surface runoff, channel flow, channel reservoir flow, soil erosion, overland sediment transport, and linkage to USGS data-management program ANNIE for formatting input data and analyzing simulated results.
Temporal scale	Storm event; one step is the storm duration.	Storm event; variable constant steps depending numerical stability.	Long term and storm event; variable steps depending numerical stability.	Storm event; variable constant steps.	Storm event; variable constant steps depending numerical stability.	Storm event; variable constant steps depending numerical stability.
Watershed representation	Uniform square areas (cells), some containing channels.	Square grids with uniform hydrologic characteristics, some having companion channel elements; 1-D simulations.	2-D square overland grids and 1-D channels.	Overland, channel, and reservoir segments defined by topographic-based natural boundaries; 1-D simulations.	Runoff surfaces or planes, channels or conduits, and ponds or detention storage; 1-D simulations.	Flow planes, channel segments, and channel reservoirs; 1-D simulations.
Rainfall excess on overland	Runoff curve number method.	Surface detention with empirical relations and infiltration with modified Holton-Overton relation.	Interception and ET loss, infiltration using Green-Ampt method, and overland flow retention.	Two options: simple runoff curve number procedure for computing time varying rainfall intensities, or extensive interception and Smith-Parlange infiltration procedure.	Interception loss and extensive infiltration procedure by Smith and Parlange.	Interception and infiltration using an empirically based areal distribution of point infiltration (Green-Ampt equation), similar to HSPF.
Runoff on overland	Runoff volume using runoff curve number, and flow peak using an empirical relation similar to Rational formula or SCS TR-55 method.	Manning and continuity equations (temporarily variable and spatially uniform) solved using an explicit numerical scheme.	2-D diffusive wave equations solved by explicit finite-difference scheme.	Kinematic wave equations solved using analytical and an approximate shock-fitting solutions.	Kinematic wave equations solved by an implicit numerical scheme.	Kinematic wave equations solved using a numerical scheme.

Table A.2 Summary of watershed-scale hydrologic and non-point source pollution models: single-event models (continued)

Description/ Criteria	AGNPS	ANSWERS	CASC2D	DWSM	KINEROS	PRMS Storm Mode
Subsurface flow	Not simulated.	Water moving from a control zone to tile drainage and groundwater release or interflow depending on infiltration rate, total porosity, and field capacity.	Not simulated.	Combined interflow, tile drain flow, and base flow using Sloan et al. (1983) kinematic storage equation and spatially uniform and temporarily varying continuity equation.	Not simulated.	No subsurface simulation in the storm mode.
Runoff in channel	Included in the overland cells.	Same as overland.	Two options: 1-D diffusive wave equations solved by explicit finite-difference method mostly for headwater channels, or implicit finite-difference solution of the 1-D full dynamic equations for limited subcritical flows.	Same as overland.	Same as overland.	Same as overland.
Flow in reservoir	Flow routing through impoundments associated with terrace systems having pipe outlets.	Not simulated.	Not simulated.	Modified-Puls method; solving analytically the temporarily varying and spatially uniform continuity equation.	Finite difference solution of the temporarily varying and spatially uniform continuity equation.	Modified-Puls method; solving the temporarily varying and spatially uniform continuity equation.
Overland sediment	Soil erosion using USLE and routing of clay, silt, sand, and small and large aggregates through cells based on steady-state continuity, effective transport capacity from a modification of the Bagnold stream power equation, fall velocity, and Manning's equation.	Raindrop detachment using USLE factors and flow erosion and transport of four sizes (0.01 to 0.30 mm) using modified Yalin's equation and an explicit numerical solution of the steady-state continuity equation.	Soil erosion and sediment deposition are computed using modified Kilinc-Richardson equation with USLE factors and conservation of mass.	Raindrop detachment and sediment transport, scour, and deposition of user-specified particle size groups based on sediment transport capacity and approximate analytical solution of temporarily and spatially varying continuity equation.	Raindrop detachment and sediment transport, scour, and deposition of one particle size based on sediment transport capacity and explicit numerical solution of temporarily and spatially varying continuity equation.	Raindrop detachment based on rainfall intensity, overland flow detachment based on transport capacity, and routing based on sediment continuity.
Channel sediment	Included in overland cells.	Assumed negligible and not simulated.	Sand-size total sediment load is computed using Yang's unit stream power method.	Streambed scour/deposition and sediment transport of the same size groups based on sediment transport capacity and approximate analytical solution of temporarily and spatially varying continuity equation.	Streambed scour/deposition and sediment transport of the same sediment size based on sediment transport capacity and explicit numerical solution of temporarily and spatially varying continuity equation.	Sediment delivered from flow planes is transported as conservative substance without detachment and deposition.

Table A.2 Summary of watershed-scale hydrologic and non-point source pollution models: single-event models (continued)

Description/ Criteria	AGNPS	ANSWERS	CASC2D	DWSM	KINEROS	PRMS Storm Mode
Reservoir sediment	Sediment routing through impoundments associated with terrace systems having pipe outlets.	Not simulated.	Not simulated.	Assumes all sediments are trapped and no downstream discharge.	For shallow ponds, erosion and deposition are simulated with a mean particle diameter; for reservoirs, deposition is simulated with a particle size distribution.	Not simulated.
Chemical simulation	Nitrogen and phosphorous in runoff using extraction coefficients, and sediment using enrichment ratios and chemical oxygen demand in runoff water assuming accumulative without loss.	Not simulated.	Not simulated.	Nutrients and pesticides are simulated in dissolved and adsorbed phases with water and sediment, respectively, through mixing and exchange between rainfall, runoff, soil, and pore water, and routing through overland and channel segments using approximate analytical solutions of spatially and temporarily varying continuity equations.	Not simulated.	Not simulated.
BMP evaluation	Agricultural management.	Agricultural management.	No information.	Detention basins, alternative ground covers, and alterations to hydrologic and hydraulic conditions.	Detention basins and alterations to hydrologic and hydraulic conditions.	No information.

APPENDIX B

APPLICATION SUMMARY OF SWAT

Table B.1 Application summary of SWAT (Borah and Bera, 2004)

Watershed	Model Calibration	Model Validation	BMP or Other Use	Comments
Richland and Chambers (RC) Creeks watershed, Upper Trinity River basin, Texas (Srinivasan et al., 1998b); 5,080 km^2.	Monthly flow and six−year sediment yield.	Monthly flow and three− and seven−year sediment yields.	None	SWAT performed well for monthly flows and multiyear sediment yields.
Ariel Creek watershed, Pennsylvania (Peterson and Hamlett, 1998); 39.4 km^2.	Daily flow: deviation of runoff volumes (D_v) = 39.9%, and Nash−Sutcliffe (1970) coefficient (NSC) = 0.04. Monthly flow: NSC = 0.14.	None	None	SWAT requires calibration, and is better suited to longer−period (monthly) simulations and not adequate for severe single events.
Warner Creek watershed, Maryland (Shirmohammadi et al., 2001); 3.46 km^2.	Monthly flow. Monthly nitrate−N load: coefficients of determination (COD or r^2) = 0.27.	Monthly flow and nitrate−N. Yearly nitrate−N load: COD = 0.96.	None	SWAT predicted monthly flows well, except in extreme weather. Monthly nitrate−N predictions were poor, but did well on annual loadings.
Little Washita River Experimental Watershed, Oklahoma (Van Liew and Garbrecht, 2001); 538 km^2.	Monthly flow: COD = 0.74.	None	Climate (precipitation) variations.	SWAT was useful in predicting effects of precipitation variations on monthly water budgets.
Cannonsville Reservoir watershed, New York (Benaman et al., 2001); 1,178 km^2.	Monthly and daily flows and monthly sediment yield.	None	None	SWAT requires a significant amount of data and empirical parameters, and its sediment routing is weak.
Ali Efenti watershed, Greece (Varanou et al., 2002); 2,796 km^2.	Daily flow: NSC = 0.62. Monthly flow: NSC = 0.81. Monthly nitrate−N.	None	Impacts of climate change (temperature and precipitation) on surface, lateral, and groundwater flows, and N losses.	SWAT was useful in studying climate change. Monthly flow predictions were better than daily. Seasonal nitrate−N trends were predicted well.
Walnut (51.3 km^2) and Buck Creek (88.2 km^2) watersheds, Iowa (Vache et al., 2002).	Monthly flows: COD for Walnut and Buck = 0.67 and 0.64, respectively. Monthly sediment and nitrate−N loads.	None	Impacts of three BMP scenarios on annual sediment and nitrate loadings.	SWAT was useful in evaluating BMP scenarios.
Bosque River watershed, Texas (Santhi et al., 2001); 4,277 km^2.	Annual and monthly flows: COD > 0.6 and NSC > 0.72. Monthly sediment yield: COD > 0.81 and NSC > 0.69. Monthly organic N and P yields: COD > 0.6 and NSC > 0.57. Mineral N and P yields.	Monthly flow volumes, sediment yields, and nutrient yields (organic N and P, mineral N and P).	Impacts of management practices on dairy manure and WWTP effluents on P loadings.	SWAT was found adequate in predicting annual and monthly responses, and useful in analyzing management of dairy manure applications and WWTP effluents.
Goodwater Creek watershed, Missouri (Qiu and Prato, 2001); 77.42 km^2.	No information.	No information.	Surface water quality impacts (sediment yield and concentrations of N and atrazine) of riparian buffers.	SWAT provided a tool to estimate surface water quality impacts from riparian buffers while determining their economic values.
Missouri River basin (Stone et al., 2001).	None	None	Changes in basin water yield from doubled CO_2 climate.	SWAT was useful in studying impact of climate change (doubled CO_2) on water yield.
University of Kentucky Animal Research Center, Kentucky (Spruill et al., 2000); 5.5 km^2.	Daily and monthly flows: NSC = 0.19 and 0.89, respectively.	Daily and monthly flows: NSC = −0.04 and 0.58, respectively.	Sensitive parameters determined: saturated hydraulic conductivity, alpha base flow factor, recharge, drainage area, and channel length and width.	Daily flows yielded much lower NSC than monthly. Simulated peak and recession flows were often faster than the observed.
Upper Mississippi River basin at Cairo, Illinois (Arnold et al., 2000); 491,700 km^2.	Average annual flows at 131 hydrologic unit areas ("8−digit" watersheds): COD = 0.89. Monthly flows at Alton, Illinois (90% of the basin): COD = 0.63.	Monthly flows at Alton: COD = 0.65.	Groundwater discharge (base flow) and recharge were verified with estimates from: (1) digital recursive filter to separate base flow from total daily flow, and (2) modified hydrograph recession curve displacement technique to estimate groundwater recharge, respectively.	SWAT reasonably predicted annual flow volumes at the 131 eight−digit watersheds and monthly flows near the outlet. The model underpredicted spring peaks and sometimes overpredicted fall flows.

Table B.1 Application summary of SWAT (continued)

Watershed	Model Calibration	Model Validation	BMP or Other Use	Comments
Lower Colorado River basin, Texas (Rosenthal et al., 1995); 8,927 km^2.	Monthly flows near the outlet: COD = 0.66.	None	Land use change scenarios: changing irrigated rice fields to dry lands and increase urban developments.	SWAT closely simulated monthly flows, but underpredicted during extreme events.
Upper Wind River basin, Wyoming (Stonefelt et al., 2000); 5,000 km^2.	Monthly water yields: COD = 0.91.	None	Potential impacts on water yield from climate change: temperature, precipitation, CO_2, radiation, and humidity.	SWAT was useful in this climate change study. Precipitation was the most influential variable on annual water yield, and temperature on timing of streamflow.
Leon River watershed, Texas (Rosenthal and Hoffman, 1999); 9,000 km^2.	Monthly flows: correlation coefficient (r) = 0.83 and NSC = 0.57.	None	Locations of new monitoring stations were selected based on higher per−acre average annual sediment yield predictions.	SWAT was useful in selecting new monitoring station locations.
Goodwin Creek watershed, Mississippi (King et al., 1999); 21.3 km^2.	No calibration performed.	Monthly and daily runoff using SCS runoff curve number method: NSC = 0.84 and 0.43 (0.78 in one of the 8−year simulations − 1984), respectively.	Green−Ampt Mein−Larson (GAML) excess rainfall method (Green and Ampt, 1911; Mein and Larson, 1973) was added, which yielded NSC = 0.69 and 0.53 (0.63 in 1984) in monthly and daily runoff simulations, respectively. Storm event simulations yielded reasonable hydrographs.	The GAML excess rainfall method was added to SWAT for sub-daily time step simulations, but no significant advantage was gained. The model was run for eight years using non−calibrated methodology, and the results were not calibrated.
Goodwin Creek watershed, Mississippi (Bingner, 1996); 21.3 km^2.	Annual runoff vol. for 14 subbasins: COD > 0.80 for individual storms.	None	None	SWAT simulated the relative trends of annual runoff in the subbasins. Simulations of individual storm events were less accurate.

APPENDIX C

SOLP EXPORT COEFFICIENTS

Table C.1 SOLP export coefficients for different sub-basins with respect to Scenario I-a, Scenario I-b and Scenario I-c

Sub-basin Number	**Drainage Area (ha)**	**Scenario I-a SOLP (kg/year/ha)**	**Scenario I-b SOLP (kg/year/ha)**	**Scenario I-c SOLP (kg/year/ha)**
1	12432.72	0.039	0.044	0.048
2	44556.52	0.151	0.217	0.285
3	5566.64	0.045	0.045	0.045
4	8724.44	0.023	0.029	0.036
5	1.00	0.000	0.000	0.000
6	23009.56	0.049	0.070	0.090
7	11620.16	0.046	0.061	0.077
8	18728.84	0.030	0.039	0.048
9	6172.40	0.056	0.071	0.087
10	45340.48	0.082	0.119	0.156
11	21036.64	0.049	0.072	0.094
12	3189.08	0.031	0.045	0.058
13	1231.20	0.051	0.077	0.102
14	12824.24	0.055	0.081	0.107
15	11345.64	0.064	0.095	0.126
16	4350.76	0.101	0.151	0.200
17	18574.56	0.021	0.028	0.036
18	21459.76	0.105	0.154	0.201
19	17111.08	0.099	0.149	0.198
20	50911.00	0.076	0.115	0.152
21	11210.84	0.127	0.186	0.244
22	25090.40	0.069	0.104	0.138
23	23729.40	0.139	0.203	0.266
24	37871.12	0.112	0.167	0.218
25	25.12	0.017	0.023	0.029
26	30347.88	0.041	0.060	0.079
27	22235.48	0.094	0.138	0.178
28	6227.88	0.074	0.109	0.142
29	15213.00	0.108	0.162	0.212
Overall	**510137.84**	**0.081**	**0.118**	**0.154**

Table C.2 SOLP export coefficients for different sub-basins with respect to Scenario II-a, Scenario II-b, Scenario II-c and Scenario II-d

Sub-basin Number	**Drainage Area (ha)**	**Scenario II-a**	**Scenario II-b**	**Scenario II-c**	**Scenario II-d**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**
1	12432.72	0.035	0.034	0.034	0.034
2	44556.52	0.076	0.070	0.065	0.059
3	5566.64	0.045	0.045	0.045	0.045
4	8724.44	0.014	0.014	0.014	0.013
5	1.00	0.000	0.000	0.000	0.000
6	23009.56	0.025	0.023	0.022	0.020
7	11620.16	0.026	0.025	0.023	0.022
8	18728.84	0.018	0.018	0.017	0.017
9	6172.40	0.036	0.035	0.034	0.032
10	45340.48	0.038	0.035	0.032	0.028
11	21036.64	0.023	0.021	0.019	0.017
12	3189.08	0.014	0.013	0.012	0.011
13	1231.20	0.021	0.019	0.018	0.015
14	12824.24	0.024	0.021	0.019	0.017
15	11345.64	0.026	0.023	0.021	0.018
16	4350.76	0.042	0.037	0.033	0.029
17	18574.56	0.011	0.010	0.010	0.009
18	21459.76	0.048	0.043	0.038	0.034
19	17111.08	0.040	0.034	0.031	0.026
20	50911.00	0.032	0.028	0.025	0.022
21	11210.84	0.057	0.052	0.047	0.042
22	25090.40	0.028	0.024	0.022	0.019
23	23729.40	0.062	0.056	0.051	0.045
24	37871.12	0.046	0.040	0.035	0.031
25	25.12	0.009	0.008	0.008	0.008
26	30347.88	0.018	0.016	0.014	0.013
27	22235.48	0.041	0.037	0.032	0.028
28	6227.88	0.032	0.028	0.025	0.022
29	15213.00	0.041	0.036	0.031	0.026
Overall	**510137.84**	**0.037**	**0.034**	**0.031**	**0.028**

Table C.3 SOLP export coefficients for different sub-basins with respect to Scenario III-a, Scenario III-b, Scenario III-c and Scenario III-d

Sub-basin Number	**Drainage Area (ha)**	**Scenario III-a**	**Scenario III-b**	**Scenario III-c**	**Scenario III-d**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**
1	12432.72	0.035	0.035	0.035	0.035
2	44556.52	0.090	0.090	0.090	0.090
3	5566.64	0.045	0.045	0.045	0.045
4	8724.44	0.016	0.016	0.016	0.016
5	1.00	0.000	0.000	0.000	0.000
6	23009.56	0.029	0.029	0.029	0.029
7	11620.16	0.029	0.029	0.029	0.029
8	18728.84	0.021	0.021	0.021	0.021
9	6172.40	0.040	0.040	0.040	0.040
10	45340.48	0.045	0.045	0.045	0.045
11	21036.64	0.028	0.028	0.028	0.028
12	3189.08	0.018	0.018	0.018	0.018
13	1231.20	0.026	0.026	0.026	0.026
14	12824.24	0.028	0.028	0.028	0.028
15	11345.64	0.032	0.032	0.032	0.032
16	4350.76	0.051	0.051	0.051	0.051
17	18574.56	0.012	0.012	0.012	0.012
18	21459.76	0.057	0.057	0.057	0.057
19	17111.08	0.050	0.050	0.050	0.050
20	50911.00	0.039	0.039	0.039	0.039
21	11210.84	0.069	0.069	0.069	0.069
22	25090.40	0.035	0.035	0.035	0.035
23	23729.40	0.074	0.074	0.074	0.074
24	37871.12	0.056	0.056	0.056	0.056
25	25.12	0.010	0.010	0.010	0.010
26	30347.88	0.022	0.022	0.022	0.022
27	22235.48	0.050	0.050	0.050	0.050
28	6227.88	0.038	0.038	0.038	0.038
29	15213.00	0.052	0.052	0.052	0.052
Overall	**510137.84**	**0.045**	**0.045**	**0.045**	**0.045**

Table C.4 SOLP export coefficients for different sub-basins with respect to Scenario IV-a and Scenario IV-b

Sub-basin Number	**Drainage Area (ha)**	**Scenario IV-a**	**Scenario IV-b**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**
1	12432.72	0.037	0.037
2	44556.52	0.108	0.108
3	5566.64	0.045	0.045
4	8724.44	0.018	0.018
5	1.00	0.000	0.000
6	23009.56	0.035	0.035
7	11620.16	0.034	0.034
8	18728.84	0.023	0.023
9	6172.40	0.044	0.044
10	45340.48	0.056	0.056
11	21036.64	0.034	0.034
12	3189.08	0.021	0.021
13	1231.20	0.032	0.032
14	12824.24	0.035	0.035
15	11345.64	0.041	0.041
16	4350.76	0.065	0.065
17	18574.56	0.015	0.015
18	21459.76	0.070	0.070
19	17111.08	0.062	0.062
20	50911.00	0.049	0.049
21	11210.84	0.085	0.085
22	25090.40	0.044	0.044
23	23729.40	0.091	0.091
24	37871.12	0.071	0.071
25	25.12	0.012	0.012
26	30347.88	0.027	0.027
27	22235.48	0.061	0.061
28	6227.88	0.048	0.048
29	15213.00	0.068	0.068
Overall	**510137.84**	**0.055**	**0.055**

Table C.5 SOLP export coefficients for different sub-basins with respect to Scenario V

Sub-basin Number	**Drainage Area (ha)**	**Scenario V**	**Sub-basin Number**	**Drainage Area (ha)**	**Scenario V**
		SOLP (kg/year/ha)			**SOLP (kg/year/ha)**
1	12432.72	0.036	16	4350.76	0.065
2	44556.52	0.107	17	18574.56	0.015
3	5566.64	0.046	18	21459.76	0.070
4	8724.44	0.018	19	17111.08	0.062
5	1.00	0.000	20	50911.00	0.049
6	23009.56	0.037	21	11210.84	0.085
7	11620.16	0.034	22	25090.40	0.044
8	18728.84	0.024	23	23729.40	0.091
9	6172.40	0.046	24	37871.12	0.071
10	45340.48	0.056	25	25.12	0.012
11	21036.64	0.034	26	30347.88	0.027
12	3189.08	0.021	27	22235.48	0.061
13	1231.20	0.032	28	6227.88	0.048
14	12824.24	0.036	29	15213.00	0.068
15	11345.64	0.041	**Overall**	**510137.84**	**0.055**

Table C.6 SOLP export coefficients for different sub-basins with respect to Scenario VI-a, Scenario VI-b, Scenario VI-c, Scenario VI-d and Scenario VI-e

Sub-basin Number	**Drainage Area (ha)**	**Scenario VI-a**	**Scenario VI-b**	**Scenario VI-c**	**Scenario VI-d**	**Scenario VI-e**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**	**SOLP (kg/year/ha)**
1	12432.72	0.035	0.035	0.035	0.035	0.035
2	44556.52	0.091	0.091	0.091	0.091	0.091
3	5566.64	0.045	0.045	0.045	0.045	0.045
4	8724.44	0.016	0.016	0.016	0.016	0.016
5	1.00	0.000	0.000	0.000	0.000	0.000
6	23009.56	0.029	0.029	0.029	0.029	0.029
7	11620.16	0.029	0.029	0.029	0.029	0.029
8	18728.84	0.021	0.021	0.021	0.021	0.021
9	6172.40	0.040	0.040	0.040	0.040	0.040
10	45340.48	0.047	0.047	0.047	0.047	0.047
11	21036.64	0.028	0.028	0.028	0.028	0.028
12	3189.08	0.018	0.018	0.018	0.018	0.018
13	1231.20	0.027	0.027	0.027	0.027	0.027
14	12824.24	0.030	0.030	0.030	0.030	0.030
15	11345.64	0.032	0.032	0.032	0.032	0.032
16	4350.76	0.053	0.053	0.053	0.053	0.053
17	18574.56	0.012	0.012	0.012	0.012	0.012
18	21459.76	0.059	0.059	0.059	0.059	0.059
19	17111.08	0.051	0.051	0.051	0.051	0.051
20	50911.00	0.041	0.041	0.041	0.041	0.041
21	11210.84	0.072	0.072	0.072	0.072	0.072
22	25090.40	0.036	0.036	0.036	0.036	0.036
23	23729.40	0.078	0.078	0.078	0.078	0.078
24	37871.12	0.058	0.058	0.058	0.058	0.058
25	25.12	0.010	0.010	0.010	0.010	0.010
26	30347.88	0.023	0.023	0.023	0.023	0.023
27	22235.48	0.050	0.050	0.050	0.050	0.050
28	6227.88	0.039	0.039	0.039	0.039	0.039
29	15213.00	0.053	0.053	0.053	0.053	0.053
Overall	**510137.84**	**0.046**	**0.046**	**0.046**	**0.046**	**0.046**

Table C.7 SOLP export coefficients for different sub-basins with respect to Scenario VII

Sub-basin Number	**Drainage Area (ha)**	**Scenario VII**	**Sub-basin Number**	**Drainage Area (ha)**	**Scenario VII**
		SOLP (kg/year/ha)			**SOLP (kg/year/ha)**
1	12432.72	0.026	16	4350.76	0.004
2	44556.52	0.030	17	18574.56	0.005
3	5566.64	0.045	18	21459.76	0.010
4	8724.44	0.007	19	17111.08	0.004
5	1.00	0.000	20	50911.00	0.004
6	23009.56	0.006	21	11210.84	0.007
7	11620.16	0.015	22	25090.40	0.004
8	18728.84	0.011	23	23729.40	0.015
9	6172.40	0.023	24	37871.12	0.007
10	45340.48	0.010	25	25.12	0.002
11	21036.64	0.006	26	30347.88	0.005
12	3189.08	0.004	27	22235.48	0.008
13	1231.20	0.003	28	6227.88	0.005
14	12824.24	0.004	29	15213.00	0.005
15	11345.64	0.004	**Overall**	**510137.84**	**0.010**

Table C.8 SOLP export coefficients for different sub-basins with respect to Scenario VIII-a and Scenario VIII-b

Sub-basin Number	**Drainage Area (ha)**	**Scenario VIII-a**	**Scenario VIII-b**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**
1	12432.72	0.026	0.036
2	44556.52	0.030	0.054
3	5566.64	0.045	0.045
4	8724.44	0.007	0.018
5	1.00	0.000	0.000
6	23009.56	0.006	0.017
7	11620.16	0.015	0.034
8	18728.84	0.011	0.014
9	6172.40	0.023	0.044
10	45340.48	0.010	0.057
11	21036.64	0.005	0.034
12	3189.08	0.004	0.021
13	1231.20	0.003	0.034
14	12824.24	0.003	0.036
15	11345.64	0.004	0.041
16	4350.76	0.003	0.067
17	18574.56	0.005	0.015
18	21459.76	0.009	0.071
19	17111.08	0.004	0.064
20	50911.00	0.004	0.051
21	11210.84	0.006	0.087
22	25090.40	0.004	0.045
23	23729.40	0.015	0.094
24	37871.12	0.007	0.073
25	25.12	0.002	0.012
26	30347.88	0.005	0.028
27	22235.48	0.008	0.063
28	6227.88	0.005	0.049
29	15213.00	0.005	0.068
Overall	**510137.84**	**0.010**	**0.050**

Table C.9 SOLP export coefficients for different sub-basins with respect to Scenario IX-a and Scenario IX-b

Sub-basin Number	**Drainage Area (ha)**	**Scenario IX-a**	**Scenario IX-b**
		SOLP (kg/year/ha)	**SOLP (kg/year/ha)**
1	12432.72	0.026	0.036
2	44556.52	0.030	0.109
3	5566.64	0.045	0.045
4	8724.44	0.007	0.018
5	1.00	0.000	0.000
6	23009.56	0.005	0.036
7	11620.16	0.015	0.034
8	18728.84	0.011	0.014
9	6172.40	0.023	0.028
10	45340.48	0.010	0.057
11	21036.64	0.006	0.012
12	3189.08	0.004	0.021
13	1231.20	0.003	0.034
14	12824.24	0.003	0.036
15	11345.64	0.004	0.041
16	4350.76	0.003	0.067
17	18574.56	0.005	0.010
18	21459.76	0.009	0.071
19	17111.08	0.004	0.064
20	50911.00	0.004	0.051
21	11210.84	0.007	0.033
22	25090.40	0.004	0.045
23	23729.40	0.015	0.083
24	37871.12	0.007	0.073
25	25.12	0.002	0.012
26	30347.88	0.005	0.028
27	22235.48	0.008	0.063
28	6227.88	0.005	0.016
29	15213.00	0.005	0.068
Overall	**510137.84**	**0.010**	**0.052**