ASSESSMENT OF MANAGEMENT POLICIES FOR LAKE ULUABAT BASIN USING AVSWAT

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ABSTRACT

ASSESSMENT OF MANAGEMENT POLICIES FOR LAKE ULUABAT BASIN USING AVSWAT

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This thesis assesses phosphorus loads and management practices to control nutrient transport to Lake Uluabat. It analyzes nonpoint sources of pollution, especially agricultural pollution, throughout Uluabat Basin (watershed). AVSWAT (Arcview™ Interface of Soil and Water Assessment Tool 2000) was used in determination of phosphorus and sediment loads to Lake Uluabat. Contribution of soluble phosphorus (SOLP) loads from agricultural sites was discussed. Seven scenarios were applied through watershed area to see effects of fertilizer and irrigation application rates, landuse changes, point source and watershed inlet loads on phosphorus loads.

Calibration of the model was performed annually due to lack of data. First stream flow, next sediment and finally nutrient (SOLP) was calibrated at two gages. At the first gage, simulation results were satisfactory in terms of Nash-Sutcliffe Efficiency

(E_{NS}) and percentage deviation between observation and simulation values (Dv). E_{NS} values for stream, sediment and SOLP were >=0.99. Dv values for stream, sediment and SOLP were <±1%. At the second gage, after calibration, following values were obtained for E_{NS} and Dv: Stream flow - E_{NS}=0.75, Dv<10%; sediment - E_{NS}=0.71, Dv=25%; SOLP - E_{NS}=0.55, Dv< 20%.

It was concluded that agricultural sites were among major contributors of phosphorus load to Lake Uluabat. SOLP load to lake was about 4.0 gP/m^2/year, greater than the target value of 1.0 gP/m^2/year (DHKD, 2002).

Scenario results showed that removing agricultural lands around Lake Uluabat and decreasing fertilizer application rates were necessary to reduce SOLP loads to lake. Moreover, phosphorus load from Emet and Orhaneli Watersheds seemed significant.

Keywords: Lake Uluabat, SWAT, modeling, phosphorus

ÖZ

AVSWAT KULLANILARAK ULUABAT GÖLÜ HAVZASI YÖNETİM BİÇİMLERİNİN DEĞERLENDİRİLMESİ

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Bu çalışma, Uluabat Gölü'ne giden fosfor yüklerini ve besi maddesi taşınımı çerçevesinde yönetim biçimlerini değerlendirmektedir. Uluabat Havzası'nda yayılı kirletici kaynakları, özellikle tarımsal kirliliğin, analizi yapılmıştır. Uluabat Gölü'ne giden çözünebilir fosfor (ÇÖZP) ve sediman yüklerinin miktarlarını belirlemek üzere AVSWAT (Soil and Water Assessment Tool, 2000, Arcview^{TM} Arayüzü) kullanılmıştır. Tarımsal alanların fosfor yüklerine olan katkısı değerlendirmiştir. Havza üzerindeki gübre ve sulama uygulamalarının, arazi kullanımındaki değişikliklerin ve noktasal kaynak ve havza girişi yüklerinin Uluabat Gölü'ne giden fosfor yükleri üzerine etkilerini görmek amacıyla yedi adet senaryo uygulanmıştır.

Modelin kalibrasyonu, veri yetersizliğinden dolayı yıllık olarak için gerçekleştirilmiştir. İlk önce akım, daha sonra sediman ve son olarak da besi maddesi (ÇÖZP) yükleri, iki gözlem istasyonunda kalibre edilmiştir. İlk istasyonda, simulasyon sonuçları Nash-Sutcliffe verimlilik katsayısı (E_{NS}) ve ölçüm ve simulasyon sonuçları arasındaki yüzde değişim (Dv) değerleri göz önüne alındığında başarılı bulunmuştur. Akım, sediman ve ÇÖZP için elde edilen E_{NS} değerleri >=0.99 olarak bulunmuştur. Akım, sediman ve ÇÖZP için elde edilen Dv değerleri <±%1 olarak hesaplanmıştır. İkinci istasyonda, kalibrasyon sonrasında, E_{NS} ve Dv için elde edilen değerler; akım için - E_{NS}=0.75, Dv<%10; sediman için - E_{NS}=0.71, Dv=%25; çözünebilir fosfor - E_{NS}=0.55, Dv<%20 şeklindedir.

Sonuç olarak, Uluabat Gölü'ne giden fosfor miktarının önemli bir bölümü tarımsal alanlardan kaynaklanmaktadır. Uluabat Gölü'ne giden fosfor miktarı yaklaşık 4.0 gP/m^2/yıl olup, bu değer hedef gösterilen 1.0 gP/m^2/yıl'dan fazladır (DHKD, 2002).

Senaryo sonuçları, Uluabat Gölü etrafındaki tarımsal alanların kaldırılması ve gübre kullanımının azaltılması gerektiğini göstemiştir. Ayrıca, Emet ve Orhaneli Hazvaları'ndaki kirlilik kaynaklarının da önemli ölçüde etkili olduğu görülmüştür.

Anahtar Kelimeler : Uluabat Gölü, SWAT, modelleme, fosfor

To My Family

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LIST OF ABBREVIATIONS

AGRC	Agricultural Land-Close-Grown
ANION_EXCL	Fraction of Porosity (Void Space) From Which Anions Are Excluded
AVSWAT	Arcview^{TM} Interface of Soil and Water Assessment Tool 2000
B	Garden
BRFRST	Brown Forest Soils
C	Clay
CANMX	Maximum Canopy Storage (mm H_2O)
CH_COV	Channel Cover Factor
CH_EROD	Channel Erodibility Factor (cm/hr/Pa)
CL	Clay Loam
CN2	Curve number
Ç	Grass-Natural Vegetation Cover
DAP	Diammonium Phosphate
DEM	Digital Elevation Model
DHKD	Natural Life Protection Association
Dv	Deviation Between Observation and Simulation Values (%)
EİE	General Directorate of Electrical Power Resources Survey and Development Administration
E_{NS}	Nash-Sutcliffe Efficiency
EPCO	Plant Uptake Compensation Factor
ESCO	Soil Evaporation Compensation Factor
F	Shrubbery
FGDRS	Former General Directorate of Rural Services
FRST	Forest-Mixed
GCS	Geographic Coordination System
GL	Lake

GIS	Geographic Information System
GWDELAY	Groundwater Delay Time
GWQMN	Threshold Depth (mm) of Water in the Shallow Aquifer Required for Base Flow to Occur
HRU	Hydrologic Response Unit
HYDAL	Hydromorphic Alluvial Soils
HYDGRP	Soil Hydrologic Group
IR	River
KM	Sandy Dunes
L	Loam
LS	Loamy Sand
M	Pasture
MTA	General Directorate of Mineral Research and Exploration
MUSLE	Modified Universal Soil Loss Equation
N	Non-irrigated Agriculture
O	Forest
PAST	Pasture
PHOSKD	P Soil Partitioning Coefficient (m^3/Mg)
RCHRG_DP	Aquifer Percolation Coefficient
RNGE	Range-Grasses
S	Sand
S	Irrigated Agriculture
SB	Marshy Places
SC	Sandy Clay
SCL	Sandy Clay Loam
SED_OUT	Modeled Sediment Load at the Outlet of A Subbasin
SED P	Soluble Phosphorus Transported With Sediment
SHW	State Hydraulic Works
SiC	Silty Clay
SiCL	Silty Clay Loam
SiL	Silt Loam

SL	Sandy Loam
SIS	Prime Ministry State Institute of Statistics
SNAM	Soil Name
SOL_AWC	Soil Available Water Capacity (mm H_2O/mm soil)
SOL_BD	Soil Bulk Density (Mg/m^3)
SOL_CBN	Organic Carbon Content (% soil weight)
SOL_CRK	Potential or Maximum Crack Volume of the Soil Profile Expressed As A Fraction of the Total Soil Volume (%)
SOL_K	Saturated Hydraulic Conductivity (mm/h)
SOL P	Soluble Phosphorus Transported With Surface Runoff
SOLP_OUT	Modeled Soluble Phosphorus Load At the Outlet of A Subbasin
SOL_Z	Depth From Soil Surface to Bottom of Layer (mm)
SOL_ZMX	Maximum Rooting Depth of Soil Profile (mm)
SWAT	Soil and Water Assessment Tool 2000
Sy	Insufficient-irrigated Agriculture
SYLD	Sediment Yield
TOMA	Tomato
URML	Residential – Med/Low Density
US EPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
USLE_C	USLE Cover and Management Factor
USLE_K	USLE Equation Soil Erodibility (K) Factor (units: 0.013 (metric ton m^2 hr)/(m^3-metric ton cm))
UTM	Universal Transverse Mercator
Ü	Grape
WATR	Water
WETN	Nonforested Wetland
WWF	World Wildlife Fund
YR	Residential Area

CHAPTER 1

INTRODUCTION

The water quality of lakes is affected by their watersheds through the transport of sediments, nutrients and pesticides. These loads, especially phosphorus (P), accelerate the eutrophication of surface waters. Due to landuse practices and rapid landuse changes in many parts of the world, nonpoint P loading has become a serious threat to water quality (National Research Council, 1992; Duda, 1993; Soranno *et al.*, 1996).

Water quality problems cannot be solved unless nonpoint sources of pollution are controlled. Agriculture and urban activities are the major nonpoint sources of P and nitrogen (N) to aquatic ecosystems. It is diffucult to measure and control these nonpoint sources of nutrients, since they are dispersed over wide areas of land and change with time due to weather and other conditions. In aquatic ecosystems, these nutrients cause diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity, loss of aquatic plant beds, and other problems (Carpenter *et.al.*, 1998); resulting in water use (drinking, industry, agriculture, recreation, etc.) impairments in water bodies such as lakes.

Fertilizer application and livestock waste/manure are the primary sources of P in agricultural/pastoral catchments (Lambert *et al.*, 1985; Cooke, 1988; Sharpley *et al.*, 1994). The application of P in excess of plant requirements leads to a buildup of P and saturation of sorption sites. Therefore, there is a greater potential for P desorption into soil solution and loss by transport mechanisms such as leaching and surface runoff (McDowell *et al.*, 2002; McDowell and Sharpley, 2001). In Norwegian surface waters, 45% of the anthropogenic P inputs originate from agricultural areas. Agricultural areas contribute 61% of P in the Chesapeake Bay in

U.S.A. (Bechmann, *et al.,* 2005). Therefore, agricultural activities can be a significant contributor for the enrichment of water bodies with nutrients.

Lake Uluabat is one of the lakes under stress in Turkey. It is located in between 40°12' N latitude and 28°40' E longitude in Bursa (Kurttaş *et al.*, 2002). Lake Uluabat had been considered as a potential potable water source through 1970s (Class I-II). However, since 1990s, its water class has changed to Class III and even Class IV according to the Turkish Water Quality Control Regulation. Occasional fish deaths are observed because of the DO deficiency resulting from wastewater discharges and drainage water discharges coming from agricultural lands (N and P loads) and/or increase in algal population (Yersiz *et al.*, 2001). Decrease in biodiversity has been observed in recent years due to water quality problems in lake (DHKD, 2002).

In a study (Bursa Region Water Resources Pollution Research) conducted by General Directorate of State Hydraulic Works (SHW), it was determined that the limiting nutrient in Lake Uluabat was P (Celtemen *et al.*, 2000). P concentration in the lake has been increasing. Through 1986-1990, orthophosphate (PO_4) concentration was 0.25 ppm (max. value), in 2001 it increased to about 0.25-0.6 ppm (Yersiz *et al.*, 2001). One of the main sources of PO_4 has been the fertilizers applied throughout the watershed and reached to the lake via drainage and surface runoff (Personal Contact, Bursa Agricultural Directorate, 2005).

The lake and its surrounding area, together with the protected habitats were included in the RAMSAR Agreement on April 15, 1998. As a result, protection of natural structure and ecological character of Lake Uluabat is undertaken internationally (Celtemen *et al.*, 2000; Yersiz *et al.*, 2001). In 1998, Natural Life Protection Association (DHKD) started a project with the Ministry and Environment and SHW to prepare an integrated management plan for Lake Uluabat. It was stated that P load entering to the lake should be decreased to below

1 g/m^2/year in 5 years to control the eutrophication problem in the lake, whereas its actual range is given as 1-8 gP/m^2/year (WWF- Turkey, 2000).

In this study, Arcview Interface of SWAT2000 model (AVSWAT2000) was used to assess the P load to Lake Uluabat, critical subwatersheds responsible for high loads and the effects of different management practices on P transport. AVSWAT2000 is a watershed scale model supported by US EPA and used to simulate the P loads from point and nonpoint sources (Caruso, 2000; USEPA, 1998; Olsen and Garcia, 1996; Soranno *et al.,* 1996). Therefore, it can be used to obtain an overall insight about the impact of different activities in a watershed on the transport of P and evaluate the management plans for the control of quality and eutrophication in Lake Uluabat.

CHAPTER 2

BACKGROUND

2.1. AVSWAT2000 (ARCVIEW^{TM} INTERFACE OF SOIL AND WATER ASSESSMENT TOOL)

AVSWAT2000, from herein will be referred to as SWAT, is a physically based, continuous time model. SWAT requires specific information about weather (daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity), soil properties, topography, vegetation, land use and land management practices through the watershed. The physical processes related with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using the input data. The model has the capability of generating values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed and relative humidity as well. As a result, watersheds with no monitoring data (e.g. stream gage data) can be modeled (Neitsch *et al.*, 2002a).

In SWAT, a watershed can be partitioned into a number of subwatersheds or subbasins. The user can allocate different landuse and soil classes to the sub-basins, and depict the spatial variations with the ArcView interface (Neitsch *et al.*, 2002a). Inputs for each subbasin are grouped into the following categories: climate; hydrologic response units (HRUs); ponds/wetlands; groundwater; and the main channel, or reach, draining the subbasin. HRUs are lumped land areas within the subbasin that are comprised of unique land cover, soil, and management combinations. Mass balance is the primary approach for calculations. Water balance is the driving force behind the transport of P in the watershed. As a result, to satisfactorily predict the movement of pesticides, sediments or nutrients through the watershed, the hydrologic cycle simulated by the model must conform to the hydrologic cycle in the watershed (Neitsch *et al.*, 2002a). That is, stream flow and/or surface runoff calibration should be performed first.

SWAT uses a single plant growth model to simulate all types of land covers. The model is able to distinguish between annual and perennial plants. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production. The potential water uptake from the soil surface to any depth in the root zone is estimated with the function given in Equation 2.1 (Neitsch *et al.*, 2002b).

$$w_{up,z} = \frac{E_t}{\left[1-\exp(-\beta_w)\right]} \cdot \left[1-\exp\left(-\beta_w \cdot \frac{z}{z_{root}}\right)\right] \qquad (2.1)$$

where $w_{up,z}$ is the potential water uptake from the soil surface to a specified depth, z, on a given day (mm H_2O), E_t is the maximum plant transpiration on a given day (mm H_2O), β_w is the water-use distribution parameter, z is the depth from the soil surface (mm), and z_{root} is the depth of root development in the soil (mm). The potential water uptake from any soil layer is calculated by Equation 2.2 (Neitsch *et al.*, 2002b).

$$w_{up,ly} = w_{up,zl} - w_{up,zu} \qquad (2.2)$$

where $w_{up,ly}$ is the potential water uptake for layer *ly* (mm H_2O), $w_{up,zl}$ is the potential water uptake from the soil surface to the lower boundary of the soil layer (mm H_2O), and $w_{up,zu}$ is the potential water uptake from the soil surface to the upper boundary of the soil layer (mm H_2O) (Neitsch *et al.*, 2002b).

SWAT tracks the movement and transformation of several forms of N and P in the watershed. Moreover, it simulates the pesticide movement. However, as the Uluabat

Lake is P limited, its control is essential for eutrophication control. Therefore, only P load will be simulated through the watershed in this study. Plant use of P is estimated using the supply and demand approach for plant growth. The plant P demand for a given day is estimated as the difference between the P content of the plant biomass expected for the plant's growth stage and the actual P content as given in Equation 2.3.

$$P_{up} = 1.5 \cdot (bio_{P,opt} - bio_P) \tag{2.3}$$

where P_{up} is the potential P uptake (kg P/ha), $bio_{P,opt}$ is the optimal mass of P stored in plant material for the current growth stage (kg P/ha), and bio_P is the actual mass of P stored in plant material (kg P/ha). The difference between the P content of the plant biomass expected for the plant's growth stage and the actual P content is multiplied by 1.5 to simulate luxury P uptake (Neitsch *et al.*, 2002b).

The depth distribution of P uptake is calculated using the function given in Equation 2.4.

$$P_{up,z} = \frac{P_{up}}{\left[1 - \exp(-\beta_p)\right]} \cdot \left[1 - \exp\left(-\beta_p \cdot \frac{z}{z_{root}}\right)\right] \tag{2.4}$$

where $P_{up,z}$ is the potential P uptake from the soil surface to depth z (kg P/ha), P_{up} is the potential P uptake (kg P/ha), β_P is the P uptake distribution parameter, z is the depth from the soil surface (mm), and z_{root} is the depth of root development in the soil (mm). The potential P uptake for a soil layer is calculated by Equation 2.5 (Neitsch *et al.*, 2002b).

$$P_{up,ly} = P_{up,zl} - P_{up,zu} \tag{2.5}$$

where $P_{up,ly}$ is the potential P uptake for layer *ly* (kg P/ha), $P_{up,zl}$ is the potential P uptake from the soil surface to the lower boundary of the soil layer (kg P/ha), and $P_{up,zu}$ is the potential P uptake from the soil surface to the upper boundary of the soil layer (kg P/ha) (Neitsch *et al.*, 2002b).

The amount of P removed in the yield is calculated as given in Equation 2.6.

$$yld_P = fr_{P,yld} \cdot yld \tag{2.6}$$

where yld_P is the amount of P removed in the yield (kg P/ha), $fr_{P,yld}$ is the fraction of P in the yield, and *yld* is the crop yield (kg/ha) (Neitsch *et al.*, 2002b).

In addition to plant use, soluble P and organic P may be removed from the soil by mass flow of water. The amount of soluble P removed in runoff is estimated using the solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor. The amount of solution P transported in surface runoff is calculated with Equation 2.7 (Neitsch *et al.*, 2002b).

$$P_{surf} = \frac{P_{solution,surf} \cdot Q_{surf}}{\rho_b \cdot depth_{surf} \cdot k_{d,surf}} \tag{2.7}$$

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

Erosion and sediment yield are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE). While the traditional USLE equation uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield (Neitsch *et al.*, 2002b).

SWAT has options to define the management practices taking place in every HRU. The user may define the beginning and the ending of the growing season, specify timing and amounts of fertilizer utilized, pesticide and irrigation applications, as well as timing of the tillage operations. At the end of the growing season, the biomass may be removed from the HRU as yield or placed on the surface as residue. In addition, operations such as grazing, automated fertilizer and irrigation applications, and incorporation of several management option for water use are available. The latest build-up to land management is the incorporation of routines to calculate sediment and nutrient loadings from urban areas (Neitsch *et al.*, 2002b).

SWAT has been used widely all around the world to simulate runoff, landuse change effects on water quality and climate impacts on watershed hydrology (Peterson and Hamlett, 1998). Manguerra and Engel (1998) studied hydrologic parameterization of synthetic and actual watersheds for runoff prediction using SWAT; and they obtained improved runoff predictions by easy adjustments of return flow contribution to stream flow, and curve numbers with time and space. Santhi, *et al.* (2001) studied the calibration and validation of SWAT model on a large basin with point and nonpoint sources and stated that predicted values obtained in their study generally matched with the observed values during calibration and validation ($R^2 \geq 0.6$ and Nash-Sutcliffe Efficiency ≥ 0.5, in most instances), except for some under prediction of N during calibration, and sediment and organic nutrient during validation. Please refer to Chapter 4.1 for the definition of Nash-Sutcliffe efficiency.

Tripathi *et al.,* (2003) identified critical sub-watersheds of a watershed in India for soil conservation management using the SWAT model, and concluded that SWAT model could accurately predict runoff, sediment yield and nutrient losses particularly from small agricultural watersheds. Tripathi *et al.,* (2003) also stated that not all of the sub-watersheds of a small agricultural watershed contribute to the discharge, sediment yield and nutrient losses at an outlet. SWAT model was successful in identifying the critical sub-watersheds, which had major contributions to the pollution load.

Grizzetti *et al.* (2003) modeled the N and P removal in a basin in Finland using SWAT and obtained satisfactory performance. In daily time step simulations of flow, N and P, the Nash-Suttcliffe coefficient ranged between 0.59-0.81 for calibration and between 0.43-0.57 for validation. Grizzetti *et al.* (2003) compared diffuse emissions predicted by SWAT with those evaluated with traditional statistical methods, and concluded that predictions of the SWAT model were reasonable.

Peterson and Hamlett (1998) studied hydrological calibration of the SWAT model in a watershed containing fragipan (a soil class) soils. The data period used for calibration was May 1, 1992 to September 30, 1994; and the observed stream flow data was of April 1, 1992 to September 30, 1994. The calibration period was about 2 years for this study. Peterson and Hamlett (1998) suggested that the SWAT model was better suited to longer period of simulations of hydrologic yields. Chanasyk *et al.* (2003) simulated surface runoff from fescue grassland watersheds using SWAT and evaluated the performance statistically. The calibrated SWAT model under predicted the surface runoff for all of the watersheds being simulated. Chanasyk *et al.* (2003) concluded that the model would be more useful when run with larger datasets.

Van Liew and Garbrecht (2003) used the SWAT model to predict the stream flow under varying climatic conditions and obtained unsatisfactory results when default parameter values were used to simulate the stream flow. Calibration was performed for a wetter than the average period of record. Then, validation was performed for dry, average and wet climatic conditions. The results showed that once the model was calibrated for wet period records, it predicted satisfactory stream flow responses.

2.2. WATERSHED OF LAKE ULUABAT (APOLYONT)

Lake Uluabat is located in south of Marmara Sea, about 30 km away from Bursa. It is surrounded by Karaağaç-Kirmikir (North), Mustafakemalpaşa (West), Akçalar Plain (East), Çamlıtepe and Hisartepe Mountains (South). The minimum and maximum water levels in the lake are 2.5 and 7.5 m, respectively. Lake Uluabat has a triangle-like shape having a length of 23-24 km in East-West direction, and a width of about 12 km. The maximum surface area value measured is 24,000 ha; and the minimum value is 13,500 ha. South-West shores of the Lake Uluabat were encircled in 1993 in order to prevent the extension of lake to an area open for agricultural use (Celtemen *et al.*, 2000). Figure 2.1 shows the Lake Uluabat and the boundary set by the RAMSAR Agreement. The red dashed line indicates the RAMSAR boundary.

Figure 2.1. Lake Uluabat and Boundary Set by the RAMSAR Agreement (depicted by red dashed line)

Average storage volume of the lake is 300 hm^3. Celtemen *et al.* (2000) reported the total drainage area as about 10,413 km^2. Kurttaş *et al.* (2002) reported it as 10,756 km^2. Mustafakemalpaşa Stream is the main stream feeding Lake Uluabat. Lake Uluabat discharges to Uluabat Stream and connects to Karadere which is at the downstream of the Susurluk Stream and Manyas Lake, flows through Karacabey passage and finally discharges to the Marmara Sea. The immediate drainage area of Lake Uluabat can be divided into 3 parts as Mustafakemalpaşa Watershed covering a drainage area of 9,913 km^2 (%95.2 of total); lake surface covering an area of 160 km^2 (%1.5) of the total drainage area; and a remaining area of 343 km^2 (%3.3 of total drainage area) (Celtemen *et al.*, 2000).

Lake water has always been turbid because of the colloidal clays. Depending on the concentration of phytoplankton in the lake, its color changes to greenish-yellow and grayish-yellow. The water is used for irrigation, and fishing activities are dominant. The east and west shores of Akçalar, Kirmikir and Mustafakemalpaşa are irrigated by the water diverted from the Uluabat Lake as well as the Mustafakemalpaşa Stream (Celtemen *et al.*, 2000).

Mustafakemalpaşa Stream, which is the main feed for the Uluabat Lake, is formed by joining of Orhaneli and Emet Streams, and discharges to Lake Uluabat after flowing in a channel of about 43 km long (Yersiz *et al.*, 2001). There are no significant agricultural activities in districts in the Orhaneli and Emet Watersheds as compared to agricultural activities in Mustafakemalpaşa and Karacabey districts. The main reason is the unsuitability of land for agricultural activities in these watersheds (Kurttaş *et al.*, 2002). On the other hand there are industries that are discharging to Orhaneli and Emet Streams. Therefore, nonpoint pollution sources through Orhaneli and Emet Watersheds are not significant, whereas point sources are. Majority of the nonpoint agricultural pollution arises from the Mustafakemalpaşa Watershed.

CHAPTER 3

METHODOLOGY

In this chapter, information about the data used in modeling and the steps through model runs are given and explained. P load to the Lake Uluabat was simulated for the conditions specified.

3.1. METEOROLOGICAL DATA

SWAT requires daily data of minimum and maximum temperatures, precipitation, solar radiation, wind speed and relative humidity. Meteorological data used in SWAT was obtained from the Turkish State Meteorological Service. Bursa, Mustafakemalpaşa, Balıkesir, Dursunbey and Keles Meteorological Stations were chosen for this study. 15 years (1990-2004) of daily meteorological data of Bursa and Mustafakemalpaşa Stations were used. For Bursa, Balıkesir, Dursunbey and Keles Meteorological Stations, 20 years (1985-2004) of daily data was obtained. These data were used as the weather generator input data in SWAT. The model selected the appropriate station for calculations itself based on relative distances. Required data on wind speed and solar radiation are not measured at the Mustafakemalpaşa Station which was the closest to Uluabat Lake. Thus, daily wind speed and solar radiation data of Bursa Meteorological Station were used during the simulations. Locations of meteorological stations used as potential stations for calculations in SWAT are given in Figure 3.1.

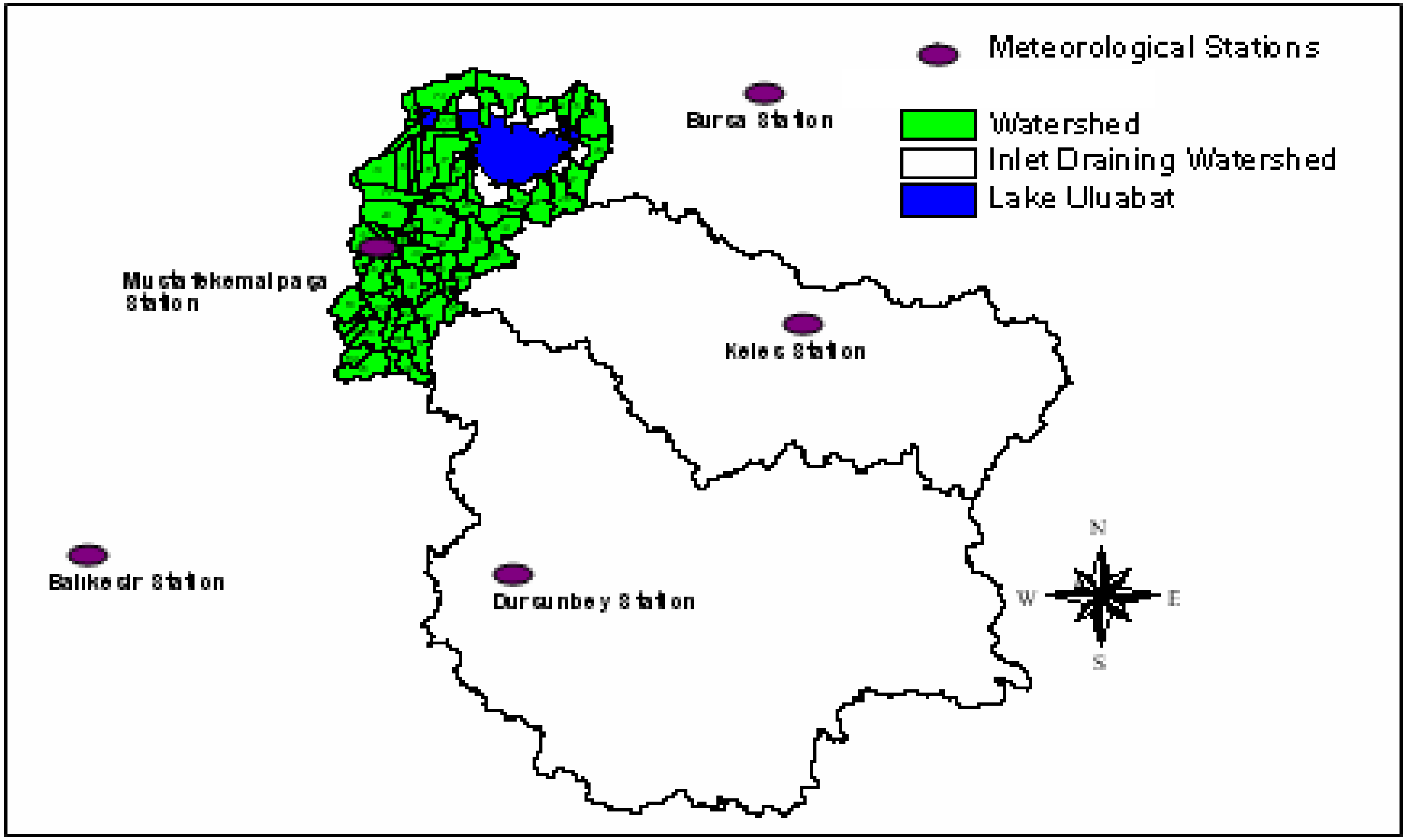

Figure 3.1. Meteorological Stations in the Area

Meteorological files were prepared in *.dbf format. SWAT, uses long-term monthly averages of data. In addition, statistical parameters are generated from these long-term daily data in order to simulate the missing observation data and the input data set for the SWAT simulation (Figure 3.2). For this purpose, the codes by Stefan Liersch (2003) were employed.

The required data for the weather generator are:

- Average daily maximum air temperature for month (^{o}C)
- Average daily minimum air temperature for month (^{o}C)
- Standard deviation for daily maximum air temperatures in month (^{o}C)
- Standard deviation for daily minimum air temperature in month (^{o}C)
- Average total monthly precipitation (mm H_2O)
- Standard deviation for daily precipitation in month (mm H_2O/day).
- Skewness coefficient for daily precipitation in month.
- Probability of a wet day following a dry day in the month.
- Probability of a wet day following a wet day in the month.
- Average number of days of precipitation in month.
- Average daily solar radiation for month (MJ/m^2/day).
- Average daily dew point temperature in month (ºC).
- Average daily wind speed in month (m/s).

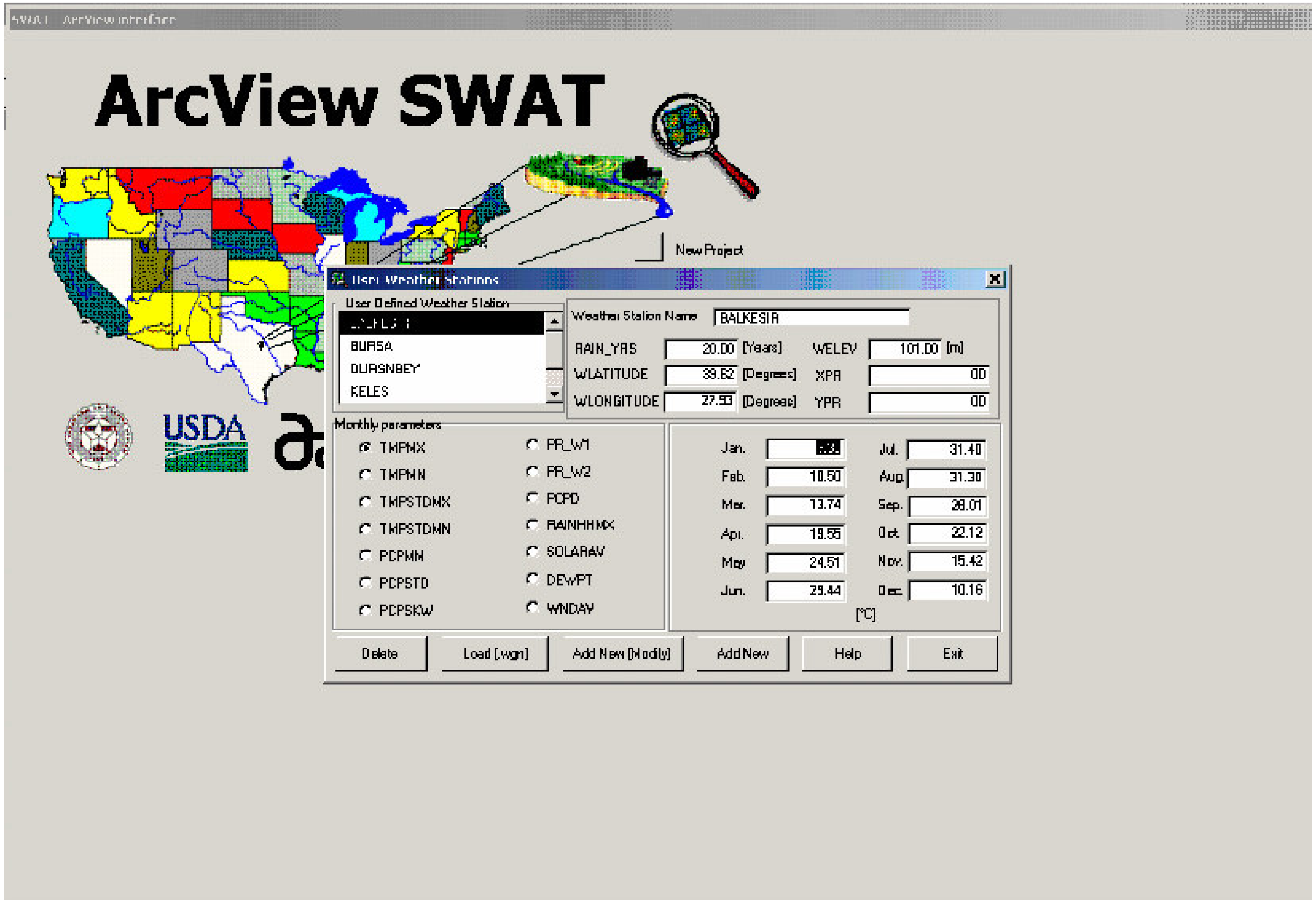

Figure 3.2. Meteorological Data Input Screen

3.2. DELINEATION OF LAKE ULUABAT WATERSHED

Automatic Delineation Tool of SWAT uses the Digital Elevation Model (DEM) to delineate subbasins based on an automatic procedure. With this tool, watershed is segmented into hydrologically connected subbasins to be used in the watershed modeling (Di Luzio *et al.*, 2002).

"Watershed Delineation" tool delineates watershed using the Arcview and Spatial Analyst extensions. Delineation process requires DEM in ArcInfo grid format. The user can also use the digital river network prepared in Arcview *.shp format (Di Luzio *et al.*, 2002). Once the delineation is completed, a detailed topographic report is prepared and added to the project. In addition, *Subbasins*, *Streams* and *Outlets* are added to the watershed view (Di Luzio *et al.*, 2002).

The DEM used in the study (Figure 3.3) was obtained from the General Directorate of Mineral Research and Exploration (MTA). DEM characteristics are given in Table 3.1. In addition to the DEM, a river network produced from 1/100,000 scaled topographic maps were used in the delineation process of Lake Uluabat Watershed. Working area was specified after several trials, and a focused area boundary was prepared as "boundary.shp file. This focused area was used in the delineation process.

Table 3.1. DEM Characteristics

Parameter	Value
Projection	Universal Transverse Mercator (UTM)
False Northing	500000.000000
False Easting	0.000000
Central Meridian	27.000000
Scale Factor	0.999600
Reference Latitude	0.000000
Geographic Coordination System	GCS_European_1950
Datum	D_European_1950
Zone	35
Scale	1/250,000
Pixel Size	30 m x 30 m

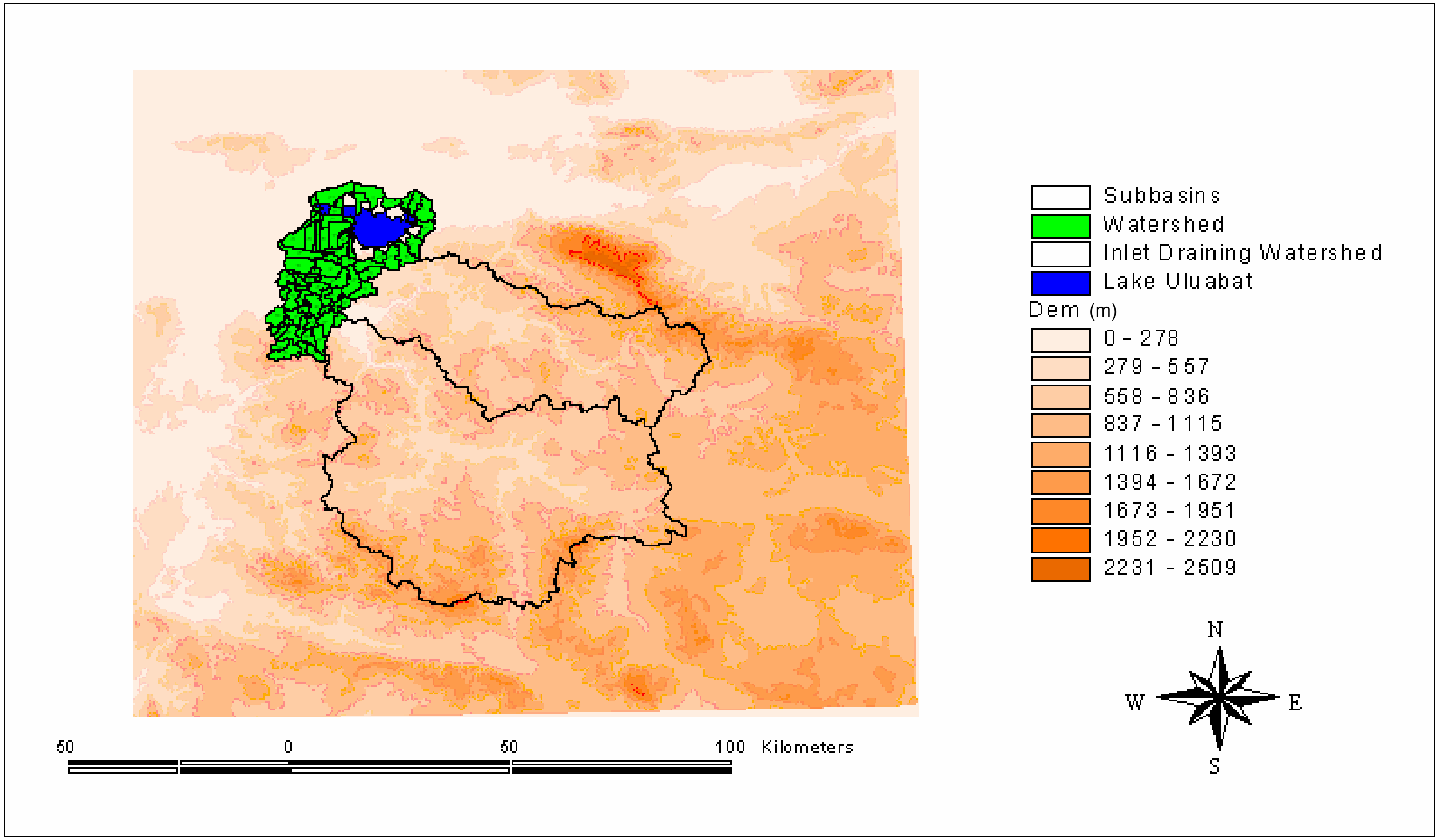

Figure 3.3. DEM Used In the Study

Once the preprocessing of DEM was complete; minimum, suggested and maximum threshold values are calculated by SWAT and displayed on the delineation window as 618.727 ha, 12300 ha and 247491 ha, respectively. A threshold value close to the minimum one (620 ha) was chosen in order to be able to determine the watersheds of small streams. At the end of this process, streams and outlets were defined through the watershed by SWAT. In addition, six outlets were added manually. Two of these were close to the SHW water quality observation stations in the Mustafakemalpaşa Watershed. This approach was utilized in order to compare the results for those specific outlets with the observation data of these stations. The remaining 4 additional outlets were located on the boundary of Uluabat Lake. To form the watersheds for each river, down-most outlet of each stream should be defined as a main watershed outlet. Therefore, down-most outlet of each stream among 13 streams discharging to the lake was defined as main watershed outlet and 78 subbasins were formed (Figure 3.4). Most of these streams are perennial.

In the views of watershed, white areas around the lake are the areas which could not be processed by the model because of the plane topography of the area. High resolution DEMs may be used to overcome this problem.

SWAT can also compute the impact of point-sources. However, due to lack of data, only one point source discharge was defined through the Mustafakemalpaşa watershed. This point source was the sewage discharge from the Mustafakemalpaşa City (Yersiz *et al.,* 2001). No industrial point discharges were considered in this study due to lack of data.

Several data required for simulations were lacking for the Emet and Orhaneli watersheds. These were the watersheds where point sources were dominant. Thus, in order to include the pollution contribution from these watersheds, the water quality data was used. This is managed by defining the inlets of these watersheds as “the inlet of a draining watershed”. The data obtained from SHW water quality observation station M-1 on Mustafakemalpaşa Stream, and flow data obtained from

Station AGİ-302 of the General Directorate of Electrical Power Resources Survey and Development Administration (EİE) were used. These stations were approximately 2.8 km downstream from the “inlet of a draining watershed point”. Therefore, they were representative of the total flow and pollutant concentrations carried by the Emet and Orhaneli watersheds. Inlet of the draining watersheds (Emet and Orhaneli) is located at the inlet of subbasin 73 as depicted in Figure 3.5.

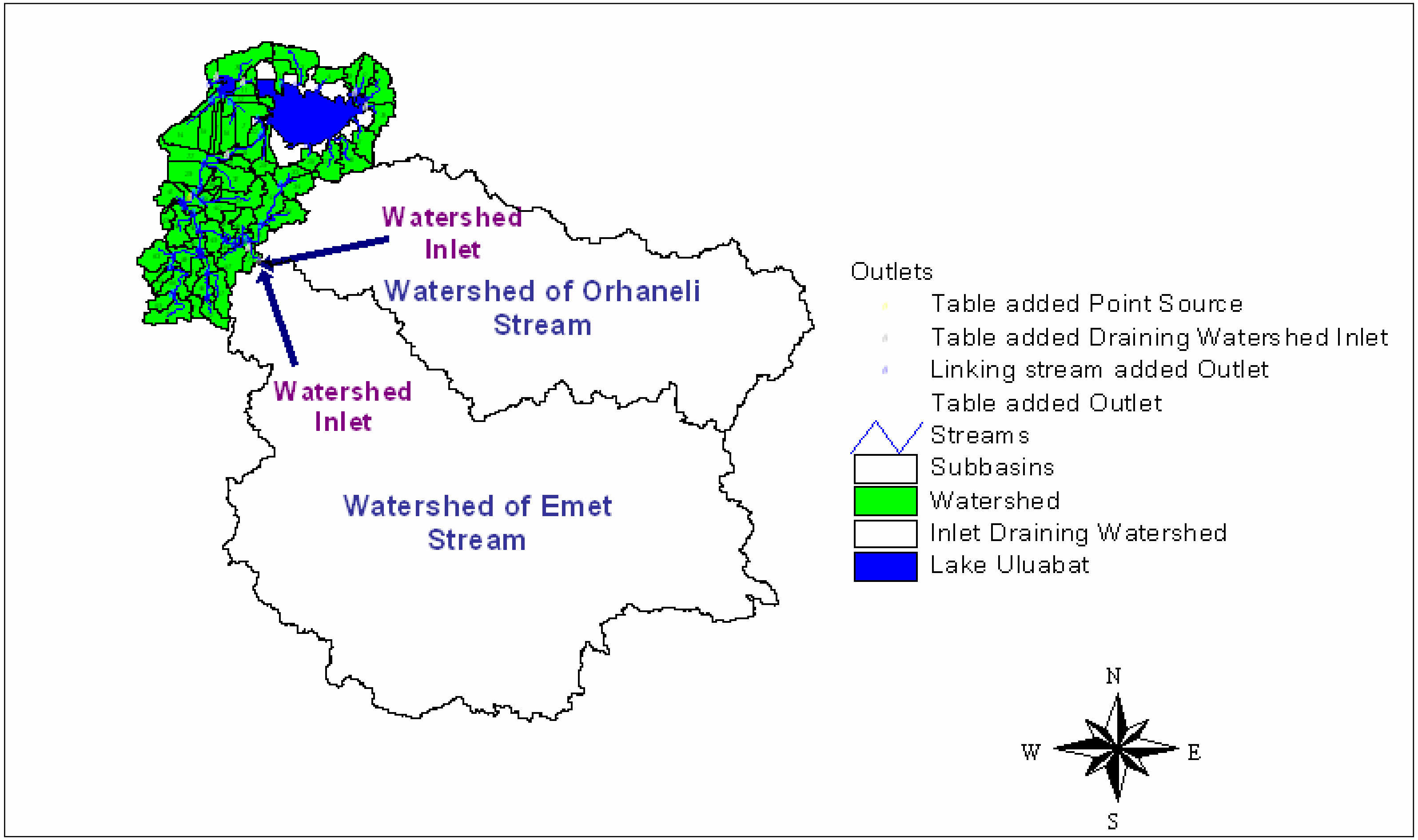

Figure 3.4. Lake Uluabat Watershed and Subbasins Delineated by SWAT

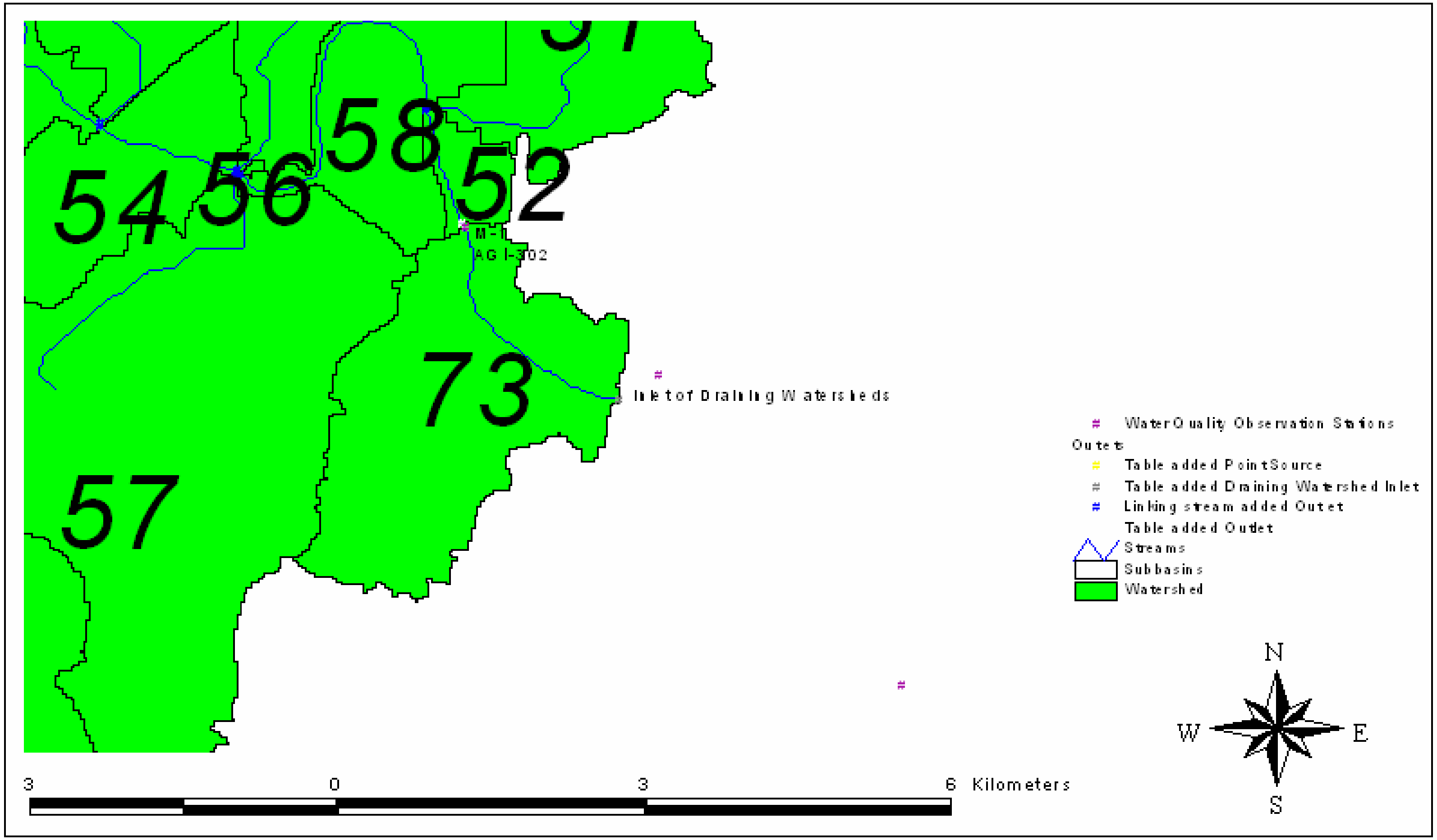

Figure 3.5. Inlet of Draining Watersheds, M-1 and AGİ-302 Stations

As stated before, DEM in the scale of 1/250,000 and having a pixel size of 30 m x 30 m was used in the study. Cotter *et al.* (2003) studied the effect of spatial resolution of GIS input data on the water quality model output uncertainty. The required resolutions in order to get satisfactory model results are given in Table 3.2.

Table 3.2. Required Minimum GIS Spatial Resolution In Order to Get Less Than %10 Error In Results (Cotter et al., 2003)

Result	**Maximum Data Resolution (m)**		
	DEM	**Landuse**	**Soils**
Flow	300	1000	1000
Sediment	30	30	500
NO_3-N	200	500	500
TP (Total-P)	30	300	500

According to Cotter's (2003) findings, SWAT results are more sensitive to the DEM resolution than the resolutions of landuse and soil data. In order to get results with less than %10 error in SWAT, required DEM resolutions for flow, NO_3-N, sediment and TP (total P) should be at most 300m, 200m, 30 m and 30 m, respectively. Since the pixel size was 30 m x 30 m, the resolution of the DEM used in the study is acceptable for sediment and P modeling. Landuse and soil data layer were produced from 1/25,000 scaled maps of the Former General Directorate of Rural Services (FGDRS) and incorporated into SWAT. SWAT converts those files to grid format from the shape format. The cell sizes of both landuse and soil data layers were stated as 30 m x 30. Therefore, the landuse map was sufficiently in detail, however for soil data, approximations were employed due to lack of data as will be discussed in the next sections.

3.3. SOIL CLASS AND LANDUSE LAYERS

There are not available data for all soil classes existing through the watershed area. Thus, in addition to the limited available data, average values from literature were used in preparation of soil class layer information. 1/25,000 scaled landuse layer was purchased from FGDRS. Since the data was of 1970s-1980s, landuse layer was updated with the use of landuse map (Scale: 1/250,000 - Period:1987-1990) prepared by the Prime Ministry State Institute of Statistics (SIS).

3.3.1. SOIL CLASS LAYER

Since there was no available complete data for all soil classes through the watershed area, first, soil texture classes were assigned by using the following maps: (1) SHW, Etude and Plan Division Chairmanship Project Archives (i) Mustafakemalpaşa Apolyont Project Döllük-Güllüce Plain Texture Distribution Map (Project No. 0306-13-939, Scale: 1/25,000), (ii) Mustafakemalpaşa Plain Detailed Land Classification Texture Distribution Map (Project No. 0306/20, Scale: 1/25,000, 1976); (2) FGDRS Soil Map (Scale: 1/25,000 – 1970s-1980s). For some areas, no texture data could be obtained. For those locations, clay loam (CL) texture was assigned based on the information given in Başar (2001), stating that among 1018 soil samples analyzed in Bursa region, 63% samples were found to have a CL texture.

Initial values for soil parameters required in SWAT were determined by taking the average values given for those parameters for each soil texture class in literature. Required data are listed below including explanations (Neitsch *et al.*, 2002a):

SNAM Soil Name

HYDGRP Soil Hydrologic Group (A, B, C or D)

A Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of sands or gravel that are deep and well to excessively drained. These soils have a high rate of water transmission (low runoff potential).

B Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C Soils having slow infiltration rates when thoroughly wetted, chiefly with a layer that impedes the downward movement of water or of moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission (high runoff potential).

D Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay pan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.

SOL_ZMX	Maximum rooting depth of soil profile (mm). If no value is entered, the model assumes the roots can develop throughout the entire depth of the soil profile. Since data only for the first 20 cm of soil is available, no value was entered for this data.
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded. Most soil minerals are negatively charged at normal pH and the net interaction with anions such as nitrate is repulsion from particle surfaces. This repulsion is termed negative adsorption or anion exclusion. If no value for ANION_EXCL is entered, the model will set ANION_EXCL = 0.50. In the study no value was entered, since this parameter is used in nitrogen cycle/runoff (Neitsch *et al.*, 2002a).

SOL_CRK	Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume (Optional, no value was entered for this data).
TEXTURE	Texture of soil layer. This data is not processed by the model.
SOL_Z (layer #)	Depth from soil surface to bottom of layer (mm). Since limited data was available for soil classes through the watershed and only P load caused by fertilizer application was modeled, data only for the first 20 cm of soil layer was entered to the model. ***NOTE:*** Fertilizers including P are applied to the first 15-20 cm of the soil layer (Susurluk Watershed Soils, 1971).
SOL_BD (layer #)	Moist bulk density (Mg/m^3 or g/cm^3). The soil bulk density expresses the ratio of the mass of solid particles to the total volume of the soil. Average values for different soil textures from literature were used in the model.
SOL_AWC (layer #)	Available water capacity of the soil layer (mm H_2O/mm soil). The plant available water, also referred to as the available water capacity, is calculated by subtracting the fraction of water present at permanent wilting point from that present at field capacity. Average values for different soil textures from literature were used in the model.
SOL_K (layer #)	Saturated hydraulic conductivity (mm/hr). Average values for different soil textures from literature were used in the model.

SOL_CBN (layer #)	Organic carbon content (% soil weight). It is stated by Mr. Mustafa Kaya (Agricultural Engineer, Bursa Agricultural Directorate) that organic matter content of Bursa soils is about 2%. Therefore, organic matter contents of all soil textures through the watershed were assumed to be %2. OM = 1.72 * OC (Organic Carbon)(Rosewell, 1993) and OC = 0.02 / 1.72 = %1.16.
CLAY (layer #)	Clay content (% soil weight). Values used for this data were determined as described in Section 3.3.1.1.
SILT (layer #)	Silt content (% soil weight). Values used for this data were determined as described in Section 3.3.1.1.
SAND (layer #)	Sand content (% soil weight). Values used for this data were determined as described in Section 3.3.1.1.
ROCK (layer #)	Rock fragment content (% total weight). The percent of the sample which has a particle diameter > 2 mm. Başar (2001), stated that among 1018 soil samples analyzed in Bursa region, no rock fragment was present.
USLE_K (layer #)	USLE equation soil erodibility (K) factor (units: 0.013 (metric ton/m^2 hr)/(m^3-metric ton cm)). Values used for this data were determined as described in Section 3.3.1.1.

3.3.1.1. SOIL TEXTURE CLASSIFICATION THROUGH THE WATERSHED

Soil textures in landuse map (Scale: 1/25,000 – Data Period: 1970s-1980s) purchased from FGDRS are classified as fine, medium, coarse, varied and mixed; and soil textures in soil texture distribution maps obtained from SHW are classified as fine, medium, coarse and very coarse (coarse and very coarse classes are grouped in coarse). Soil classes and included soil textures within these classes are given below (Table of Standards Used In Land Classification Studies, SHW, Soil and Drainage Division, Personal Contact, 2005)

Fine : ***C*** (Clay), ***SC*** (Sandy Clay), ***SiC*** (Silty Clay)

Medium : ***SiL*** (Silt Loam), ***CL*** (Clay Loam), ***SCL*** (Sandy Clay Loam), ***SiCL*** (Silty Clay Loam)

Coarse : ***L*** (Loam), ***SL*** (Sandy Loam), ***LS*** (Loamy Sand), ***S*** (Sand)

In order to determine the %sand, % silt and % clay values to be used in the model, soil analysis results given in the report of "Susurluk Watershed Soils" (1971) prepared by the Ministry of Rural Works, General Directorate of Soilwater, Division of Soil Study of the Department of Soil Studies and Mapping were used. Several samples were obtained from the region and sand, silt and clay percentages were determined. The summary of the analysis results in the report are given in Table 3.3.

Table 3.3. Analysis Results (Average Values) for Fine, Medium and Coarse Soils Throughout the Watershed Area

Soil Class	Soil Texture	Sand %	Silt %	Clay %
Fine	C (clay)	15.08	28.57	56.35
	SC (sandy clay)	No data	No data	No data
	SiC (silty clay)	4.38	47.25	48.38
Medium	SiL (silt loam)	No data	No data	No data
	CL (clay loam)	33.00	32.33	34.67
	SCL (sandy clay loam)	54.25	16.13	29.63
	SiL (silty clay loam)	14.27	50.90	34.83
Coarse	L (loam)	32.00	42.70	25.30
	SL (sandy loam)	72.00	18.60	9.40
	LS (loamy sand)	78.50	17.50	4.00
	S (sand)	No data	No data	No data

The results of the analysis were within the ranges given in literature for different soil textures. These average values were used in the model. Therefore, for soil textures which do not have representative analysis results in the report, average values given in literature were used. Ranges for sand, silt and clay percentages for different soil textures in literature are listed in Table 3.4.

Soils through the watershed area were grouped in six classes as FINE, MEDIUM, COARSE, HYDAL (Hydromorphic Alluvial Soils), BRFRST (Brown Forest Soils) and CLAY LOAM in the FGDRS map. In the legend of FGDRS map, the texture of HYDAL soils is stated as mixed. Thus the sand, silt and clay percentages for this type of soils were determined by taking the average of values determined for fine, medium and coarse textures. Main materials forming the BRFRST Soils are stated as mainly clay-rich and lime-rich in the report of "Susurluk Watershed Soils" (1971). The texture of the soil sample taken from the Tavşanlı-Emet Road, 4 km to Emet, was given as Clay (C) in the report. Therefore, values for clay soils were used for BRFRST soils in the model. The remaining areas for which there was no available data for soil classes were assumed as CLAY LOAM textured soils based on Başar's work (2001). Sand, silt and clay percentages used in the model for each soil class are given in Table 3.5.

Table 3.4. Clay, Silt, and Sand Composition for Fine, Medium and Coarse Soil Textures

Fine		
C (CLAY)	**SC (SANDY CLAY)**	**SiC (SILTY CLAY)**
≥ 40% clay (40-60%) < 45% sand < 40% silt	35%-55% clay 45%-65% sand Remaining silt	≥ 40% clay (40-60%) ≥ 40% silt (40-60%) ≤ 20% sand

Medium			
SiL (SILT LOAM)	**CL (CLAY LOAM)**	**SCL (SANDY CLAY LOAM)**	**SiCL (SILTY CLAY LOAM)**
20%-50% sand ≥ 50% silt 12%-27% clay ***OR*** 50%-80% silt < 12% clay Remaining sand	27%-40% clay 20%-45% sand Remaining silt	20%-35% clay < 28% silt ≥ 45% sand	27%-40% clay < 20% sand Remaining silt

Coarse			
L (LOAM)	**SL (SANDY LOAM)**	**LS (LOAMY SAND)**	**S (SAND)**
7%-27% clay 28%-50% silt 23%-52% sand	≥ 52% sand 0%-20% clay (silt %+ 2 * clay% > 30%)	Upper Limit: 85%-90% sand (silt%+1.5*clay%≥15%) Lower Limit:≥ 70%-85% sand (silt% + 2*clay% ≤%30)	≥ 85% sand (silt% + 1.5*clay% ≤15%)

Source: *Soil Texture Classes Triangle, Ley et al., 1994,*
Document No. 3.1.4 Texture, ***,*** *Classifications,1998 (http://www.sama.sk.ca/98manual/3.1.4.html).*

Table 3.5. Sand, Silt and Clay Percentages Used for Different Soil Textures In SWAT

FINE		
Sand %	**Silt %**	**Clay %**
23.15	34.35	42.50
MEDIUM		
Sand %	**Silt %**	**Clay %**
32.88	39.84	27.28
COARSE		
Sand %	**Silt %**	**Clay %**
66.60	22.98	10.42
HYDAL		
Sand %	**Silt %**	**Clay %**
40.88	32.39	26.73
BRWFRST		
Sand %	**Silt %**	**Clay %**
15.08	28.57	56.35
CLAY LOAM		
Sand %	**Silt %**	**Clay %**
33.00	32.33	34.67

3.3.1.2. DETERMINATION OF USLE_K FACTOR

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor (Neitsch *et al.*, 2002b). USLE_K factor is used in MUSLE as well as USLE.

Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself (Neitsch *et al.*, 2002b). USLE_K factors to be used in SWAT were determined based on the soil textures. In FGDRS soil map, only the textures of alluvial soils were indicated among the other great soil groups through the watershed modeled. Textures of the Hydromorphic Alluvial Soils and Brown Forest

Soils were determined using the soil analyses given in the Susurluk Watershed Soils Report (1971). Once the textures were determined, values given in Table 3.6 were set. These factors were also used by Özden and Özden (1998) in their study of the Soil Erosion Prediction Model of Turkey. The value of USLE_K will always be greater than zero and generally less than 0.1. A value of < 0.02 indicates a soil of low erodibility; 0.02 - 0.04 indicates moderate erodibility; and > 0.04 indicates high erodibility. Usually a soil type becomes more erodible with an increase in silt content, regardless of whether the corresponding decrease is in the sand or clay fraction (Rosewell, 1993).

Table 3.6. USLE_K Values Based On Soil Texture

Texture	**Symbol**	**Suggested K factor**	**Texture**	**Symbol**	**Suggested K factor**
Sand	S	0.015	Clay Loam	CL	0.030
Clayey Sand	CLS	0.025	Silty Clay Loam	SiCL	0.040
Loamy Sand	LS	0.020	Fine Sandy Clay Loam	FSCL	0.025
Sandy Loam	SL	0.030	Sandy Clay	SC	0.017
Fine Sandy Loam	FSL	0.035	Silty Clay	SiC	0.025
Sandy Clay Loam	SCL	0.025	Light Clay	LC	0.025
Loam	L	0.040	Light Medium Clay	LMC	0.018
Loam, Fine Sandy	Lfsy	0.050	Medium Clay	MC	0.015
Silt Loam	SiL	0.055	Heavy Clay	HC	0.012

Source: *Rosewell, 1993.*

Erodibility factors for alluvial soils, hydromorphic soils and brown forest soils were determined as described below.

Alluvial Soils:

In FGDRS soil map, alluvial soils are classified based on their soil textures as follows: A1, A4, A7 – Fine textured; A2, A5, A8 – Medium Textured; A3, A6, A9 – Coarse textured. Averages of USLE_K values given for fine (C, SC, SiC), medium (SiL, CL, SCL, SiCL) and coarse (L, SL, LS, S) textured soils in Table 3.6

were used to determine the USLE_K factors of alluvial soils. USLE_K values used in SWAT for fine, medium and coarse textured soils are given in Table 3.7. In Table 3.6 clay texture was grouped as 'light clay', 'light medium clay, 'medium clay' and 'heavy clay'. Value given for (C) in Table 3.7 was determined by taking the average of values given for clay textures (LC, LMC, MC, HC) in Table 3.6.

Table 3.7. USLE_K Values For Alluvial Soils

Texture	Symbol	USLE_K	Average USLE_K
Fine Textured Alluvial Soils (A1, A4, A7)	C SC SiC	0.017 0.017 0.025	0.020
Medium Textured Alluvial Soils (A2, A5, A8)	SiL CL SCL SiCL	0.055 0.030 0.025 0.040	0.037
Coarse Textured Alluvial Soils (A3, A6, A9)	L SL LS S	0.040 0.030 0.020 0.015	0.026

Hydromorphic Alluvial Soils:

The texture of the soil sampled from the earlier bed of Lake Simav, about 2 km away from the centre of lake, was stated as silty clay (SiC) in the Susurluk Watershed Soils Report (1971). USLE_K value given for SiC texture in Table 3.6 is 0.025. Moreover, this great soil group is classified as mixed textured soils in the legend of FGDRS soil map. Based on this information, average of USLE_K values for all textures given in Table 3.6 was taken and a value of 0.029 was obtained and used in the study.

Brown Forest Soils:

The "Susurluk Watershed Soils" Report (1971) stated that main materials forming the Brown Forest Soils are ***clay-rich*** and lime-rich blocks. The soil texture of a soil sample taken from the Tavşanlı-Emet region was reported to be clay (C). Therefore, USLE_K value for C was accepted as 0.017.

3.3.1.3. DETERMINATION OF SOL_BD (SOIL BULK DENSITY)

SOL_BD values used in SWAT were obtained from literature because of lack of data. SOL_BD values based on soil textures are given in Table 3.8. SOL_BD values for fine (C-SC-SiC), medium (SiL-CL-SCL-SiCL) and coarse (L-SL-LS-S) texture groups were determined by taking the averages of SOL_BD values of the textures included in each texture group.

Table 3.8. SOL_BD Values Based on Soil Textures (Mg/m^3)

Texture	**Symbol**	**Suggested SOL_BD**		**Texture**	**Symbol**	**Suggested SOL_BD**	
		Range	**Avg.**			**Range**	**Avg.**
Sand	S	1.60 - 1.70	1.65	Clayey Loam	CL	1.40 - 1.50	1.45
Loamy Sand	LS	1.55 - 1.65	1.60	Silty Clay Loam	SiCL	1.45 - 1.55	1.50
Sandy Loam	SL	1.50 - 1.60	1.55	Sandy Clay	SC	1.35 - 1.45	1.40
Clay Loam	SiL	1.45 - 1.55	1.50	Silty Clay	SiC	1.40 - 1.50	1.45
Sandy Clay Loam	SCL	1.45 - 1.55	1.50	Clay	C	1.25 – 1.45	1.35
Loam	L	1.45 - 1.55	1.50				

Source: *Guides For Editing Soil Properties, 2005.*

3.3.1.4. DETERMINATION OF SOL_AWC (SOIL AVAILABLE WATER CAPACITY)

Available soil capacity values used in SWAT were obtained from literature because of lack of data. SOL_AWC values based on soil textures are given in Table 3.9. SOL_AWC values for fine (C-SC-SiC), medium (SiL-CL-SCL-SiCL) and coarse (L-SL-LS-S) texture groups were determined by taking the averages of SOL_AWC values of textures included in each texture group.

Table 3.9. SOL_AWC Values Based on Soil Textures (mm H_2O/mm soil)

Texture	Symbol	Suggested SOL_AWC		Texture	Symbol	Suggested SOL_AWC	
		Range	Avg.			Range	Avg.
Sand	S	0.06-0.08	0.07	Clayey Loam	CL	0.15-0.19	0.17
Loamy Sand	LS	0.09-0.11	0.10	Silty Clay Loam	SiCL	0.18-0.20	0.19
Sandy Loam	SL	0.12-0.14	0.13	*Sandy Clay	*SC†	0.16-0.21	0.19
Clay Loam	SiL	0.20-0.22	0.21	Silty Clay	SiC	0.11-0.13	0.12
Sandy Clay Loam	SCL	0.16-0.18	0.17	Clay	C	0.09-0.11	0.10
Loam	L	0.17-0.19	0.18				

Source: *Guides For Editing Soil Properties, 2005.(*Ley et al., 1994).†Except value given for SC texture, the values are for soil having organic material content of 0.5-3%.*

3.3.1.5. DETERMINATION OF SOL_K (SATURATED HYDRAULIC CONDUCT.)

Saturated hydraulic conductivity values used in SWAT were obtained from literature. SOL_K values based on soil textures are given in Table 3.10. SOL_K values for fine (C-SC-SiC), medium (SiL-CL-SCL-SiCL) and coarse (L-SL-LS-S) texture groups were the averages of SOL_K values of textures included in each texture group. Since, hydromorphic soils are mixed textured soils, SOL_K of them was determined by taking the averages of SOL_K values given for each soil texture. Brown forest soils are mainly formed by clay-rich and lime-rich materials (Susurluk Watershed Soils, 1971). Therefore, SOL_K value for clay texture (C) was used for this soil group. The soil class map used by SWAT is depicted in Figure 3.6.

Table 3.10. SOL_K Values Based on Soil Textures (mm/h)

Texture	Symbol	Suggested SOL_K		Texture	Symbol	Suggested SOL_K	
		Range	Avg.			Range	Avg.
Sand	S	152.40-508.10	330.25	Clayey Loam	CL	5.10-15.20	10.15
Loamy Sand	LS	152.40-508.10	330.25	Silty Clay Loam	SiCL	5.10-15.20	10.15
Sandy Loam	SL	50.80-152.40	101.60	Sandy Clay	SC	1.50-5.10	3.3
Clay Loam	SiL	15.20-50.80	33.00	Silty Clay	SiC	1.50-5.10	3.3
Sandy Clay Loam	SCL	5.10-15.20	10.15	Clay	C	1.50-5.10	3.3
Loam	L	15.20-50.80	33.00				

Source: *Guides For Editing Soil Properties, 2005.*

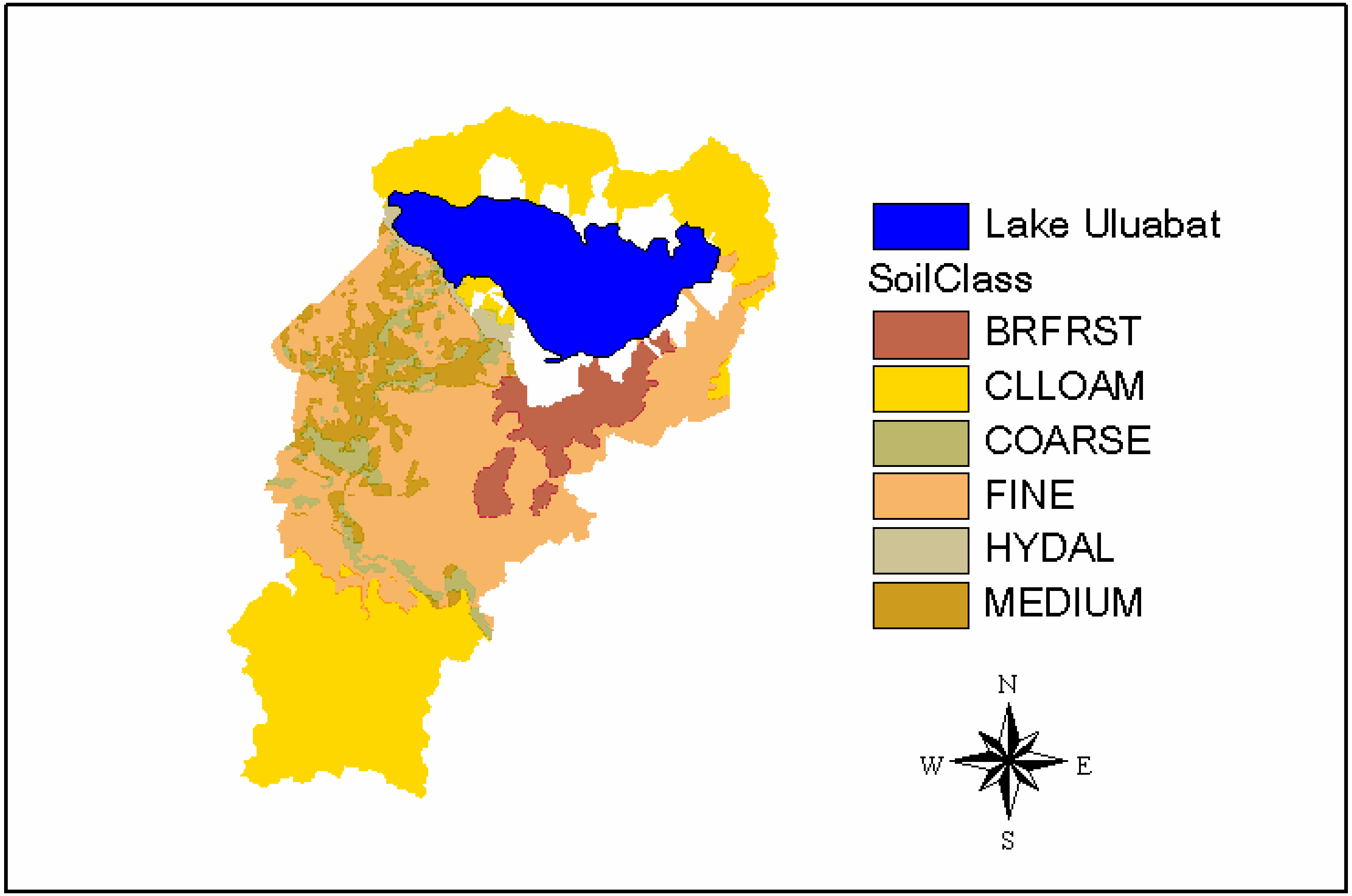

Figure 3.6. Soil Class Layer

The summary of the initial values for soil parameters required for SWAT runs and their corresponding ranges in literature are given in Table A.1 in Appendix A.

3.3.2 LANDUSE LAYER

Water movement depends on both soil characteristics and vegetation cover. Amount of rain kept by vegetation cover varies depending on the type of vegetation. Dense vegetation on soil prevents soil from rain impacts and decreases erosion. Conversely, light vegetation results in high surface runoff and therefore high amounts of nutrients may be transferred to the water bodies following fertilization and a proceeding storm.

Landuse data of the simulated watershed area of Lake Uluabat was obtained by using FGDRS soil map as a base map. Landuse data are of 1970s-1980s, thus a new landuse layer was produced by updating FGDRS soil map with the use of landuse map prepared by SIS (Scale: 1/250,000 - Period:1987-1990). The produced landuse map was imported in SWAT in *.shp format, and converted to grid format by SWAT. Landuse data in the updated FGDRS landuse map was matched with the appropriate landuses in the SWAT database (Table 3.11). Simulated area of the watershed of Lake Uluabat included in Mustafakemalpaşa and Karacabey Districts (1997 Village Inventory, 2002). Top three agricultural products in these districts are wheat, tomato and corn. Irrigated agricultural lands in the FGDRS map were linked with tomato and corn in SWAT. Wheat is produced by non-irrigated agriculture and it is a close-grown crop, thus non-irrigated agriculture was linked with AGRC in SWAT database. Tomato can be produced in gardens, thus, gardens in FGDRS map was linked with TOMA, too. Grape was linked with AGRC since it covers a very small area over the watershed area and surrounded by non-irrigated agricultural lands.

As given in Table 3.11, non-irrigated agriculture and irrigated agriculture are comprised 21.67% and 21.77 % of the simulated watershed, respectively. 33.53% of the watershed area is covered with forests. In Bursa, non-irrigated agriculture, irrigated agriculture and forests comprise 28%, 14.2 % and 29.2%, respectively, within the total area of about 11,043 km^2 (GDRS, 1995). However, in this study, modeling is applied to a watershed area of 813 km^2. Therefore, not all Bursa region is simulated. The resultant landuse layer is depicted in Figure 3.7.

Table 3.11. Landuse Matching of FGDRS Soil Map and SWAT Landuse Database

Grid Value	Area (%)	Current Landuse in FGDRS Map		Landuse Defined In SWAT Database	
		Definition	**Symbol Used**	**Definition**	**Symbol Used**
1	1.02	Residential Area	YR	Residential – Med/Low Density	URML
2	2.37	Shrubbery	F	Range-Grasses	RNGE
4	19.35	Irrigated Agriculture	S	Tomato	TOMA
5	33.53	Forest	O	Forest-Mixed	FRST
6	21.67	Non-irrigated Agriculture	N	Agricultural Land-Close-Grown	AGRC
7	1.31	Pasture	M	Pasture	PAST
9	0.42	River	IR	Water	WATR
11	2.42	Insufficient-irrigated Agriculture	Sy	Corn	CORN
14	0.06	Garden	B	Tomato	TOMA
16	4.26	Lake	GL	Water	WATR
22	11.97	Grass-Natural Vegetation Cover	Ç	Range-Grasses	RNGE
25	1.07	Marshy Places	SB	Nonforested Wetland	WETN
27	0.29	Sandy Dunes	KM	Hay	HAY
33	0.27	Grape	Ü	Agricultural Land-Close-Grown	AGRC

3.4. HRU DISTRIBUTION AND INPUTS FOR INITIAL SWAT RUNS

Once the land use and soil themes were imported and linked to the SWAT databases, they were overlaid through SWAT to determine land use/soil class combinations, and distributions for the delineated watershed(s) and for each respective subbasin. After this step, the distribution of HRUs within the watershed was determined. "Multiple hydrologic response units" option was selected to include all soil class-landuse combinations through the watershed. SWAT eliminates the land uses and soil classes that cover an area less than the threshold level (Di Luzio *et al.,* 2002). In order not to ignore any landuse and soil class combination, a threshold level of 0% was applied. 546 HRUs were generated through the simulated watershed of Lake Uluabat. Weather data to be used in the watershed simulation was imported through the weather data definition dialog box, once the HRU distribution was defined.

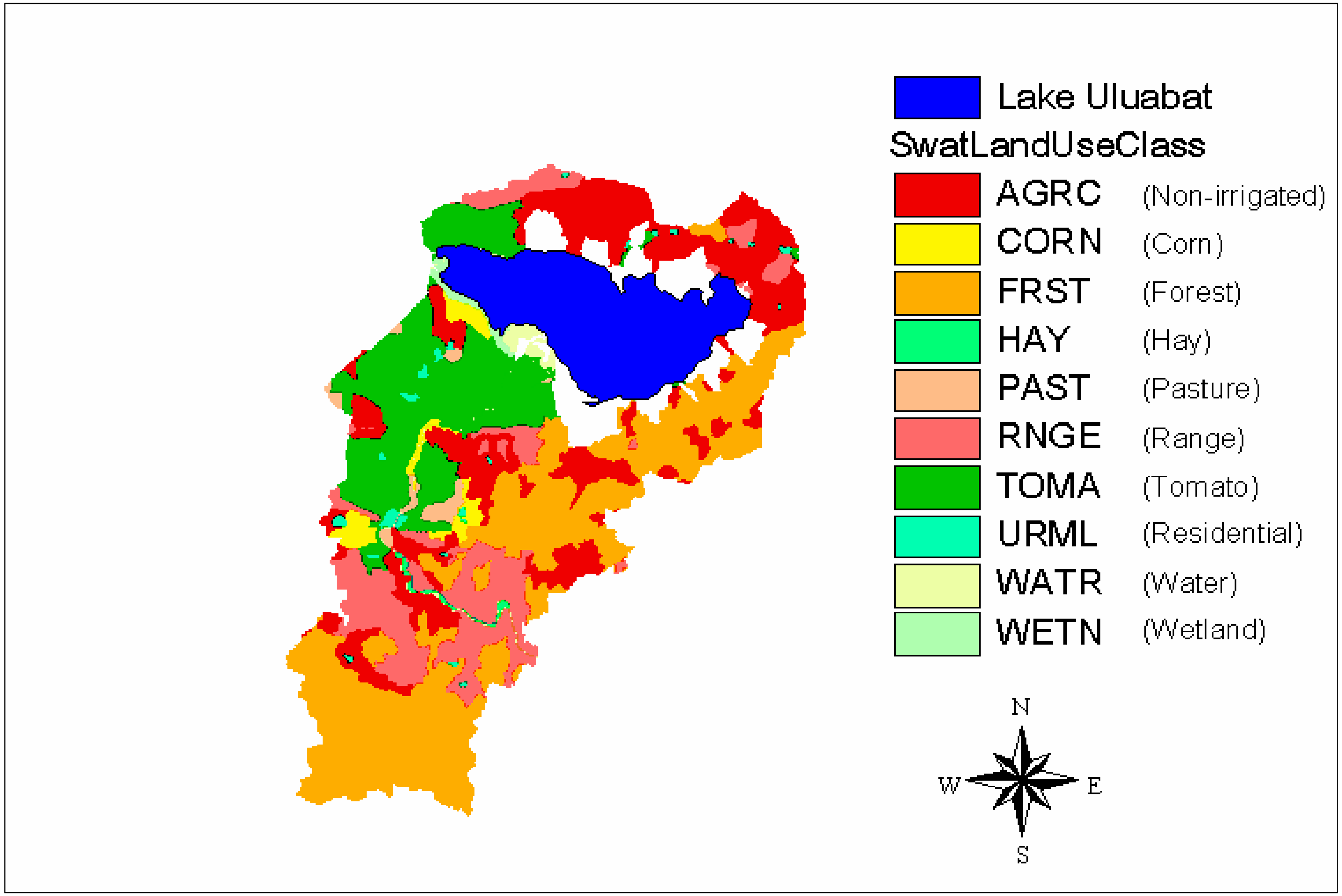

Figure 3.7. Landuse Layer

Before SWAT can be activated, the initial watershed input values must be defined. These values were set automatically based on the watershed delineation, land use-soil characterization and from parameter default values if not defined by the user.

Point source discharge (Sewage discharge from Mustafakemalpaşa) and watershed inlet discharges (Orhaneli and Emet Stream inlets) were edited. Inputs of sewage discharge and inlet discharge were incorporated into SWAT as a constant daily load (Table 3.12) and average annual daily loads (Table 3.13), respectively. Data given in Table 3.13 were calculated using flow and quality data obtained from SHW M-1 Water Quality Observation Station and EİE - AGİ-302. Only P and sediment data were included since P load was modeled. In SHW data, there is no specific data for soluble P. In order to simulate the worst case, in terms of eutrophication, Total P data was imported into SWAT as the Soluble P quantity. Initial soil labile P concentrations of 8 kg/da were assigned to TOMA, AGRC and CORN in each subbasin throughout the watershed. Başar (2001) stated that 52.16% of 1018 soil samples taken from the region had a medium range (4-12 kg/da) of available P.

Table 3.12. Point Source Discharge Data

Parameter	**Quantity**
Water Flow* (m^3/day)	7000
Sediment** (ton/day)	2.45
Organic P** (kg/day)	35
Soluble P** (kg/day)	70

**Obtained from Mustafakemalpaşa Municipality.*
***Typical Wastewater Composition, Topacık (1987).*

Table 3.13. Inlet Discharge Data

Parameter	**2001**	**2002**	**2003**	**2004**
Flow* (m^3/day)	1738886.400	4235760.000	2056320.000	2558131.200
Sediment* (ton/day)	35.799	332.860	88.093	162.189
Soluble P* (kg/day)	84.004	912.686	475.762	238.108

**Sum of Orhaneli and Emet Streams.*

For simulations, the initial conditions for the management practices were assigned to each subbasin in which agricultural activities (TOMA, AGRC (wheat), CORN) occur. Information about these practices was obtained through personal contact with the Agricultural Engineers in Bursa Agricultural Directorate and from "Handbook of Agriculturist" (1989). Management practices applied for tomato, wheat and corn are given in Table 3.14. It was assumed that these conditions were valid in 2001-2004.

Table 3.14. Agricultural Management Practices for Tomato (TOMA), Wheat (AGRC) and Corn (CORN)

Application Type	**Date of Application/Application Amount**
TOMA	
Tillage by Finishing Harrow	April 10
Fertilizer Application (DAP-Diammonium Phosphate, 18-46)	May 10 – 2500 kg/ha
Plant/begin. Growing season	May 15
Irrigation	May 15 – 342 mm
Irrigation	May 30 - 342 mm
Irrigation	June 15 - 342 mm
Irrigation	June 30 - 342 mm
Irrigation	July 15 - 342 mm
Irrigation	July 30 - 342 mm
Harvest and Kill Operation	September 1
AGRC	
Tillage by Paraplow	November 1
Tillage by Field Cultivator	November 15
Fertilizer Application (20-20 Composite)	December 1 – 2500 kg/ha
Plant/begin. Growing season	December 1
Fertilizer Application (Urea)	March 1 – 2000 kg/ha
Harvest and Kill Operation	July 1
CORN	
Tillage by Paraplow	March 10
Fertilizer Application (Elemental N)	March 15 – 2500 kg/ha
Fertilizer Application (Elemental P)	March 15 – 1000 kg/ha
Plant/begin. Growing season	April 15
Fertilizer Application (15-15-15 Composite)	April 15 – 4000 kg/ha
Fertilizer Application (Urea)	April 15 – 2000 kg/ha
Irrigation	April 17 – 424 mm
Irrigation	May 30- 424 mm
Irrigation	June 30 - 424 mm
Harvest and Kill Operation	July 30

Note: *Irrigation data was obtained from Mustafakemalpaşa Irrigation tables (SHW).*

The initial conditions for the stream water quality at the inlet of the watershed area (inlet of draining watersheds) are assigned using the water quality data of station M-1. Since insignificant agricultural or other activities are taking place at this subbasin (subbasin 73), this approach is deemed valid. In fact, the calibration results given in the next section provide justification for this assumption.

Irrigation demand was also incorporated into SWAT. SHW provides irrigation in subbasin 37. Minimum in-stream flow to allow irrigation diversions from the Mustafakemalpaşa Stream was set to 0.05 m^3/s. The minimum flow observed in 2002 and 2003, May through October, was 10.5 m^3/s. May through October flow data was considered since water diversion from Mustafakemalpaşa for irrigation was applied in this period. Maximum daily irrigation diversion from the reach in subbasin 37 was set to 7100 mm. This value was determined using the plant water demand values given in Mustafakemalpaşa Irrigation table obtained from SHW.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. CALIBRATION

Calibration of the model was performed in three steps for annual average conditions as Neitsch et al. (2002a) suggested:

- Water balance and stream flow
- Sediment
- Nutrients

Stream flow, sediment and nutrient (P) were calibrated for two gages located within the watershed. Calibration was done first at the upstream gage located at the outlet of subbasin 73 (M-1), and then at the downstream gage located at the outlet of subbasin 77 (M-2). In order to judge the success of the calibration, two different coefficients were used. These were the percent deviation from the observed value and Nash-Stucliffe Coefficient (E_{NS}) stated by equations 4.1 and 4.2, respectively.

$$Dv_i = \frac{Q_{Mi} - Q_{Si}}{Q_{Mi}} \cdot 100 \tag{4.1}$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (Q_{Si} - Q_{Mi})^2}{\sum_{i=1}^{n} (Q_{Si} - \overline{Q}_M)^2} \tag{4.2}$$

where,

Dv : Percent deviation from observed value
Q_{Si} : Simulated value
Q_{Mi} : Observed (Measured) value
$\overline{Q}_M$: Average measured value for the simulation period
n : Number of observed values

Observed flow data was obtained from Stream Flow Observation Station AGİ-302 of EİE and from SHW station M-1 (Figure 4.1). Both stations are at the same location. Observed water quality data was obtained from M-1 and M-2. Flow and water quality data of station M-1 were used in calculating the observed sediment and soluble P (SOL P) annual loads in mass per time. In order to determine the sediment and SOL P loads, water quality data obtained for flows within ±20% of AGİ-302 flow data were used; others were ignored. Flow data of station AGİ-302 are more reliable since they are recorded daily. Monthly averages of them were used as references while choosing the representative flow and water quality data from M-1. Monthly flow and water quality data reported by SHW are derived from grab samples, and moreover, represent instantaneous values.

In order to apply any modeling study, calibration is required. In order to determine whether a successful calibration has been achieved or not some criteria are required. Van Liew and Garbrecht (2003) considered simulation results

- good for values of $E_{NS} \geq 0.75$,
- satisfactory for values of $0.75 > E_{NS} > 0.36$
- unsatisfactory for E_{NS} values less than 0.36.

Santhi et al. (2001) terminated calibration when the following criteria were obtained.

- If average of simulated surface runoff is within ±15% of average measured surface runoff and $E_{NS} \geq 0.50$ and $R^2 \geq 0.60$.

- If average of simulated sediment is ±20% of average measured sediment and $E_{NS} \geq 0.50$ and $R^2 \geq 0.60$.
- If average of simulated MIN N&P is ±25% of average measured MIN N&P and $E_{NS} \geq 0.50$ and $R^2 \geq 0.60$.

In this study, calibration was terminated when the criteria stated below were obtained. R^2 term was not calculated, since calibration was performed for only 2002 and 2004.

- If average of simulated surface runoff is within ±15% of average measured surface runoff and $E_{NS} \geq 0.50$.
- If average of simulated sediment is ±20% of average measured sediment and $E_{NS} \geq 0.50$.
- If average of simulated SOL P is ±25% of average measured SOL P and $E^{NS} \geq 0.50$.

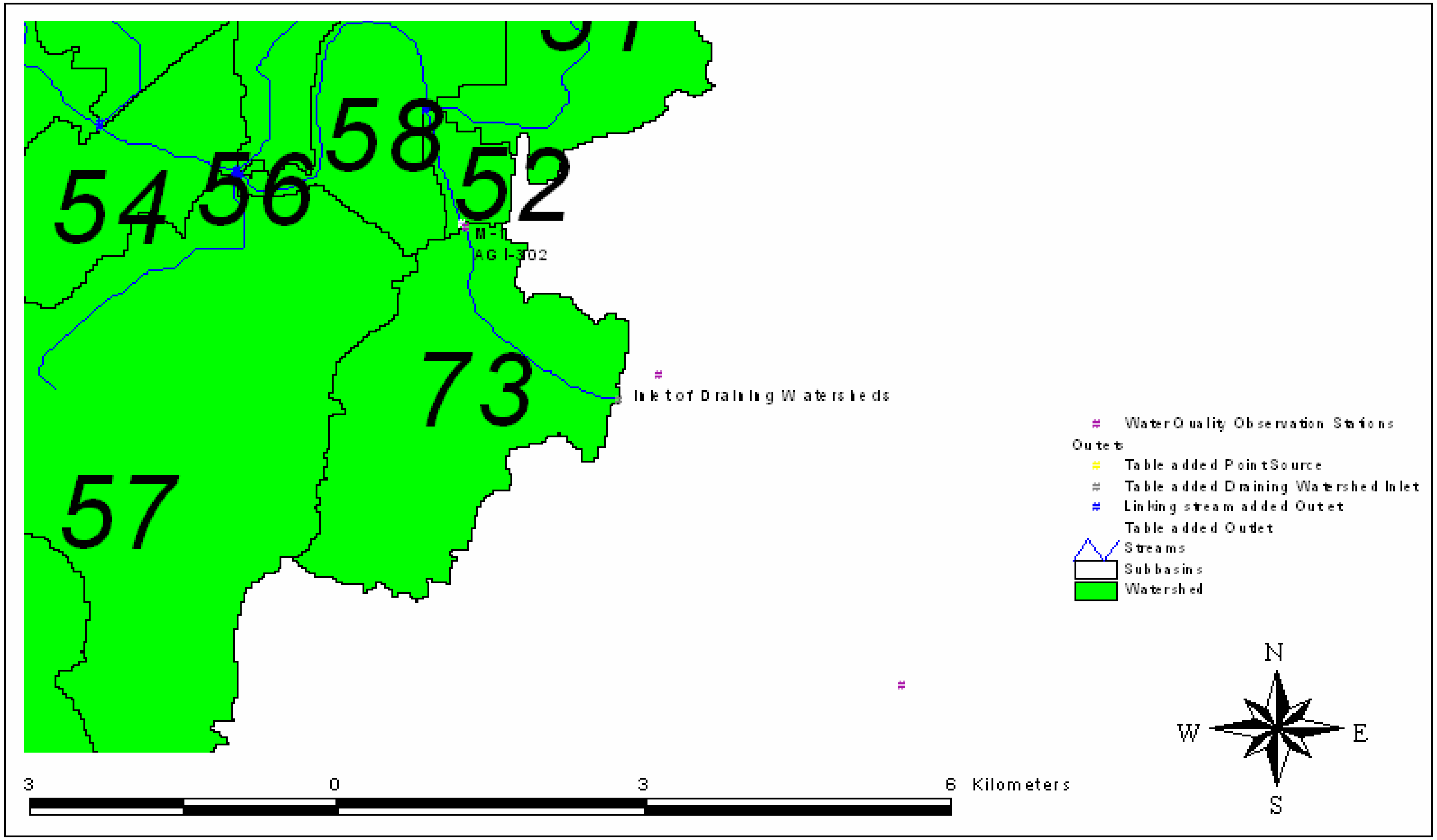

Figure 4.1. Inlet of Draining Watersheds, M-1 and AGİ-302 Stations

In Table 4.1, initial run results for subbasin 73 are given. Runs were performed for a time period including the years 2001, 2002, and 2004. Year 2001was used to adjust the initial hydrologic conditions through the watershed. Year 2003 was not included in the results due to the inappropriate data of SHW showing no similar trend in flow data with the AGİ-302 station data.

Table 4.1. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 73 (Average Annual Values)

Year	Flow (m^3/s)			Sediment (ton/year)			SOL P (kg/year)		
	Obs.	**Sim.**	**Dv (%)**	**Obs.**	**Sim.**	**Dv (%)**	**Obs.**	**Sim.**	**Dv (%)**
2001	20.13	20.17	-0.22	13067	13140	-0.56	30661	30680	-0.06
2002	49.03	49.14	-0.23	121494	121500	-0.01	333131	333200	-0.02
2004	29.61	29.70	-0.31	59361	59370	-0.01	87148	87160	-0.01
Avg.*	39.32	39.42	-0.26	90427	90435	-0.01	210139	210180	-0.02
E_{NS}*	0.99			0.99			1.00		

**Avg., E_{NS} values were calculated using 2002, 2004 years' values.*
† Observed are for SHW.

Initial run with default values for subbasin 73 was satisfactory. As a result, in terms of the criteria stated above, model input values used in the run were justified and the initial run for subbasin 73 was successful.

In addition to flow, initial run results were checked based on the average sediment load for 2002-2004. The relevant data was obtained from AGİ-302-Döllük Station. The relationship between daily sediment load (ton/day) and the flow (m^3/s) is depicted in Figure 4.2.

As seen in Table 4.1, the average flow and sediment load simulated by SWAT at AGİ-302 Station are 39.42 m^3/s and 90435 ton/year, respectively. Average sediment load calculated by using the curve produced from EİE sediment load-flow data, for the simulated flow of 39.42 m^3/s, is 84467 ton/year. Dv between these values is -7.1%.

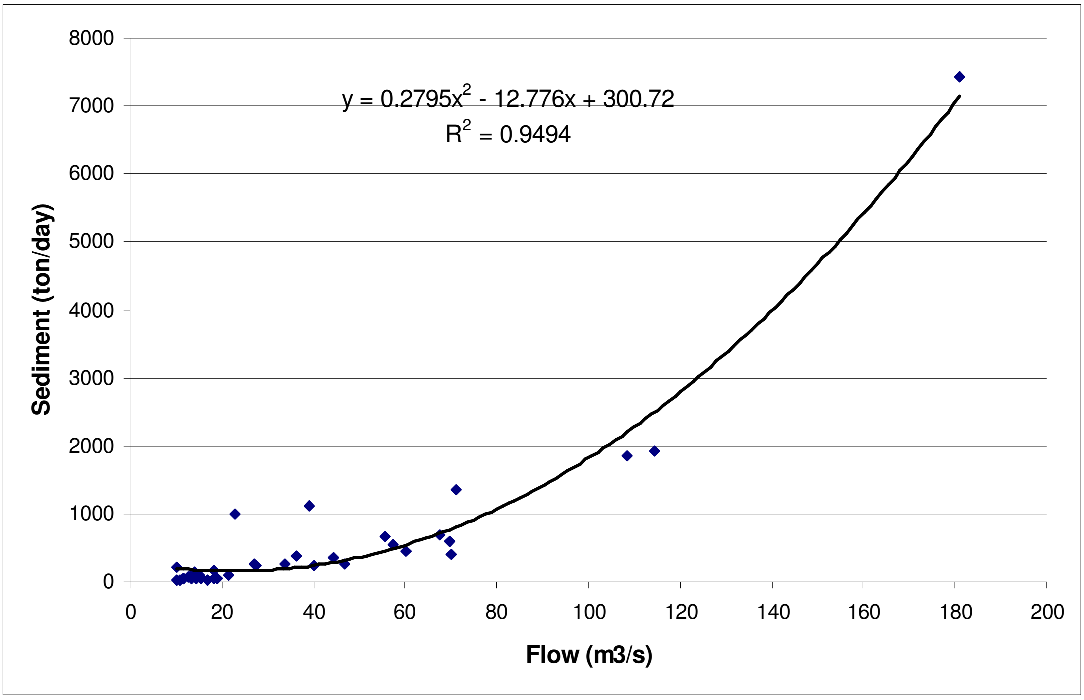

Figure 4.2. EİE-302, Sediment Load vs. Flow, 2002-2004

After completion of calibration for subbasin 73, calibration for subbasin 77 was performed. This subbasin is close to Lake Uluabat and receives the loads from other subbasins including subbasin 73. Calibration for subbasin 77 was done for the years 2002 and 2004. Year 2001 was used to adjust the initial hydrologic conditions through the watershed. Year 2003 was not included in the calibration period due to the inappropriate flow data showing no similar trend with AGİ-302 data.

The results of the initial run for the downstream gage M-2 using the model parameter default values are given in Table 4.2. Flow data of M-2 were not reliable in terms of sampling methods and reporting. Therefore, for calibration, the SHW observation data for flows close (±20%) to the average monthly flow observed in AGİ-302 were used. Observed sediment and P loads were calculated based on M-2 flow and water quality data. Water quality measurements for flows deviated (within ±20%) from the average flow of AGİ-302 were ignored while calculating the observed sediment and P loads. As seen in Table 4.2, the model generally overestimated the flow, and underestimated the sediment and SOL P loads. Since sediment and P loads are directly related with flow, first flow calibration was performed as directed in SWAT User's Manual.

Table 4.2. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***
2001	15.71	23.51	-49.65	0.70	10990	44420	-304.19	0.63	128812	143000	-11.01	0.05
2002	49.54	56.61	-14.27		198036	142100	28.25		431193	439800	-2.00	
2004	36.60	35.68	2.52		67522	70880	-4.97		296249	198700	32.93	
Avg.*	43.07	46.14	-7.14		132779	106490	19.80		363721	319250	12.23	

**Avg., E_{NS} values were calculated using 2002, 2004 years' values.*

4.1.1. STREAM FLOW CALIBRATION AT GAGE M-2, OUTLET OF SUBBASIN 77

In order to perform stream flow calibration at gage M-2, suggested parameters by Neitsch *et al.* (2002a) and Muleta and Nicklow (2005) were modified. These parameters are listed below:

- Curve number (CN2)
- Soil available water capacity (SOL_AWC)
- Soil evaporation compensation factor (ESCO)
- Aquifer percolation coefficient (RCHRG_DP)
- Threshold depth (mm) of water in the shallow aquifer required for base flow to occur (GWQMN)
- Groundwater delay time (GWDELAY)
- Maximum canopy storage, mm H_2O (CANMX)
- The plant uptake compensation factor (EPCO)

Parameters listed above were changed within the ranges given in Neitsch *et al.* (2002b), and Muleta and Nicklow (2005). It was observed that maximum improvement in stream flow calibration was obtained by modifying RCHRG_DP and GWQMN. Thus, parameters other than RCHRG_DP and GWQMN were left as default. Modifications were applied to the subbasins draining into the subbasin 77. These were subbasins 29-72, and subbasin 77.

A fraction of the total daily recharge can be routed to the deep aquifer. Percolation to the deep aquifer can occur only if the amount of water stored in the shallow aquifer exceeds a threshold value (*REVAPMN)* (Neitsch *et al.*, 2002b). It was set to 1.00 mm (default) by the model. The maximum amount of water than will be removed from the shallow aquifer via percolation to the deep aquifer on a given day is:

$$w_{deep,mx} = \beta_{deep} \cdot w_{rchrg} \tag{4.3}$$

where $w_{deep,mx}$ is the maximum amount of water moving into the deep aquifer on day i (mm H_2O), β_{deep} (RCHRG_DP) is the aquifer percolation coefficient, and w_{rchrg} is the amount of recharge entering the aquifer on day i (mm H_2O). Water entering the deep aquifer is not considered in future water budget calculations and can be considered to be lost from the system (Neitsch *et al.*, 2002b). Since, the model overestimates the flow, aquifer percolation coefficient to deep aquifer was increased from 0.05 (default) to 0.4 in *.gw file, to decrease the contribution to stream flow. Simulation results for this modification are given in Table 4.3.

Table 4.3. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After 1st RCHRG_DP Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***
2001	15.71	23.33	-48.50	0.58	10990	44420	-304.19	0.63	128812	143000	-11.01	0.06
2002	49.54	55.07	-11.16		198036	142100	28.25		431193	439700	-2.00	
2004	36.60	34.38	6.07		67522	70880	-4.97		296249	198500	32.93	
Avg.*	43.07	44.72	-3.84		132779	106490	19.80		363721	319100	12.23	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

As seen in Table 4.3, Dvs of year 2002 and avg. annual flow were improved. Then, in order to obtain further improvement in stream flow simulation, RCHRG_DP was increased to 0.6. Simulation results for this modification are given in Table 4.4. Additional improvements were obtained in Dvs of year 2002 and the avg. annual flow. Dv of the average annual flow decreased to -2.80%.

Table 4.4. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After 2nd RCHRG_DP Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***
2001	15.71	23.20	-47.67	0.63	10990	44420	-304.19	0.63	128812	143000	-11.01	-0.06
2002	49.54	54.49	-9.99		198036	142100	28.25		431193	439600	-1.95	
2004	36.60	34.06	6.94		67522	70880	-4.97		296249	198500	33.00	
avg*	43.07	44.27	-2.80		132779	106490	19.80		363721	319050	12.28	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

SWAT sets GWQMN to "0 mm" as default. That is, when depth of water is greater than "0 mm", return flow occurs. Return flow, or base flow, is the volume of stream flow originating from groundwater (Neitsch *et al.*, 2002b). In order to decrease return flow GWQMN was increased to 50 mm. Simulation results for this modification are given in Table 4.5. With this approach, E_{NS} was increased to 0.72

and Dv of avg. annual flow was decreased to -0.10%. In order to obtain further improvement, GWQMN was increased to 100 mm. Results are given in Table 4.6.

Table 4.5 Observed and Simulated Flow, Sediment and SOL P Loads; Subbasin 77; After 1st GWQMN Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*
2001	15.71	21.60	-37.49	0.72	10990	44060	-300.91	0.63	128812	143200	-11.17	-0.06
2002	49.54	53.03	-7.04		198036	142000	28.30		431193	439400	-1.90	
2004	36.60	33.20	9.29		67522	70870	-4.96		296249	198200	33.10	
Avg.*	43.07	43.11	-0.10		132779	106435	19.84		363721	318800	12.35	

**Avg., E_{NS} values were calculated using 2002, 2004 years' values.*

Table 4.6. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After 2nd GWQMN Modification

Year	Flow (m3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*
2001	15.71	21.32	-35.71	0.75	10990	42950	-290.81	0.63	128812	143100	-11.09	-0.06
2002	49.54	52.58	-6.14		198036	142000	28.30		431193	439400	-1.90	
2004	36.60	33.20	9.29		67522	70870	-4.96		296249	198200	33.10	
Avg.*	43.07	42.89	-0.42		132779	106435	19.84		363721	318800	12.35	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

Stream flow calibration was terminated at this point, since satisfactory results were obtained. E_{NS} and maximum Dv values achieved after calibration are 0.75 and 9.29%, respectively. These values are reasonable, since there are numerous potential errors in the observation data. Spatial variability in rainfall and errors in flow rates are the potential errors (Santhi *et al.,* 2001). Winter (1981) suggests errors in annual estimates of precipitation, stream flow and evaporation can easily reach up to 2 to 15%.

4.1.2. SEDIMENT LOAD CALIBRATION AT GAGE M-2

As seen in Table 4.6, SWAT highly underestimated the sediment load in year 2002. Sediment calibration was done to increase the simulated sediment load at the outlet of subbasin 77. Sediment calibration was performed as directed in SWAT User's Manual (Neitsch et al., 2002a) and following the steps done by Santhi et al. (2001), and Muleta and Nicklow (2005). Calibrations were performed for 2002 and 2004.

Sediment degradation through the main channel was simulated as zero degradation, since channel erodibility factor (CH_EROD) and channel cover factor (CH_COV) were set to "zero" by SWAT, initially. Their range were given as -0.05-0.6 cm/hr/Pa and -0.001-1.0, respectively, in Muleta and Nicklow (2005). Degradation in the reach segment is calculated as follows (Neitsch *et al.*, 2002b):

$$sed_{\deg} = \left(conc_{sed,ch,mx} - conc_{sed,ch,i}\right) \cdot V_{ch} \cdot K_{CH} \cdot C_{CH} \qquad (4.4)$$

where sed_{deg} is the amount of sediment reentrained in the reach segment (metric tons), $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/L or ton/m^3), $conc_{sed,ch,i}$ is the initial sediment concentration in the reach (kg/L or ton/m^3), V_{ch} is the volume of water in the reach segment (m^3 H_2O), K_{CH} is the channel erodibility factor (cm/hr/Pa), and C_{CH} is the channel cover factor.

CH_EROD and CH_COV were increased to 0.01 and 0.001, respectively, through the subbasins draining into subbasin 77, in *.rte file. Simulation results obtained after this modification were given in Table 4.7.

Table 4.7. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After the 1st CH_EROD and CH_COV Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***
2001	15.71	21.32	-35.71	0.75	10990	43530	-296.09	0.65	128812	143100	-11.09	-0.06
2002	49.54	52.58	-6.14		198036	143500	27.54		431193	439400	-1.90	
2004	36.60	33.20	9.29		67522	71850	-6.41		296249	198200	33.10	
Avg.*	43.07	42.89	-0.42		132779	107675	18.91		363721	318800	12.35	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

In Table 4.7, it is given that sediment simulation was improved and E_{NS} increased to 0.65 and Dv of the avg. annual sediment load was decreased to 18.91%. Next, CH_EROD was increased to 0.02. Simulation results obtained after this modification are given in Table 4.8. As seen in Table 4.8, sediment simulation was improved. E_{NS} increased to 0.67 and Dv of the avg. annual sediment load was decreased to 18.01%.

Table 4.8. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After the 2nd CH_EROD Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***	**Obs.**	**Sim.**	**Dv (%)**	**E_{NS}***
2001	15.71	21.32	-35.71	0.75	10990	44110	-301.36	0.67	128812	143900	-11.09	-0.06
2002	49.54	52.58	-6.14		198036	144900	26.83		431193	439400	-1.90	
2004	36.60	33.20	9.29		67522	72830	-7.86		296249	198200	33.10	
Avg.*	43.07	42.89	-0.42		132779	108865	18.01		363721	318800	12.35	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

Sediment yield is calculated by modified universal soil loss equation (Williams, 1995):

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \quad (4.5)$$

where *sed* is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)), C_{USLE} (USLE_C) is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor (Neitsch *et al.*, 2002b). First of all, USLE_C factor was modified for all landuses through the watersheds draining to subbasin 77. The range of USLE_C given in SWAT is 0.001-0.5. USLE_C factors were modified in crop.dat and crop.dbf files. Default and modified USLE_C factors are given in Table 4.9. Simulation results after 1st and 2nd USLE_C modifications are given in Table 4.10 and Table 4.11, respectively.

Table 4.9. Default and Modified USLE_C Factors

Landuse	**Default USLE_C**	**1st USLE_C Modification**	**2nd USLE_C Modification**
AGRC	0.03	0.30	0.30
HAY	0.003	0.10	0.003
FOREST MIXED	0.001	0.004	0.001
WETN NONFORESTED	0.003	0.006	0.003
PASTURE	0.003	0.006	0.003
RNGE-GRASSES	0.003	0.10	0.003
CORN	0.2	0.30	0.30
TOMA	0.03	0.10	0.10

Table 4.10. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After the 1st USLE_C Modification

<table>
<tr><th rowspan="2">Year</th><th colspan="4">Flow (m^3/s)</th><th colspan="4">Sediment (ton/year)</th><th colspan="4">SOL P (kg/year)</th></tr>
<tr><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th></tr>
<tr><td>2001</td><td>15.71</td><td>21.32</td><td>-35.71</td><td rowspan="4">0.75</td><td>10990</td><td>46310</td><td>-321.38</td><td rowspan="4">0.76</td><td>128812</td><td>147000</td><td>-14.12</td><td rowspan="4">0.33</td></tr>
<tr><td>2002</td><td>49.54</td><td>52.58</td><td>-6.14</td><td>198036</td><td>158600</td><td>19.91</td><td>431193</td><td>453600</td><td>-5.20</td></tr>
<tr><td>2004</td><td>36.60</td><td>33.20</td><td>9.29</td><td>67522</td><td>89620</td><td>-32.73</td><td>296249</td><td>221400</td><td>25.27</td></tr>
<tr><td>Avg.*</td><td>43.07</td><td>42.89</td><td>-0.42</td><td>132779</td><td>124110</td><td>18.01</td><td>363721</td><td>337500</td><td>7.21</td></tr>
</table>

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

Table 4.11. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After the 2nd USLE_C Modification

<table>
<tr><th rowspan="2">Year</th><th colspan="4">Flow (m^3/s)</th><th colspan="4">Sediment (ton/year)</th><th colspan="4">SOL P (kg/year)</th></tr>
<tr><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th><th>Obs.</th><th>Sim.</th><th>Dv (%)</th><th>E_{NS}*</th></tr>
<tr><td>2001</td><td>15.71</td><td>21.32</td><td>-35.71</td><td rowspan="4">0.75</td><td>10990</td><td>44610</td><td>-305.91</td><td rowspan="4">0.71</td><td>128812</td><td>145500</td><td>-12.96</td><td rowspan="4">0.31</td></tr>
<tr><td>2002</td><td>49.54</td><td>52.58</td><td>-6.14</td><td>198036</td><td>151700</td><td>23.40</td><td>431193</td><td>450900</td><td>-4.57</td></tr>
<tr><td>2004</td><td>36.60</td><td>33.20</td><td>9.29</td><td>67522</td><td>84620</td><td>-25.32</td><td>296249</td><td>219400</td><td>25.94</td></tr>
<tr><td>Avg.*</td><td>43.07</td><td>42.89</td><td>-0.42</td><td>132779</td><td>118160</td><td>11.01</td><td>363721</td><td>335150</td><td>7.86</td></tr>
</table>

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

As gathered from the tables above, E_{NS} was decreased to 0.71 following the 2nd USLE_C modification. Dv for 2004 was greater than 25% after the 1st modification and was not acceptable. Thus, the 2nd modification was accepted as the final modification. Although, Dv for year 2004 was still slightly over 25%, calibration for sediment transport was terminated, since this was the best based on the observation data. Santhi *et al.* (2001) stated that errors in sampling strategies can also be significant in calibration of SWAT. Walling and Webb (1988) determined that even using continuous turbidity and daily flow data resulted in errors of up to 23 to 83 percent while calculating annual sediment loads. Santhi *et al.* (2001) evolved the calibration criteria given in Chapter 4.1 based on these potential errors pointed out in literature.

Yersiz *et al.* (2001) performed suspended solids (SS) measurements at M-2 for the period of June1999-May 2000. Average SS concentration measured was 55.98 mg/l. Simulated average SS concentration for years 2002, 2004 at M-2 is 77.04 mg/l. This difference is mainly due to the difference in precipitation amounts occurred in 1999-2000 and 2002, 2004. Average annual total precipitation observed in 1999-2000 is about 618.55 mm, however average annual total precipitation observed in 2002-2004 is about 672.80 mm.

4.1.3. P LOAD CALIBRATION AT GAGE M-2, OUTLET OF SUBBASIN 77

In Table 4.11, it is observed that SWAT overestimated SOL P load in 2002, and underestimated SOL P load in 2004. P calibration was done to increase the simulated P load at the outlet of subbasin 77 for year 2004, since Dv of year 2004 is much higher than Dv of year 2002. P calibration was performed as directed in SWAT User's Manual (Neitsch *et al.*, 2002a) and following the steps done by Santhi et al. (2001); and it was performed for 2002 and 2004.

In P load calibration, $k_{d,surf}$ (PHOSKD, P soil partitioning coefficient (m^3/Mg)) was modified to change the amount of soluble P transported in surface runoff. PHOSKD was initially set to 175. Its range is 100-200 (Neitsch et al., 2002b). PHOSKD was decreased to 100, to increase P in surface runoff. Results of this run are given in Table 4.12. With this adjustment, P simulation was improved. E_{NS} of 0.55 was achieved, and maximum Dv was about 17%. Calibration was terminated at this point.

Table 4.12. Observed and Simulated Flow, Sediment and SOL P Load; Subbasin 77; After PHOSKD Modification

Year	Flow (m^3/s)				Sediment (ton/year)				SOL P (kg/year)			
	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*	Obs.	Sim.	Dv (%)	E_{NS}*
2001	15.71	21.32	-35.71	0.75	10990	44610	-305.91	0.71	128812	159300	-23.67	0.55
2002	49.54	52.58	-6.14		198036	151700	23.40		431193	469800	-8.95	
2004	36.60	33.20	9.29		67522	84620	-25.32		296249	245100	17.27	
Avg.*	43.07	42.89	-0.42		132779	118160	11.01		363721	357450	1.72	

**Avg., E_{NS} values were calculated using 2002-2004 years' values. Year 2001 was left to adjust the initial hydrologic conditions through the watershed.*

Average of measured P concentration obtained from June 1999-May 2000 shows that the water quality class is III (Yersiz et al., 2001). Average annual SOL P concentration simulated by SWAT is within the range of Class III in terms of P concentration. As a conclusion of the calibration phase of the study, flow, sediment and SOL P loads were calibrated annually for 2002 and 2004 satisfactorily. Summary of calibration process is given in Table 4.13, in terms of annual averages. Model parameter default values were used throughout all other subbasins (subbasins 1-28, 74-76, and subbasin 78).

Table 4.13. Summary of Calibration Process At Gage M-2

Year	Obs.	Sim.	Dv (%)	E_{NS}
Flow (m^3/s)	43.07	42.89	-0.42	0.75
Sediment Load (ton/year)	132779	118160	11.01	0.71
SOL P (kg/year)	363721	368950	-1.44	0.52

4.2. SEDIMENT AND SOL P LOAD TO LAKE ULUABAT; SIMULATION RESULTS

Subbasins 1-5, 13, 20-23 and 26-28 directly discharge to Lake Uluabat. Modeled sediment (SED_OUT) and SOL P loads (SOLP_OUT) to Lake Uluabat at the outlets of these subbasins are given in Table 4.14. Subbasin 22 is the most downstream subbasin of Mustafakemalpaşa Stream. As far as simulated conditions are concerned, 85.39% of the sediment load and 80.26% of the SOL P load to Lake Uluabat are arising from Mustafakemalpaşa Stream.

Table 4.14. Sediment and SOL P Load to the Lake Uluabat

Subbasin No.	**SED_OUT (ton/year)**	**SOLP_OUT (kg/year)**
1	1315.50	2903.50
2	4004.50	15910.00
3	2271.00	7226.50
4	1931.50	3997.00
5	1812.50	39265.00
13	2101.50	4904.50
20	3602.50	10549.50
21	955.00	1493.50
22	119915.00	374350.00
23	680.50	2177.00
26	561.70	1344.50
27	720.60	1406.00
28	558.15	894.50
Total	140430.00	466421.5

In Table 4.15, sediment yield (SYLD), SOL P transported with sediment (SED P) and SOL P transported by surface runoff (SOL P) to the surface waters through the watershed are given with respect to landuses simulated in this study. According to the simulation results, 97.4% of SYLD, 99.8% of SED P and 99.0% of SOL P are contributed from agricultural lands. Among these agricultural landuses, SYLD and SED P contribution from AGRC (close grown crops, no irrigation) is higher than SYLD and SED P contribution from TOMA and CORN (tomato and corn production, irrigation applied). This is due to the different frequencies of tillage operations on those lands. Tillage operations increase the sensitivity of soil to erosion. On the other hand, SOL P contribution from TOMA and CORN is 69%, where SOL P contribution from AGRC is 30%. This difference is related with fertilizer application and irrigation operation, since TOMA and CORN lands are irrigated after fertilizer application.

Table 4.15. SYLD, SED P and SOL P Contributions From Each Landuses Through the Watershed Area Simulated

Landuse	**SYLD (ton/year)**	**SED P (kg P/year)**	**SOL P (kg P/year)**	**% SYLD**	**% SED P**	**% SOL P**
AGRC	32849.37	59469.80	36407.75	68.72	51.66	30.03
TOMA	9760.14	31341.25	64488.82	20.42	27.22	53.19
CORN	3945.67	24130.20	19139.36	8.25	20.96	15.79
FRST	879.28	131.90	828.59	1.84	0.11	0.68
RNGE	306.77	45.21	268.97	0.64	0.04	0.22
PAST	8.32	1.82	37.08	0.02	0.00	0.03
HAY	3.16	0.61	6.30	0.01	0.00	0.01
URML	45.07	3.47	39.00	0.10	0.00	0.03
WETN	1.76	0.88	15.95	0.00	0.00	0.01
TOTAL	47800.00	115125.14	121231.80	100.00	100.00	100.00

Applied and transported SOL P distribution with respect to agricultural activities is given in Table 4.16. 1.6% of SOL P applied through the watershed area was transported to the surface waters within the watershed area. Although, about 2.4% of the watershed area is occupied by CORN, 18% of transported SOL P is contributed from CORN landuses. This is due to frequent fertilizer applications on CORN lands. % area of AGRC and TOMA, and % of transported SOL P contributed from AGRC and TOMA are 21.9%, 19.4% and 40.8%, 40.8% respectively. The model results showed that transport of SOL P from agricultural lands where irrigation was applied is much higher than the transport of SOL P from non-irrigated agricultural lands. Although the areas of irrigated and non-irrigated agricultural lands are approximately equal to each other (% area of irrigated lands = 21.9%, % area of non-irrigated lands = 21.8%); 58.8% of transported SOL P was contributed from irrigated agricultural lands (TOMA and CORN); whereas, 40.8% of transported SOL P was contributed from non-irrigated agricultural lands (AGRC). Average annual loads of SED P (kg P/ha), SOL P (kg P/ha), P (SEDP+SOLP, kg P/ha) and SYLD (ton/ha, sediment yield) from subbasins are depicted in Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6, respectively.

Table 4.16 Applied and Transported SOL P Distribution With Respect To Agricultural Activities

Agricultural Activity	Average Annual SOL P Application (kg/ha)	Area (ha)	SOL P Applied (kg/year)	SOL P (kg/year)	SED P (kg/year)	Transported P % With Respect To Landuses	Transported P % Within Overall SOL P Application
AGRC	220	17828	3922226	36407.75	59469.80	2.44	0.67
TOMA	505	15791	7974253	64488.82	31341.25	1.20	0.67
CORN	1264	1971	2491470	19139.36	24130.20	1.74	0.30
TOTAL	-	35590	14387949	120036.00	114941.30	-	1.63

It was stated in the Lake Uluabat Management Plan (DHKD, 2002) draft documents that P load to the Lake Uluabat was 1-8 g P/m^2/year. Once the project started by DHKD, Ministry of Environment and SHW in 1998 was completed, it was concluded that P load to the Lake Uluabat should be decreased to 1 g P/m^2/year within five years (WWF-Turkey, 2000). However, simulation results show that, as far as simulated conditions and lake surface area in 1998 (116 km^2 (Aksoy, 2004)) are concerned, SOL P load to the Lake Uluabat is about 4 g P/m^2/year.

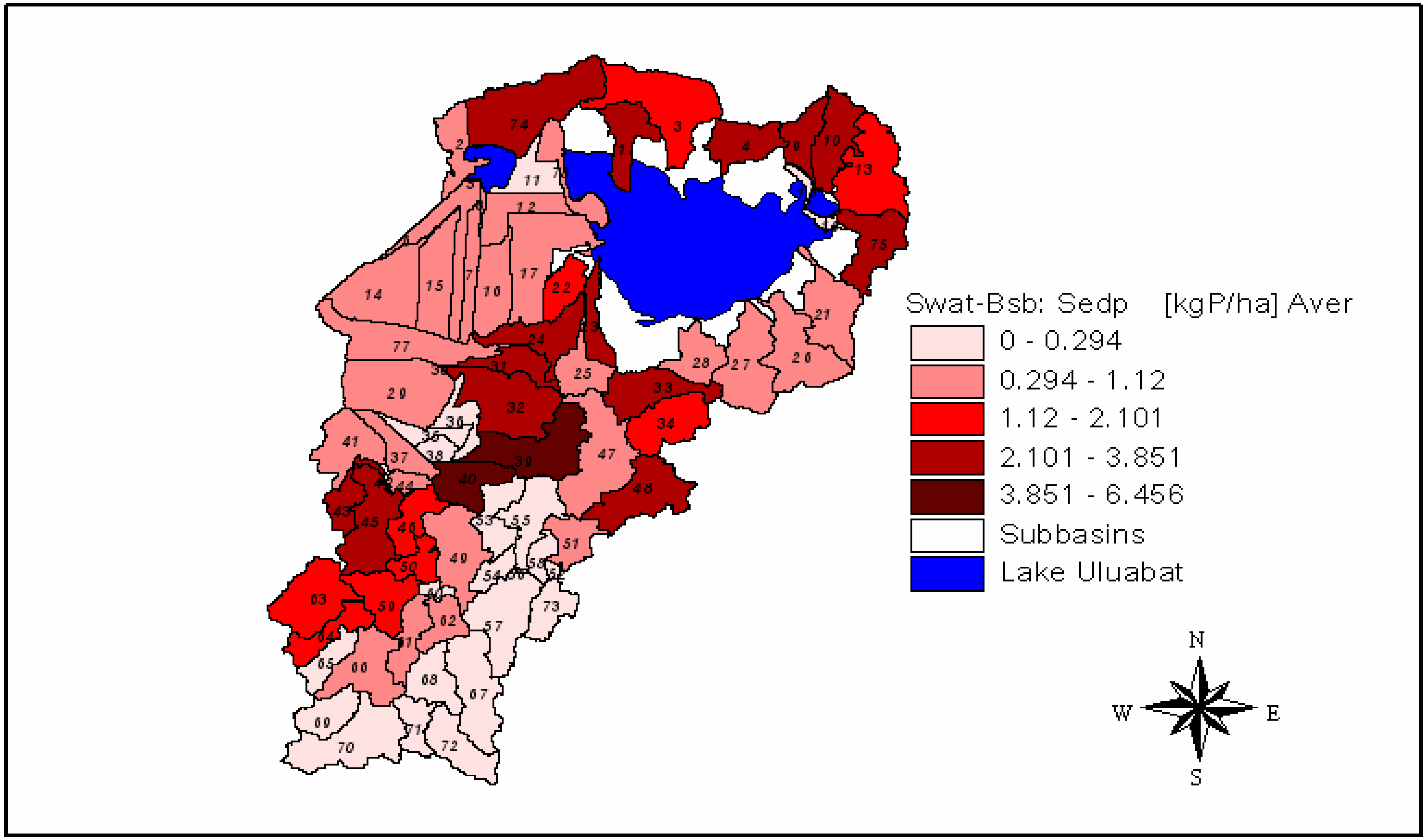

Figure 4.3. Annual Average SED P Load From Subbasins

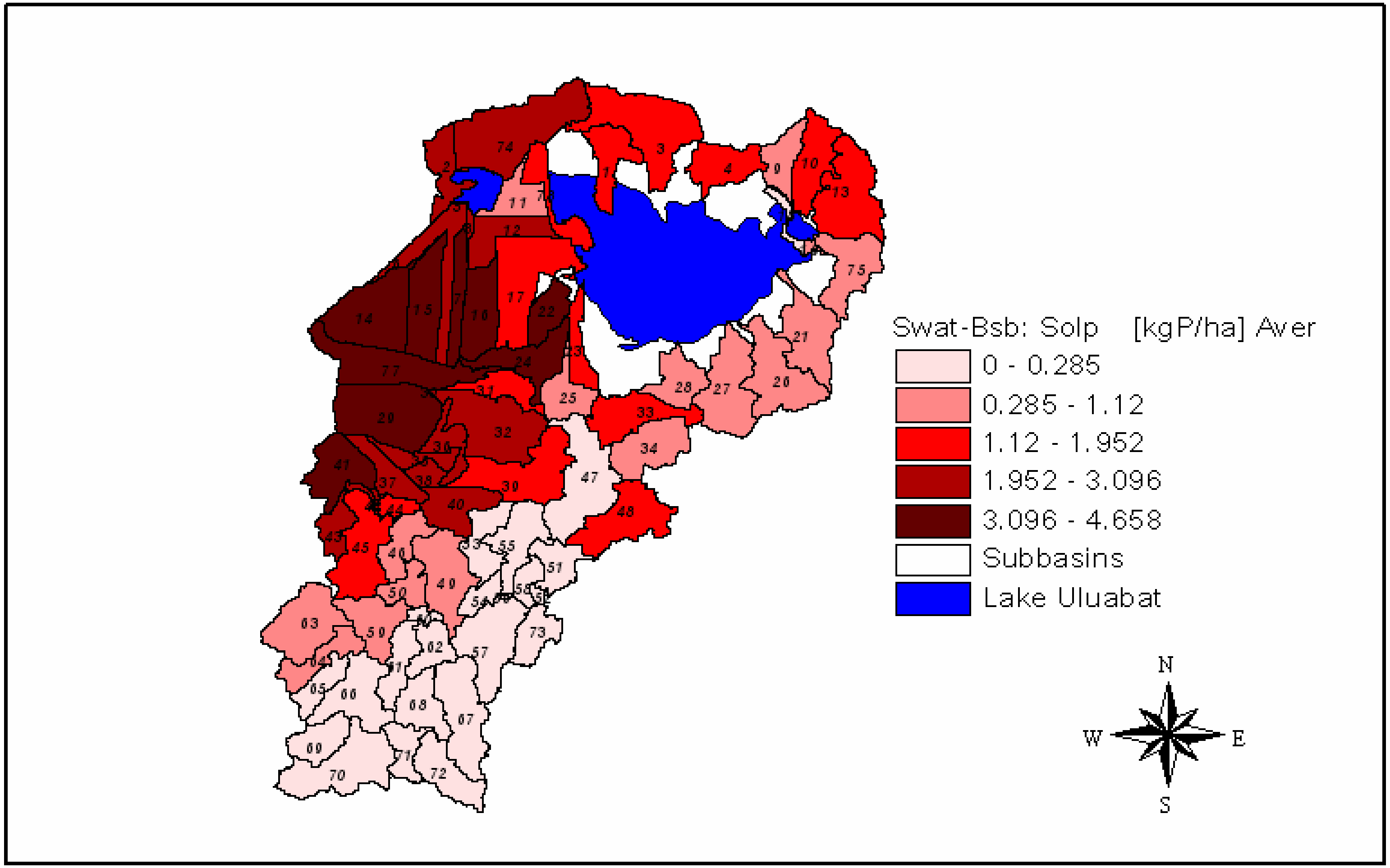

Figure 4.4. Annual Average SOL P Load From Subbasins

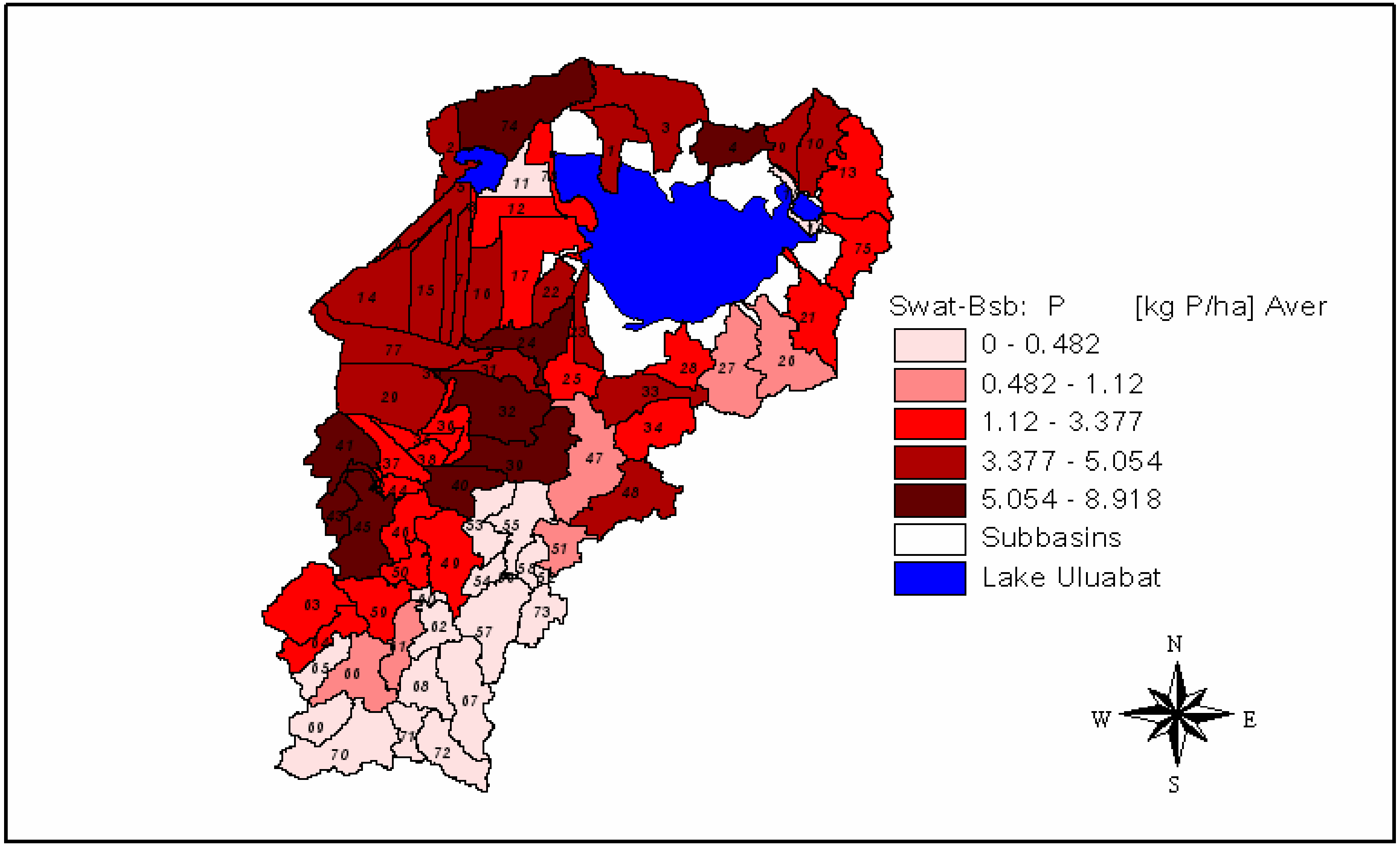

Figure 4.5. Annual Average P (SEDP + SOLP) Load From Subbasins

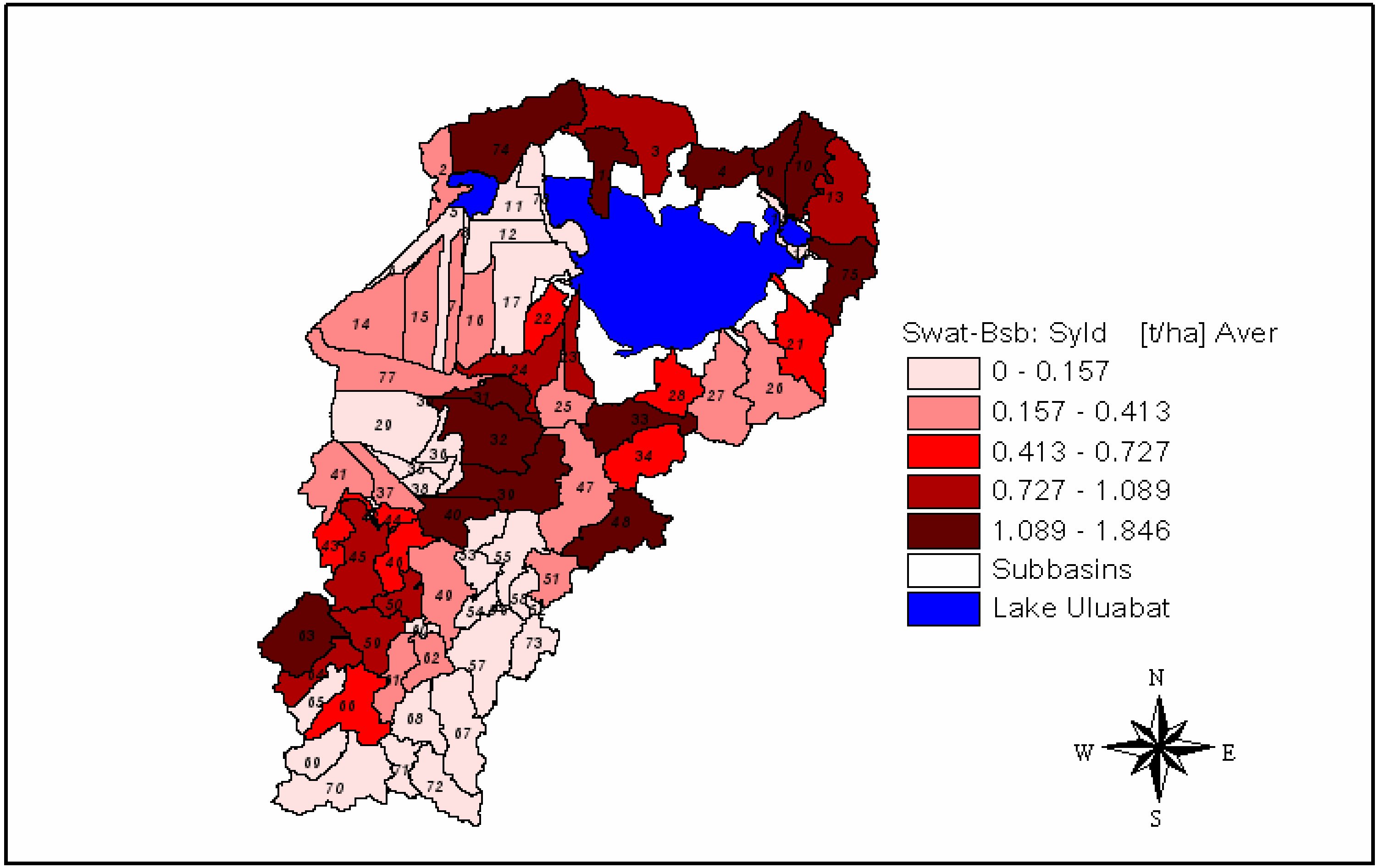

Figure 4.6. Annual Average SYLD Load From Subbasins

Critical subbasins were determined by using the threshold values in terms of soil loss and P loading rate. Triphathi *et al.* (2003) used permissible soil loss value of 11.2 ton/ha/year (Mannering, 1981). Tim *et al.* (1992) considered a threshold value for the P loading rate of 1.12 kg P/ha/year. In this study, these criteria were used to identify the critical subbasins in terms of P and sediment loads for the conditions simulated. As far as threshold value of 11.2 ton/ha/year of soil loss from subbasins is concerned, there is no critical subbasin in the watershed area. However, as seen in Figure 4.5, 50 subbasins within 78 subbasins are critical in terms of P loading rate. As expected, there are agricultural activities on these critical subbasins.

4.3. APPLICATION OF DIFFERENT MANAGEMENT PRACTICES

Seven scenarios were studied in order to assess the alternatives that may impact the P loads to the Uluabat Lake. In scenario I, the amount of fertilizer application in agricultural sites (AGRC, TOMA, and CORN) was varied. In scenario II, irrigation amount through the irrigated agricultural lands were increased by four times to examine the impact of irrigation on P transport. In scenarios III and IV, "riparian zones" were inserted to create "buffer zones" around the lake and the Mustafakemalpaşa Stream, respectively. Scenario V is evaluated to see the impact of P loads carried by Emet and Orhaneli Streams on the discharge of P loads to the lake. Scenario VI looked for the contribution of the sewage system of the Mustafakemalpaşa District on the total P loads. Finally, in scenario VII, agricultural activities around Lake Uluabat were replaced by range-grasses type landuse, P load contributing from Mustafakemalpaşa District sewage system, and from Emet and Orhaneli Watersheds were decsreased by 50% in addition to 50% decrease in fertilizer usage through the agricultural lands, to see almost total effect of the scenarios. Results obtained for each scenario was compared with the ones obtained for the base case. The base case represents the conditions set following the completion of the calibration phase.

4.3.1. SCENARIO I

Scenario I is studied in two parts; Scenario I-a and Scenario I-b. In scenario I-a, the amount of fertilizer application on agricultural sites (AGRC, TOMA, CORN) were doubled while the lands were irrigated with the same amount of water assumed for the base case. The management practice information is given in Table 4.17. Simulation results are given in Table 4.18 with the results obtained for the base case for comparison.

Table 4.17.Management Practices for Scenario I-a

Application Type	**Date of Application/Application Amount**
TOMA	
Tillage by Finishing Harrow	April 10
Fertilizer Application (DAP-Diammonium Phosphate, 18-46)	May 10 – 5000 kg/ha
Plant/begin. Growing season	May 15
Irrigation	May 15 – 342 mm
Irrigation	May 30 - 342 mm
Irrigation	June 15 - 342 mm
Irrigation	June 30 - 342 mm
Irrigation	July 15 - 342 mm
Irrigation	July 30 - 342 mm
Harvest and Kill Operation	September 1
Wheat (AGRC)	
Tillage by Paraplow	November 1
Tillage by Field Cultivator	November 15
Fertilizer Application (20-20 Composite)	December 1 – 5000 kg/ha
Plant/begin. Growing season	December 1
Fertilizer Application (Urea)	March 1 – 4000 kg/ha
Harvest and Kill Operation	July 1
CORN	
Tillage by Paraplow	March 10
Fertilizer Application (Elemental N)	March 15 – 5000 kg/ha
Fertilizer Application (Elemental P)	March 15 – 2000 kg/ha
Plant/begin. Growing season	April 15
Fertilizer Application (15-15-15 Composite)	April 15 – 8000 kg/ha
Fertilizer Application (Urea)	April 15 – 4000 kg/ha
Irrigation	April 17 – 424 mm
Irrigation	May 30- 424 mm
Irrigation	June 30 - 424 mm
Harvest and Kill Operation	July 30

Table 4.18. SOL P Load to the Lake Uluabat; Scenario I-a

Subbasin No.	SOL P, Base Case (kg/year)	SOL P, Scenario I-a (kg/year)
1	2903.50	4807.00
2	15910.00	27545.00
3	7226.50	12126.00
4	3997.00	6637.00
5	39265.00	70120.00
13	4904.50	8134.00
20	10549.50	16130.00
21	1493.50	2425.50
22	374350.00	460000.00
23	2177.00	3832.50
26	1344.50	2207.00
27	1406.00	2296.00
28	894.50	1447.50
Total	466421.5	617707.50

As seen in Table 4.18, SOL P load to the Lake Uluabat increased by about 32% when the amount of fertilizer applied was increased by two times. Consequently, SOL P load to the Lake Uluabat in mass P/area/time was 5.3 gP/m^2/year, whereas it was 4.0 gP/m^2/year for the base case. These values show that the amount of fertilizer application has a significant effect on the amount of P load to the lake.

Amount of P transported from different agricultural lands for Scenario I-a and the base case is given in Table 4.19. SOL P from agricultural sites were increased by 35 to 47% for different productions; 35% for AGRC, 43% for TOMA, and 47% for CORN. As expected, SOL P contribution from subbasins increased. Average annual loads of SED P (kg P/ha), SOL P (kg P/ha) and P (SEDP+SOLP, kgP/ha) from subbasins are shown in Figure 4.7, Figure 4.8, and Figure 4.9, respectively.

Table 4.19. Applied and Transported SOL P Distribution With Respect To Different Agricultural Productions; Scenario I-a

Agricultural Activity	Scenario I-a					Base Case	
	Average Annual SOL P Application (kg/ha)	**Area (ha)**	**SOL P Applied (kg/year)**	**SOL P (kg/year)**	**SED P (kg/year)**	**SOL P (kg/year)**	**SED P (kg/year)**
AGRC	440	17828	7844320	63141.5	84936.8	36407.75	59469.80
TOMA	1010	15791	15948910	117896.6	50736.6	64488.82	31341.25
CORN	2528	1971	4982688	37127.6	44976.1	19139.36	24130.20
TOTAL	-	35590	28775918	218165.7	180649.5	120036.00	114941.30

For the P loading threshold rate of 1.12 kg P/ha/year, 56 subbasins over 78 subbasins were critical for Scenario I-a. That is, six subbasins were added to the critical subbasins through the watershed area compared to the base case. Every subbasin that has agricultural activities is found to be critical, in terms of SOL P contribution.

In addition to increase in the fertilizer usage, impact of reduction in the fertilizer application was studied by Scenario I-b. Fertilizer application rates through the agricultural lands over the watershed area were decreased by 20%, 30% and 50%. Fertilizer application programs are given in Table 4.20.

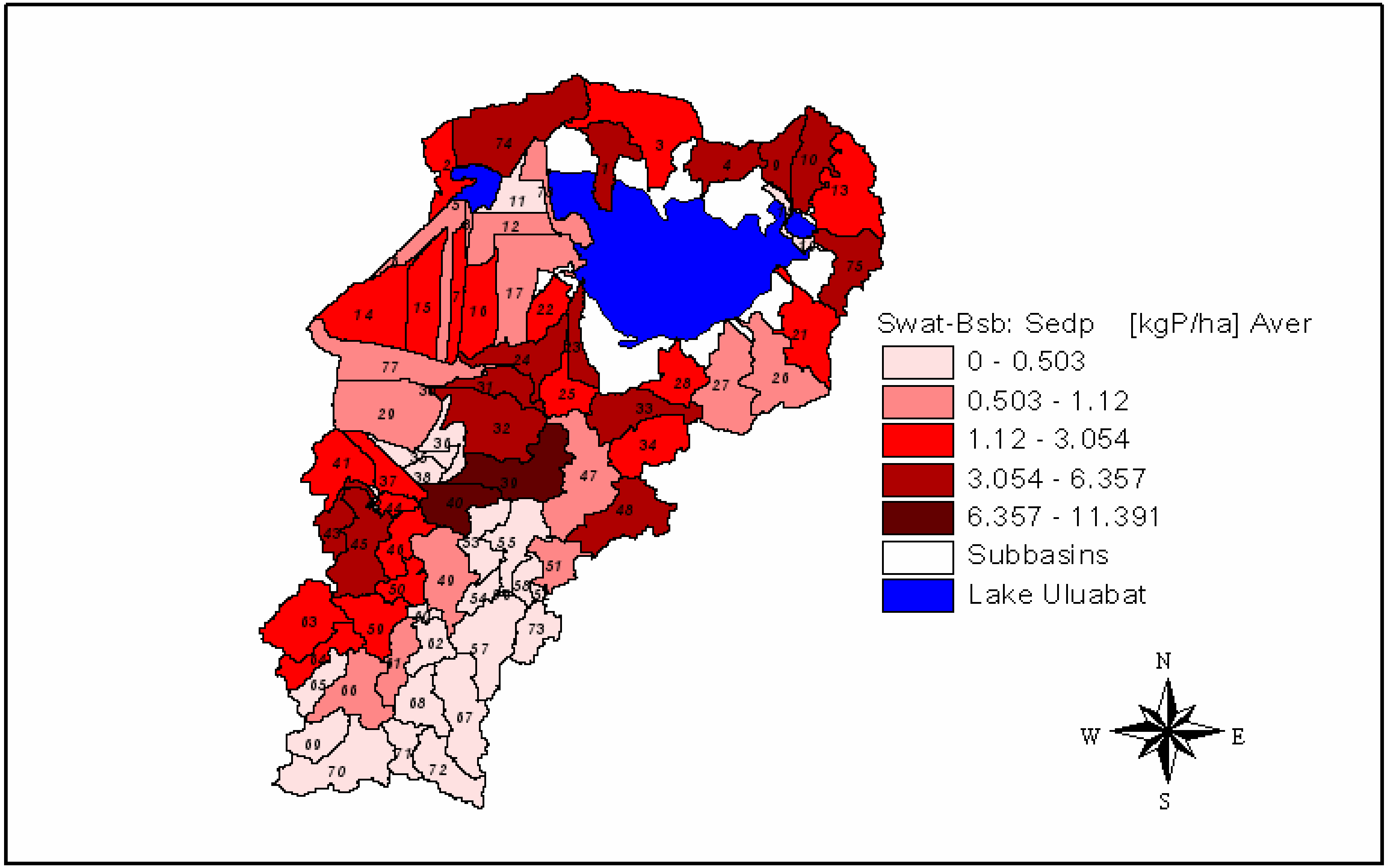

Figure 4.7. Annual Average SED P Load From Subbasins, Scenario I

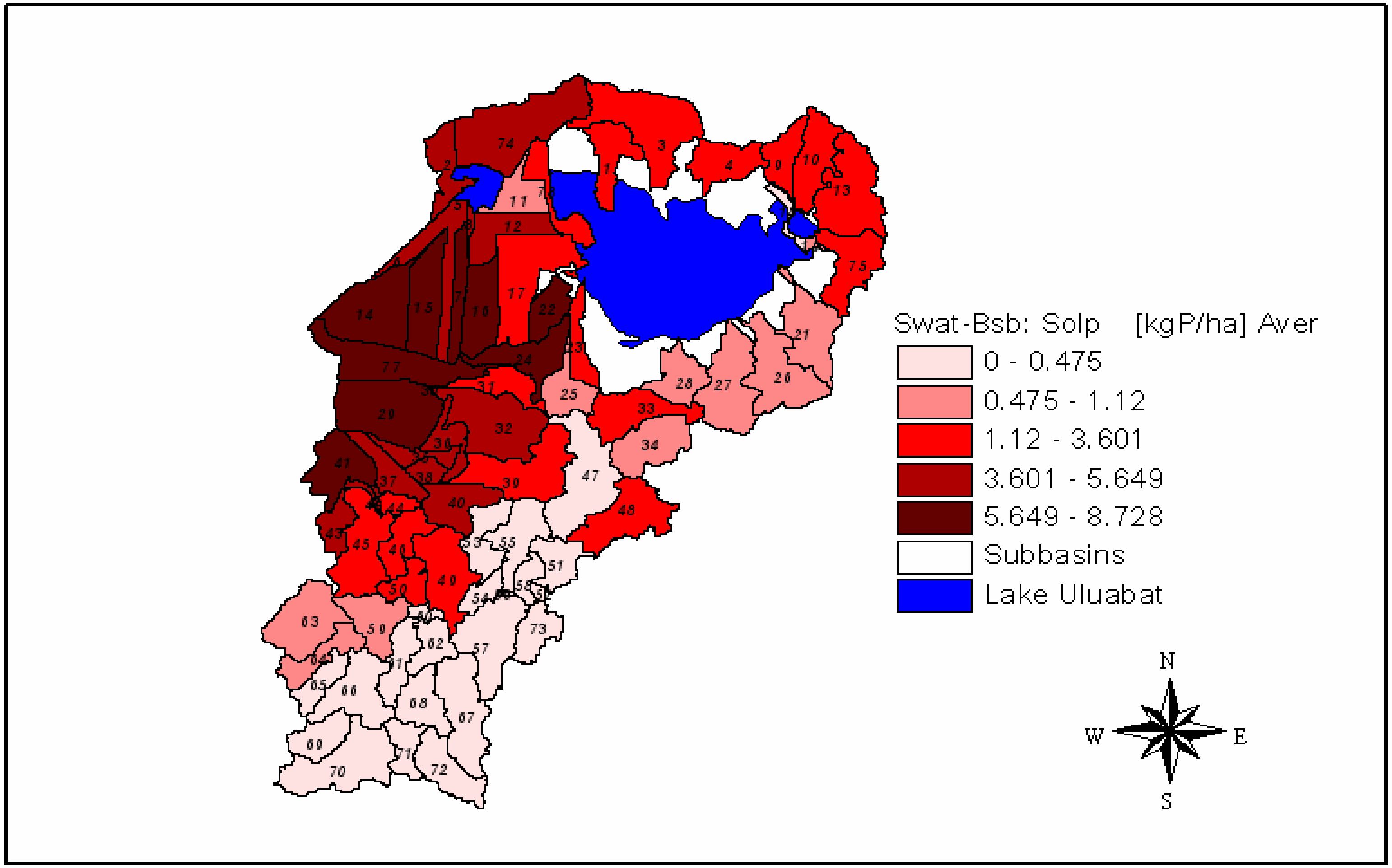

Figure 4.8. Annual Average SOL P Load From Subbasins, Scenario I

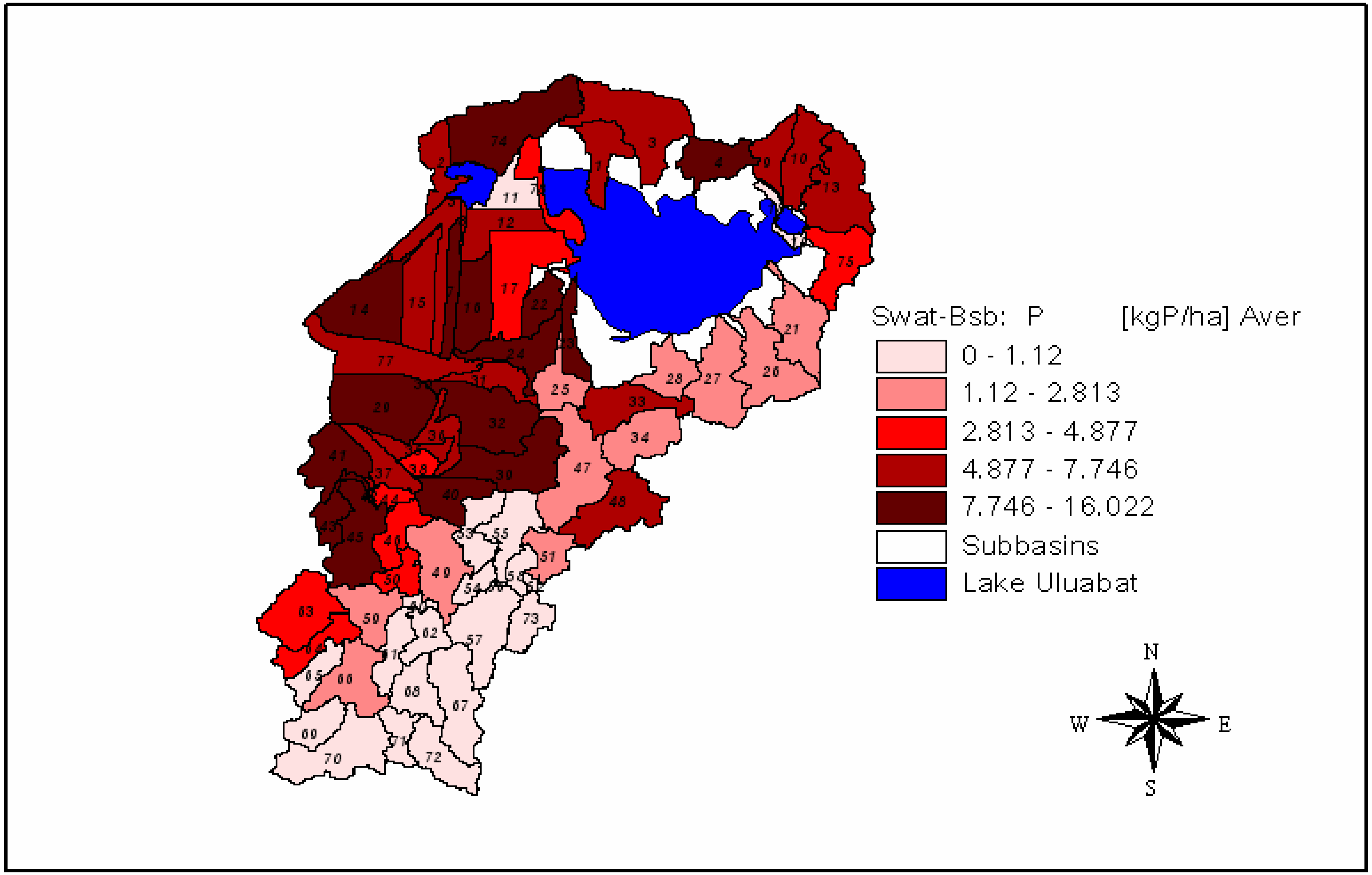

Figure 4.9. Annual Average P (SEDP + SOLP) Load From Subbasins, Scenario I

Table 4.20. Fertilizer Application and Irrigation Programs for Scenario I-b

TOMA				
Practice	**Base Case**	**20% Dec.**	**30% Dec.**	**50% Dec.**
Tillage by Finishing Harrow	April 10	April 10	April 10	April 10
Fertilizer Application (DAP-Diammonium Phosphate, 18-46)	May 10 – 2500 kg/ha	May 10 – 2000 kg/ha	May 10 – 1750 kg/ha	May 10 – 1250 kg/ha
Plant/begin. Growing season	May 15	May 15	May 15	May 15
Irrigation	May 15 – 342 mm	May 15 – 342 mm	May 15 – 342 mm	May 15 – 342 mm
Irrigation	May 30 - 342 mm	May 30 - 342 mm	May 30 - 342 mm	May 30 - 342 mm
Irrigation	June 15 - 342 mm	June 15 - 342 mm	June 15 - 342 mm	June 15 - 342 mm
Irrigation	June 30 - 342 mm	June 30 - 342 mm	June 30 - 342 mm	June 30 - 342 mm
Irrigation	July 15 - 342 mm	July 15 - 342 mm	July 15 - 342 mm	July 15 - 342 mm
Irrigation	July 30 - 342 mm	July 30 - 342 mm	July 30 - 342 mm	July 30 - 342 mm
Harvest and Kill Operation	September 1	September 1	September 1	September 1
Wheat (AGRC)				
Practice	**Base Case**	**20% Dec.**	**30% Dec.**	**50% Dec.**
Tillage by Paraplow	November 1	November 1	November 1	November 1
Tillage by Field Cultivator	November 15	November 15	November 15	November 15
Fertilizer Application (20-20 Composite)	December 1 – 2500 kg/ha	December 1 – 2000 kg/ha	December 1 – 1750 kg/ha	December 1 – 1250 kg/ha
Plant/begin. Growing season	December 1	December 1	December 1	December 1
Fertilizer Application (Urea)	March 1 – 2000 kg/ha	March 1 – 1600 kg/ha	March 1 – 1400 kg/ha	March 1 – 1000 kg/ha
Harvest and Kill Operation	July 1	July 1	July 1	July 1
CORN				
Practice	**Base Case**	**20% Dec.**	**30% Dec.**	**50% Dec.**
Tillage by Paraplow	March 10	March 10	March 10	March 10
Fertilizer Application (Elemental N)	March 15 – 2500 kg/ha	March 15 – 2000 kg/ha	March 15 – 1750 kg/ha	March 15 – 1250 kg/ha
Fertilizer Application (Elemental P)	March 15 – 1000 kg/ha	March 15 – 800 kg/ha	March 15 – 700 kg/ha	March 15 – 500 kg/ha
Plant/begin. Growing season	April 15	April 15	April 15	April 15
Fertilizer Application (15-15-15 Composite)	April 15 – 4000 kg/ha	April 15 – 3200 kg/ha	April 15 – 2800 kg/ha	April 15 – 2000 kg/ha
Fertilizer Application (Urea)	April 15 – 2000 kg/ha	April 15 – 1600 kg/ha	April 15 – 1400 kg/ha	April 15 – 1000 kg/ha
Irrigation	April 17 – 424 mm	April 17 – 424 mm	April 17 – 424 mm	April 17 – 424 mm
Irrigation	May 30 - 424 mm	May 30 - 424 mm	May 30 - 424 mm	May 30 - 424 mm
Irrigation	June 30 - 424 mm	June 30 - 424 mm	June 30 - 424 mm	June 30 - 424 mm
Harvest and Kill Operation	July 30	July 30	July 30	July 30

Note: *Irrigation data was obtained from Mustafakemalpaşa Irrigation tables (SHW).*

As given in Table 4.21, SOL P load to the Lake Uluabat decreased by about 6.5%, 9.7% and 16.2%, when the amount of fertilizer applied were decreased by 20%, 30% and 50%, respectively. Consequently, SOL P load to the Lake Uluabat in mass P/area/time was found to be 3.8 gP/m^2/year for 20% decrease in fertilizer application amount, 3.6 gP/m^2/year for 30% decrease in fertilizer application amount and 3.4 gP/m^2/year for 50% decrease in fertilizer application amount; whereas it was 4.0 gP/m^2/year for the base case. Relationship between fertilizer application rates through the agricultural lands over the watershed area simulated and SOL P load to the Lake Uluabat is given in Figure 4.10. There exits a direct linear relationship between SOL P load to the Lake Uluabat and fertilizer application rates over the watershed area simulated. Therefore, in order to identify the best management practice over the Lake Uluabat watershed area, care should be given to the fertilizer usage over the watershed area and also to the agricultural practices applied.

Table 4.21. SOL P Load to the Lake Uluabat; Scenario I-b

Subbasin No.	**SOL P, Base Case (kg/year)**	**SOL P, Scenario I-b, 20% Decrease (kg/year)**	**SOL P, Scenario I-b, 30% Decrease (kg/year)**	**SOL P, Scenario I-b, 50% Decrease (kg/year)**
1	2903.50	2523.00	2332.50	1952.00
2	15910.00	13585.00	12420.00	10077.00
3	7226.50	6247.00	5757.00	4777.00
4	3997.00	3469.00	3206.00	2677.00
5	39265.00	33095.00	30010.00	23820.00
13	4904.50	4258.50	3934.00	3285.00
20	10549.50	9437.00	8878.00	7763.00
21	1493.50	1307.50	1215.00	1028.95
22	374350.00	357200.00	348600.00	331500.00
23	2177.00	1846.50	1681.00	1348.00
26	1344.50	1172.50	1086.30	914.30
27	1406.00	1228.00	1139.00	961.85
28	894.50	783.75	728.45	617.85
Total	466421.50	436152.80	420987.30	390721.95

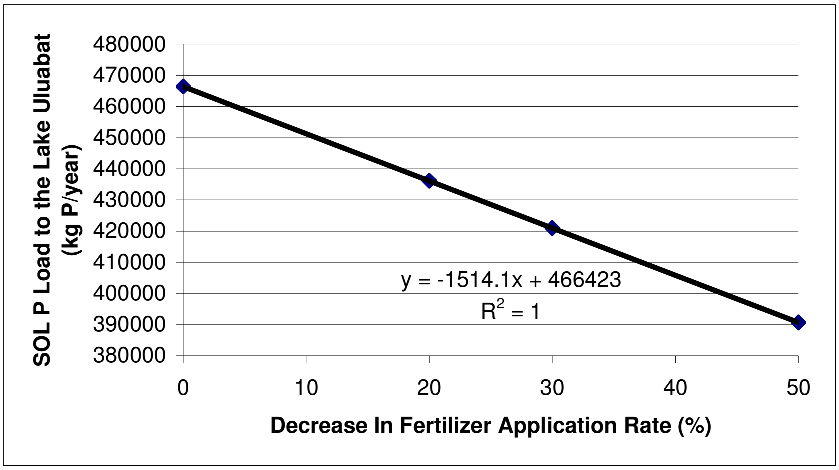

Figure 4.10. SOL P Load to the Lake Uluabat Versus Percent Decrease in Fertilizer Application Rates

4.3.2. SCENARIO II

In scenario II, irrigation amount through the irrigated agricultural lands were increased by four times to assess the effect of irrigation application on P load to Lake Uluabat. Fertilization rate was similar to that of the base case. SWAT was run for the management conditions given in Table 4.22. The simulation results are given in Table 4.23 with the results for the base case for comparison.

As seen in Table 4.23, SOL P load to the Lake Uluabat did not change when the irrigation amount was increased by four times. As a result, irrigation amount by itself, for the conditions studied, did not have a significant impact on SOL P loads to the lake. Although, concentrations may be different, the total amount in mass/time was not affected.

Table 4.22. Fertilization and Irrigation Management; Scenario II

Application Type	**Date of Application/Application Amount**
TOMA	
Tillage by Finishing Harrow	April 10
Fertilizer Application (DAP-Diammonium Phosphate, 18-46)	May 10 – 2500 kg/ha
Plant/begin. Growing season	May 15
Irrigation	May 15 – 1368 mm
Irrigation	May 30 - 1368 mm
Irrigation	June 15 - 1368 mm
Irrigation	June 30 - 1368 mm
Irrigation	July 15 - 1368 mm
Irrigation	July 30 - 1368 mm
Harvest and Kill Operation	September 1
Wheat (AGRC)	
Tillage by Paraplow	November 1
Tillage by Field Cultivator	November 15
Fertilizer Application (20-20 Composite)	December 1 – 2500 kg/ha
Plant/begin. Growing season	December 1
Fertilizer Application (Urea)	March 1 – 2000 kg/ha
Harvest and Kill Operation	July 1
CORN	
Tillage by Paraplow	March 10
Fertilizer Application (Elemental N)	March 15 – 2500 kg/ha
Fertilizer Application (Elemental P)	March 15 – 1000 kg/ha
Plant/begin. Growing season	April 15
Fertilizer Application (15-15-15 Composite)	April 15 – 4000 kg/ha
Fertilizer Application (Urea)	April 15 – 2000 kg/ha
Irrigation	April 17 – 1696 mm
Irrigation	May 30 - 1696 mm
Irrigation	June 30 - 1696 mm
Harvest and Kill Operation	July 30

Table 4.23. SOL P Load to the Lake Uluabat; Scenario II

Subbasin No.	SOL P, Base Case (kg/year)	SOL P, Scenario II (kg/year)
1	2903.50	2903.50
2	15910.00	15910.00
3	7226.50	7226.50
4	3997.00	3997.00
5	39265.00	39265.00
13	4904.50	4904.50
20	10549.50	10549.50
21	1493.50	1493.50
22	374350.00	374350.00
23	2177.00	2177.00
26	1344.50	1344.50
27	1406.00	1406.00
28	894.50	894.50
Total	466421.5”	466421.5

4.3.3. SCENARIO III

In scenario III, agricultural landuses on the areas surrounding the Lake Uluabat were removed and set with landuse of range-grasses. Landuse map for scenario III is given in Figure 4.11 and respective area percentages for this landuse map is given in Table 4.24. After this landuse modification for scenario III, RNGE increased by an amount of 11.95%, whereas AGRC, TOMA, and CORN areas decreased by the amounts of 2.73%, 8.61%, and 0.61%, respectively. In order to apply this scenario to the watershed area simulated, a new project was produced including 78 subbasins and 540 HRUs. The purpose of this approach is to produce a buffer zone around the lake, and to assess the effect of this buffer zone on SOL P and sediment load. As expected, SOL P (SOLP_OUT) and sediment (SED_OUT) loads decreased. Simulation results for Scenario III are given in Table 4.25.

Table 4.24 Linking Table of Landuse in FGDRS Soil Map and SWAT Landuse Database, Scenario III

Grid Value	**Area (%)**	**Current Landuse in FGDRS Map**		**Landuse Defined In SWAT Database**	
		Definition	**Symbol Used**	**Definition**	**Symbol Used**
1	1.02	Residential Area	YR	Residential – Med/Low Density	URML
2	13.26	Shrubbery	F	Range-Grasses	RNGE
4	10.74	Irrigated Agriculture	S	Tomato	TOMA
5	33.53	Forest	O	Forest-Mixed	FRST
6	19.21	Non-irrigated Agriculture	N	Agricultural Land-Close-Grown	AGRC
7	1.31	Pasture	M	Pasture	PAST
9	0.42	River	IR	Water	WATR
11	1.81	Insufficient-irrigated Agriculture	Sy	Corn	CORN
14	0.06	Garden	B	Tomato	TOMA
16	4.26	Lake	GL	Water	WATR
22	11.97	Grass-Natural Vegetation Cover	Ç	Range-Grasses	RNGE
25	1.07	Marshy Places	SB	Nonforested Wetland	WETN
27	0.29	Sandy Dunes	KM	Hay	HAY
29	1.06	Shrubbery	F	Range-Grasses	RNGE

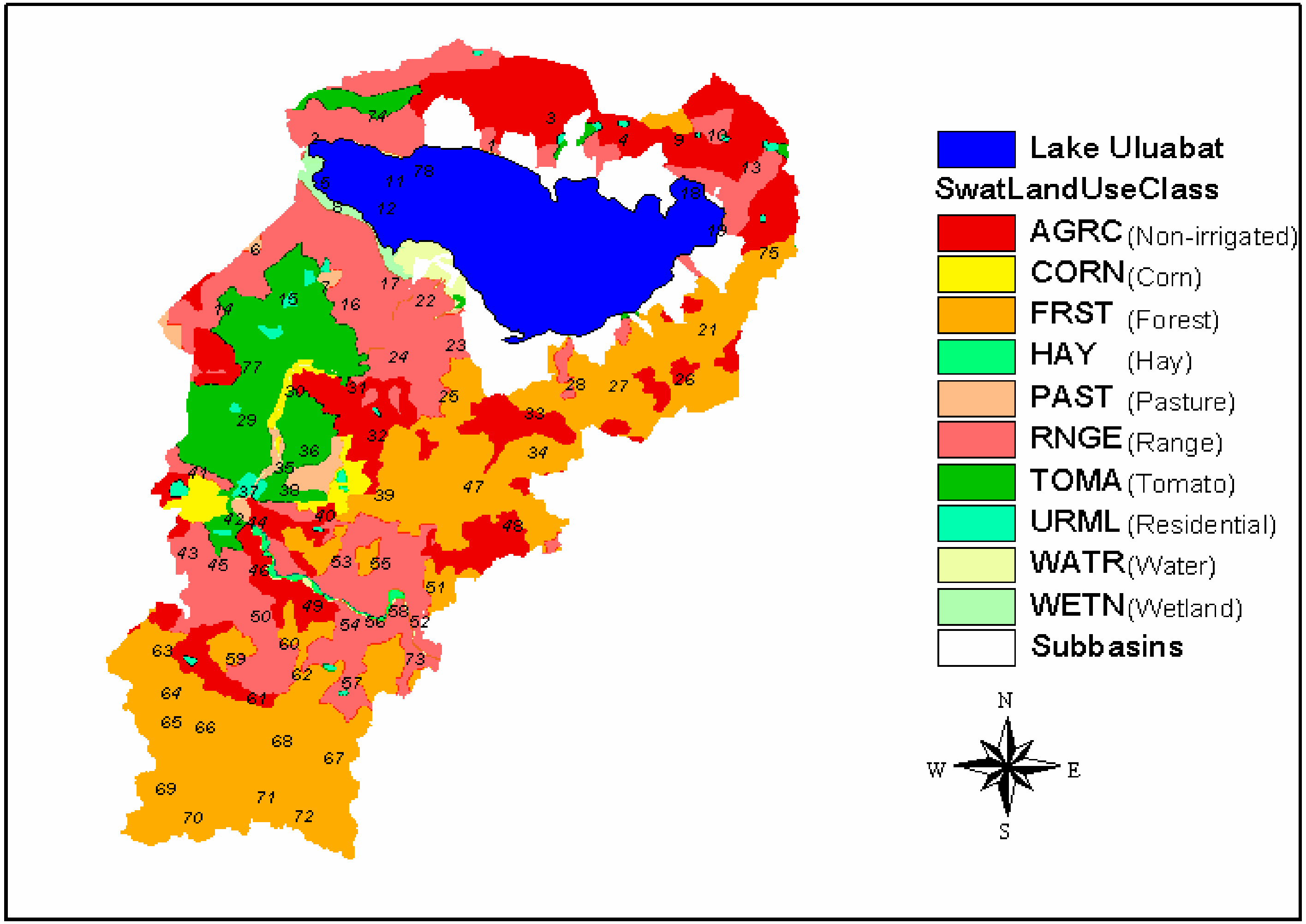

Figure 4.11. Landuse Map For Scenario III

Table 4.25 Sediment and SOL P Load to the Lake Uluabat, Scenario III

Subbasin No.	SED_OUT (ton/year)	% Decrease	SOLP_OUT (kg/year)	% Decrease
1	1079.00	17.98	2405.00	17.17
2	1960.50	51.04	6855.50	56.91
3	2143.00	5.64	6804.50	5.84
4	1369.50	29.10	2931.50	26.66
5	703.70	61.18	13900.00	64.60
13	1652.50	21.37	3897.50	20.53
20	3146.50	12.66	9087.00	13.86
21	797.50	16.49	1212.50	18.81
22	118230.00	1.41	365200.00	2.44
23	65.55	90.37	188.50	91.34
26	561.70	0.00	1344.50	0.00
27	516.05	28.39	978.90	30.38
28	51.33	90.80	34.75	96.12
Total	132276.80	5.81	414840.20	11.06

In Table 4.25, it is observed that SOL P and sediment loads to the Lake Uluabat decreased by percentages of 5.81 and 11.06, respectively. Mass P/area/time was 3.58 gP/m^2/year, whereas it was 4.0 gP/m^2/year for the base case. These results show that when the agricultural practices were halted in the surrounding of Lake Uluabat, SOL P load to the lake was decreased by about 10%. These outcomes indicate that buffering zones are important in terms of controlling nutrient loads to water bodies. Just by banning the agricultural activities around the perimeter of the lake may benefit the water quality and lessen the nutrient transport to the lake.

Average annual loads of SED P (kg P/ha), SOL P (kg P/ha) and P (SEDP+SOLP, kgP/ha) from subbasins are shown in Figure 4.12, Figure 4.13, and Figure 4.14, respectively. As threshold value for the P loading rate of 1.12 kg P/ha/year was considered, 38 subbasins over 78 subbasins were critical. That represents a deduction of 14 subbasins compared to the base case.

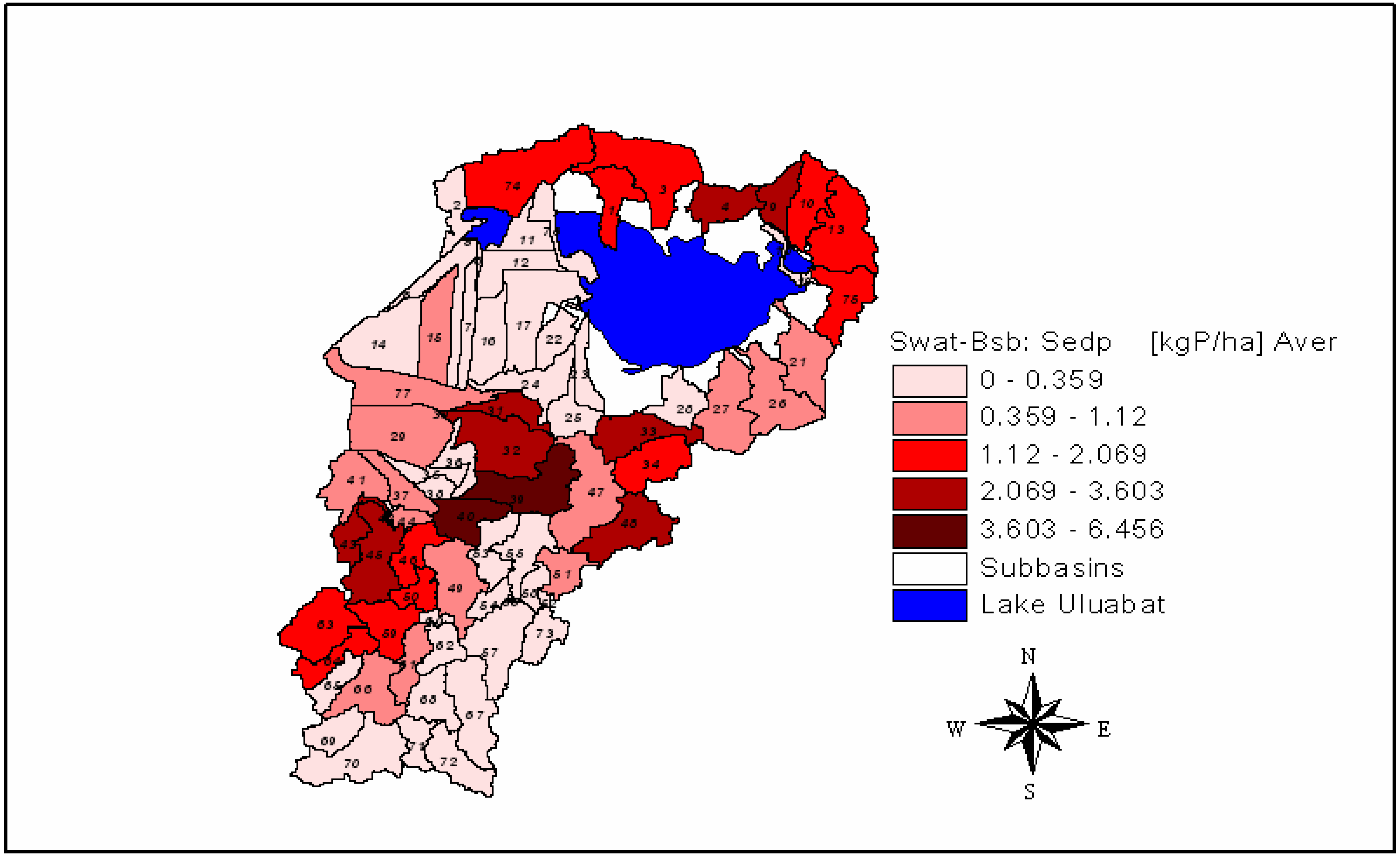

Figure 4.12. Annual Average SED P Load From Subbasins, Scenario III

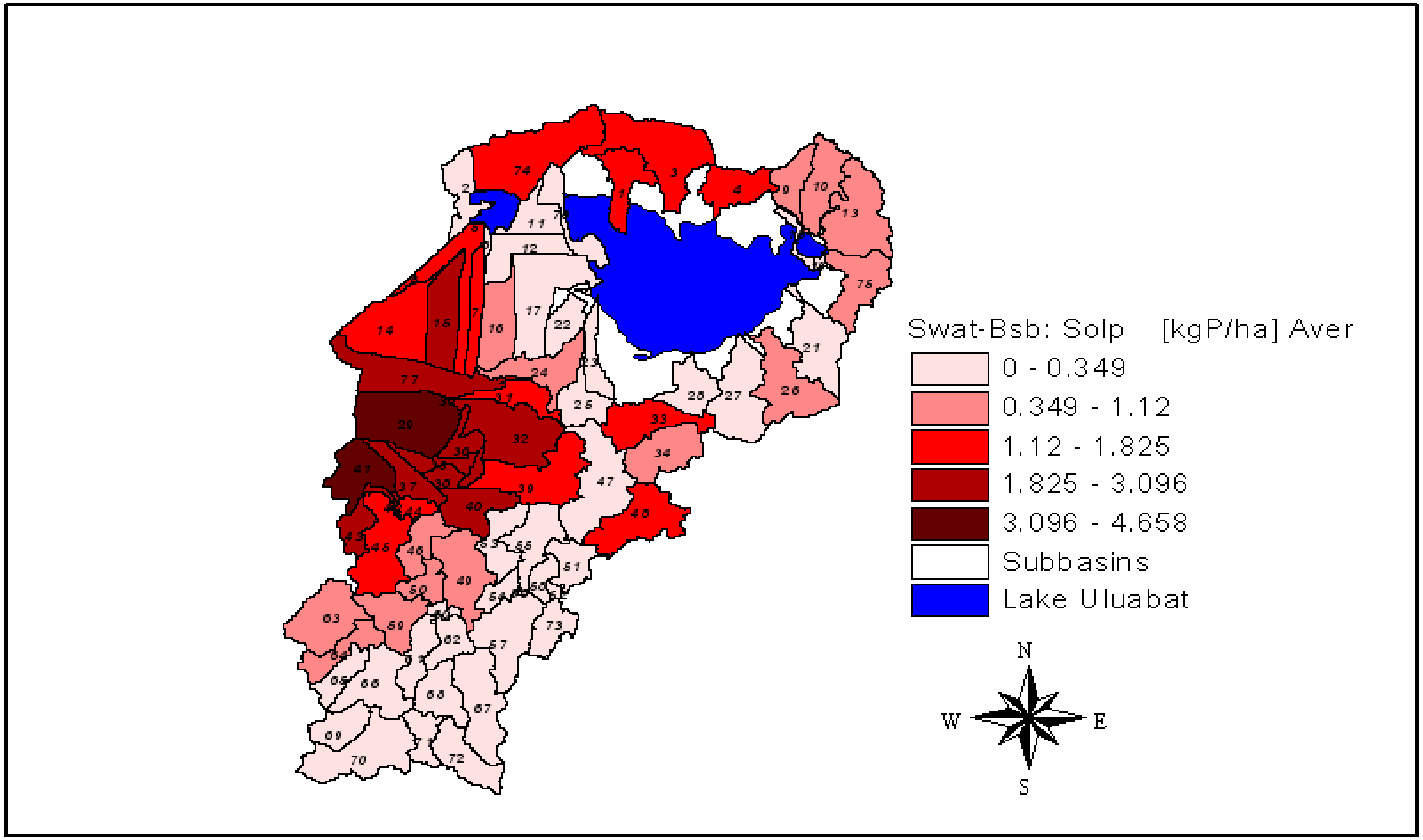

Figure 4.13. Annual Average SOLP Load From Subbasins, Scenario III

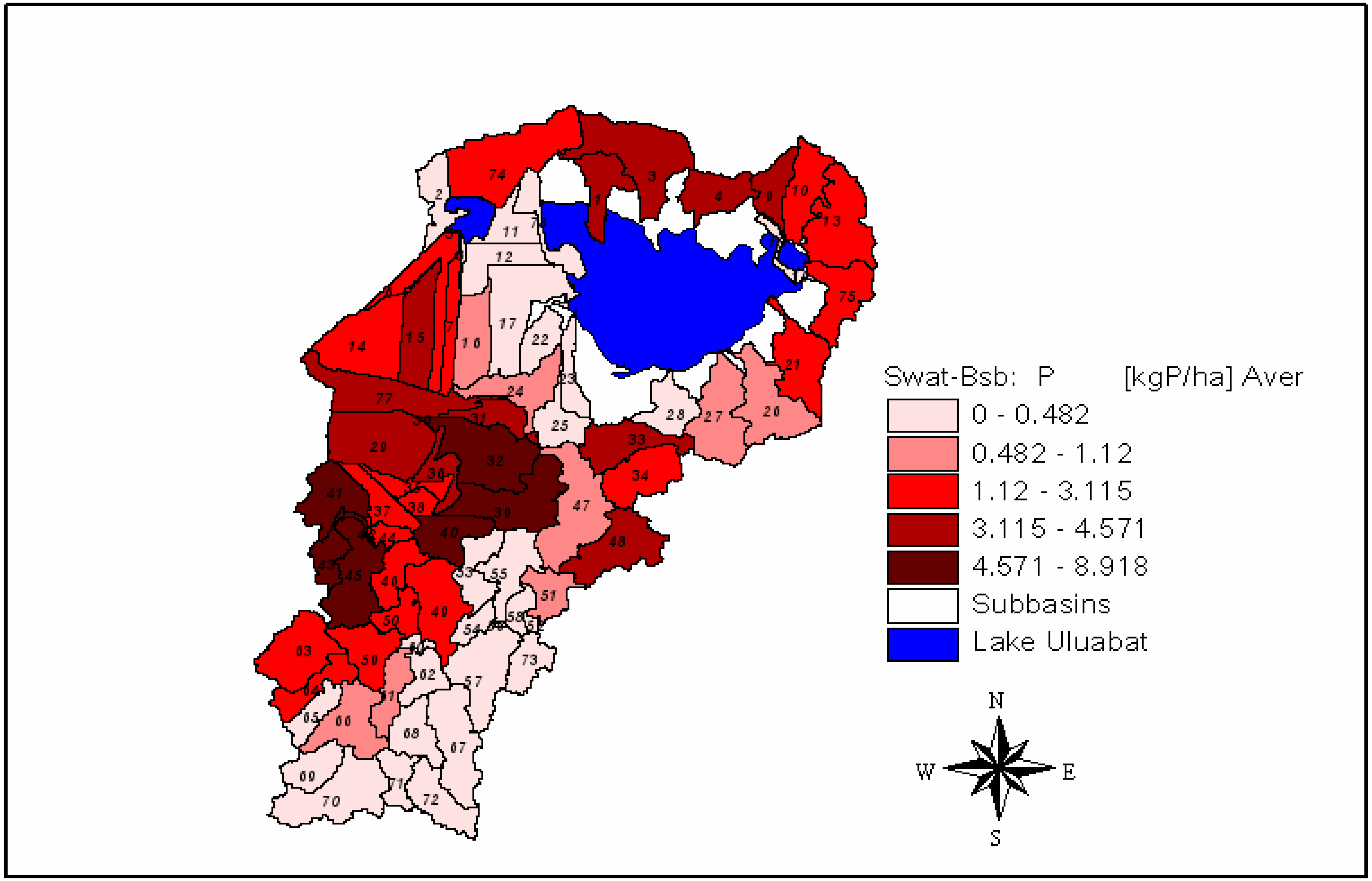

Figure 4.14. Annual Average P (SEDP+SOLP) Load From Subbasins, Scenario III

4.3.4. SCENARIO IV

In scenario IV, agricultural landuses on the areas surrounding the Mustafakemalpaşa Stream were removed and set with the landuse of range-grasses. Landuse map for scenario IV is given in Figure 4.15. and respective area percentages for this landuse map are given in Table 4.26. Following the landuse modification for scenario IV, RNGE area increased by an amount of 1.72%, whereas AGRC, TOMA and CORN areas decreased by the amounts of 1.03%, 0.34% and 0.35%, respectively. In order to apply this scenario to the watershed area simulated, a new project was produced including 78 subbasins and 549 HRUs. The purpose of this approach was to produce a buffer zone around the Mustafakemalpaşa Stream which fed the Uluabat Lake, and to assess the effect of this buffer zone on SOL P and sediment loads. According to the results, SOL P (SOLP_OUT) and sediment (SED_OUT) loads decreased. Simulation results of Scenario IV are given in Table 4.27.

Table 4.26 Linking Table of Landuse in FGDRS Soil Map and SWAT Landuse Database, Scenario IV

Grid Value	**Area (%)**	**Current Landuse in FGDRS Map**		**Landuse Defined In SWAT Database**	
		Definition	**Symbol Used**	**Definition**	**Symbol Used**
1	1.02	Residential Area	YR	Residential – Med/Low Density	URML
2	4.09	Shrubbery	F	Range-Grasses	RNGE
4	19.01	Irrigated Agriculture	S	Tomato	TOMA
5	33.53	Forest	O	Forest-Mixed	FRST
6	20.64	Non-irrigated Agriculture	N	Agricultural Land-Close-Grown	AGRC
7	1.31	Pasture	M	Pasture	PAST
9	0.42	River	IR	Water	WATR
11	2.07	Insufficient-irrigated Agriculture	Sy	Corn	CORN
14	0.06	Garden	B	Tomato	TOMA
16	4.26	Lake	GL	Water	WATR
22	11.97	Grass-Natural Vegetation Cover	Ç	Range-Grasses	RNGE
25	1.07	Marshy Places	SB	Nonforested Wetland	WETN
27	0.29	Sandy Dunes	KM	Hay	HAY
29	0.27	Grape	Ü	Agricultural Land-Close-Grown	AGRC

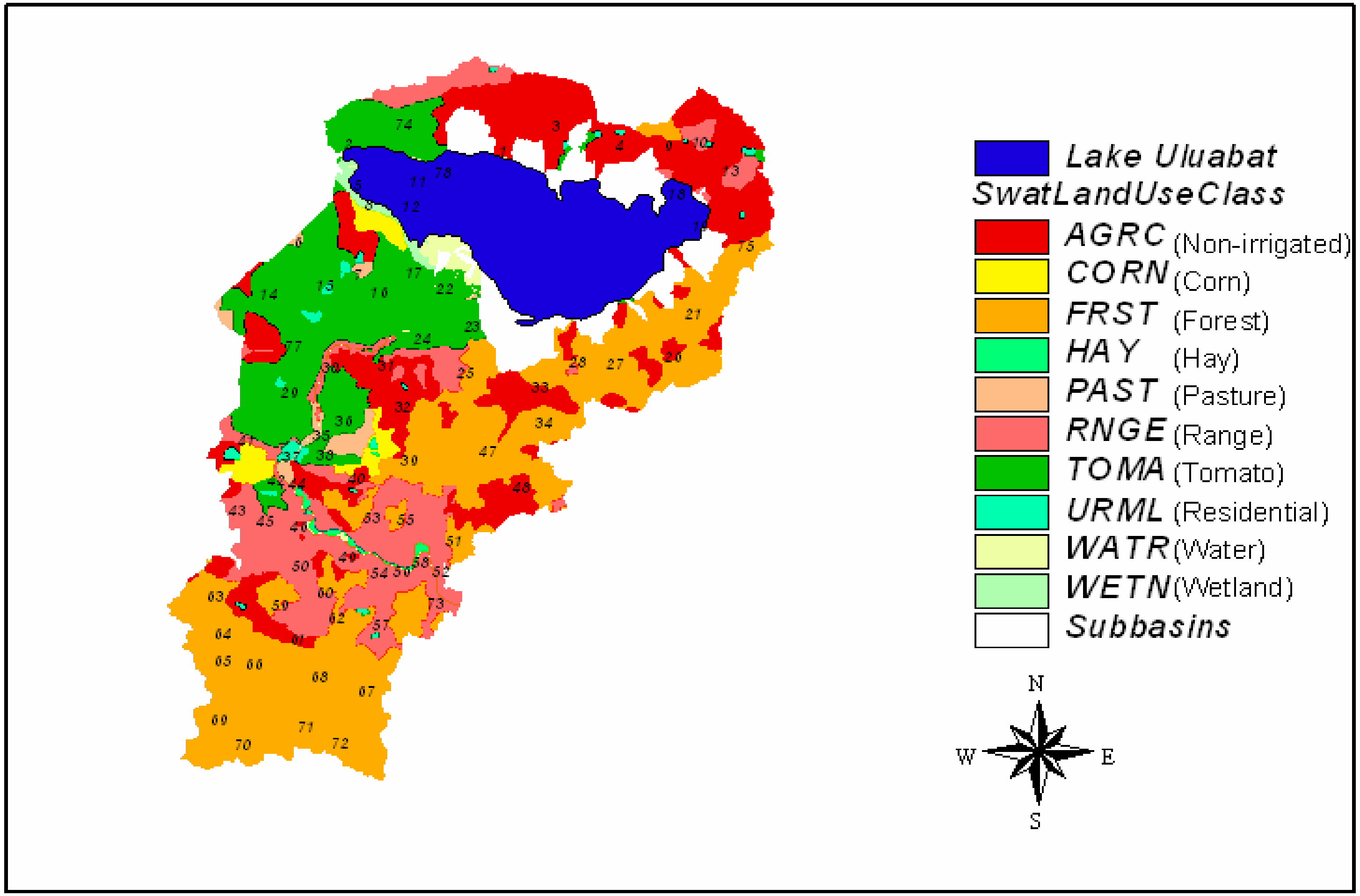

Figure 4.15. Landuse Map For Scenario IV

Table 4.27 Sediment and SOL P Load to the Lake Uluabat, Scenario IV

Subbasin No.	**SED_OUT (ton/year)**	**% Decrease**	**SOLP_OUT (kg/year)**	**% Decrease**
1	1315.50	0.00	2903.50	0.00
2	4004.50	0.00	15910.00	0.00
3	2271.00	0.00	7226.50	0.00
4	1931.50	0.00	3997.00	0.00
5	1812.00	0.00	39110.00	0.40
13	2101.50	0.00	4904.50	0.00
20	3602.50	0.00	10546.00	0.03
21	955.00	0.00	1486.00	0.50
22	118480.00	1.20	365800.00	2.28
23	680.50	0.00	2170.50	0.30
26	561.70	0.00	1330.00	1.08
27	720.60	0.00	1395.50	0.75
28	558.15	0.00	894.35	0.02
Total	138994.50	1.02	457673.90	1.88

According to Scenario IV (Table 4.27), sediment and SOL P load to the Lake Uluabat decreased by a percentage of 1.02 and 1.88, respectively. Mass P/area/time was found to be 3.95 gP/m^2/year, whereas it was 4.0 gP/m^2/year for the base case. Although a decrease in P load was possible, the quantity of this reduction was not as significant as for the buffer zone around the perimeter of the lake for the conditions considered in this study.

Average annual loads of SED P (kg P/ha), SOL P (kg P/ha) and P (SEDP+SOLP, kgP/ha) from subbasins are shown in Figures 4.16, 4.17, and 4.18, respectively.

For the threshold value of 1.12 kg P/ha/year of P loading, 47 subbasins within the 78 were critical for Scenario IV. That is, the number of critical subbasins decreased by 3 compared to the base case.

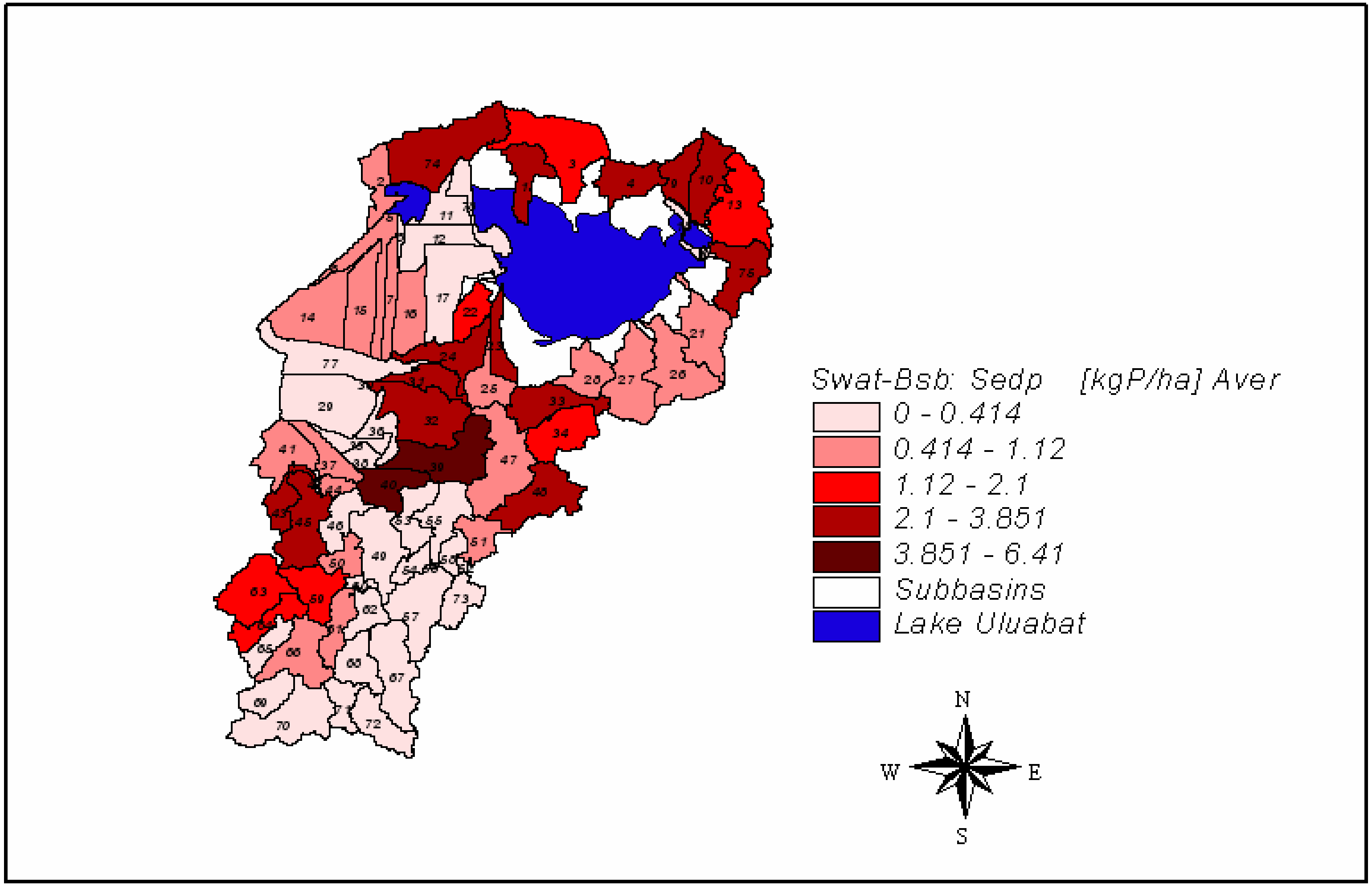

Figure 4.16. Annual Average SED P Load From Subbasins, Scenario IV

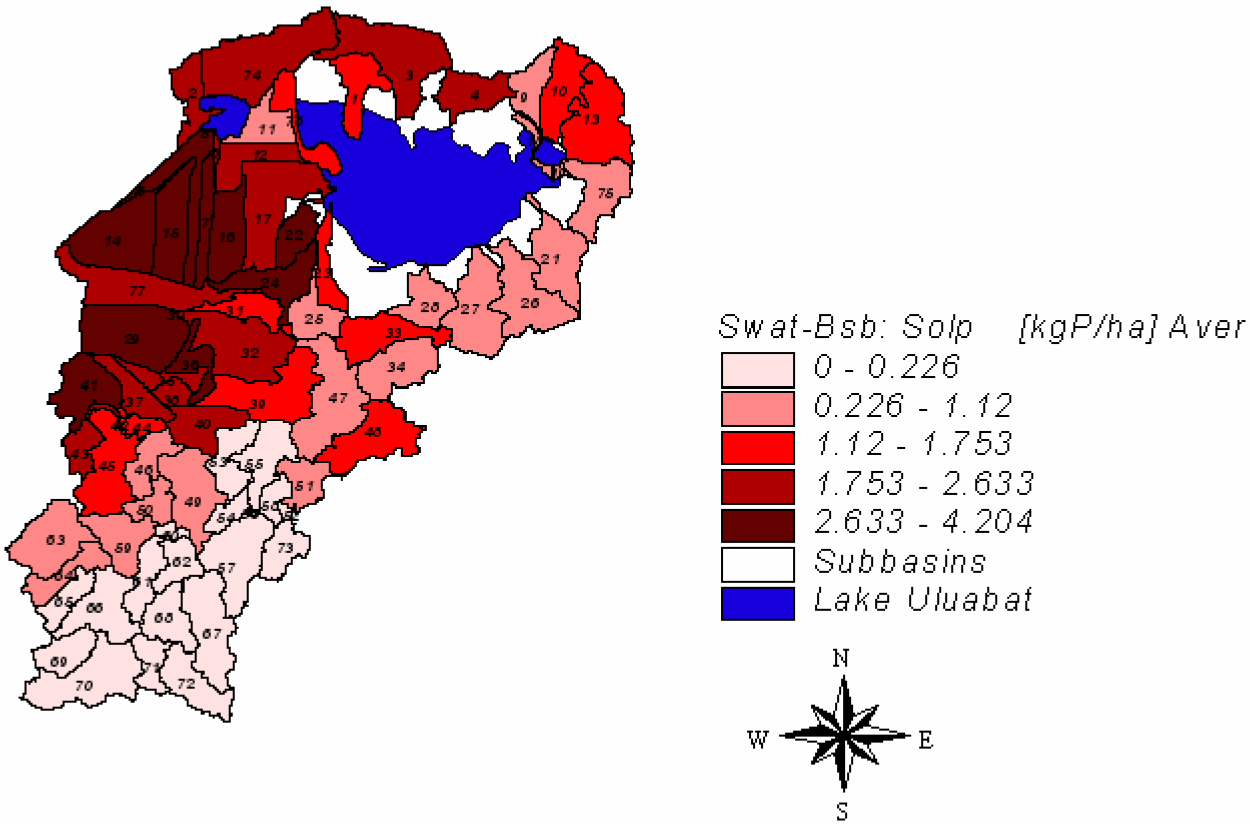

Figure 4.17. Annual Average SOL P Load From Subbasins, Scenario IV

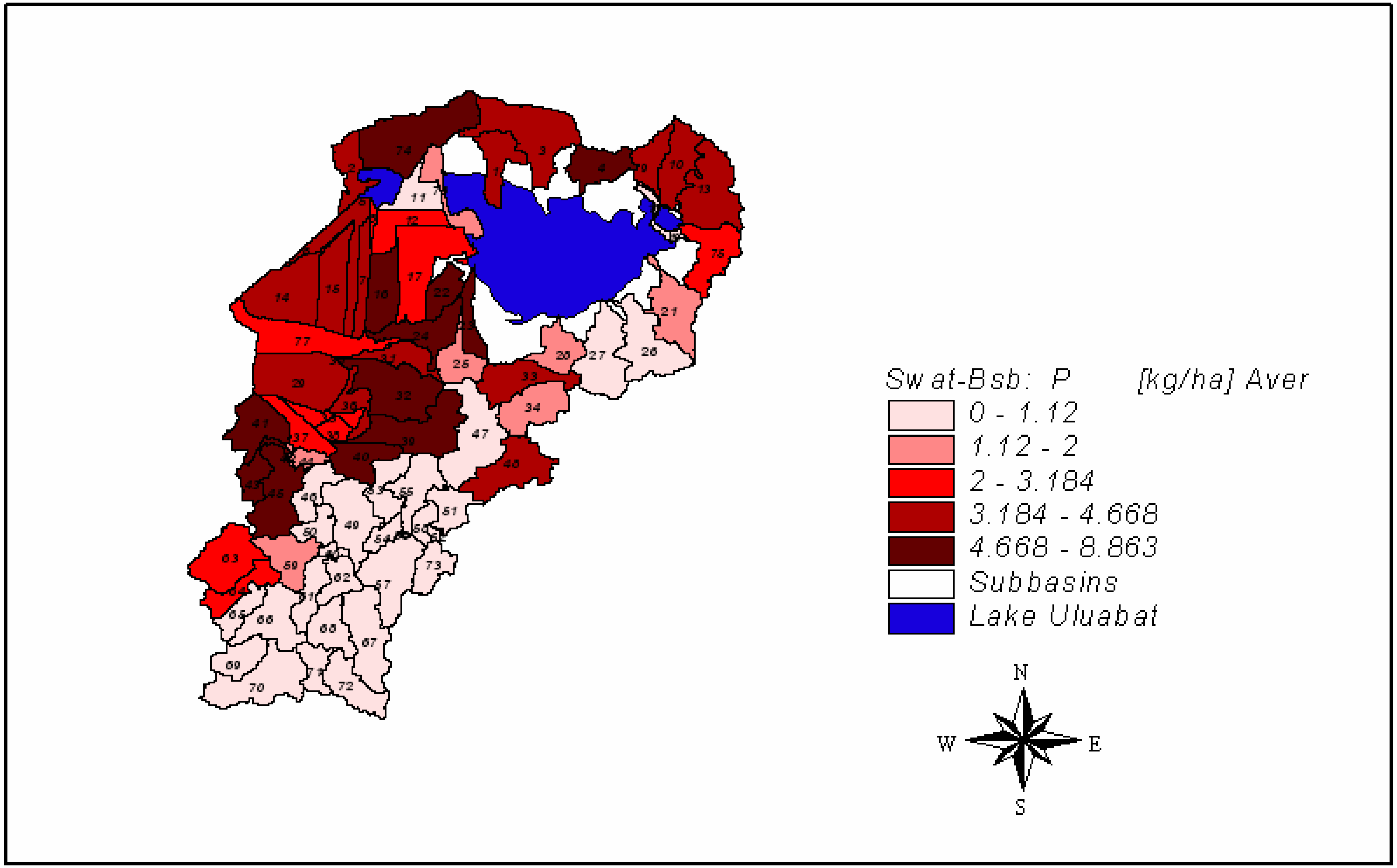

Figure 4.18. Annual Average P (SEDP+SOLP) Load From Subbasins, Scenario IV

4.3.5. SCENARIO V

In Scenario V, watershed inlet load of SOL P coming from Emet and Orhaneli Streams was decreased by 20%, 30% and 50%. Overall P loads for different years are presented in Table 4.28. Results are presented in Table 4.28 and Table 4.29.

Table 4.28. SOL P Loads to Lake Uluabat for Different P Load Reductions at the Inlet of the Watershed; Scenario V

Years	**Base Case (kg/year)**	**20% Decrease (kg/year)**	**30% Decrease (kg/year)**	**50% Decrease (kg/year)**
2001	84.004	67.203	58.803	42.002
2002	912.686	730.149	638.880	456.343
2003	475.762	380.610	333.033	237.881
2004	238.108	190.486	166.676	119.054

Table 4.29. SOL P Load to Lake Uluabat; Scenario V

Subbasin No.	**SOL P, Base Case (kg/year)**	**SOL P, Scenario V, 20% Decrease (kg/year)**	**SOL P, Scenario V, 30% Decrease (kg/year)**	**SOL P, Scenario V, 50% Decrease (kg/year)**
1	2903.50	2903.50	2903.50	2903.50
2	15910.00	15910.00	15910.00	15910.00
3	7226.50	7226.50	7226.50	7226.50
4	3997.00	3997.00	3997.00	3997.00
5	39265.00	39265.00	39265.00	39265.00
13	4904.50	4904.50	4904.50	4904.50
20	10549.50	10549.50	10549.50	10549.50
21	1493.50	1493.50	1493.50	1493.50
22	***374350.00***	***332300.00***	***311300.00***	***269300.00***
23	2177.00	2177.00	2177.00	2177.00
26	1344.50	1344.50	1344.50	1344.50
27	1406.00	1406.00	1406.00	1406.00
28	894.50	894.50	894.50	894.50
Total	466421.50	424371.50	403371.50	361371.50

As seen in Table 4.29, there is a change in SOL P load only at the outlet of subbasin 22, which is the last subbasin before Mustafakemalpaşa stream discharges to Lake Uluabat. Other subbasins surrounding the Lake are not impacted. SOL P load to Lake Uluabat through the Mustafakemalpaşa Stream decreased by about 11.2%, 16.8% and 28.4%, when the amount of SOL P load coming from Emet and Orhaneli Streams were decreased by 20%, 30% and 50%, respectively. Consequently, SOL P load to the Lake Uluabat in mass P/area/time was found to be 3.7 gP/m^2/year for 20% decrease in SOL P load coming from the watershed inlet, 3.5 gP/m^2/year for 30% decrease in SOL P load coming from the watershed inlet and 3.1 gP/m^2/year for 50% decrease in SOL P load coming from the watershed inlet; whereas it was 4.0 gP/m^2/year for the base case. As seen in Figure 4.19, there is a perfect linear relationship between the SOL P load to Lake Uluabat through the Mustafakemalpaşa Stream and the SOL P load coming from the Emet and Orhaneli Streams.

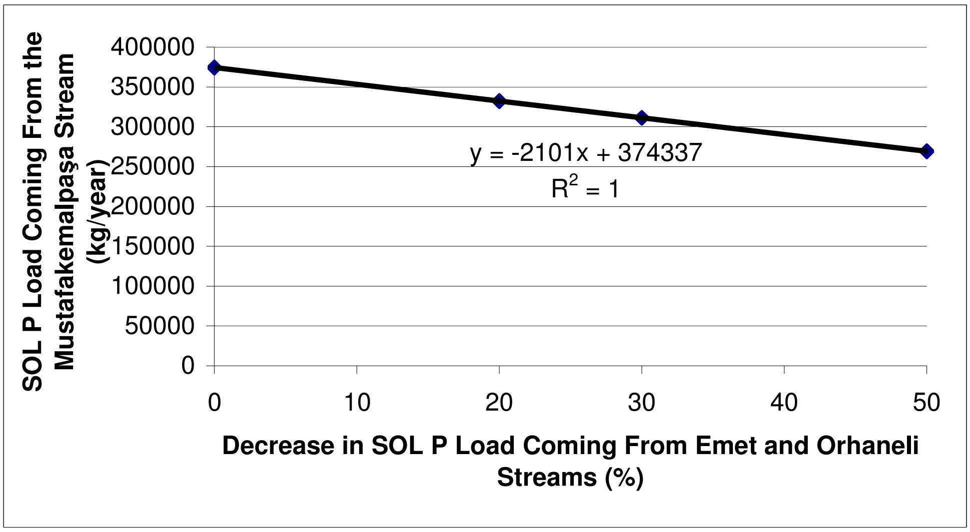

Figure 4.19. SOL P Load Coming From the Mustafakemalpaşa Stream versus Percent Decrease In SOL P Load Coming From Emet and Orhaneli Streams

Emet and Orhaneli Streams are dominated by point sources rather than nonpoint sources. Therefore, together with agricultural activities in Mustafakemalpaşa Watershed, point sources in Emet and Orhaneli Watersheds must be controlled to decrease the P loads to Lake Uluabat.

4.3.6. SCENARIO VI

In Scenario VI, point source load of SOL P coming from Mustafakemalpaşa District sewage system was decreased by 20%, 30% and 50% with respect to the base case value of 70 kg/day of SOL P. Resulting SOL P loads for Scenario VI are given in Table 4.30.

Table 4.30. SOL P Load to the Lake Uluabat; Scenario VI

Subbasin No.	**SOL P, Base Case (kg/year)**	**SOL P, Scenario VI, 20% Decrease (kg/year)**	**SOL P, Scenario VI, 30% Decrease (kg/year)**	**SOL P, Scenario VI, 50% Decrease (kg/year)**
1	2903.50	2903.50	2903.50	2903.50
2	15910.00	15910.00	15910.00	15910.00
3	7226.50	7226.50	7226.50	7226.50
4	3997.00	3997.00	3997.00	3997.00
5	39265.00	39265.00	39265.00	39265.00
13	4904.50	4904.50	4904.50	4904.50
20	10549.50	10549.50	10549.50	10549.50
21	1493.50	1493.50	1493.50	1493.50
22	***374350.00***	***369200.00***	***366650.00***	***361550.00***
23	2177.00	2177.00	2177.00	2177.00
26	1344.50	1344.50	1344.50	1344.50
27	1406.00	1406.00	1406.00	1406.00
28	894.50	894.50	894.50	894.50
Total	466421.50	461271.50	458721.50	453621.50

As seen in Table 4.30, there is change in SOL P load at subbasin 22. SOL P load to Lake Uluabat through the Mustafakemalpaşa Stream decreased by about 1.4%, 2.1% and 3.4%, when the amount of SOL P load coming from the sewage system of the Mustafakemalpaşa District was decreased by 20%, 30% and 50%, respectively. Consequently, SOL P load to the Lake Uluabat in mass P/area/time was found to be 4.0 gP/m^2/year for 20% and 30% reduction in SOL P load coming from the sewage system of the Mustafakemalpaşa District. This value was 3.9 gP/m^2/year for 50% decrease in SOL P load from the sewage system.

As seen in Figure 4.20, there is a perfect linear relationship between the SOL P load to Lake Uluabat through the Mustafakemalpaşa Stream and the SOL P load coming from the sewage system of the Mustafakemalpaşa District. However, the impact of sewage disposal in SOL P loads to the lake is minimal compared to other factors.

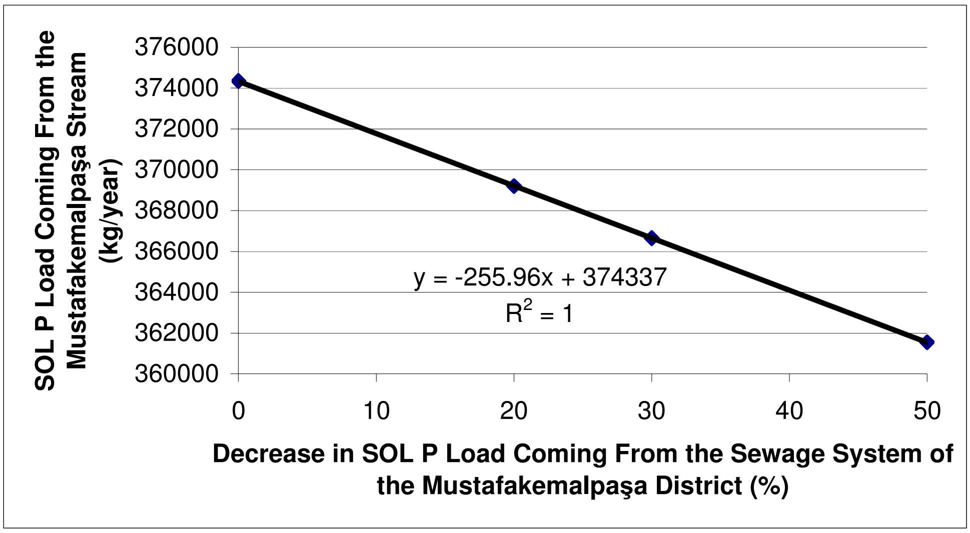

Figure 4.20. SOL P Load Coming From the Mustafakemalpaşa Stream Versus Percent Decrease In SOL P Load Coming From the Sewage System of the Mustafakemalpaşa District

4.3.7. SCENARIO VII

In Scenario VII, agricultural activities around Lake Uluabat were replaced by range-grasses type landuse, P load contributing from Mustafakemalpaşa District sewage system, and from Emet and Orhaneli Watersheds were decsreased by 50% in addition to 50% decrease in fertilizer usage through the agricultural lands, to see almost total effect of the scenarios. Results are presented in Table 4.31.

Table 4.31. SOL P Load to the Lake Uluabat; Scenario VII

Subbasin No.	SOLP, Base Case (kg/year)	SOLP, Scenario VII, (kg/year)
1	2903.50	1617.00
2	15910.00	4442.50
3	7226.50	4502.00
4	3997.00	1958.00
5	39265.00	8739.00
13	4904.50	2607.00
20	10549.50	6712.00
21	1493.50	838.60
22	374350.00	208700.00
23	2177.00	121.90
26	1344.50	914.30
27	1406.00	674.20
28	894.50	34.75
Total	466421.50	241861.30

As seen in Table 4.31, SOLP load to the Lake Uluabat decreased by about 48.15%. Consequently, SOL P load to the Lake Uluabat in mass P/area/time was found to be 2.1 gP/m^2/year, whereas it was 4.0 gP/m^2/year simulated after calibration.

Average annual loads of SED P (kg P/ha), SOL P (kg P/ha) and P (SEDP+SOLP, kgP/ha) from subbasins are shown in Figure 4.21, Figure 4.22, and Figure 4.23, respectively.

As threshold value for the phosphorus loading rate of 1.12 kg P/ha/year was concerned, 35 subbasins over 78 subbasins are critical subbasins for Scenario VII. That is, the number of critical subbasins decreased by 15.

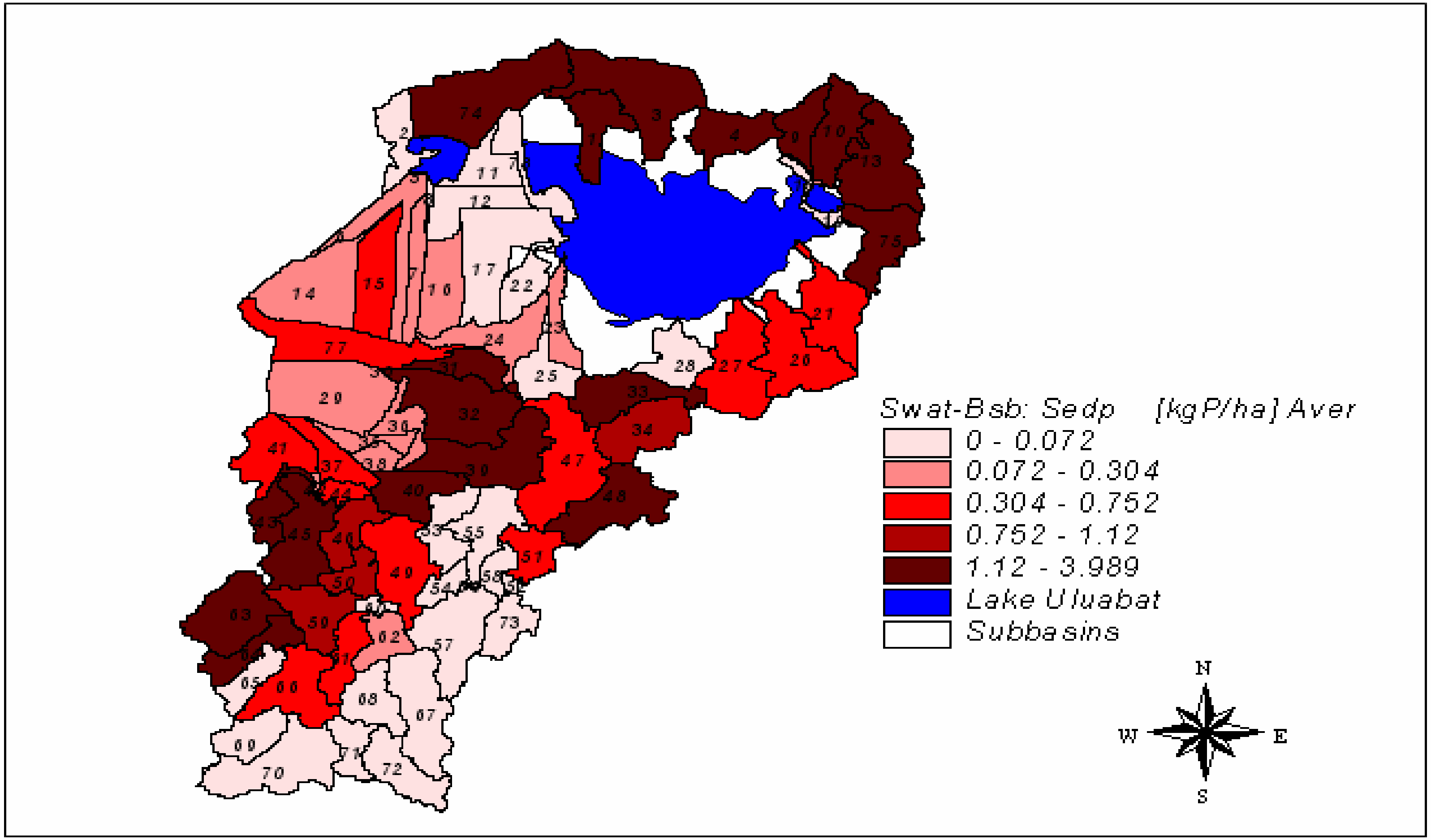

Figure 4.21. Annual Average SED P Load From Subbasins, Scenario VII

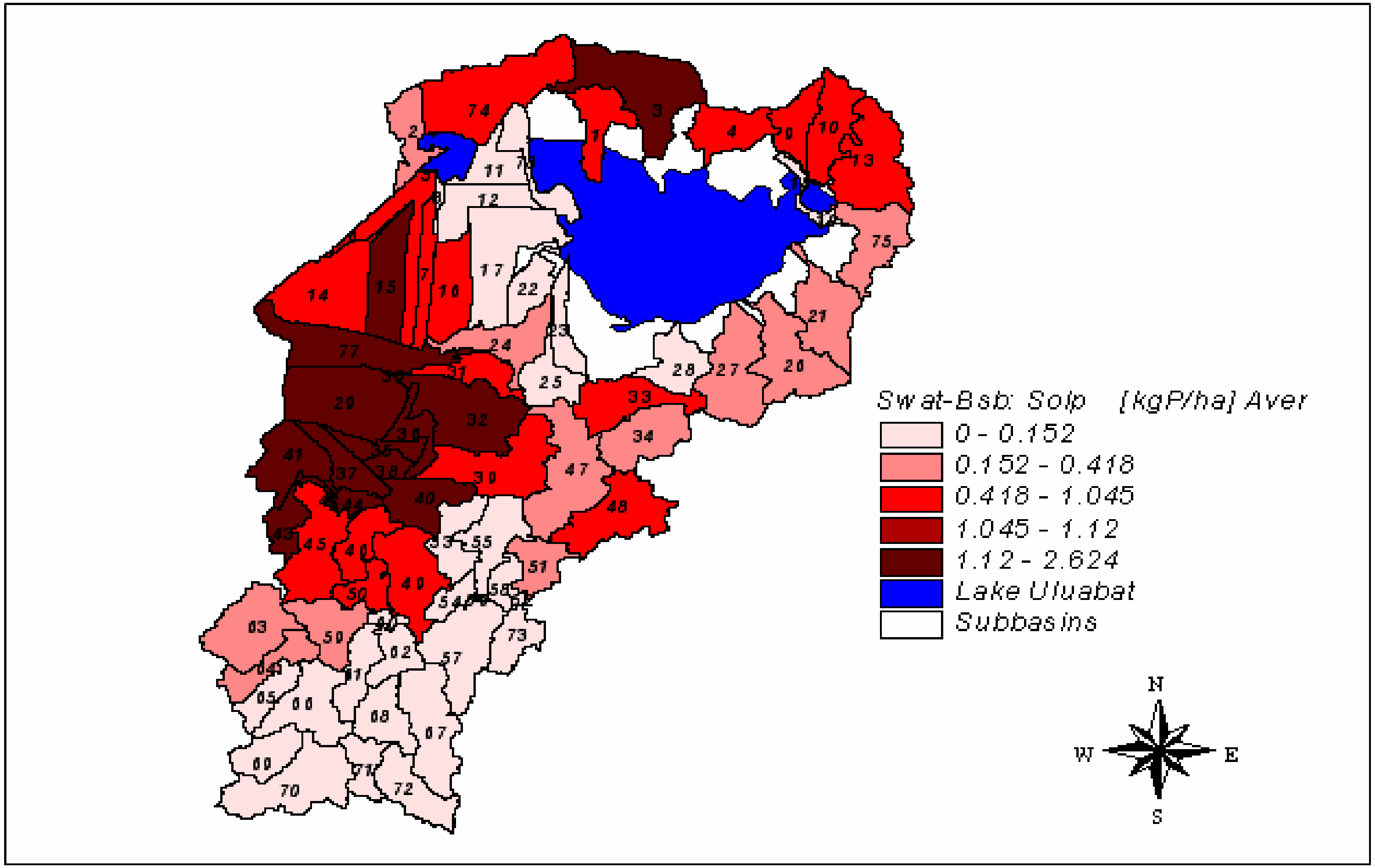

Figure 4.22. Annual Average SOL P Load From Subbasins, Scenario VII

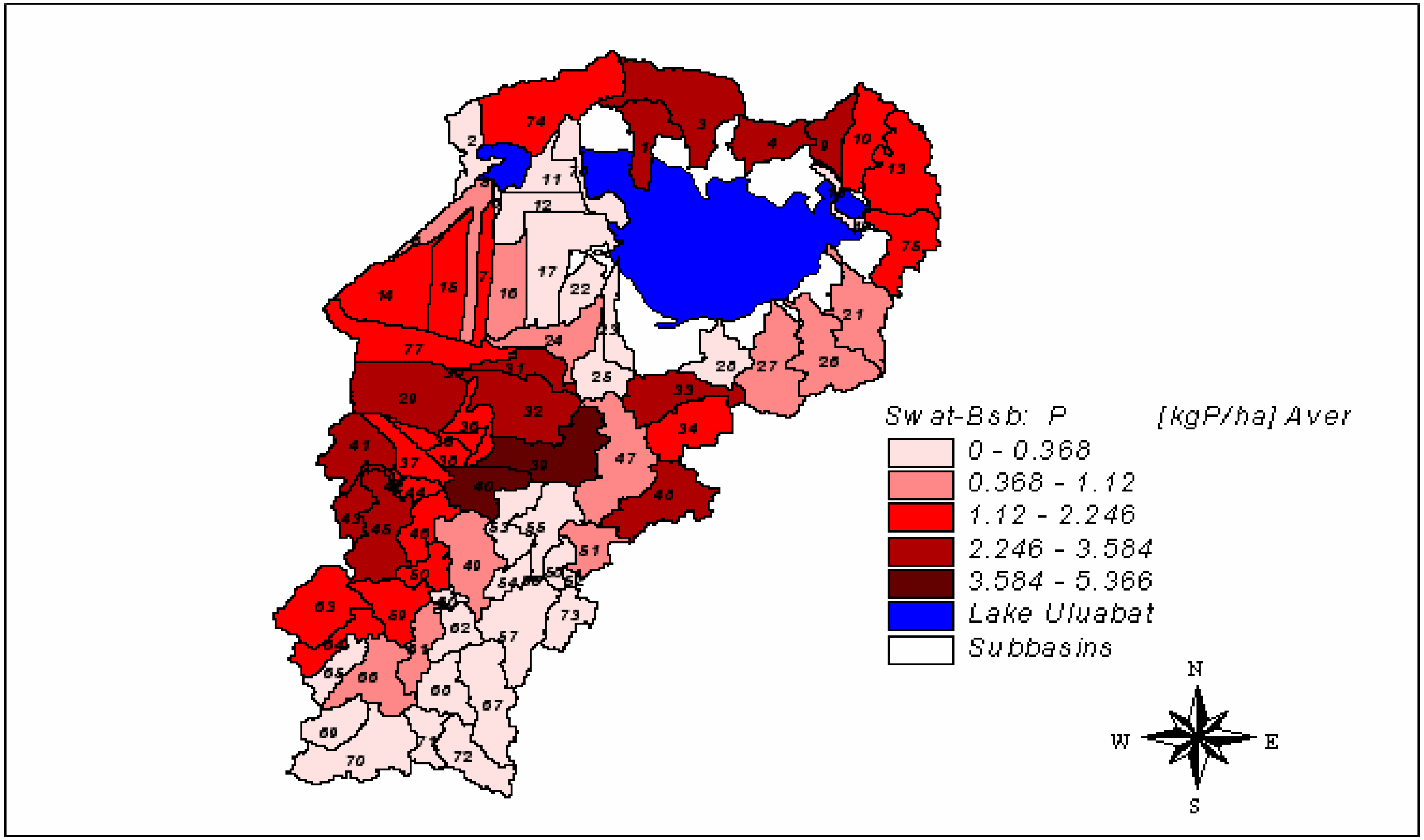

Figure 4.23. Annual Average P (SEDP+SOLP) Load From Subbasins, Scenario VII

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

In this study, agricultural nonpoint source pollution in terms of SOL P load to the Lake Uluabat has been simulated by using ArcView Interface of Soil and Water Assessment Tool 2000 (AVSWAT2000). Data used in this study was composed of meteorological data, flow and water quality data, soil class and landuse data in addition to the DEM of the area simulated. DEM was used to delineate the watershed of the Lake Uluabat in SWAT. Although the watershed of Lake Uluabat includes Emet and Orhaneli Watersheds, these watersheds were integrated into the model as watershed inlets due to lack of soil class data. That is, flow and stream water quality data obtained from SHW were used to calculate the loads originating from Emet and Orhaneli Watersheds, and incorporated into SWAT as watershed inlets (point sources). In addition to the watershed inlets, sewage discharge of Mustafakemalpaşa District was integrated into the model as a point source.

Calibration of SWAT was performed at two SHW gages on the Mustafakemalpaşa Stream. Calibration was performed first at the upper stream gage (M-1, at the outlet of subbasin 73) and then at the lower stream gage (M-2, at the outlet of subbasin 77). in three steps for the annual average conditions. First stream flow, next sediment and finally nutrients were calibrated as suggested by Neitsch et al. (2002a) using the 2001, 2002 and 2004 data.

Calibration results for subbasin 73 showed that default model parameter values were adequate for modeling. No significant agricultural activities were present in this subbasin. However, for subbasin 77 several adjustments were required in model parameter values. This subbasin had several other subbasins with agricultural activities draining into it. SWAT overestimated the stream flow while underestimating the sediment load with default values. For different years, SOL P values were either above or below the observation data. In flow calibration, aquifer percolation coefficient (RCHRG_DP) and threshold depth (mm) of water in the shallow aquifer required for occurance of base flow (GWQMN) were modified to decrease the stream flow. Resultant maximum Dv, and E_{NS} were 9.29%, and 0.75, respectively.

Sediment calibration was made to increase the simulated sediment load at the outlet of subbasin 77. Channel erodibility factor (CH_EROD) and channel cover factor (CH_COV) were increased to 0.02 and 0.001, respectively, through the subbasins draining into subbasin 77. USLE_C (USLE cover and management factor) was also modified for AGRC, TOMA and CORN landuses. Sediment calibration was terminated when maximum value of Dv of 25% and maximum value of E_{NS} of 0.71 were achieved.

SWAT overestimated SOL P load in 2002, and underestimated SOL P load in 2004. P calibration was done to increase the simulated P load at the outlet of subbasin 77 for 2004, since Dv for year 2004 was much compared to that of 2002. P soil partitioning coefficient (PHOSKD) was modified to change the amount of solution P transported in surface runoff. As a result, E_{NS} of 0.55 was achieved. The maximum Dv was about 17%.

Simulation results for the conditions studied showed that Mustafakemalpaşa Stream was the major contributor of sediment and SOL P load to Lake Uluabat. In addition, contribution of the watershed area to the sediment, SED P and SOL P loads to the lake was greater than 95%. Fertilizer applications and tillage operations applied through agricultural lands impacted the quantity of loads in addition to loads carried through Emet and Orhaneli Watersheds. Simulation results showed that, for the specified conditions and lake surface area, SOL P load to Lake Uluabat was about 4 g P/m^2/year. This value is greater than the goal amount (1 g P/m^2/year) stated by the Lake Uluabat Management Plan (WWF-Turkey, 2000). 50 subbasins within 78 subbasins were critical in terms of P loading, which were also dominated by agricultural activities.

In order to assess the impact of different management alternatives on P loading to the lake, seven scenarios were considered. In scenario I, the amount of fertilizer application on agricultural sites (AGRC, TOMA, CORN) were varied. Scenario II, looked for the impact of increased irrigation rate on the P load. In scenario III and IV, "riparian zones" were inserted at the perimeter of surface waters to create buffer zones. In scenarios III and IV the buffer zones were around the lake and the Mustafakemalpaşa Stream, respectively. Scenario V investigated the impacts of Emet and Orhaneli Streams on the amount of P carried to the lake. Scenario VI analyzed the impact of a point load, the discharge of sewage of the Mustafakemalpaşa District, on the total load reaching to the lake. Finally, in scenario VII agricultural activities around Lake Uluabat were replaced by range-grasses type landuse, P load contributing from Mustafakemalpaşa District sewage system, and from Emet and Orhaneli Watersheds were decsreased by 50% in addition to 50% decrease in fertilizer usage through the agricultural lands, to see almost total effect of the scenarios.

In conclusion, fertilizer application, buffer zone around lake, and control of pollution sources in the Orhaneli and Emet Streams were the most effective alternatives among the ones analyzed in this study for the conditions considered. In order to reach to the goal P load stated by the Lake Uluabat Management Plan (1 gP/m^2/year) a number of management alternatives may be necessary. However, simulation results states that, for control of P load to the lake, a management strategy in a watershed scale is essential. Although agricultural activities may have great impact on the pollution of the lake, other point and non-point sources should be considered as well.

5.2. RECOMMENDATIONS FOR FUTURE STUDY

In this study, some areas around lake could not be processed (delineated) by SWAT due to existence of plane areas around lake. High resolution DEM may be used or the DEM may be modified to increase the elevation differences through those areas in order to make SWAT perform delineation totally.

In this study, the simulations were performed with limited data. With advancement of data production in future, the conditions used in this study can be updated to include more recent landuse applications. The results obtained in this study is based on specific productions and agricultural management practices; such as the fertilization methods and scheduling employed, irrigation patterns and scheduling. Different practices or even products may impact the P and sediment loads to lake Uluabat. Future studies may focus on the significance of different agricultural activities.

In this study, loads from the Emet and Orhaneli Streams were treated as point loads. However, simulations indicate that these streams and their watersheds may be important in terms of application of sound management alternatives for pollution and eutrophication control in Lake Uluabat. Therefore, these watersheds can be modeled in detail to analyze the impact of different pollution sources at these watersheds. However, large scale, significant data production would be demanded for such an application.

In this study calibration could only be performed annually due to lack of daily and monthly data. Based on the availability of data in future, it is recommended to perform a daily or at least monthly calibration to get most accurate results representing the actual conditions over the watershed area.

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APPENDIX A. SUMMARY OF INPUT SOIL PARAMETERS USED IN SWAT

Table A.1. Initial Values For Soil Parameters Required by SWAT and Their Corresponding Ranges In Literature

Swat Parameter	Fine Texture		Medium Texture		Coarse Texture		Hydromorphic Alluvial Soils (1)	Brown Forest Soils (7)	Clay Loam
	Range	Used*	Range	Used*	Range	Used*	Used*	Used	Used
HYDGRP	A,B,C,D	C	A,B,C,D	B	A,B,C,D	A	B	C	B
SOL_ZMX	-	Default	-	Default	-	Default	Default	Default	Default
ANION_EXCL		Default		Default		Default	Default	Default	Default
SOL_Z (mm)	-	200	-	200	-	200	200	200	200
SOL_BD (Mg/m^3)	1.35-1.45	1.40	1.45-1.50	1.48	1.50-1.65	1.58	1.48	1.35	1.45
SOL_AWC (mm H_2O/mm soil)	0.10-0.19	0.14	0.17-0.21	0.18	0.07-0.18	0.12	0.15	0.10	0.17
SOL_K (mm/h)	1.5-5.1	3.30	5.1-15.2 (2) 15.2-50.8 (3)	15.86	15.2-50.8 (4) 50.8-152.4 (5) 152.4-508.1 (6)	33.00	40.03	3.30	10.15
SOL_CBN (% weight)	-	1.16	-	1.16	-	1.16	1.16	1.16	1.16
CLAY (%)		42.50		27.28		10.43	26.74	56.34 (8)	34.67 (8)
SILT(%)		34.35		39.84		22.20	32.13	28.57 (8)	32.33 (8)
SAND (%)		23.15		32.88		63.67	39.90	15.08 (8)	33.00 (8)
ROCK(%)		-		-		-		-	-
USLE_K	0.017- 0.025	0.020	0.025-0.055	0.037	0.015- 0.040	0.026	0.029	0.017	0.030

***Source:* 1.** *Guides For Editing Soil Properties, 2005.* **2.** *Rosewell, 1993.* **3.** *Ley et al., 1994.*

(1) *Hydromorphic alluvial soils are defined as mixed textured soils in the legend of GDRS soil map.Therefore SOL_BD, SOL_AWC, SOL_K, CLAY%, SILT% and SAND% values for this great soil group were determined by taking the averages of the values given for each soil texture for each parameter in literature.* ***(2)*** *for CL-SCL-SiCL.* ***(3)*** *forSiL.* ***(4)*** *for L.* ***(5)*** *for SL.* ***(6)*** *for S-LS.* ***(7)****Values were determined based on clay texture class.****(8)*** *clay%, silt% and sand% were determined by taking the averages of analysis results given in the report of Susurluk Havzası Toprakları (1971)*

** Avg. values were used.*