MODELING CONTAMINANT TRANSPORT IN THE MARMARA REGION AND ANALYZING THE ASSOCIATED PARAMETRIC SENSITIVITY

by
ZEYNEP AKDOĞAN
BS. in Environmental Engineering, Istanbul University, 2008

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ABSTRACT

The increasing human activities, urbanization and land use changes in recent years have contributed to water quality degradation by affecting the transport of contaminants to receiving waters by overland flow. This necessitates the development of modeling approaches for planning and management of catchments that play a significant role on water supply. Geographical Information Systems (GIS) has become an important methodological approach in catchment modeling with the facilities to obtain spatial data and advanced visualization of topographical features. The main objective of this study is to determine the effects of land use changes on nutrient and heavy metal loads by modeling the transport of these contaminants in the Marmara Region and to assess the sensitivity of parameters affecting the transport processes.

Storm Water Management Model (SWMM) was chosen to develop the catchment hydrological model. GIS based maps and data including land use and cover were used to determine catchment boundaries and develop the input parameters required for SWMM with time series rainfall data. Total nitrogen, total phosphorus, copper, zinc and nickel concentrations in runoff were estimated by using previously analyzed soil samples collected from the different lands of the Marmara Region. Spatial data and concentrations obtained were transferred to SWMM to develop the catchment hydrological model and describe the relationships between contaminant load and land use. Finally, parametric sensitivity analysis was carried out to determine the most important parameters affecting SWMM model outcomes.

The model results revealed that increase in rainfall intensities and % imperviousness values contribute to runoff production and associated contaminant loads in catchments. Area of subcatchments, rainfall and maximum buildup of contaminants are the most significant parameters in SWMM to predict runoff and event loads. Percent imperviousness and percent slope are the least significant parameters amongst other parameters affecting output.

ÖZET

Son yıllarda gelişen faaliyetler, yerleşim bölgelerinin artması ve arazi kullanımındaki değişimler kirleticilerin yüzeysel akışla taşınımını etkileyerek yüzey sularının kalitesinin düşmesinde etkili olmuştur. Bu durum su temininde önemli rol oynayan havzaların planlanması ve yönetimi için modelleme çalışmalarının geliştirilmesini gerekli kılmıştır. Coğrafi Bilgi Sistemleri (CBS), konumsal verileri elde etmede sağladığı kolaylık ve sunduğu topografik haritalarla havza modelleme çalışmalarında başvurulan önemli araçlardan bir tanesi olmuştur. Bu çalışmanın amacı Marmara Bölgesi'ndeki kirletici taşınımını modelleyerek arazi kullanım değişimlerinin nütrient ve ağır metal kirlilik yüklerine etkisinin belirlenmesi ve bu kirleticilerin taşınım prosesini etkileyen parametrelerin duyarlılığının tayin edilmesidir.

Havza hidrolojik modelinin oluşturulması amacıyla Yağmur Suyu Yönetim Modeli (SWMM) kullanılmıştır. Arazi kullanımı ve örtüsünü içeren CBS tabanlı harita ve verilere başvurularak bölgedeki havzaların sınırları belirlenmiş, yağış verileri ile birlikte SWMM modelin çalıştırılması için gerekli veri giriş parametreleri düzenlenmiştir. Yüzeysel akıştaki toplam azot, toplam fosfor, bakır, çinko ve nikel konsantrasyonları Marmara Bölgesi'nin farklı noktalarından toplanarak önceden analiz edilmiş toprak numuneleri kullanılarak hesaplanmıştır. Edinilen konumsal veriler ve konsantrasyon değerleri SWMM modele aktarılarak havza hidrolojik modeli oluşturulmuş, kirletici yükleri ile arazi kullanımı arasındaki ilişki tanımlanmıştır. Son olarak SWMM model sonuçlarını etkileyen önemli parametreleri belirlemek amacıyla parametrik duyarlılık analizleri yürütülmüştür.

Model sonuçları, artan yağış ve geçirimsizliğin yüzeysel akış oluşumuna ve kirlilik yüklerine katkıda bulunduğunu ortaya koymuştur. Havza alanı, yağış ve maksimum kirletici birikimi SWMM modelin yüzeysel akış ve kirlilik yüklerini belirlemedeki en hassas parametreleridir. Havza yüzde geçirimsizliği ve yüzde eğim, mevcut parametreler içinde model sonuçlarını en az etkileyen parametrelerdir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**
ACTMO	Agricultural Chemical Transport Model
AGNPS	Agricultural Nonpoint Source
ANSWERS	Aerial, Nonpoint Source, Watershed Environmental Response Simulation
ARM	Agricultural Runoff Management
BOD_5	Biochemical Oxygen Demand (mg/L)
CBS	Coğrafi Bilgi Sistemleri
Cd	Cadmium
COD	Chemical Oxygen Demand (mg/L)
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
Cu	Copper
DEM	Digital Elevation Model
DOM	Dissolved Organic Matter
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
GIS	Geographical Information Systems
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
HSPF	Hydrologic Simulation Program-FORTRAN
KINEROS	Kinematic Runoff and Erosion
L-THIA	Long Term Hydrologic Impact Assessment
MEC	Measured Environmental Concentration
Ni	Nickel
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
Pb	Lead
PEC	Predicted Environmental Concentration
PRZM	Pesticide Root Zone Model
RIVM	National Institute of Public Health and the Environment in The Netherlands

SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
SWRRB	Simulator for Water Resources in Rural Basins
TKN	Total Kjeldahl Nitrogen (mg/L)
TN	Total Nitrogen (mg/L)
TP	Total Phosphorus (mg/L)
TSS	Total Suspended Solids (mg/L)
U.S.	United States
WEPP	Water Erosion Prediction Project
Zn	Zinc

1. INTRODUCTION

Rapid growth of the population and associated increase in human activities in recent years have contributed to alter the natural conditions of the environment. Urbanization, industrial and agricultural practices, fertilizer applications and other human activities has led to an increased accumulation of contaminants in natural resources. These contaminants affect the water quality and human health by being transported to surface and ground waters as a result of runoff, which is highly affected by land use and cover, soil structure, climate and topography (Lenzi and Di Luzio, 1997). Agricultural areas in which manure, pesticides and other chemicals being used have been recognized as important nonpoint sources (NPS) of water contamination and it has been observed that rainfall and overland flow play a significant role on transport of these pollutants (e.g. Lal et al., 1998; Parry, 1998; Delpla et al., 2011). Storm water runoff from urban areas has also been identified as critical nonpoint source of pollution (U.S. EPA, 1983), which transports some of the same pollutants found in rural and agricultural runoff (Bhaduri et al., 2000).

Excessive amounts of contaminants lead to water quality impairment and environmental risks. The nutrients (nitrogen and phosphorus) transported to freshwaters by overland flow cause eutrophication and degrade the water quality considerably. In many freshwater systems phosphorus is the limiting nutrient in eutrophication (Rekolainen et al., 2005). Besides the nutrients, heavy metals are also major contaminants in lakes, ponds and reservoirs. Those which are trace amount in nature in normal conditions access unacceptable concentrations and affect biota in view of their persistence and bioaccumulation potential (Ikem and Adisa, 2011). Certain heavy metals such as copper, lead and zinc are more soluble in water than others, and industrial and commercial land uses are the greatest contributors of those into the runoff (Tsihrintzis and Hamid, 1997). Furthermore, existence of organic carbon also affects the bioavailability of metals because of its binding properties (Buckingham et al., 2008).

The use of environmental models is significant in order to better understand and interpret the behavior of surface and subsurface water also mobility of pollutants. Analysis tools and simulation models must be developed to properly evaluate alternate management practices and to predict water quality improvements at the catchment scale (Jamieson et al., 2004). Contamination pathways and sources of pollutants in the landscape are identified through modeling thereby pollutant concentrations are estimated at any point to assess the pollutant mitigation strategies to protect water resources from contamination (Blenkinsop et al., 2008). Mathematical models can be categorized as analytical and numerical models. In analytical modeling, there is few input data since more assumptions are done to simplify the initial and boundary conditions, flow conditions, porous media, as well as physical, chemical and biochemical processes of the simulated pollutants. Therefore, analytical models are easy to use and compute. On the other hand, numerical models can overcome more complex contaminant transport issues (Chu and Marino, 2007). However, they require more input data and limited availability of input data sometimes hinder mathematical models (Schriever and Liess, 2007).

The catchment scale water quality modeling includes mostly mathematical computer simulation models. One basic component of a catchment model is rainfall-runoff modeling. During the hydrological modeling studies, water quality should be considered with runoff quantity due to the unequal distribution of water and its spatial-temporal availability at any place varying with time. For this reason, it is important to have realistic models including hydrologic or hydraulic component, which have the appropriate spatial and temporal resolution required for the problem (Zoppou, 2001). In reference to catchment models, Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) is the one model that can clearly simulate the hydrologic and hydraulic elements involved in the phenomenon of urban drainage (Ouyang et al., 2012). In this study, SWMM is employed to express the rainfall-runoff phenomenon and to compare the pollutant loads from the different types of lands to surface waters.

All the basic units such as water, soil and pollutants in environmental modeling have spatial distributions that affect the processes and their dynamics considerably (Rao et al., 2000). The necessity to identify and locate these sources requires being capable of handling large amounts of detailed input and output data. However, spatial data collection is one of the main problems during modeling studies and cause consumption of much time for data gathering. In the last few decades Geographical Information Systems (GIS) have become an important tool in environmental modeling since it poses the ability to identify nonpoint source (NPS) contaminants and serve as a common data and analysis framework for environmental models (Maidment, 1993; Ragan and Kosicki, 1993). GIS technology provides boundary conditions as a practical solution, since it is designed to collect, store, manipulate and display geographic information (Lenzi and Di Luzio, 1997; Fedra, 1999).

The input data of the model could be affected by different uncertainties due to different sources such as measurement errors and uncertainties introduced by inadequate definition. Hence, the model may not be sufficiently reliable for correct conclusions (Crosetto et al., 2000). In this context sensitivity analysis, which contributes to understand how a given model depends upon the information fed into it, are applied to identify the relationships between the outputs and the inputs and to explore the most sensitive parameters. Since analyzing how much each individual input contributes to the output variance, parametric sensitivity analysis is crucial to the validation and calibration of numerical models. Sensitivity analyses generally involve the illustration of the impact of introducing small changes to specific input parameters on evaluation outcomes (Chen et al., 2010).

In this study, transport of total nitrogen (TN), total phosphorus (TP), and heavy metals in the Marmara Region was evaluated by means of GIS and SWMM. The purpose of the study is to develop a GIS-based catchment hydrology model and investigate the overland transport and total loads of contaminants in catchments that have different land uses by carrying out sensitivity analysis in order to determine the significant parameters affecting the model outcomes.

2. THEORETICAL BACKGROUND

2.1. Transport of Contaminants in Catchments

A land area which produces runoff that drains to an outfall point is called catchment. Rainfall-runoff process is the main component affecting the contaminant behaviour and transport in catchments. Surface runoff is the water flow that occurs when incoming precipitation, snow melt intensities, or other sources flows exceeds the infiltration capacity of the soil (Horton, 1933). In other words, surface runoff is the result of a complete saturation of the soil profile (Groenendijk et al., 2005).

The surface water input or precipitation that generates runoff consists of rainfall and snowmelt. The surface water input may accumulate on the surface in depression storage, or flow towards the streams as overland flow, or infiltrate into the soil. Infiltrated water can follow subsurface pathways, in which case it is called interflow or drain to deep groundwater, which may sustain the steady flow in streams that is called baseflow. When surface water input exceeds infiltration capacity, the excess water accumulates on the soil surface and fills small depressions. With continued precipitation, the depression storage capacity is filled and surface runoff occurs (Tarboton, 2003). Figure 2.1 illustrates infiltration and runoff process.

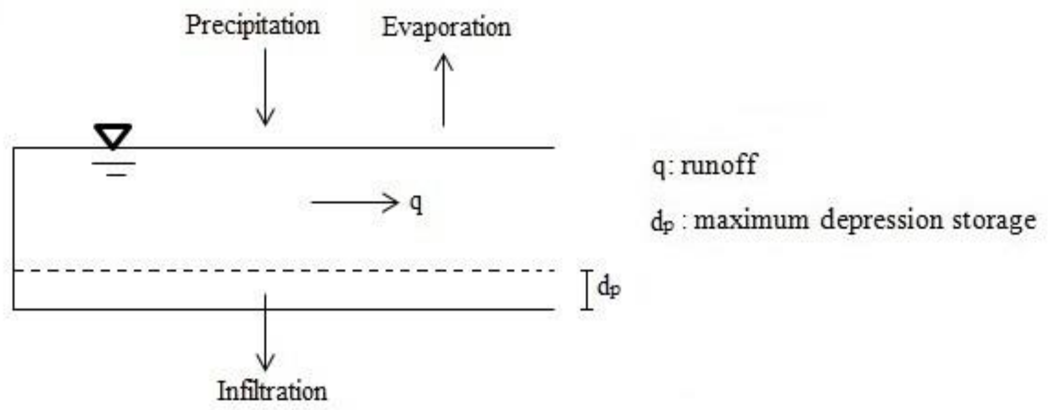


Figure 2.1. Infiltration and rainfall-runoff process in catchments.

Soil characteristics are critical for the partitioning of water at the surface and important for understanding contaminant transport by infiltration and runoff generation processes. Walton et al. (2000) carried out two different sets of experiments by the application of tracer and simulated rainfall to field scale plots and repacked soil cores. The results of their study showed that the quantities of solute in surface runoff varied greatly with soil type and structure. In this study, an empirical model developed by Sharpley et al. (1981), describing the kinetics of soil nutrient desorption and associated concentration of soluble nutrients in runoff during an event was used. The authors investigated the kinetics of P desorption for several soils at different water/soil ratios, during a short period of time, so that the results could be related to P release from agricultural soil to rainfall and runoff water. An exposure model supplied by RIVM (National Institute of Public Health and the Environment in The Netherlands) was chosen to predict heavy metal concentrations in soil pore water and runoff. According to the developed model for veterinary products by Montforts (1999), the antibiotic concentration and their capacity to adsorb to the organic material in the soil affect the concentration of those in pore water and soil, respectively. The model is also applicable for investigation of heavy metal contamination in soil and contributes to development of new model applications to assess the exposure and risk for humans (Lijzen et al., 2001; Popescu et al., 2013). The equations that supply concentrations of nutrients and heavy metals in surface runoff are given in detail in Chapter 3.3.2.

Contaminant transport by overland flow and the resulting water quality in catchments can be affected by several factors. Rainfall is the most significant parameter that has an influence on runoff (Horton, 1933), so different rainfall intensities influence transport of contaminants via surface runoff (Yuan et al., 2001; Shigaki et al., 2007; Visser et al., 2012). Another significant factor affecting the contaminant transport and water quality is the land use and land cover changes within the catchments. Agricultural activities have been identified as a dominant factor in generating large amounts of nonpoint source (NPS) pollution (Basnyat et al., 2000). Previous studies have also indicated a close relationship between water quality and urbanization. Urban expansion leads to an increase of the impervious area percentage significantly and a decrease of natural sinks for storm flows (Ouyang et al., 2012). This results in contribution to flood events and water quality impairment. The Nationwide Urban Runoff Program (U.S. EPA, 1983) revealed that storm water runoff from urban areas is a critical nonpoint source of pollution, which transports some of the same pollutants found in rural and agricultural runoff, such as sediment, nutrients, oxygen-demanding organic materials, pesticides, and also toxic contaminants, such as heavy metals (Bhaduri et al., 2000). While motor vehicles, industrial and commercial land uses are the major source of heavy metals, agricultural lands are the greatest contributors of nutrients to the environment. Furthermore, geographical features of the regions need to be considered. Casalí et al. (2008) implemented a study to illustrate the runoff and water quality of agricultural catchments. Two experimental catchments, which are similar with regard to soils, climate and land use were monitored. Difference in runoff generation, nitrate and phosphate yield were observed, which could be mainly due to differences in morphology, topography, and amount of stream channel vegetation between both sites.

2.2. Modeling Catchment Hydrology and Contaminant Transport

Hydrological models, mainly simulating processes such as runoff and the transport of pollutants in a catchment, are crucial for providing systematic and consistent information on water availability, water quality and management practices in the hydrological system (Yang et al., 2007). Hydrological models describe the physical processes controlling the transformation of precipitation to runoff (Setegn et al., 2009), while transport models are used as tools for assessment of pollutant loads in catchments. The main goals of water quality modeling are to characterize the runoff; provide data to receiving water analysis; determine effects, sizes and combination of different control approaches; perform frequency analysis of quality parameters; and provide input to cost-benefit analyses (Huber, 1986; Tsihrintzis and Hamid, 1997). Some of the important and widely used models for nonpoint source pollution are shown in Table 2.1.

Table 2.1. Characteristics of commonly used NPS models.

Model	Functions			Source
	Hydrology	Water Quality	Land Use	
ANSWERS (Aerial, Nonpoint Source, Watershed Environmental Response Simulation)	Surface runoff Subsurface flow	Sediment and nutrient loads to surface waters	Agricultural	Beasley and Huggins, 1981
ACTMO (Agricultural Chemical Transport Model)	Surface runoff Subsurface flow	Sediment, pesticide, and nutrient loads to surface waters	Agricultural	Frere et al., 1975
AGNPS (Agricultural Nonpoint Source)	Surface runoff Subsurface flow	Sediment and nutrient loads to surface waters	Agricultural	Young, 1986
ARM (Agricultural Runoff Management)	Surface runoff Subsurface flow	Sediment, pesticide, and nutrient loads to surface waters	Agricultural	Donigian and Davis, 1978
CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems)	Surface runoff	Sediment, pesticide, and nutrient loads to surface waters	Agricultural	Knisel, 1980
GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)	Subsurface flow	Sediment, pesticide, and nutrient loads to groundwater	Agricultural	Leonard et al., 1987
PRZM (Pesticide Root Zone Model)	Surface runoff Subsurface flow	Pesticide and nitrogen species movement in unsaturated zone	Agricultural	Suárez, 2005
SWAT (Soil and Water Assessment Tool)	Surface runoff Subsurface flow	Sediment, pesticide, and nutrient loads to surface waters	Agricultural	Arnold et al., 1994
HSPF (Hydrologic Simulation Program-FORTRAN)	Surface runoff Subsurface flow	Sediment, pesticide, and nutrient loads to surface waters	Agricultural and urban	Johanson et al., 1984
KINEROS (Kinematic Runoff and Erosion)	Surface runoff Subsurface flow	Sediment yield	Agricultural and urban	Woolhiser et al., 1990
STORM (Storage Treatment Overflow Runoff Model)	Surface runoff Subsurface flow	Sediment and nutrient loads to surface waters	Urban	USACE, 1977
SWMM (Storm Water Management Model)	Surface runoff Subsurface flow	Sediment and nutrient loads to surface waters	Urban	Huber and Dickinson, 1988

SWMM, one of the most suitable models used specifically for urban runoff pollution and assessing the environmental impact of land use change (Singh, 2012), is used in present study.

In the literature, different modeling approaches have been developed to investigate the transport of organic pollutants, nutrients and metals. In most of the modeling studies, hydrology, sediment load and transport, organic carbon yield and nutrient loads in agricultural catchments have been assessed by using mathematical descriptions (Varanou et al., 2002; Baginska et al., 2003; Oeurng et al., 2011). The performance and suitability of some of these models have also been evaluated by the literaute (Haregeweyn and Yohannes, 2003; Shamshad et al., 2008; Xie and Lian, 2013). For example, Oeurng et al. (2011) applied the SWAT model to evaluate catchment hydrology and associated particulate organic carbon yield in south-west France using historical flow and meteorological data. The model predicted the partition of surface runoff in mean annual catchment precipitation and an empirical correlation between annual water and organic carbon yield was developed. A simple model was developed by Vadas et al. (2008) to predict fertilizer P release during rain and the concentration of dissolved P in runoff since field or catchment scale computer models often do not simulate direct transfer of fertilizer P to runoff. The model can be incorporate into more complex P transport models, to improve their ability to predict P loss to the environment for a variety of agricultural land uses. In another study the efficiency of vegetative filter strips was modeled with a numerical model which was used to predict overland flow and sediment trapping within the filter for controlling surface runoff pollution from phosphate mining sand tailings (Kuo and Muñoz-Carpena, 2009).

The transport behavior of heavy metals strongly interacts with dissolved organic matter (DOM); therefore, complexation with DOM is additionally considered in most studies for accuracy of transport models (Weng et al., 2002; Tipping et al., 2003; Michel et al., 2007). A preliminary model was developed by Yuan et al. (2001) to predict heavy metal loading from an urban catchment by considering rainfall character in the catchment area and partitioning of the metal forms between dissolved and particulate phases of suspended sediments. In addition, the study of Visser et al. (2012) that was implemented in

The Netherlands assessed the effects of future projected climate change on the hydrology and the leaching of heavy metals (Cd and Zn) in the catchment by using 100-year simulated daily time series of precipitation including future climate scenarios.

2.3. Modeling Catchment Hydrology with SWMM

The EPA Storm Water Management Model (SWMM) is a comprehensive hydrological and water quality simulation model developed primarily for urban areas (Huber and Dickinson, 1988). It is capable of both single event and long-term (continuous) simulation of runoff quantity and quality within a catchment. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (Rossman et al., 2004).

SWMM, which was developed in 1971 (Metcalf and Eddy, 1971) , has been widely used throughout the world for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. It is a distributed model, which means that a study area can be subdivided into any number of irregular subcatchments to best capture the effect that spatial variability in topography, drainage pathways, land cover, and soil characteristics have on runoff generation (U.S. EPA, 2009). The example system layout is shown in Figure 2.2.

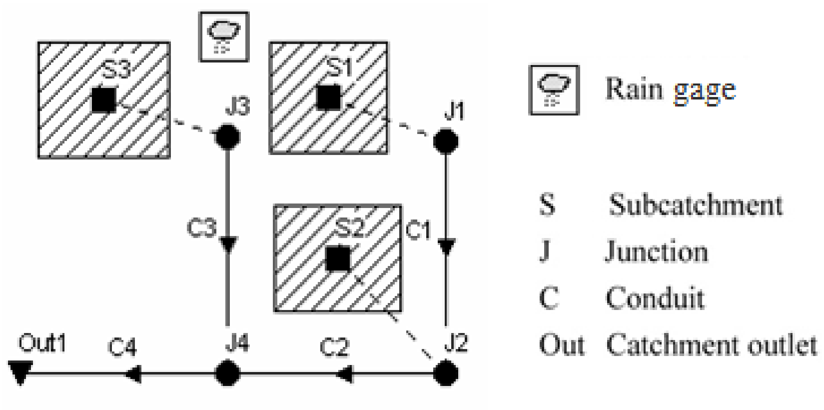


Figure 2.2. Example system layout of SWMM (Rossman et al., 2004).

Rain Gages supply precipitation data for one or more subcatchment areas in a study region. A subcatchment is an area of land containing a mix of pervious and impervious surfaces, whose runoff drains to a common outlet point, which could be either a node of the drainage network or another subcatchment. Junctions are drainage system nodes, where links join together. Physically they can represent the confluence of natural surface channels, manholes in a sewer system, or pipe connection fittings. External inflows can enter the system at junctions. Conduits are pipes or channels that move water from one node to another in the conveyance system. Their cross-sectional shapes can be selected from a variety of standard open and closed geometries. SWMM uses the Manning equation (Eq. 2.1) to express the relationship between flow rate (Q), cross-sectional area (A), hydraulic radius (R), and slope (S) in open channels and partially full closed conduits (Rossman et al., 2004).

$$Q = \frac{1.49}{n} \times A \times R^{2/3} \times \sqrt{S} \tag{2.1}$$

where n is the Manning roughness coefficient.

Outfalls are terminal nodes of the drainage system used to define final downstream boundaries under Dynamic Wave flow routing. For other types of flow routing they behave as a junction. Only a single link can be connected to an outfall node (Rossman et al., 2004).

SWMM is amongst the most widely used urban water quality simulation models. Ouyang et al. (2012) analyzed the concentration of chemical oxygen demand (COD), total suspended solids (TSS), and total phosphorus (TP) in the runoff and expressed the different impervious rates of underlying surfaces during the storm runoff process with SWMM in order to identify the removal rates of the pollutants and their interactions with precipitation and underlying surfaces. A similar study was implemented by Tsihrintzis and Hamid (1998) by using SWMM to simulate the quantity and quality of urban storm water runoff from four relatively small sites in South Florida, each with a specific predominant land use. In their study, the authors used biological oxygen demand (BOD_5), total suspended solids (TSS), total Kjeldahl nitrogen (TKN) and lead (Pb) for calibration of the model.

2.4. Use of Geographical Information Systems in Catchment Modeling

A Geographic Information System (GIS) is a system that integrates data for capturing, managing, manipulating, analyzing, and displaying all forms of geographically referenced information. In other words, GIS can be thought of the merging of cartography, statistical analysis, and computer science technology, which allows for modeling and analysis with raster (cell-based) data with the aid of the program's spatial analyst tool. This includes creating density surfaces and conducting map algebra. GIS have become an important tool for many decades to access the spatially and temporally varying data required to successfully use hydrological and NPS pollution models (Tsihrintzis and Hamid, 1997). GIS including digital elevation maps supply topographical data, such as elevation, slope, area, and subcatchment width, to conceptualize hydrological models. In addition, analysis tool and calculation components in such programs that are combined with time series rainfall and land cover data facilitate the visualization and creation of backdrop image.

Literature illustrates that multivariate statistical analyses and transport models integrated with GIS facilitates to identify the contaminants and their spatial patterns in soil and catchments by spatial data management combined with temporal variable simulation (Lenzi and Di Luzio, 1997; Facchinelli et al., 2001; Zhang, 2006). There are several studies that involve the catchment scale modeling integrated with GIS. These studies generally include agricultural nonpoint source (AGNPS) pollution models for nutrient transport. A comparative study was carried out by Huang and Hong (2010) to simulate diffuse nitrogen and phosphorus pollution in a medium-sized catchment. The study indicated that the GIS-based empirical model has its advantage in extensive studies as a decisions support tool for preliminary design, while AnnAGNPS has its advantage in detailed emission assessment and scenario development. In another study carried out by Basnyat et al. (2000), a land use/land cover-nutrient-linkage-model integrated with GIS and remote sensing analysis tools was developed to determine nitrate pollution `contributing zones' within a given basin. Strager et al. (2010) carried out catchment analysis with GIS in to support decision making and the management of water resources by putting in overland flow path model that indicates optimum water quality sampling locations, flow estimation for all streams in an identified area, an instream water quality and loading model for pollutant levels.

While several studies are encountered concerned with nutrients, the modeling studies with GIS are scarce for metals at catchment scale. Bhaduri et al. (2000) investigated the impact of urban/impervious areas and land use change on annual runoff volume and NPS pollution at catchment scale by using a long-term hydrologic impact assessment (L-THIA) model with GIS. The study state the variation of annual nutrient and heavy metal (copper, lead, and zinc) loads as a consequence of the land use change. In addition, spatial variation of the heavy metals in estuary or marine sediments based on GIS-mapping technique was examined (Zhou et al., 2007; Delgado et al., 2010) and statistical analyses were integrated with GIS to identify heavy metal sources in soil (Facchinelli et al., 2001). Ng et al. (2009) applied GIS-based interface module together with a complex three-dimensional hydrodynamic, sediment and heavy metal transport numerical model, which enhances communication of relationships and trends of hydrodynamic and pollutant transport simulation in both spatial and temporal context and thus promotes better coastal water quality planning and management.

In the literature, the semi-distributed rainfall-runoff models supported by GIS were developed for a limited consideration of spatial heterogeneity of hydrological characteristics within the catchments (Schumann, 1993**;** Smith et al., 2005). For this reason, the study aimed to conceptualize a semi-distributed hydrological and transport model via using the time series rainfall data and different values of subcatchments, such as area, width, land use and percent imperviousness with lumped parameters.

2.5. Parameter Sensitivity Analysis

The uncertainties of data inputs in numerical models also in GIS applications affect the accuracy of the output. For this reason, sensitivity analysis is applied to identify parameters of computational models and explore the relationship between the output and the inputs. Sensitivity analysis can be described as the process of determining model output sensitivity to changes in its input parameters. Sensitivity analysis of a mathematical model investigates how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input (Hamby, 1995) and involves analytical examination of input parameters to aid model validation and to provide guidance for future research and data requirements (Guven and Howard, 2011). According to Mulligan and Wainwright (2004), sensitivity analyses and subsequent derived information can be used for several purposes including:

- better understanding the behavior of the model, particularly in terms of parameter interaction;
- verification of models;
- ensuring model parsimony by the rejection of parameters or processes to which the model is not sensitive;
- targeting field parameterization and validation programs for optimal data collection; and
- providing a means of better understanding parts of or the whole system being modeled.

Sensitivity analysis methods can be classified as, mathematical, statistical and graphical. Mathematical methods typically involve calculating the output for a few values of an input that represent the possible range of the input and do not address the variance in the output due to the variance in the inputs, but they can assess the impact of range of variation in the input values on the output (Morgan and Henrion, 1990). Statistical methods involve running simulations in which inputs are assigned probability distributions and assessing the effect of variance in inputs on the output distribution. They allow one to identify the effect of interactions among multiple inputs. Graphical methods are used to give visual indication of how an output is affected by variation in inputs and complement the results of mathematical and statistical methods for better representation (Frey and Patil, 2002).

In sensitivity analysis, a common approach in order to evaluate the sensitivity of the model to input variables and parameters is one-at-a-time method, which is carried out by changing one factor at a time, while holding the others fixed. In literature there are several sensitivity analysis associated with catchment scale modeling some of which are integrated with GIS software. Muleta and Nicklow (2005) applied sensitivity analysis coupled with automatic calibration for a distributed catchment model. They identified parameters of SWAT model that contribute most to the variability of stream flow and sediment yield; thus, those that should be calibrated. Parameter sensitivity analysis was conducted constructing regression model and using correlation analysis. A study in Ethiopia was carried out to test and validate the AGNPS model integrated with GIS in Kori catchment and parametric sensitivity analysis was conducted to guide calibration efforts (Mohammed et al., 2004). In another study, runoff and sediment yield of an agricultural catchment in India were modeled by using the Water Erosion Prediction Project (WEPP) model with GIS and sensitivity analysis was carried out for the input parameters. The analysis shows that the sediment yield is highly sensitive to interrill erodibility and effective hydraulic conductivity, whereas, runoff is sensitive to effective hydraulic conductivity only (Pandey et al., 2008).

3. METHODOLOGY

A semi-distributed, physically-based catchment hydrology model was developed for the Marmara Region, to investigate the relationships between surface runoff quality, basin topography, and meteorological variables. Geographical Information Systems (GIS) and Storm Water Management Model (SWMM) were used as major modelling tools for catchment delineation, runoff and pollutant load estimation, respectively. Furthermore, a one-at-a-time parameter sensitivity analysis was carried out to determine the significant parameters affecting those variables. Figure 3.1 represents the methodology scheme and the parameters that are investigated in study are illustrated in Table 3.1.

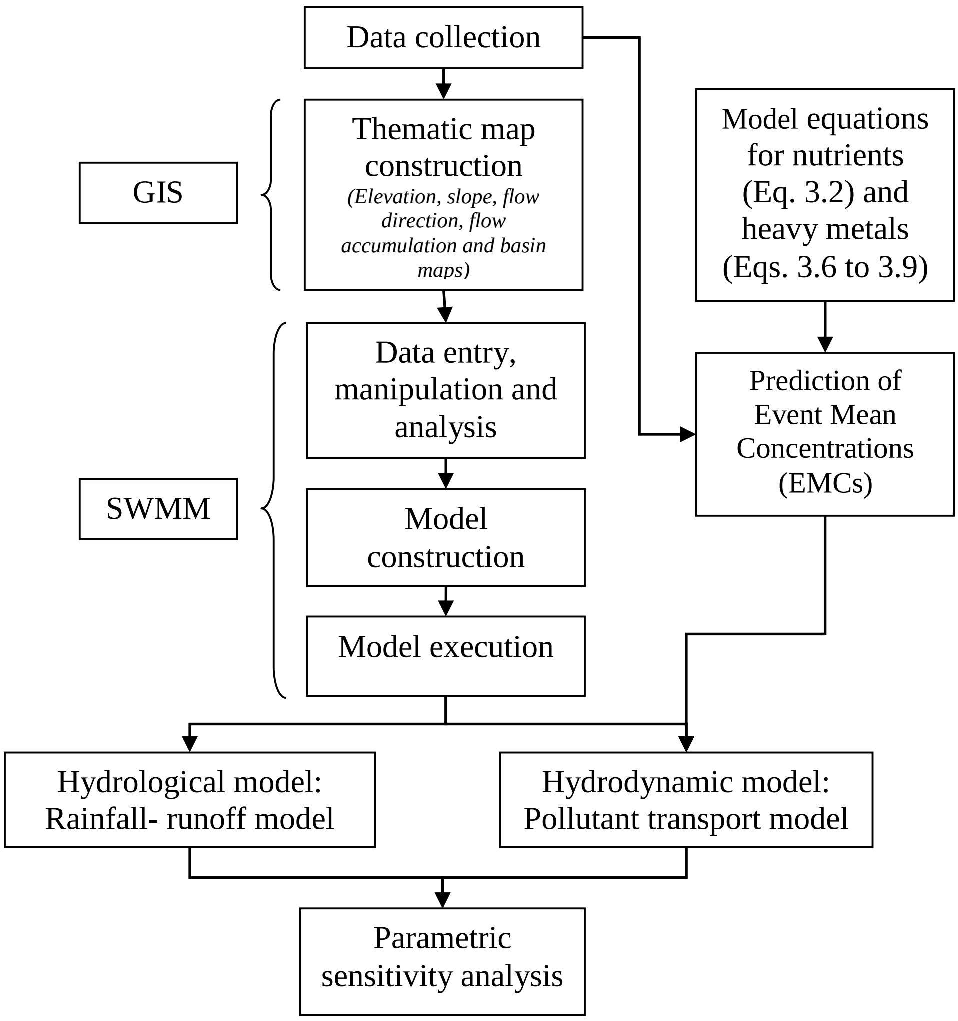


Figure 3.1. Methodology scheme.

Table 3.1. The analyzed parameters in soil samples.

Nutrients	Metals
Total Nitrogen	Cu
Total Phosphorus	Ni
	Zn

3.1. Study Area

Marmara Region is situated in the northwest of the country and occupies the 8.5 % of the Turkey with an area of 67000 km^2 approximately (Figure 3.2). There is a dense stream network throughout the region which consists of three catchments: Meriç-Ergene, Marmara, and Susurluk. The main rivers are Sakarya, Ergene, Susurluk, Meriç and Biga. The area also includes many natural and artificial lakes such as Büyükçekmece, Küçükçekmece, Durusu, İznik, Sapanca, Ulubat, and Manyas. The climatic characteristics of the Black Sea influences the north of the region, while the typical Mediterranean climate prevailing in its south. Precipitation averages about 600-700 mm annually and mainly falls between November and January. Average annual temperature is between 14^{o}C and 16^{o}C and the mean monthly temperatures range from 5^{o}C in coldest months to 25^{o}C in warm seasons (Munsuz and Ünver, 1983).

The Marmara Region generally has the slightly undulating lands. The mountains found in the northwest of the region and South Marmara, particularly Uludağ with a height of 2543 m, is the main altitudes in the area. Land use activities in the region include residential, industrial and agricultural practices. Currently about 30% of the region is arable land with intense agricultural activities and 11.5% is woodland. Forests are found particularly in Trakya region at high elevations. Major agricultural products growing in the region are wheat, sunflower, corn, sugar beads, rice, olives and vineyards. Map of the study area are shown in Figure 3.2.

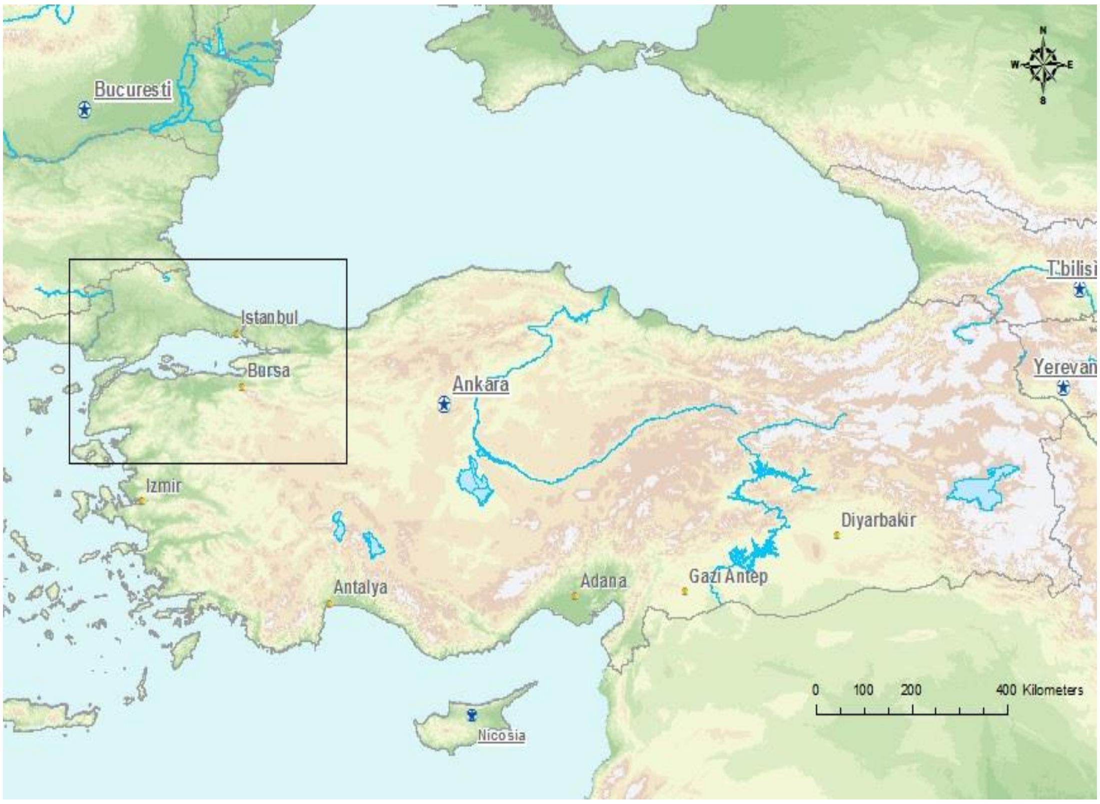


Figure 3.2. Map of the study area.

3.2. Modeling Catchment Hydrology

3.2.1. Catchment Delineation Using GIS

The data required for hydrological and hydrodynamic modeling involve spatial and temporal data. For this purpose, GIS including digital elevation maps were used to obtain topographical data, such as elevation, slope, area, and width, and to prepare the background map to be used for the hydrological model. Spatial analyst tool of the ArcGIS 10 program were combined with precipitation and land cover data for the construction of the backdrop image, and basin tool of the program was used to delineate the 51 catchments in the Marmara Region.

Digital elevation map layer were added to the ArcGIS software as backdrop to create digital elevation model (DEM) and to produce maps with the required topographical information. The coordinates of the soil sampling sites were entered to determine the spatial boundaries of the study area. The representation of the backdrop image is presented below in Figure 3.3.

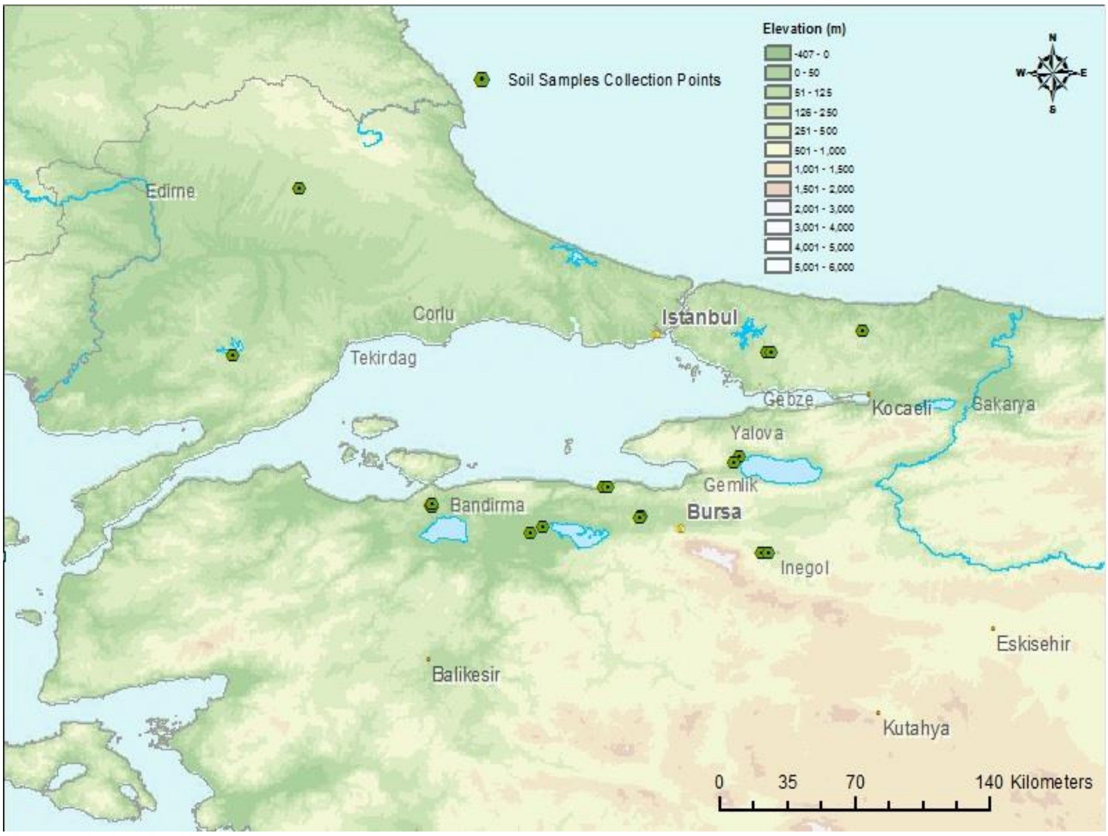


Figure 3.3. Backdrop image and soil samples collection points of the study area.

Surface elevation is the key in determining most of the GIS based maps, such as slope, flow direction and flow accumulation. Since every pixel of the digital elevation map includes elevation and coordinate information, it is used as base map. Using the spatial analyst tool of ArcGIS, maps regarding gradual elevation and slope were produced in Figures 3.4 and 3.5, respectively.

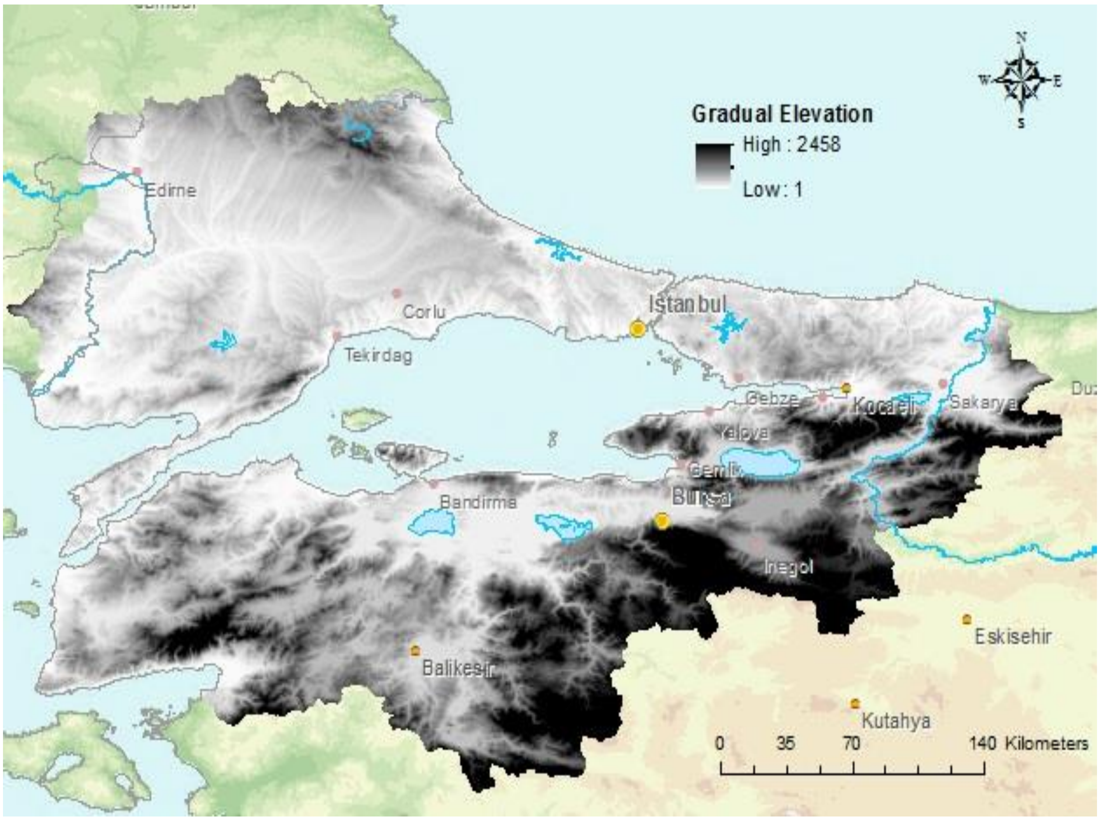


Figure 3.4. Gradual elevation map.

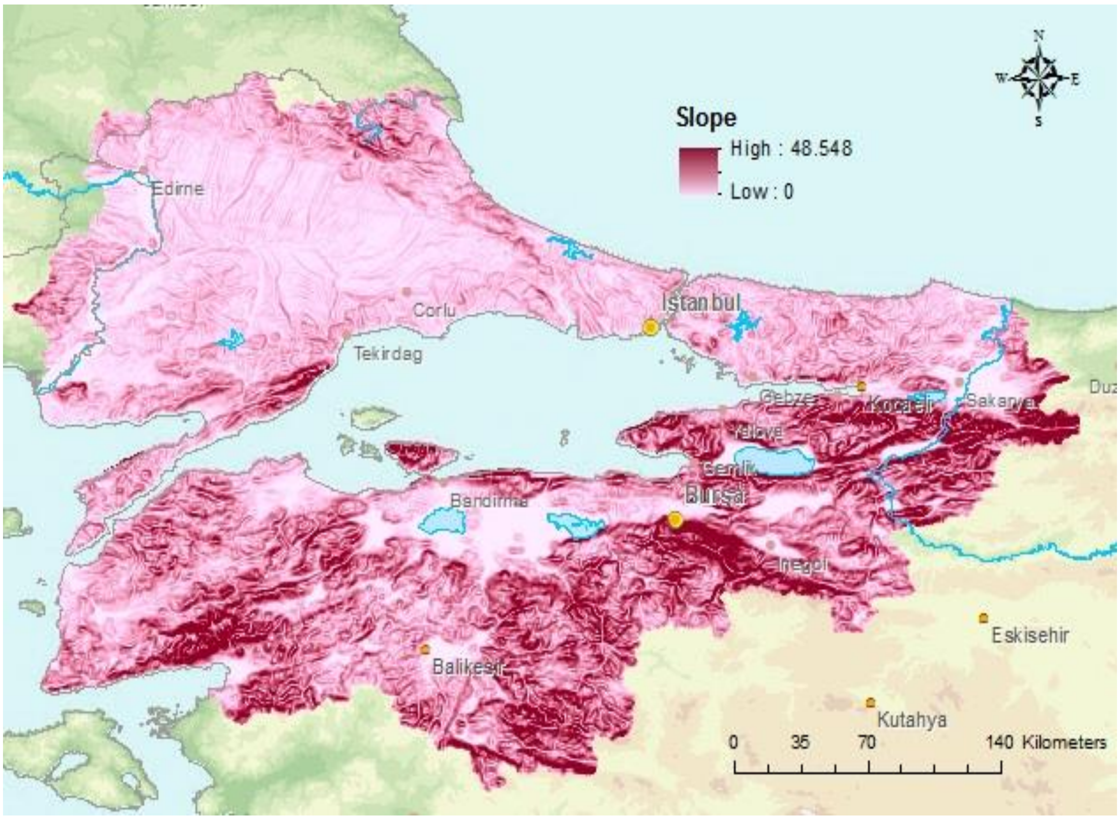


Figure 3.5. Gradual slope map.

One of the most significant factors governing the catchment hydrological behaviour is the direction of flow, which can determined by the "Flow Direction" function of the ArcGIS for every cell in the grid by using elevation and slope information. This function also acts as a preceding step for accessing flow accumulation information and determining catchment boundaries in the region by creating associated maps of flow direction and flow accumulation as represented in Figure 3.6 and 3.7, respectively. The output of flow direction is an integer raster whose values range from 1 to 128 and each color in the map corresponds to such value range. The values for each direction from the center are given in Figure 3.6.

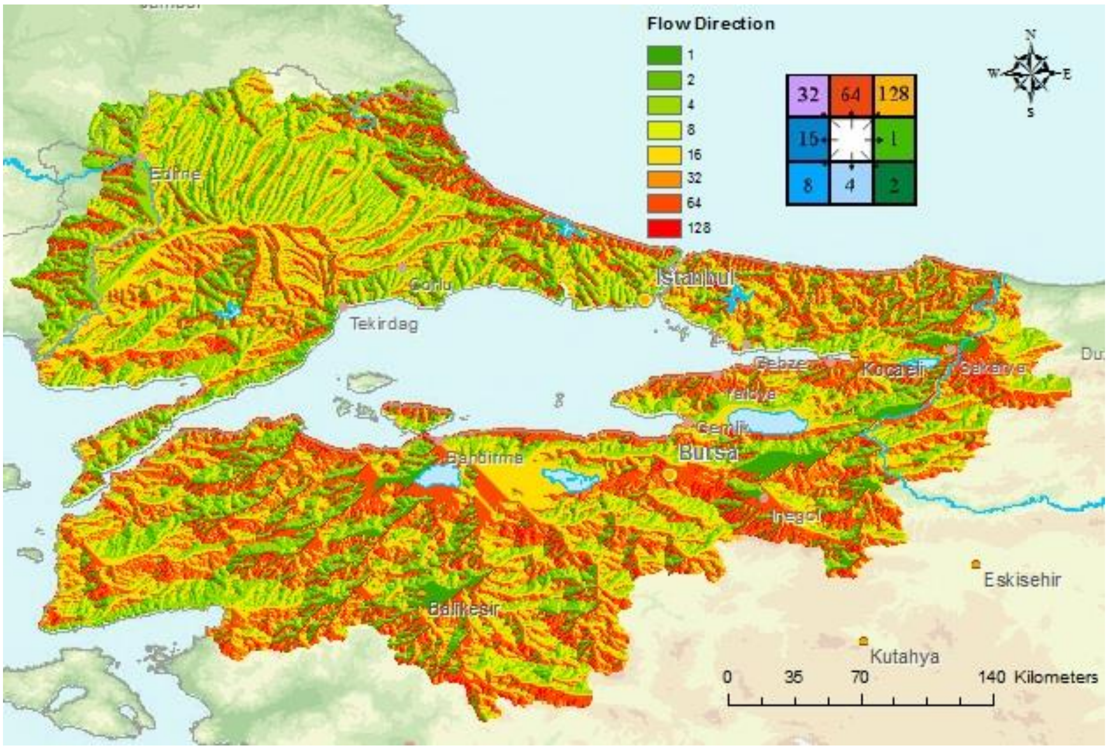


Figure 3.6. Flow direction map.

After the direction of flow were determined in each cell, the stream network, which will provide river lengths, widths, elevations, and coordinates in modeling stage was created by using "Flow Accumulation" function of the spatial analyst tool. Subsequently, the catchment boundaries were delineated by using the "Basin" tool of ArcGIS, which analyzes the input flow direction raster to find all sets of connected cells that belong to the same drainage basin. The drainage basins were delineated by locating the pour points at the edges of the analysis, raster then identifying the contributing area above each pour point.

Figure 3.8 shows the map of the discretizated catchments which were projected over the flow accumulation map.

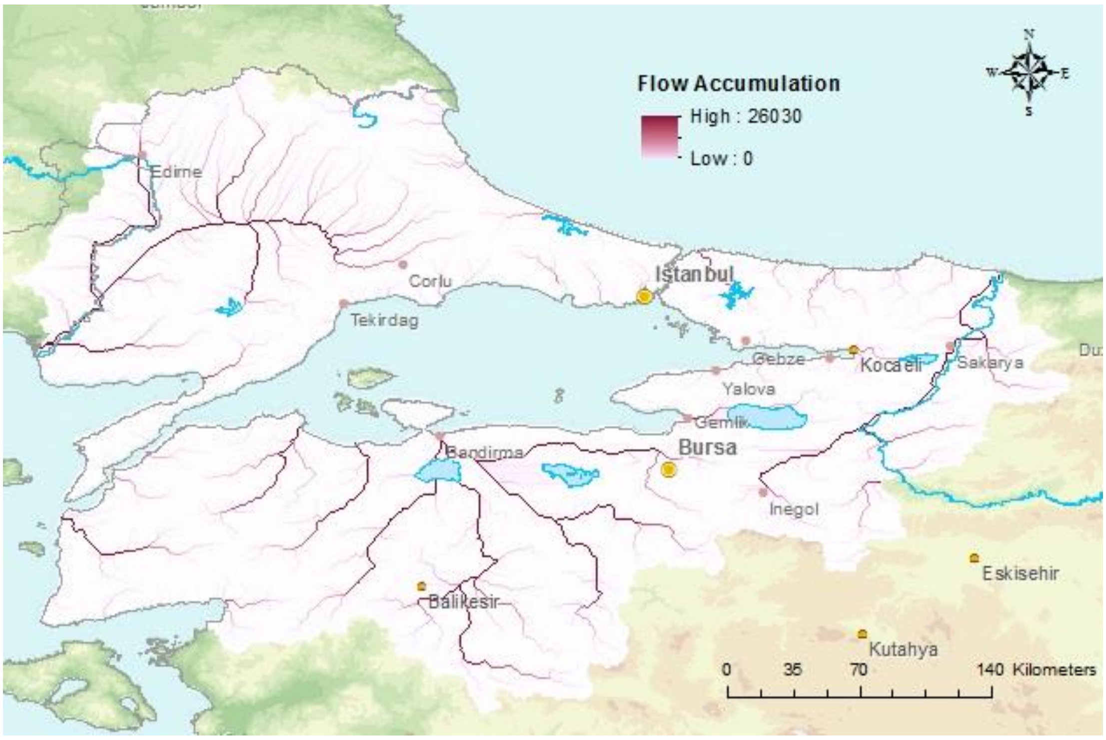


Figure 3.7. Flow accumulation map.

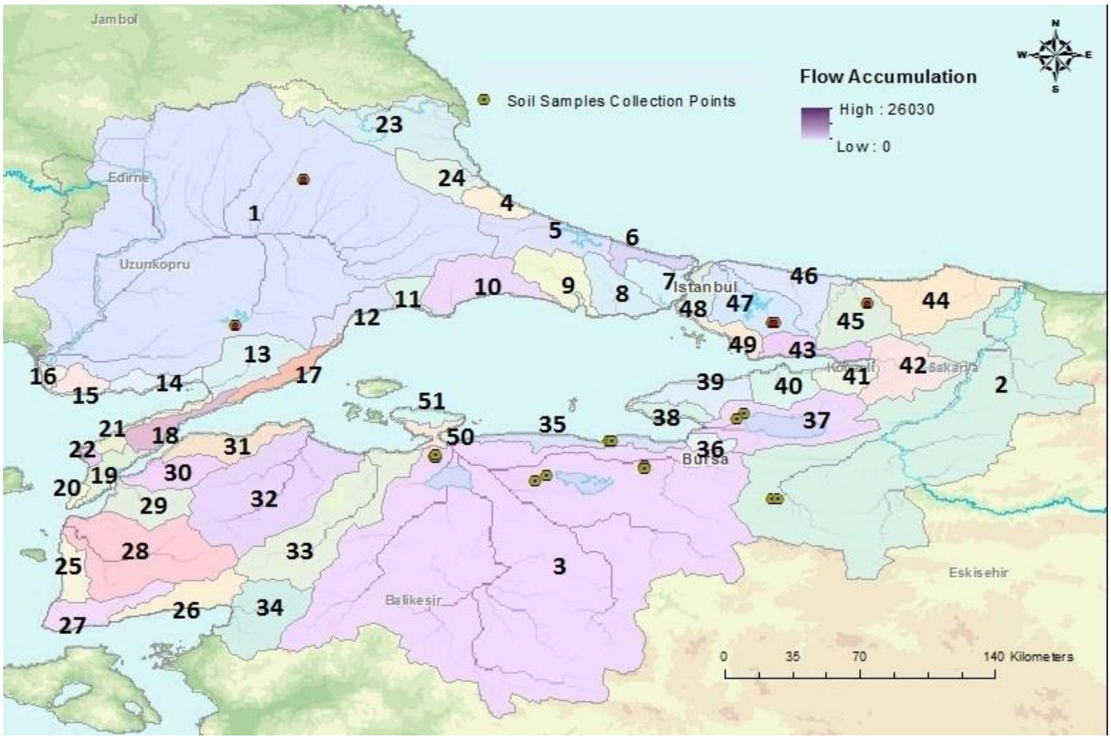


Figure 3.8. The discretizated catchments.

3.2.2. Input Data Requirements and Hydrological Modeling with SWMM

The topographical data and discretizated catchments obtained by ArcGIS were transferred to SWMM for the construction of the hydrological model. SWMM model was preferred because of its suitability for hydrological modeling procedure in urban areas (Huber and Dickinson, 1988) and convenience to operate with spatial interface.

The catchment map created in GIS (Figure 3.8) was used as backdrop map in SWMM to visualize the study area. The coordinate system of the backdrop image was converted to GIS coordinate system to be able to locate the precipitation stations and to draw hydrological elements more accurately. In order to increase the sensitivity and accuracy of the hydrological model, the catchments were divided into 499 subcatchments as provided in Figure 3.10. In addition to the subcatchments, the junctions of the rivers and rain gages were also placed and the conduits indicating the stream network were drawn. Input parameters including topographical and land use data, which were obtained by using GIS, precipitation data, and other data produced by the SWMM were entered to the model to make the program run properly. A schematized representation of the modeling procedure flow is given in Figure 3.9.

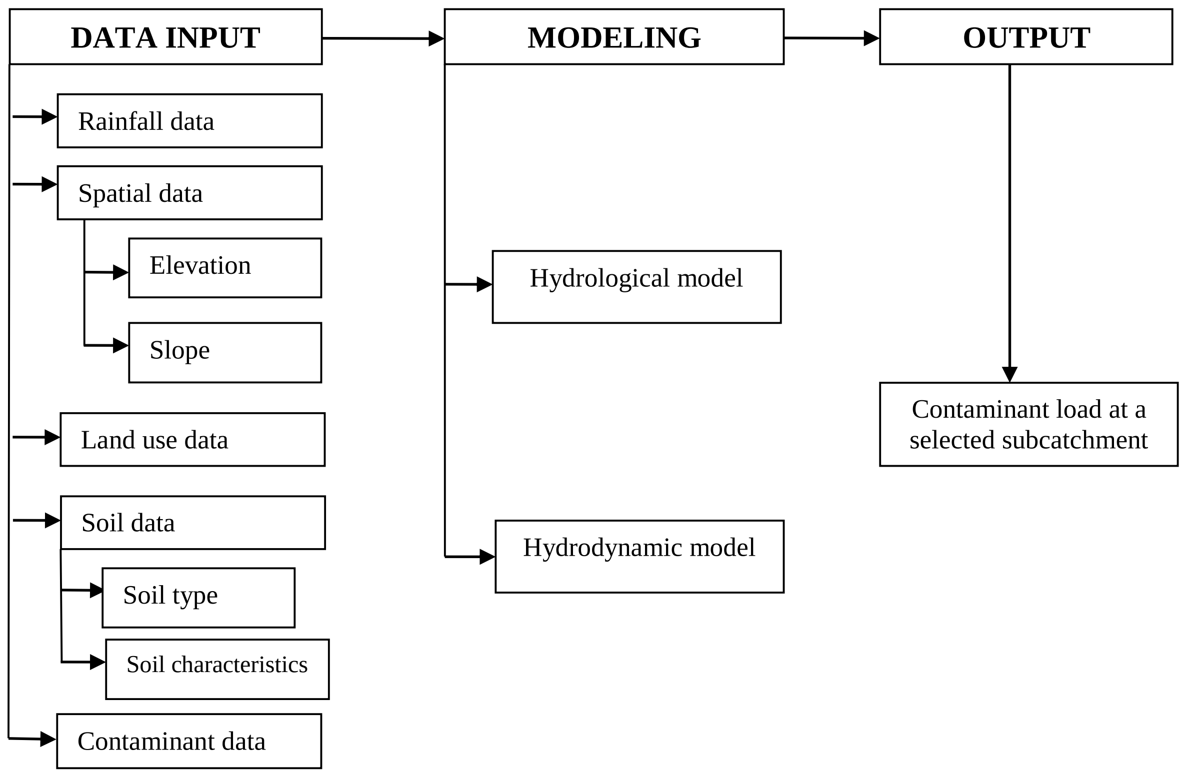


Figure 3.9. A schematized representation of the modeling procedure and associated data requirements.

Availability of daily precipitation data is particularly crucial to develop and run hydrological models as conversion of rainfall to runoff is the first step in most of the models dealing with catchment hydrology (Varanou et al., 2002; Shigaki et al., 2007; Visser et al., 2012). In this study, the required meteorology stations and their available latitudes and longitudes were arranged by using the rainfall data of the country collected by Turkish Meteorological Service stations. Twenty six precipitation stations within the study area boundary, generally located in city centers of the Marmara Region, were chosen to provide daily precipitation data for the years 1950 to 2005, to be transferred to SWMM program. These stations and corresponding coordinates are represented in Table 3.2.

Table 3.2. Precipitation stations and their locations.

Location Name	Latitude (N)	Longitude(E)
BAHÇEKÖY	41.17	28.94
BALIKESİR	39.63	27.88
BANDIRMA	40.35	27.97
BURHANİYE	39.5	26.98
BURSA	40.18	29.07
ÇANAKKALE	40.15	26.42
ÇINARCIK	40.65	29.12
ÇORLU	41.17	27.8
EDİRNE	41.67	26.57
EDREMİT	39.6	27.02
FLORYA	40.98	28.75
GEYVE	40.52	30.3
GÖNEN	40.1	27.65
GÖZTEPE	40.97	29.08
İPSALA	40.93	26.4
KARTAL	40.9	29.18
KİREÇBURNU	41.17	29.04
KIRKLARELİ	41.73	27.23
KOCAELİ	40.78	29.93
KUMKOY	41.25	29.03
MALKARA	40.9	26.92
SAKARYA	40.78	30.42
ŞİLE	41.18	29.61
TEKİRDAĞ	40.98	27.55
YALOVA	40.65	29.27
YENİŞEHIR	40.25	29.65

It is possible to classify the variables and parameters under two categories as the quantities describing subcatchment and hydraulic characteristics. These parameters and variables, which are required to construct and run the hydrological model, are given in Table 3.3.

Topographical data of the study area describing the characteristics of subcatchments such as area, width and slope and hydraulic parameters of the rivers were determined via GIS. Manning's coefficient, depression storage depths, and channel roughness were obtained from the literature. Values, descriptions and corresponding literature sources for these parameters are provided in Table 3.4.

Table 3.3. The parameters required for the hydrological model.

Subcatchment Characteristics	**Hydraulic Characteristics**
Area	Initial elevation of junction
Width	Conduit length
% Slope	Max depth
% Imperviousness	Channel roughness
Land use	Channel slope

Table 3.4. Input data for subcatchments and conduits.

Parameter	**Value**	**Description**	**Source**
N-imperv	0.011	Manning's n for overland flow over the impervious portion of the subcatchment	McCuen et al., 1996
N-perv	0.13	Manning's n for overland flow over the pervious portion of the subcatchment	
D-store-imperv	1.27	Depth of depression storage on the impervious portion of the subcatchment (mm)	ASCE, 1992
D-store-perv	3.8	Depth of depression storage on the pervious portion of the subcatchment (mm)	
Conduit Roughness	0.03	Manning's roughness coefficient	ASCE, 1982

Runoff volumes produced in subcatchments are highly affected by the changes in land use categories, such as residential, commercial and rural areas. Obtaining an average runoff volume is required in order to assess the mean load of the pollutants in surface runoff. In this respect runoff coefficients were used to help to characterize the amount of runoff produced in each subcatchment. SWMM produces runoff coefficients and applies the well-known rational method (Eq. 3.1) for each subcathment area to establish a relationship between time-series precipitation and surface runoff.

$$\text{Runoff} = \text{subcatchment area} \times \text{annual rainfall} \times \text{runoff coefficient} \qquad (3.1)$$

The model was initially run with 51 catchments, which were generated by the “Basin” tool of the GIS; however, the runoff production of the model was unsatisfactory, considering the expected relationship between rainfall and runoff. It was seen that the runoff amounts were not very sensitive to the variations in rainfall data, probably as a consequence of the larger areas constituted by the catchments. Therefore, the catchment was further divided into 499 subcatchments in SWMM, as indicated in Figure 3.10, to increase the sensitivity of the model, since area of subcatchments is one of the most sensitive parameters in catchment hydrology modeling.

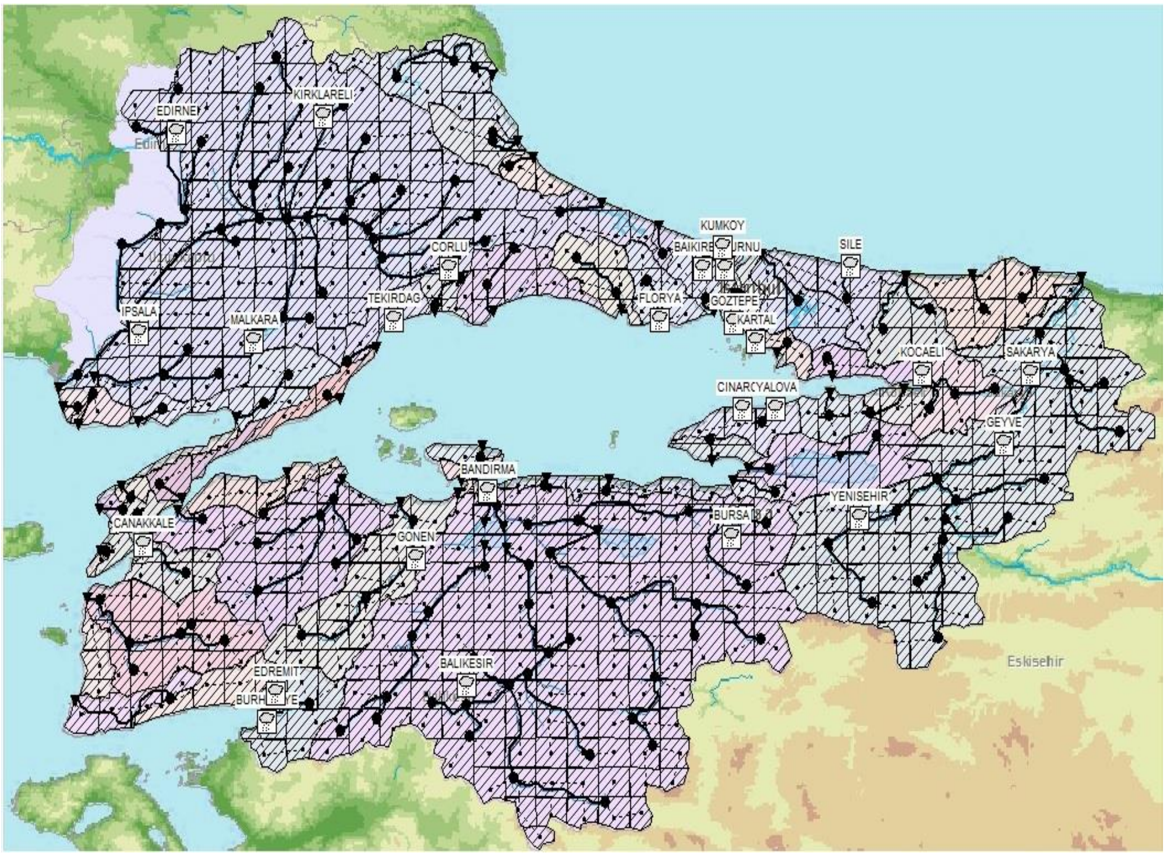


Figure 3.10. SWMM layout map with precipitation stations, subcatchments, and hydraulic objects.

The percent imperviousness values used for the estimation of surface runoff were determined by the help of land use information, which is available for the year 2005, within the catchment boundaries. This information was derived from the GIS based maps, which also included the land use and land cover data of the provinces, and were obtained from Republic of Turkey Ministry of Food, Agriculture and Livestock. The maps illustrating the residential, commercial and rural areas were transferred to SWMM, and each subcatchment was magnified to be able to analyze the land use percentages. Examples of land use maps showing the residential areas in a selected region and corresponding SWMM layout map with residential areas added are illustrated in Figures 3.11 and 3.12, respectively. An example of a detailed examination of the land use percentages for a selected subcatchment (S402) is also presented in Figure 3.13.

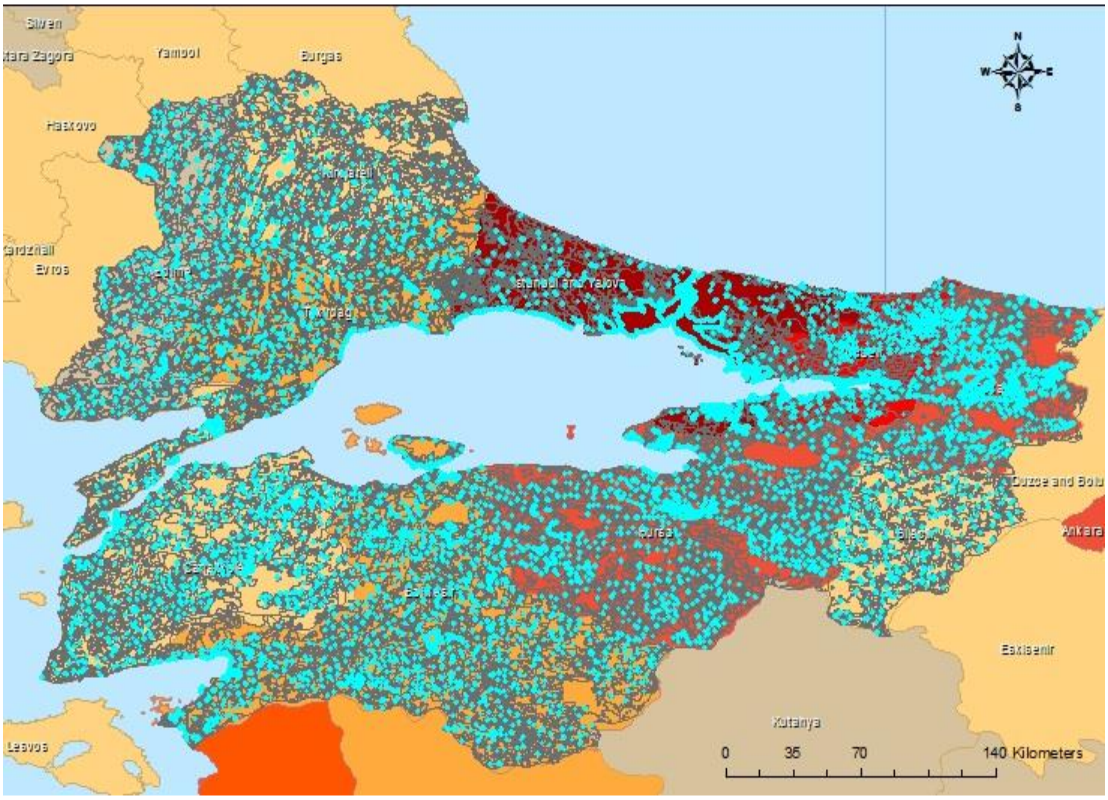


Figure 3.11. Map of residential areas (Residential areas are represented by blue polygons).

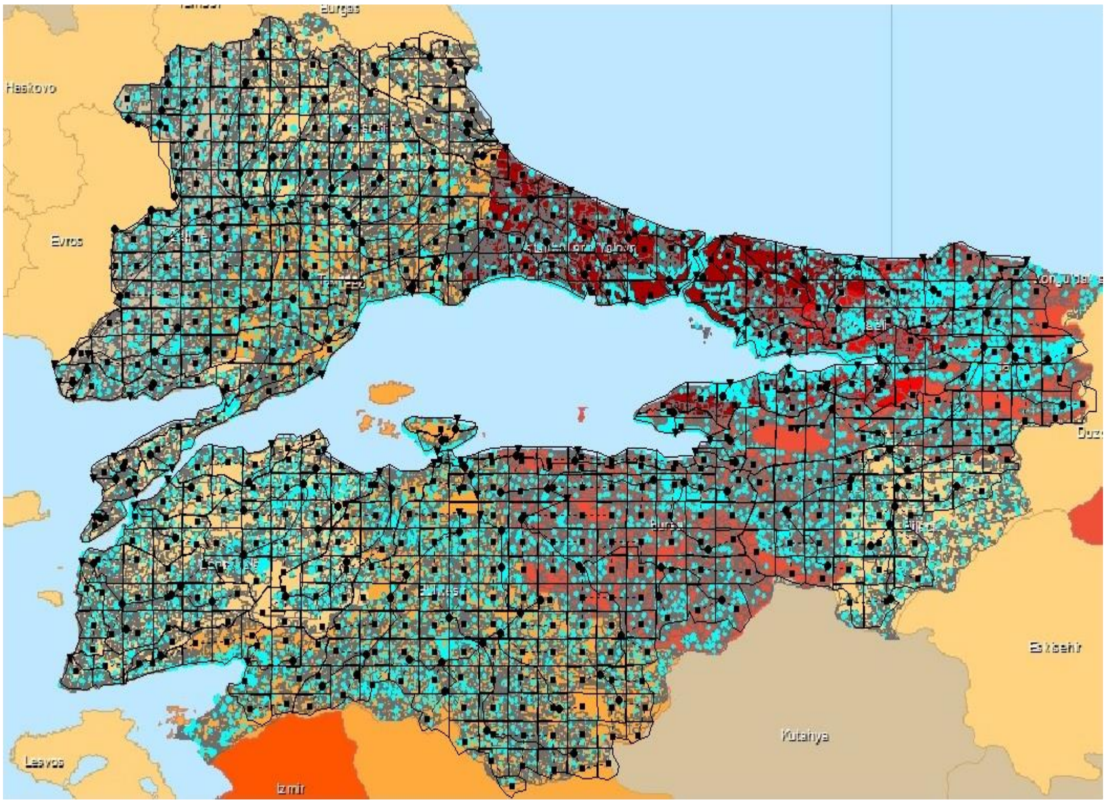


Figure 3.12. SWMM layout map with residential areas (Residential areas are represented by blue polygons).

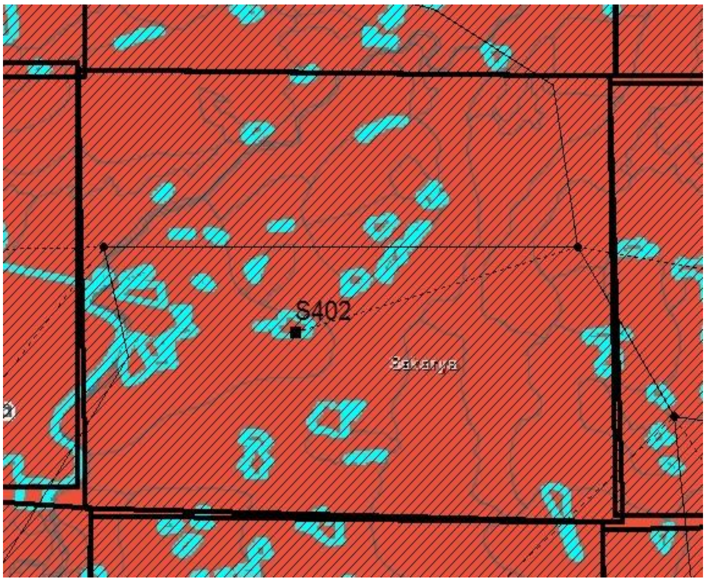


Figure 3.13. Image of the residential areas in subcathment S402.

The imperviousness values for all subcatchments were estimated via using runoff coefficients that are corresponding to 3 main land use classes; commercial, residential and rural, are taken from the literature (U.S. EPA, 2009). These values, together with the percentages of land use classes and slope are represented in Table A.1.

In the present modeling study, the topographical and land use characteristics of each subcatchment, such as area, width, and % imperviousness were calculated by using GIS. The hydraulic characteristics of rivers, such as junction elevation, conduit length, and channel slope were also estimated via GIS based maps by taking into account the spatial distributions of such parameters. On the other hand, maximum depth of the channels, Manning's coefficient, depression storage depths, and channel roughness values were selected from the literature and the average percent slope values of 51 catchments were considered as lumped parameters and a semi-distributed hydrological model was developed.

3.3. Modeling Contaminant Transport

3.3.1. Data Requirements

Soil type and characteristics are required to investigate the sorption behavior of contaminants and subsequent transport and load of those to receiving waters. According to a fate study carried out by Balcıoğlu et al. (2007), 30 manure applied soil samples collected from 10 different agricultural locations of the Marmara Region were analyzed and nitrogen, phosphorus and heavy metal concentrations were determined. The contaminants detected in soil samples and analyzed soil characterizations such as; texture, pH value, percent of water content of agricultural lands that are determined in the report (Balcıoğlu et al., 2007) are given in Table 3.5. In addition, land use data obtained by GIS-based maps and further input data required to predict contaminant loads are also given in Table 3.5.

Table 3.5. Data requirements for water quality modeling.

	Input Data	Source	Estimated Further Input Data
Soil Data	Soil texture (% clay, sand, silt)	Balcıoğlu et al., 2007	Fraction water in soil
	pH		
	Organic carbon content		Fraction solids in soil
	Water content		
	Soil texture type	USDA NRCS, 2011	Density of soil solids
	Fresh bulk density of soil	USDA NRCS, 2012	
Contaminant Data	**Nutrients:** TN and TP concentrations in soil	Balcıoğlu et al., 2007	TN and TP concentrations in runoff
	Heavy metals: Cu, Zn, and Ni concentrations in soil Soil partition coefficients	Balcıoğlu et al., 2007	Cu, Zn, and Ni concentrations in porewater
		U.S. EPA, 2005	Cu, Zn, and Ni concentrations in runoff
Land Use	Residential		Rural

Soil texture types were determined by entering the sand, clay and silt percentages, which were previously found by Balcıoğlu et al. (2007), to “Soil Texture Calculator” installed in Natural Resources Conservation Service (NRCS) website. The calculator screen and texture triangle that point out the soil type is represented in Figure 3.14.

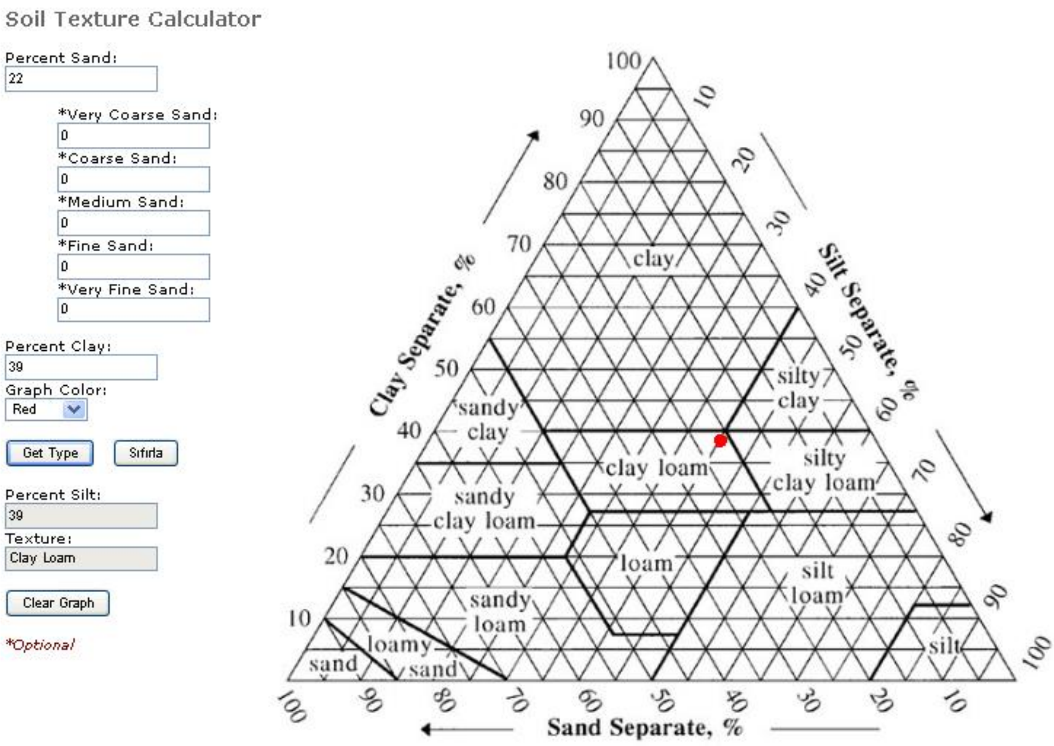


Figure 3.14. The soil texture calculator (USDA NRCS, 2011).

Fresh bulk densities of soil samples in accordance with their texture type were also obtained from NRCS website in order to calculate further input data for the model equations. Partition coefficients of each heavy metal for partitioning between soil and water were obtained from the literature (U.S. EPA, 2005), and were determined by considering soil characteristics, such as pH and concentration of dissolved organic carbon (DOC). All input data and estimated or derived further data required for computation of runoff concentrations are shown in detail in Table B.1 and B.2.

3.3.2. Prediction of Contaminant Concentrations in Runoff

3.3.2.1. Prediction of Nutrient Concentrations in Runoff. Nutrient concentrations in runoff were predicted using the following equation, which describes the kinetics of soil soluble phosphorus desorption process (Sharpley et al., 1981):

$$P_r = \frac{K \times P_0 \times \rho_{soil} \times D \times t^{\alpha} \times W^{\beta}}{V} \tag{3.2}$$

where; P_r is the average phosphorus concentration of runoff (mg/L), P_0 is the phosphorus content of the soil (mg/kg), ρ_{soil} is the fresh bulk density of the soil (Mg/m^3), D is the effective depth of interaction between surface soil and runoff (mm), t is the storm duration (min), W is runoff water/soil (suspended sediment) ratio, V is total runoff during the event (mm) and K, α, and β are constants for a given soil. Eq. 3.2 was also adapted for determination of soluble nitrogen concentrations in runoff. Since actual storm duration data were not available, in the model calculations, t was set to 30 min. The mean monthly rainfall intensities corresponding to sampling dates were entered and total runoff values (V) for each corresponding event were calculated via SWMM. Average values of D and W were obtained from the literature (Sharpley et al., 1985; Sharpley, 1983) and constants of the Eq. 3.2 were estimated from surface soil clay/organic carbon content using equations 3.3 to 3.5 (Sharpley, 1983):

$$K = 0.63 \times (\text{percent clay}/ F_{oc})^{-0.698} \tag{3.3}$$

$$\alpha = 0.779 \times (\text{percent clay}/\ F_{oc})^{-0.526} \quad (3.4)$$

$$\beta = 0.143 \times (\text{percent clay}/\ F_{oc})^{0.419} \quad (3.5)$$

where, F_{oc} is fraction organic carbon in soil (%). Soil sampling dates and calculated values of constants are given in Table B.1 together with associated predicted runoff concentrations of nitrogen and phosphorus.

3.3.2.2. Prediction of Heavy Metal Concentrations in Runoff. Exposure model equations supplied by RIVM were used for observing the sorption behavior of copper, zinc, and nickel to soil and estimation of the concentrations in pore water and runoff. As described in Chapter 2.1, the model was developed by Montforts (1999) for veterinary products but it is also applicable for investigation of heavy metals and their capacity to adsorb to the soil (Lijzen et al., 2001; Popescu et al., 2013). Each type of metal has a specific partition coefficient (Kp_{soil}) that varies according to soil characteristics. The previous studies state that the soil/sediment-water partition coefficients of metals are critical for exposure models (Popescu et al., 2013), and the relationship with standard soil characteristics, such as pH, clay content and organic carbon, must be considered for metal Kp values (Baes and Sharp, 1983; Sauve et al., 2000). Partition coefficients of metals in soil (Kp_{soil}) were obtained from the literature (U.S. EPA, 2005) by considering the similarities between the soil samples collected from the Marmara Region and samples studied in literature in terms of pH values and soil textures. After Kp_{soil} values were determined, $K_{soil\text{-}water}$ partition coefficients for each heavy metal were calculated by Eq. 3.6:

$$K_{soil\text{-}water} = (F_{airsoil} \times K_{air\text{-}water}) + F_{watersoil} + \frac{(F_{solidsoil} \times Kp_{soil} \times \rho_{solid})}{1000} \quad (3.6)$$

where; $K_{soil\text{-}water}$ is partition coefficient of metals between solids and water in soil (m^3/m^3), $F_{airsoil}$ is fraction air in soil (m^3/m^3), $K_{air\text{-}water}$ is partition coefficient between air and water in soil (m^3/m^3), $F_{watersoil}$ is fraction water in soil (m^3/m^3), $F_{solidsoil}$ is fraction solids in soil (m^3/m^3), Kp_{soil} is partition coefficients in solids and water in soil (dm^3/kg), and ρ_{solid} is density of soil solids (kg/m^3). Since metals have low vapor pressures (Amonenko et al., 1966), the partitioning to air phase is neglected. It is assumed that partitioning occurs only between soil solids and pore water (Eq 3.7).

$$K_{soil\text{-}water} = F_{watersoil} + \frac{(F_{solidsoil} \times Kp_{soil} \times \rho_{solid})}{1000} \qquad (3.7)$$

Predicted Environmental Concentrations of heavy metals in pore water ($PEC_{porewater}$) transported from contaminated soil are found by using below equation.

$$PEC_{porewater} = \frac{MEC_{soil} \times \rho_{soil}}{K_{soil\text{-}water} \times 1000} \qquad (3.8)$$

where; $PEC_{porewater}$ is predicted metal concentration in pore water (mg/L), MEC_{soil} (Measured Environmental Concentration) is metal concentration in the analyzed soil samples (mg/kg), and ρ_{soil} is fresh bulk density of soil (kg/m^3).

The fraction of metals not adsorbed to soil particles, but existing in the soil water is transported to runoff water due to rainfall events. It is assumed that metal concentration in runoff is equal to $PEC_{porewater}$ diluted by one order of magnitude (Montforts, 1999):

$$PEC_r = \frac{PEC_{porewater}}{10} \qquad (3.9)$$

where; PEC_r is predicted metal concentration in runoff water (mg/L).

3.3.3. Runoff Water Quality Prediction Using SWMM

In SWMM runoff water quality is modelled by using the pollutant and land use characteristics. In this study washoff function that is embedded in the land use editor of the program is considered to play a major role in runoff quality prediction. According to Tsihrintzis and Hamid (1997), pollutant washoff function of SWMM can be described as the process through which storm water washes off all the accumulated contaminants into receiving water in subcatchment. Predicted concentrations of each contaminant in runoff were transferred to "Quality" section of SWMM. Appropriate values of nitrogen, phosphorus, and heavy metal concentrations of runoff were entered to SWMM as Event Mean Concentrations (EMCs), which is typical pollutant values found in runoff, directly related to land uses in the drainage areas and constant independently of the duration and intensity of the rainfall events. The EMC for an individual storm event is defined as the total pollutant load divided by total runoff volume, as follows (Lee and Bang, 2000):

$$EMC = \frac{\sum q_i \times C_i}{\sum q_i} \tag{3.10}$$

where, q_i is the time variable flow (m^3/s) and C_i is the time variable concentration (mg/L).

SWMM has the ability to empirically simulate nonpoint source runoff quality by a set of mathematical functions that can be calibrated to estimate both the accumulation of pollutants on the land surface during dry weather periods and their release into runoff during storm events. Pollutant buildup and washoff from subcatchment areas are associated with the land uses assigned to the subcatchment and both Event Mean Concentrations (EMCs) and exponential functions could be used in SWMM (Rossman, 2004). Exponential buildup and washoff functions presented below (U.S. EPA, 2009):

$$B = C_1 \times (1 - e^{-C_2 t}) \tag{3.11}$$

where, B is pollutant build-up (mass per unit area), C_1 is the maximum build-up possible (mass per unit area), C_2 is the build-up rate constant (1/day) and t is the number of antecedent dry days.

$$W = C_1 \times q^{C_2} \times B \tag{3.12}$$

where, C_1 is washoff coefficient, q is the runoff rate per unit area (mm/hour), C_2 is the washoff exponent, and B is the pollutant buildup in mass per unit area.

Land uses were defined as "Residential" and "Rural" under the Quality category of SWMM. Commercial and industrial land uses were included to "Residential" and the other areas such as agricultural lands, forests, pastures and barren lands were assumed as "Rural". Event Mean Concentrations (EMCs) calculated via kinetic model and exposure model equations were selected as washoff function and concentrations were entered into the model by using Land Use Editor's Washoff page. Loads for total nitrogen, total phosphorus, Cu, Zn, and Ni were estimated by applying well-known rational method:

$$\text{Load} = \text{runoff} \times \text{EMC} \tag{3.13}$$

3.4. Assessment of Model Sensitivity

A one-at-a-time parameter sensitivity analysis was applied by changing one parameter at a time while holding the others fixed. The relative sensitivity of results to different parameters of the model was determined by taking into account the model output variations that originates from the changes in input parameters. The relative variation was calculated by the following equations (Eq. 3.13 and Eq. 3.14) (Dubus et al., 2003):

$$Input\ Variation = \frac{I - I_{BC}}{I_{BC}} \times 100 \tag{3.13}$$

$$Output\ Variation = \frac{O - O_{BC}}{O_{BC}} \times 100 \tag{3.14}$$

where; I is value of the input parameter, I_{BC} is value of the input parameter for the base-case scenario, O is value of the output variable and O_{BC} is value of the output variable for the base-case scenario.

The ratio of variation (ROV) was calculated as follows (Dubus et al., 2003):

$$ROV = \frac{Output\ Variation}{Input\ Variation} \tag{3.15}$$

$$ROV = \frac{O - O_{BC}}{I - I_{BC}} \times \frac{I_{BC}}{O_{BC}} \tag{3.16}$$

Sensitivity analysis was carried out to test the level of significance of the parameters that are associated both with hydrological and pollutant transport model. The effect of variations in % imperviousness, area, % slope, rainfall, initial nutrient and heavy metal concentration (maximum buildup and buildup rate constants) and washoff parameters were evaluated by comparing the % variations of contaminant loads at selected subcatchments.

4. RESULTS AND DISCUSSION

4.1. Results of the Hydrological Model

Prior to model set up, the wettest and relatively dry years were determined in order to conduct extreme case studies. According to the data obtained by Turkish Meteorological Service, 1981 and 1997 were considered as the wettest years in the region, while 1993 and 2000 were accepted the years of drought. After the model was run, the system precipitation and runoff graphs were produced by SWMM. The wettest time period of 1997, from October to December, and relatively dry year 1993 were chosen to visualize the differences between runoff production more vividly (Figure 4.1 and Figure 4.2).

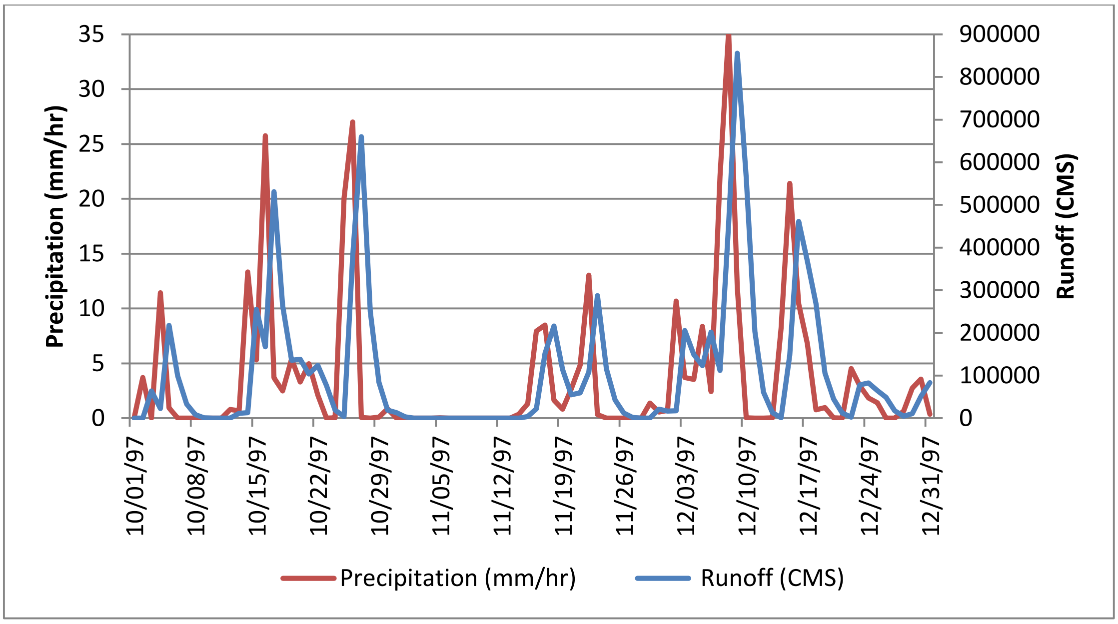


Figure 4.1. Precipitation vs. runoff results of Oct-Dec,1997.

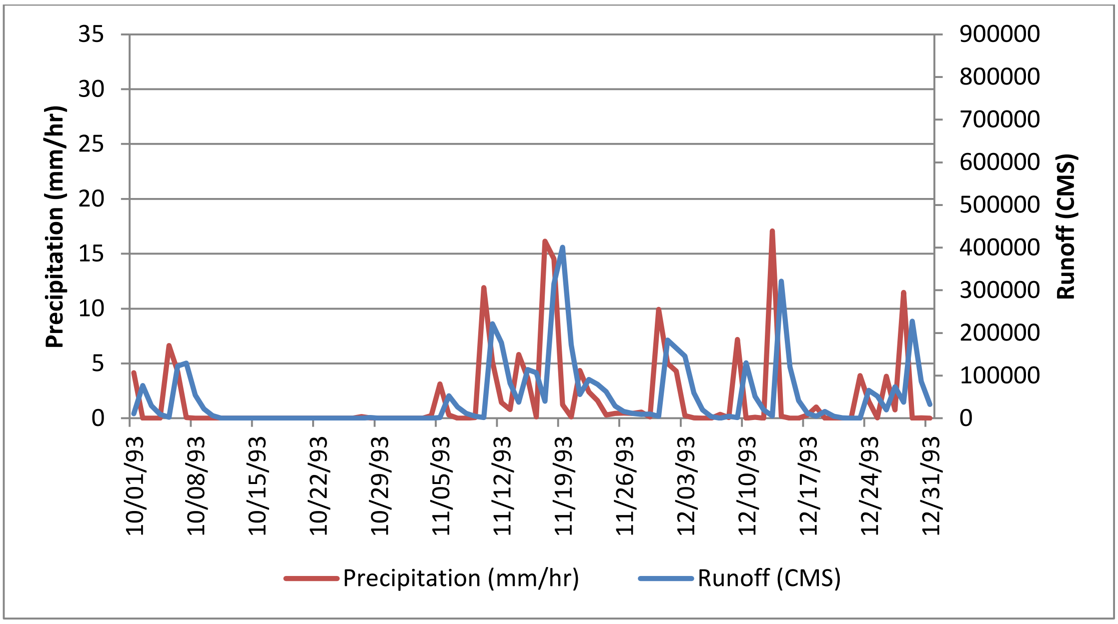


Figure 4.2. Precipitation vs. runoff results of Oct-Dec, 1993.

As can be seen from the above two graphs, a visible difference are observed in runoff depending on the rainfall intensities. As precipitation increases, the runoff production of the system increases and the model simulates well in terms of the ratio between precipitation and runoff production for the whole system.

The imperviousness is one of the significant parameters in catchment hydrology modeling, and previous studies reveal that different land use and imperviousness values have a significant influence on the total volume of runoff and the peak flows (Tsihrintzis and Hamid, 1998; Temprano et al., 2006; Ouyang et al., 2012). In this respect, three subcatchments with different imperviousness but same rainfall intensity (S647, S650, and S651) were chosen to observe the effect of imperviousness on runoff production. Since year 1997 was one of the rainiest years in the region, three rainfall events of 1997 were chosen to observe the effect of imperviousness more clearly. The low and medium rainfall events occurred in June and September, respectively, and storm rainfall event in December were used to compare the results (Table 4.1). The results indicate that the imperviousness value of a subcatchment has a positive relation with the runoff coefficient. As the runoff results provided in Table 4.1 indicate, the impact of varying imperviousness values are significantly greater for low and medium precipitation events, whereas, the effect of imperviousness on runoff production is hindered under extreme precipitation. This finding can be attributed to the assumption that precipitation is the governing factor and one of the most significant variables in runoff production. The results of the sensitivity analysis, which will be discussed further in Section 4.3.4 are in agreement with the results given in Table 4.1.

Table 4.1 Runoff coefficients produced for subcatchments under selected rainfall events.

Subcatchments	**Rain Gage**	**% Imp.**	**Rainfall Events**		
			06/14/97 - 06/19/97 (Low: Total precipitation=4.8 mm)	**09/02/97 - 09/07/97** (Medium: Total precipitation=74.4 mm)	**12/05/97 - 12/10/97** (Extreme: Total precipitation=1644 mm)
			Runoff Coefficient		
S647	Kartal	5.569	0.056	0.572	0.981
S651		44.154	0.471	0.768	0.987
S650		74.913	0.794	0.922	0.996

4.2. Results of the Transport Model

4.2.1. Event Mean Concentrations (EMC) of the Contaminants

Nutrient and heavy metal concentrations of runoff in agricultural locations were estimated via a kinetic model developed by Sharpley et al. (1981) and an exposure model developed by Montforts (1999), respectively. The calculation results regarding these models are provided in Tables B.1. and B.2. Appropriate values found for agricultural runoff were chosen as Event Mean Concentrations (EMCs) to enter to the “Quality” section of SWMM for residential and rural land use categories. The calculated EMCs from a similar study that was carried out in Maryland (Perot et al., 2002) were used to compare the results and determine the EMCs for residential areas (Table 4.2). The estimated concentrations in this study that correspond the EMC ranges for residential areas in the literature were chosen as EMCs of residential land use. EMC ranges of nitrogen, phosphorus and heavy metals for urban runoff (U.S. EPA, 1983) are also given in Table 4.3.

Table 4.2. Event Mean Concentrations (EMCs) from literature and estimated runoff concentrations of the contaminants (mg/L).

<table>
<tr><th rowspan="2" colspan="2">Land Use</th><th colspan="2">Total N</th><th colspan="2">Total P</th><th colspan="2">Cu</th><th colspan="2">Zn</th><th>Ni</th></tr>
<tr><th>Literature*</th><th>Estimated</th><th>Literature*</th><th>Estimated</th><th>Literature*</th><th>Estimated</th><th>Literature*</th><th>Estimated</th><th>Estimated</th></tr>
<tr><td>Low-Density Residential</td><td rowspan="5">Residential</td><td>2.22</td><td rowspan="5">3.46</td><td>0.32</td><td rowspan="5">0.307</td><td>0.0388</td><td rowspan="5">0.0248</td><td>0.0634</td><td rowspan="5">0.0497</td><td rowspan="5">0.0395</td></tr>
<tr><td>Medium-Density Residential</td><td>2.03</td><td>0.33</td><td>0.0143</td><td>0.0987</td></tr>
<tr><td>High-Density Residential</td><td>1.5</td><td>0.24</td><td>0.0125</td><td>0.1018</td></tr>
<tr><td>Commercial/ Industrial</td><td>2</td><td>0.2</td><td>0.0556</td><td>0.1814</td></tr>
<tr><td>Open Urban</td><td>2.69</td><td>0.39</td><td>0.0826</td><td>0.0449</td></tr>
<tr><td>Croplands</td><td rowspan="4">Rural</td><td>7.84</td><td rowspan="4">6.268</td><td>0.82</td><td rowspan="4">2.007</td><td>0.1774</td><td rowspan="4">0.0137</td><td>0.0383</td><td rowspan="4">0.0217</td><td rowspan="4">0.0148</td></tr>
<tr><td>Pasture</td><td>3.34</td><td>0.39</td><td>0.1166</td><td>0.0291</td></tr>
<tr><td>Forest</td><td>2</td><td>0.2</td><td>0.12</td><td>0.0239</td></tr>
<tr><td>Barren</td><td>2.46</td><td>0.5</td><td>0.152</td><td>0.0354</td></tr>
</table>

*Perot et al., 2002

Table 4.3. Water quality characteristics of urban runoff.

Constituent	EMC*
Total P (mg/L)	0.42 - 0.88
Soluble P (mg/L)	0.15 - 0.28
TKN (mg/L)	1.90 - 4.18
Total Cu (μg/L)	43 - 118
Total Zn (μg/L)	202 - 633

*U.S. EPA, 1983

4.2.2. Nutrient Mass Loadings

After the model was run with the chosen EMCs, load of each contaminant to outfall points of catchments that include sampling points were determined. Catchments 45 and 47 located in the north cost of the Marmara Region within the boundaries of İstanbul and Kocaeli were chosen to produce load and runoff graphs to determine the influence of changing land use and % imperviousness on runoff quality. The map of the catchments is shown in Figure 4.3. and corresponding land use and imperviousness values in 2005 together with their subcatchments are given in Table 4.4.

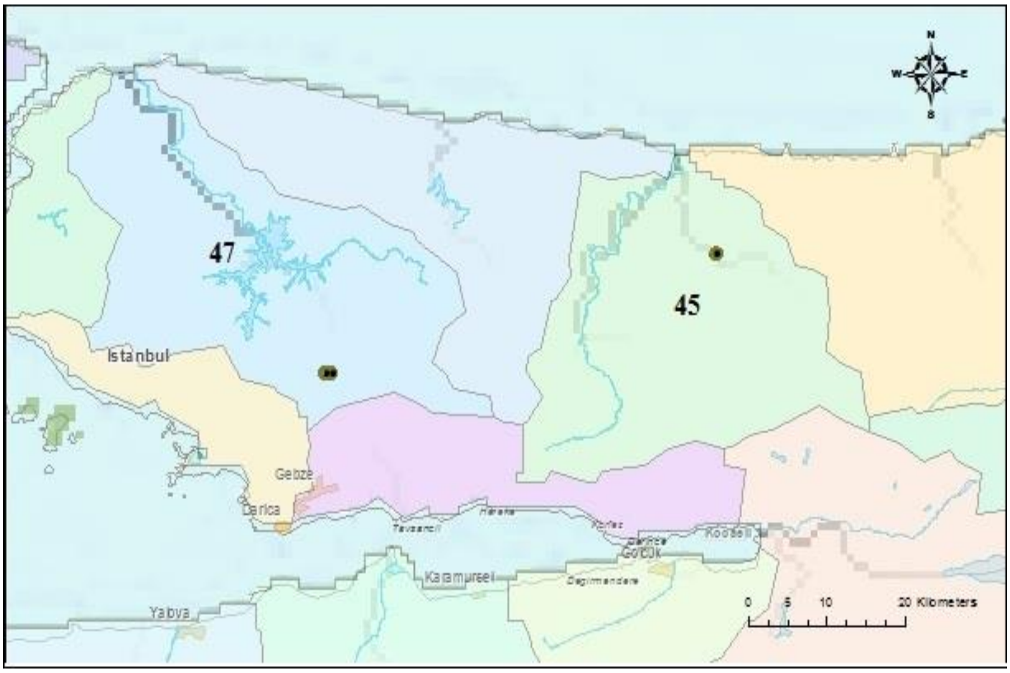


Figure 4.3. Representation of catchments 45 and 47 with soil sampling points on the GIS-based map.

Table 4.4. Land use data of selected catchments in 2005.

Catchments	Subcatchments	Land Use (%)				% Imp.	
		Residential		Rural			
45	S656	31.8	**34.1**	68.2	**65.9**	26.8	**27.1**
	S657	7.4		92.6		7.4	
	S658	48.5		51.5		37.4	
	S659	48.7		51.3		37.5	
	S660	27.4		72.6		22.0	
47	S645	8.1	**10**	91.9	**90**	8.3	**9.8**
	S646	30.5		69.5		25.8	
	S647	4.6		95.4		5.6	
	S648	6.5		93.5		7.1	
	S649	4.5		95.5		5.5	

One of the wettest years 1997 was chosen to observe the differences between contaminant load values of selected catchments. The runoff production and associated nitrogen and phosphorus load in both catchments are illustrated in Figures 4.4. and 4.5.

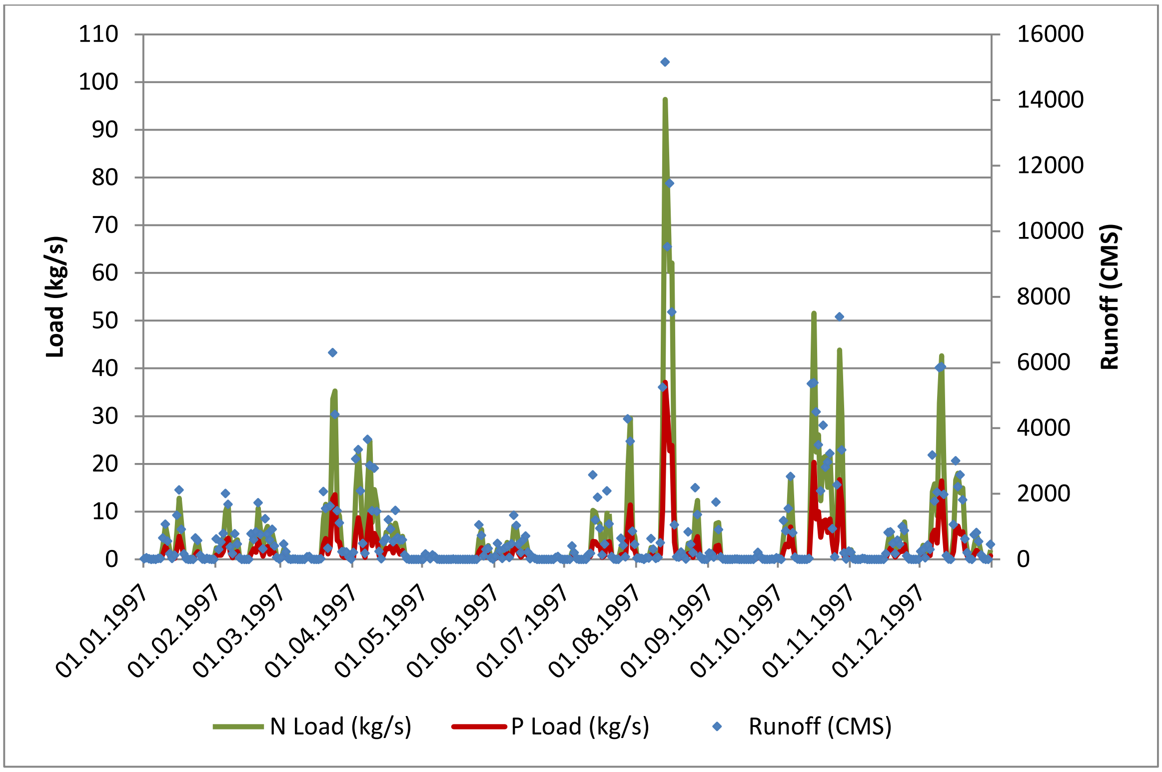


Figure 4.4. Nutrient load vs. runoff results of catchment 45 in 1997 (medium % Imp, wettest period).

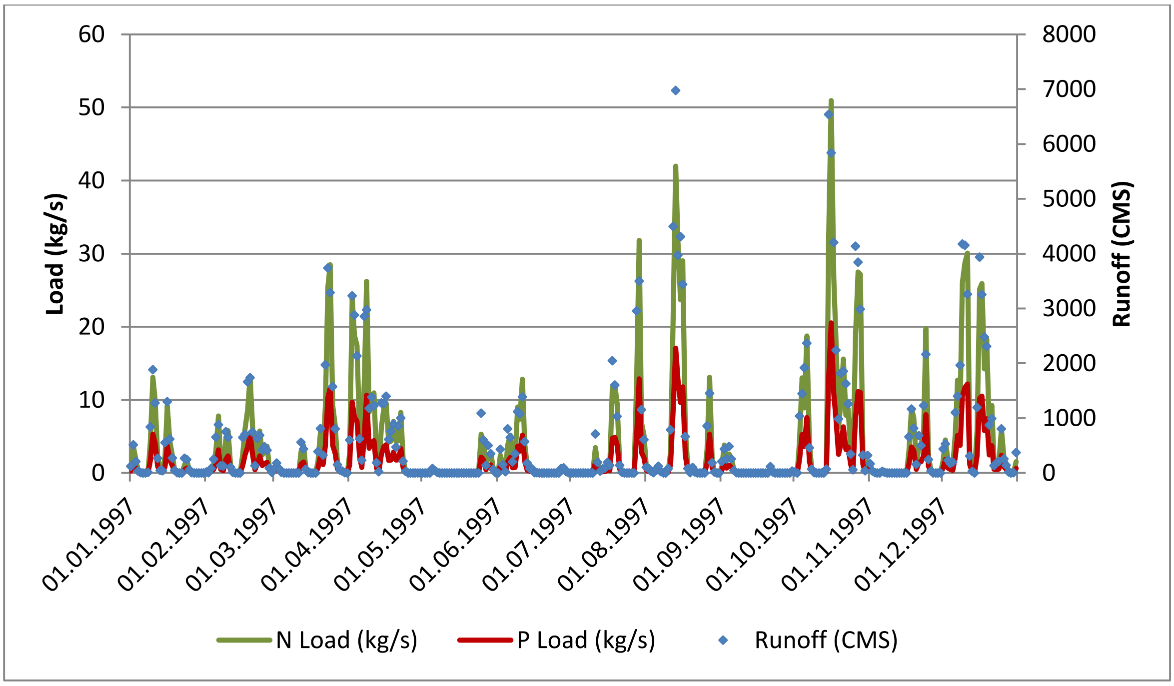


Figure 4.5. Nutrient load vs. runoff results of catchment 47 in 1997 (low % Imp, wettest period).

According to the above graphs, nitrogen load in runoff is higher than the phosphorus, and imperviousness plays an important role on runoff production and pollutant loading. Although the EMCs of nitrogen and phosphorus are higher in rural areas than those in residential, load values of these contaminants are found higher in catchment 45, which has higher percent of imperviousness, as a result of the greater volume of runoff. These results agree with the literature as previous studies that examined the runoff quality also demonstrate that pollutant loading to runoff is positively correlated with impervious rate (Ouyang et al., 2012) and different land use and rainfall are among the most important factors for determining nonpoint source (NPS) pollutants in storm water runoff (Tsihrintzis and Hamid, 1998; Temprano et al., 2006; Liu et al., 2013).

4.2.3. Heavy Metal Mass Loadings

Catchments 45 and 47 chosen for observing nutrient loads were also used to determine the heavy metal mass loadings and the influence of the imperviousness. Copper and nickel loads of both catchments to outfall points are shown in Figures 4.6 and 4.7.

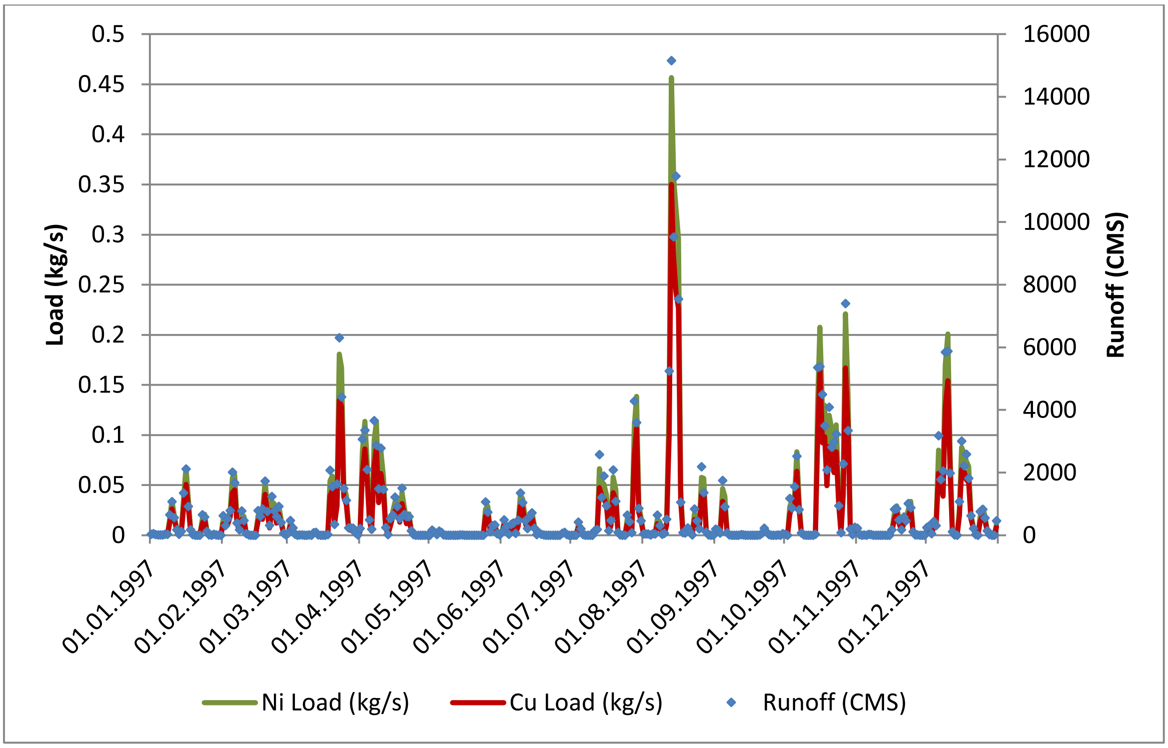


Figure 4.6. Nickel and copper load vs. runoff results of catchment 45 in 1997 (medium % Imp, wettest period).

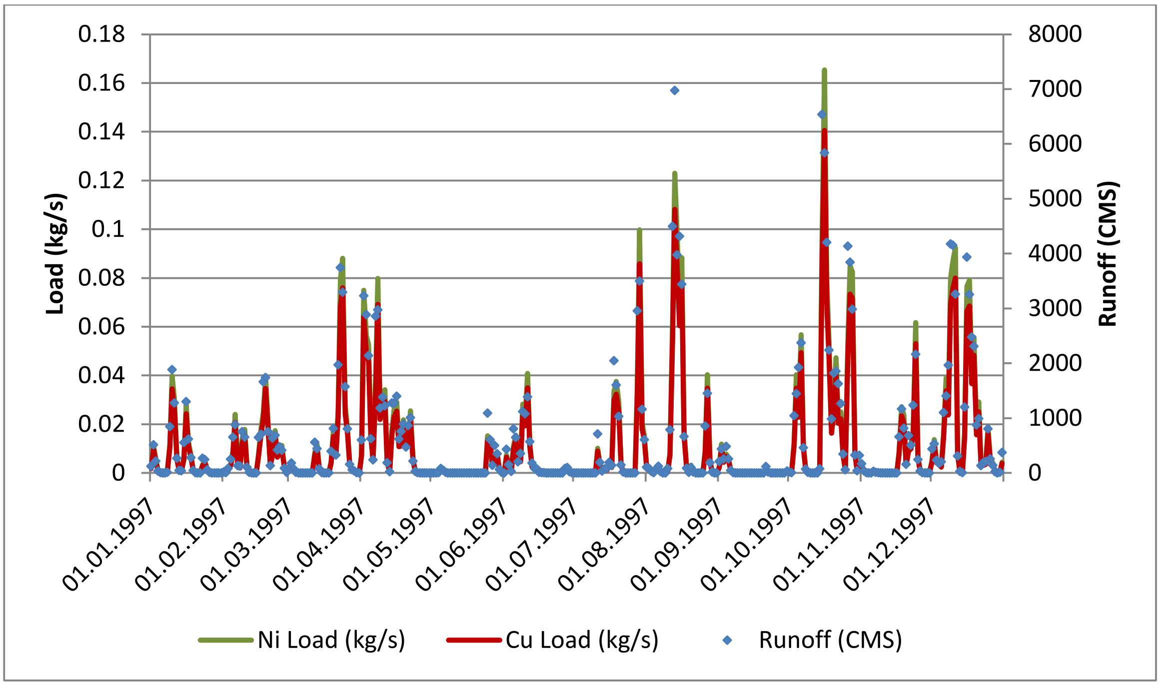


Figure 4.7. Nickel and copper load vs. runoff results of catchment 47 in 1997 (low % Imp, wettest period).

The presented graphs above reveal that load of nickel is little higher than those of copper, and imperviousness affects the loading values of both contaminants in a positively-correlated manner. Heavy metal mass loadings increase in catchment 45, which have larger residential area, as a result of greater runoff production and EMC values in residential areas.

Apart from the imperviousness, the intensity of accumulated contaminants, and their transport to the receiving water body, depends on the rainfall intensity and runoff volume during the rainfall period (Tsihrintzis and Hamid, 1997). Precipitation data regarding one of the wettest years 1997 and a relatively dry year 1977 in a chosen catchment (C45) were used to observe the effect of increased rainfall on contaminant load to catchment outfalls. Zinc and nickel were chosen to investigate the load variations with different rainfall intensities, which are shown below in Figures 4.8. and 4.9. for the wet and dry periods, respectively.

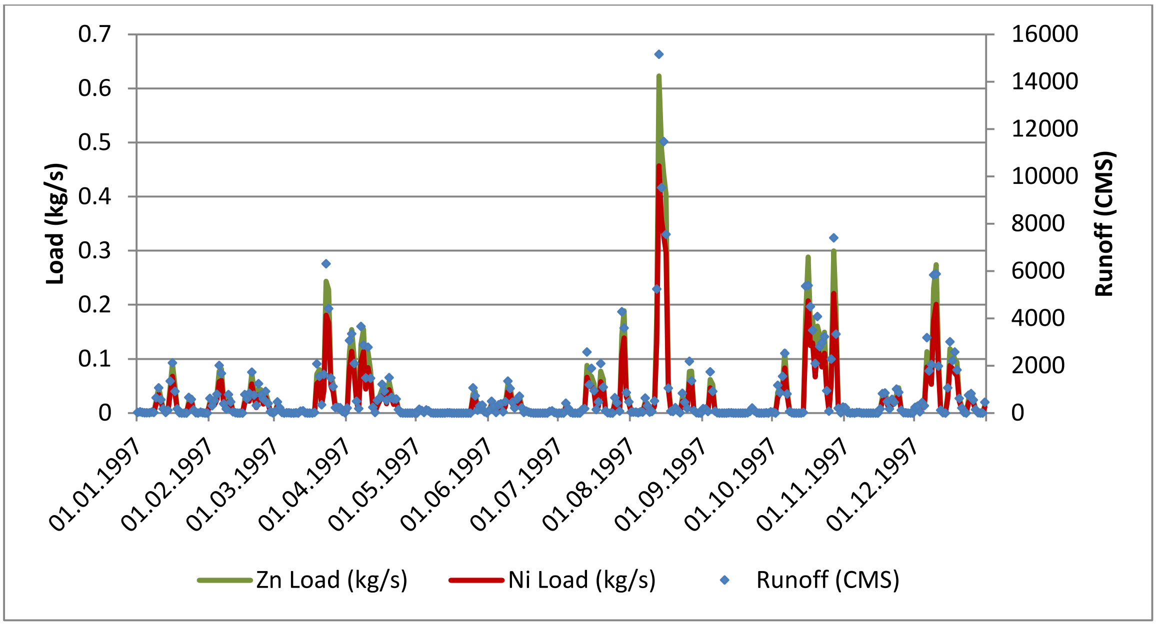


Figure 4.8. Zinc and nickel load vs. runoff results of catchment 45 in 1997 (medium % Imp, wettest period).

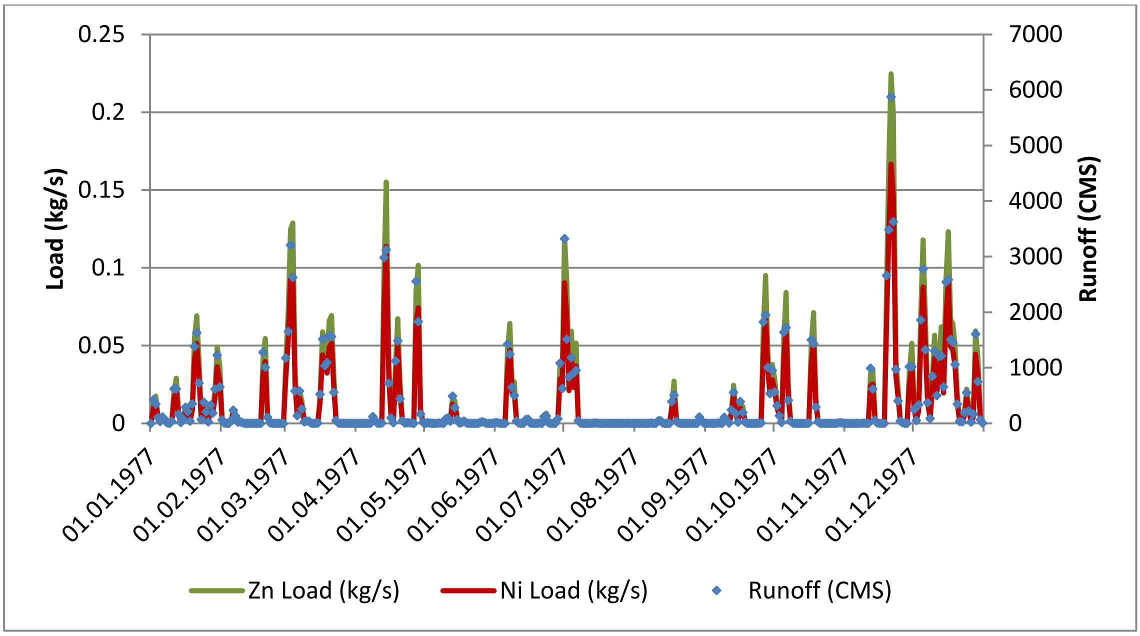


Figure 4.9. Zinc and nickel load vs. runoff results of catchment 45 in 1977 (medium % Imp, driest period).

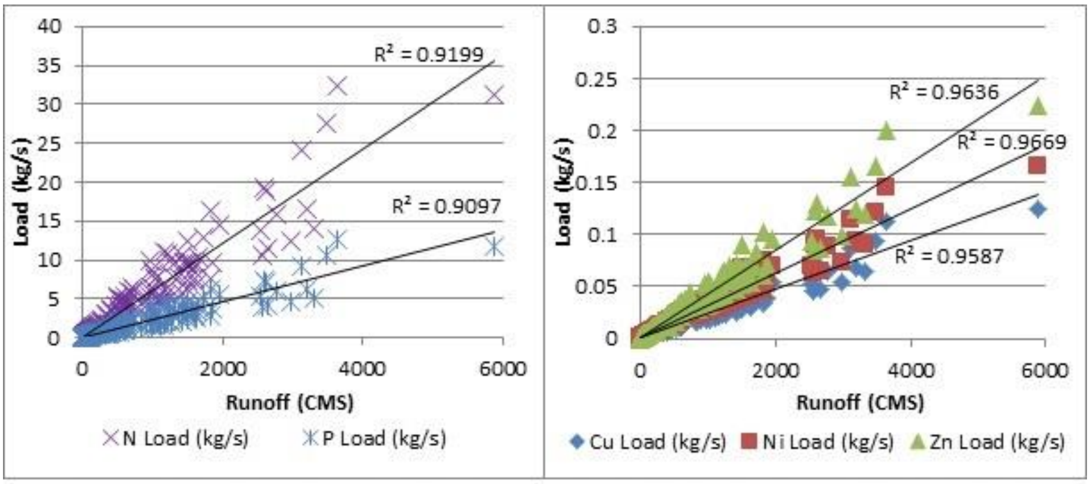
The graphs indicate that zinc has a larger loading value than nickel and also than copper, and load of both heavy metals increases in 1997, which reveal that high rainfall events increase the release of contaminants into runoff.

4.2.4. Overall Evaluation of Contaminant Load Results

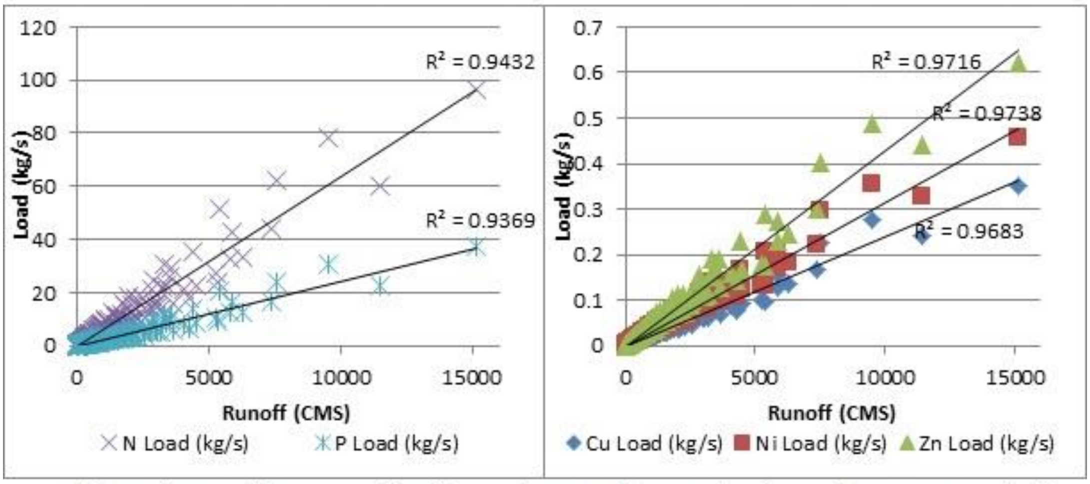
In order to observe the effect of rainfall and imperviousness on runoff production and associated pollutant loads more vividly, the regression lines that provide the relationship between load and runoff were produced. The previous studies reveal the linear relationship between pollutant mass loading and runoff with regression graphs (Bedient et al., 1980; Lee and Bang , 2000) and such graphs were drawn in this study for the chosen catchments (C45 and C47) by using the precipitation data of the years 1997 and 1977 (Figure 4.10).

The graphs presented below indicate the positive linear relationship between contaminant load and runoff and the influence of precipitation, land use and imperviousness of selected catchments on each contaminant. Nitrogen load to outfall is significantly higher than the other contaminants. Although zinc has an average soil partition coefficient, $Kp_{soil,}$ (501.19 dm^3/kg) (U.S. EPA, 2005) amongst other heavy metals, it has the highest loading values. On the other hand; despite the least Kp_{soil} value (316.23 dm^3/kg) (U.S. EPA, 2005), which means the lowest sorption capacity in the soil, copper has the lowest mass loading. Nickel loadings are little higher than those of copper, though nickel partition to soil (794.33 dm^3/kg) (U.S. EPA, 2005) is highest amongst other heavy metals. These results are attributed to differences between metal concentrations in soil samples, which are more effective factor than soil partition coefficients in release of heavy metals to runoff water and subsequent loads to outfall in the present study.

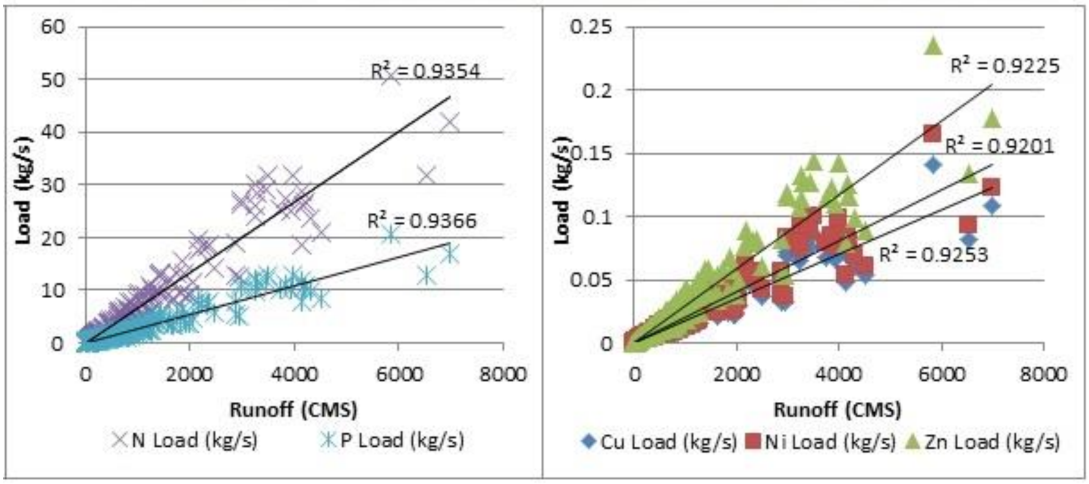
According to Figure 4.10, the runoff volume and release of nutrients and heavy metals into runoff increase in 1997, which is a significantly wetter year than 1977. In addition, runoff production and contaminant loads are higher in catchment 45, which has larger residential area and higher % imperviousness. Although EMCs of nutrients are lower in residential areas, the higher mass loadings of those are observed in catchment 45 as a result of increased runoff production. These results are consistent with the previous research, which reveal that different land use and rainfall are among the most significant factors for examining runoff quality (Tsihrintzis and Hamid, 1998; Temprano et al., 2006; Liu et al., 2013) and increasing imperviousness value contribute to increase in runoff volume and the release of the contaminants to storm water (Schueler and Holland, 1994; Bhaduri et al., 2000; Ouyang et al., 2012).



(a) Nutrient and heavy metal load for catchment 45 in 1977 (medium % imp, driest period)



(b) Nutrient and heavy metal load for catchment 45 in 1997 (medium % imp, wettest period)



(c) Nutrient and heavy metal load for catchment 47 in 1997 (low % imp, wettest period)

Figure 4.10. Relationship between pollutant load and runoff.

4.3. Parameter Sensitivity Analysis

Sensitivity analysis using a one-at-a-time approach was carried out in order to determine the influence of various parameters on SWMM. The value of each selected parameter was changed by 10% increments within a range of 100%, from -50% to +50%, and model outputs of the year 1997 were observed. A total of 8 parameters were analyzed for their sensitivities in producing total load values of nitrogen, phosphorus, copper, nickel, and zinc. The annual total loads of contaminants that correspond to the sensitivity multipliers are demonstrated in each graph below.

4.3.1. Sensitivity Analysis of Percent Imperviousness of Subcatchments

According to the analysis results, percent imperviousness has a slight and positive influence on model outcome, since as the amount of impervious surfaces increases, more runoff is created and less water is able to infiltrate into the ground. In addition, impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. Therefore, with increasing runoff value, the release of the contaminants to storm water increases (Schueler and Holland, 1994). The values of % imperviousness in a selected subcatchment (S658) that correspond to sensitivity multipliers are given in Table 4.5. In order to provide a better understanding of the sensitivity of % imperviousness, nitrogen load for the year 1997 are demonstrated in Figure 4.11.

Table 4.5. Various % imperviousness of the selected subcatchment.

S658											
Multiplier	0.5	0.6	0.7	0.8	0.9	**1**	1.1	1.2	1.3	1.4	1.5
% Imp.	18.7	22.4	26.2	29.9	33.7	**37.4**	41.1	44.9	48.6	52.4	56.1

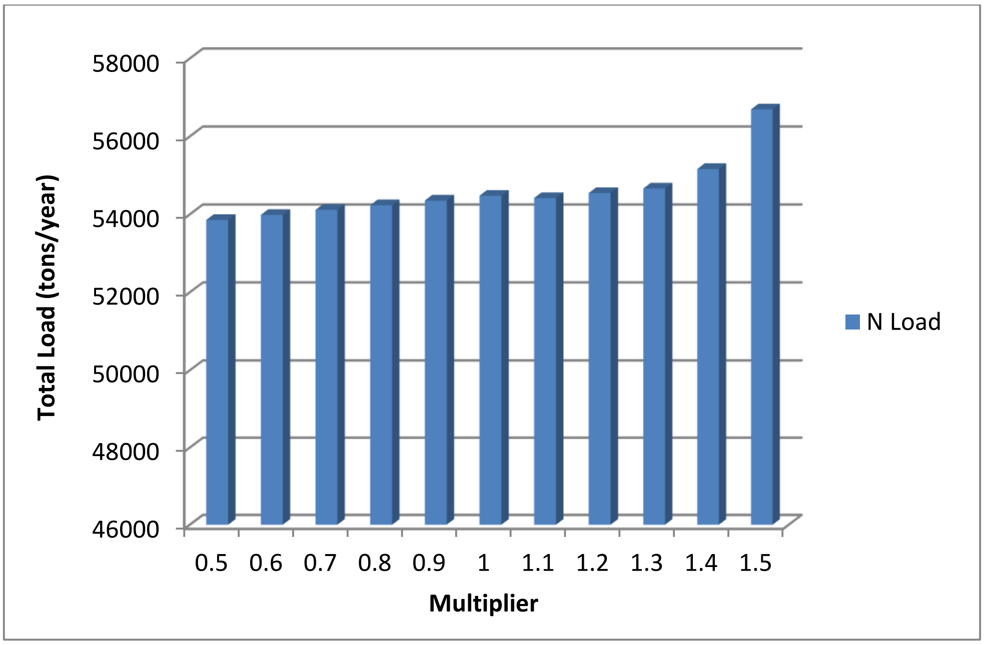


Figure 4.11. Model output results with respect to various % imperviousness of subcatchments.

4.3.2. Sensitivity Analysis of Area of Subcatchments

The area of subcatchment that collects precipitation has a positive correlation with contaminant release. Figure 4.12 indicates that, as the area of collection increases, output of the subcatchment increases. According to a previous research (Brezonik and Stadelmann, 2002), drainage area and precipitation amount are the most important variables to predict event loads. According to Figure 4.12., the result provided from the sensitivity analysis here also confirms that the area of subcatchments has a high influence on model outcome. Initial value of the subcatchment area (S658) and altered values are given in Table 4.6.

Table 4.6. Various areas of the selected subcatchment.

S658											
Multiplier	0.5	0.6	0.7	0.8	0.9	**1**	1.1	1.2	1.3	1.4	1.5
Area (ha)	7342.5	8811	10279.5	11748	13216.5	**14685**	16153.5	17622	19090.5	20559	22027.5

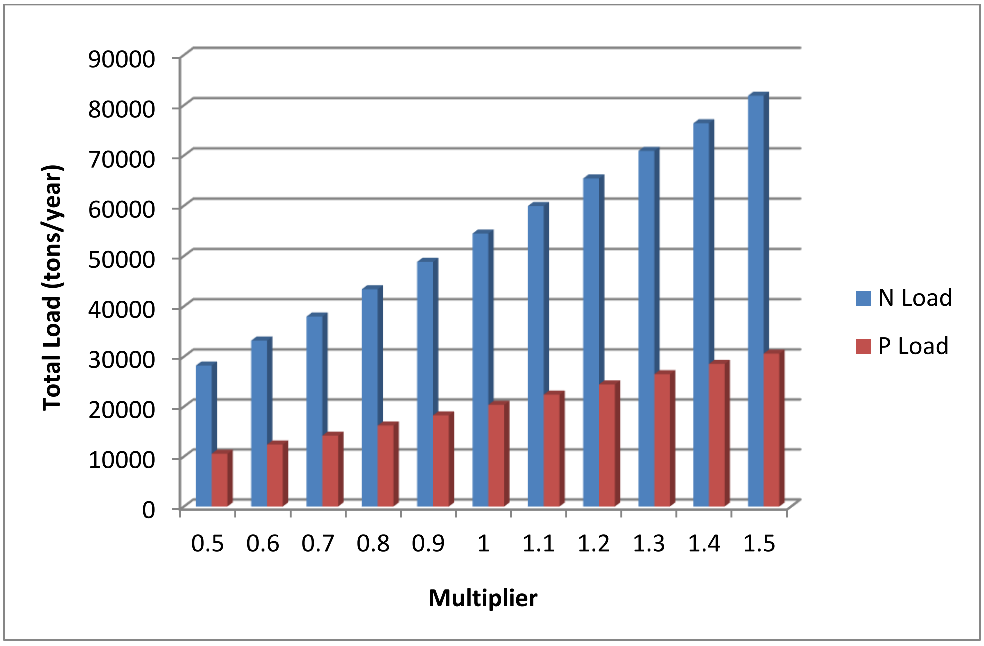


Figure 4.12. Model output results with respect to various areas of subcatchments.

4.3.3. Sensitivity Analysis of Percent Slope of Subcatchments

As can be seen from Figure 4.13., model outputs are not very sensitive to the changes in slope values. The slightly increasing trens in the graph confirms that with increasing slope, the time spent to leave the area decreases further decreasing routing value and increasing peak flow during the times of rain (Horton, 1933). A previous study carried out by El-Hassanin et al. (1993) also reveal that runoff-rainfall ratios are high under the steep slopes and soil loss per unit of rainfall and also per unit of runoff increase as the slope gradient increase, which demonstrate the influence of slope on contaminant transport and loading. The altered % slope values of the selected subcatchment (S648) that corresponds to sensitivity multipliers are given in Table 4.7.

Table 4.7. Various % slopes of the selected subcatchment.

S648											
Multiplier	0.5	0.6	0.7	0.8	0.9	**1**	1.1	1.2	1.3	1.4	1.5
% Slope	1.38	1.66	1.93	2.21	2.48	**2.76**	3.04	3.31	3.59	3.86	4.14

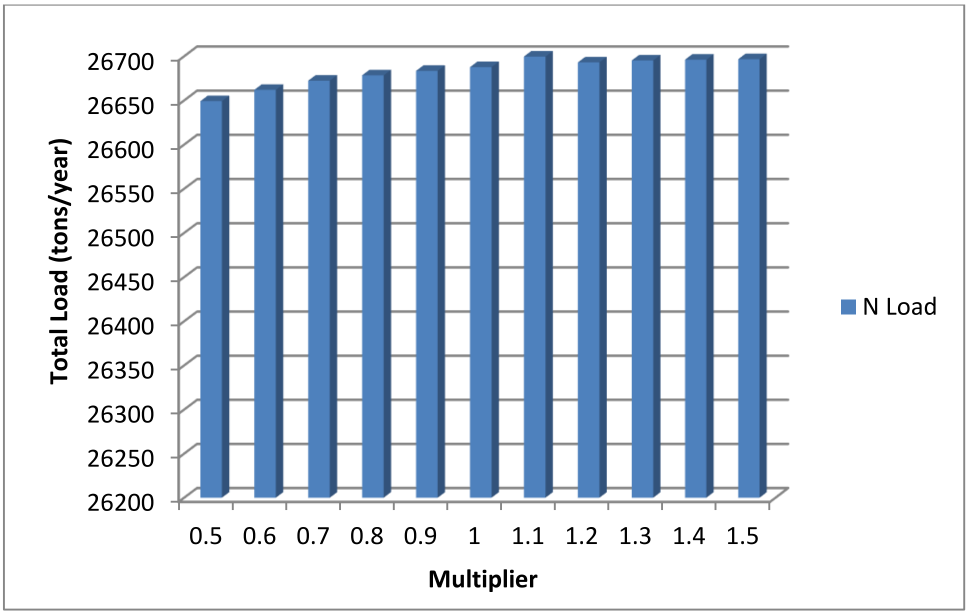


Figure 4.13. Model output results with respect to various % slopes of subcatchments.

4.3.4. Sensitivity Analysis of Precipitation

Precipitation is the most sensitive parameter that affects runoff production (Horton,1933). The analysis results agree with the published literature. For example, according to Nearing et al. (1990), the dominant parameter is precipitation amount for both soil loss and sediment delivery. Figure 4.14. clearly illustrates that as the rainfall increase, the runoff production and associated contaminant load at the output increase.

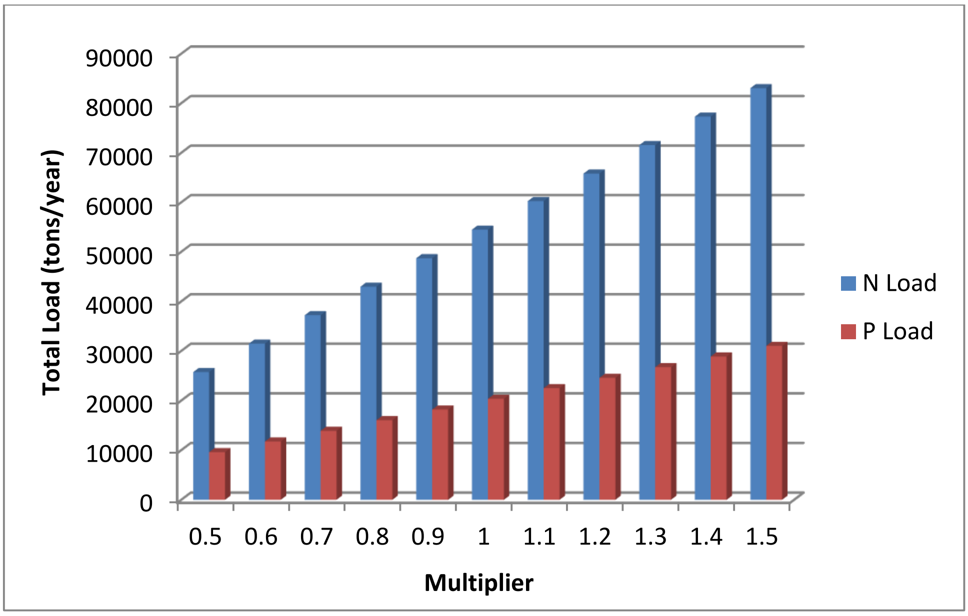


Figure 4.14. Model output results with respect to various rainfall of subcatchments.

4.3.5. Sensitivity Analysis of Buildup and Washoff Functions

SWMM has the ability to analyze the accumulation of the contaminants in dry periods and release of those in runoff in storm events by using buildup and washoff functions. In this model EMCs estimated via kinetic and exposure model were used without having to model any pollutant buildup at all. However, maximum buildup values found in literature for copper and zinc and other buildup and washoff functions were analyzed to examine the sensitivity of SWMM to the changes in those functions. The parameters associated by buildup and washoff functions are assessed for their sensitivities. SWMM uses Eq. 3.11 and Eq. 3.12 to determine the buildup of pollutants in the subcatchments and washoff that originates from this buildup, respectively. Exponential buildup and washoff values found from literature are presented below:

Table 4.8. Buildup and washoff parameters.

Land Use	**Buildup**			**Washoff**	
	C_1* (kg/ha)		**C_2** (1/day)**	**C_1****	**C_2****
	Cu	**Zn**			
Residential	0.00324	0.02637	0.222	0.0135	0.986
Rural	0.01	0.0057	0.382	0.0062	0.753

*Perot et al., 2002; **Hossain et al., 2010

Figures 4.15. and 4.16. indicates that maximum buildup has a high influence on water quality modeling and buildup rate constant is also quite effective, since both parameters are related to washoff equation.

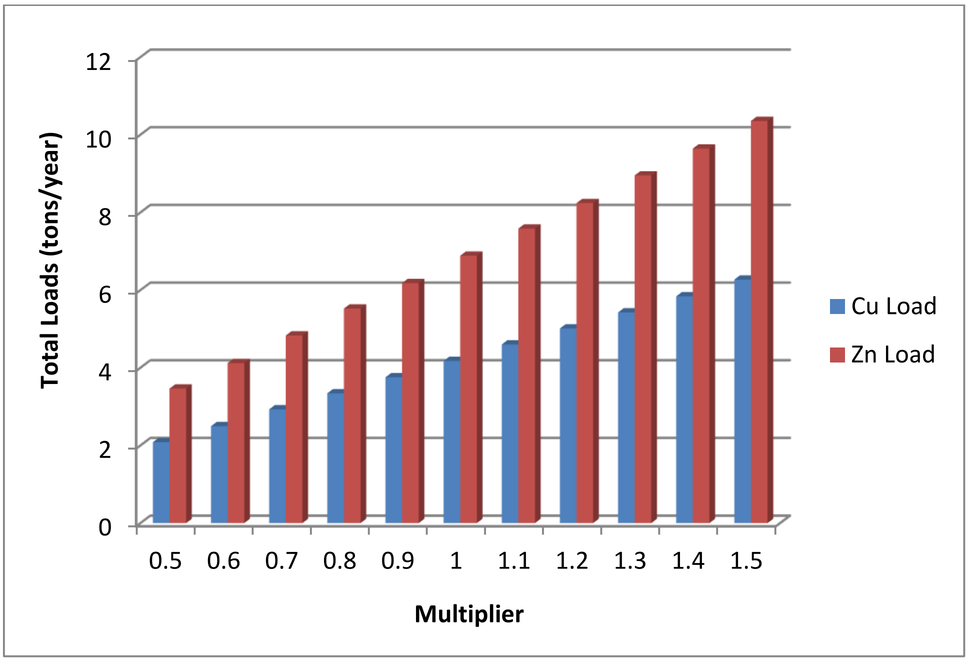


Figure 4.15. Model output results with respect to various max. buildup values of metals.

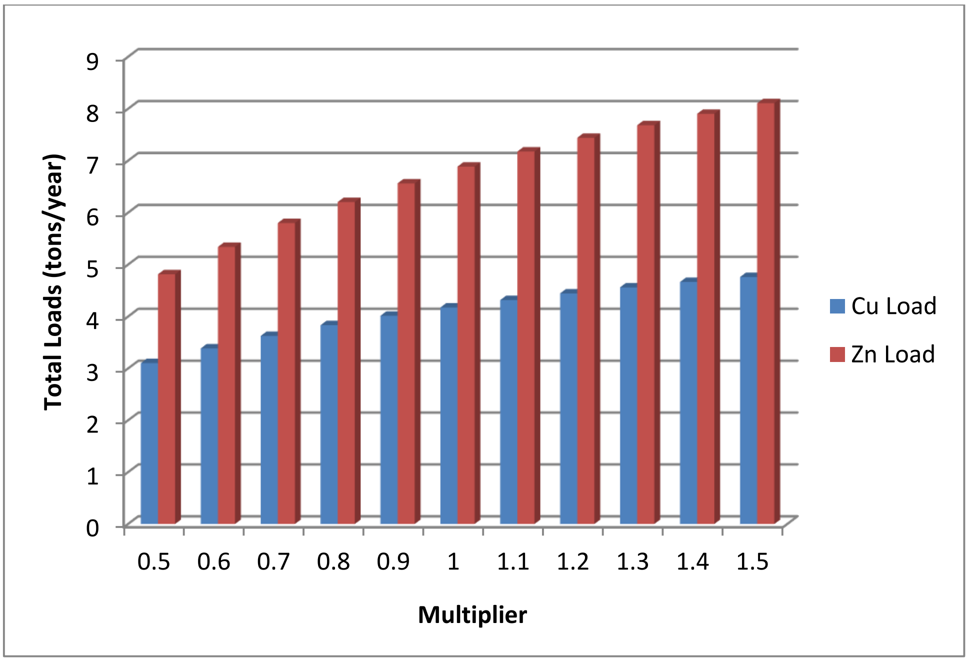


Figure 4.16. Model output results with respect to various buildup rate constant values of metals.

Washoff of contaminants is another singificant process of SWMM governing runoff water quality. The analysis results reveal that washoff functions have moderate influence on model outputs. Figures 4.17. and 4.18. suggests that, as the washoff coefficient or exponent increases, the load of the contaminants increase.

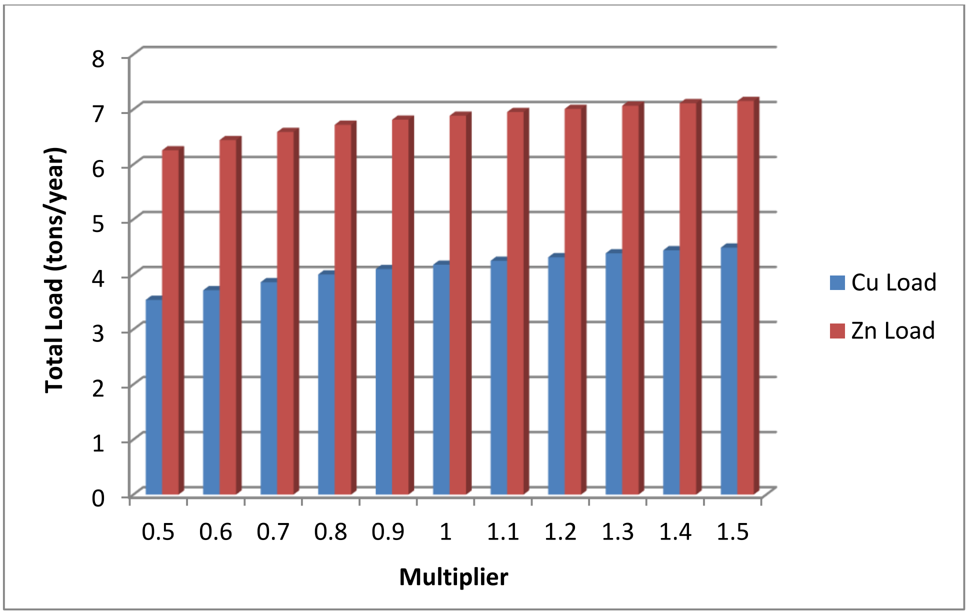


Figure 4.17. Model output results with respect to various washoff coefficient values of metals.

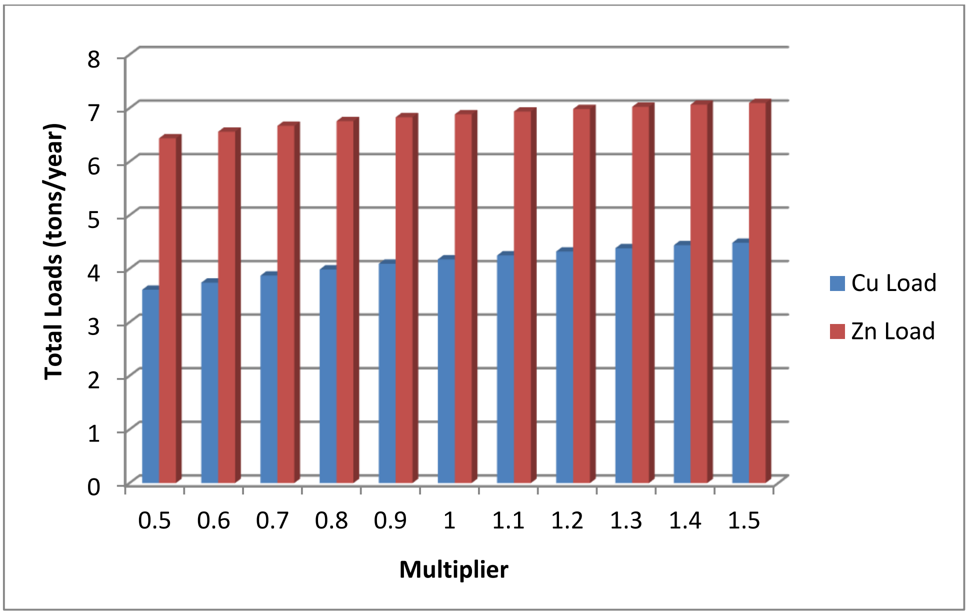


Figure 4.18. Model output results with respect to various washoff exponent values of metals.

4.3.6. Overall Evaluation of the Sensitivity Analysis

In order to better understand the sensitivity of SWMM to changes in various parameters, output variations of each parameter are shown in Figure 4.19. The outcome of the sensitivity analysis reveal that area, rainfall and maximum buildup are the most important parameters and buildup rate constant has considerable influence on model output. While washoff functions have an average influence, percent imperviousness and percent slope are the least significant parameters affecting the output.

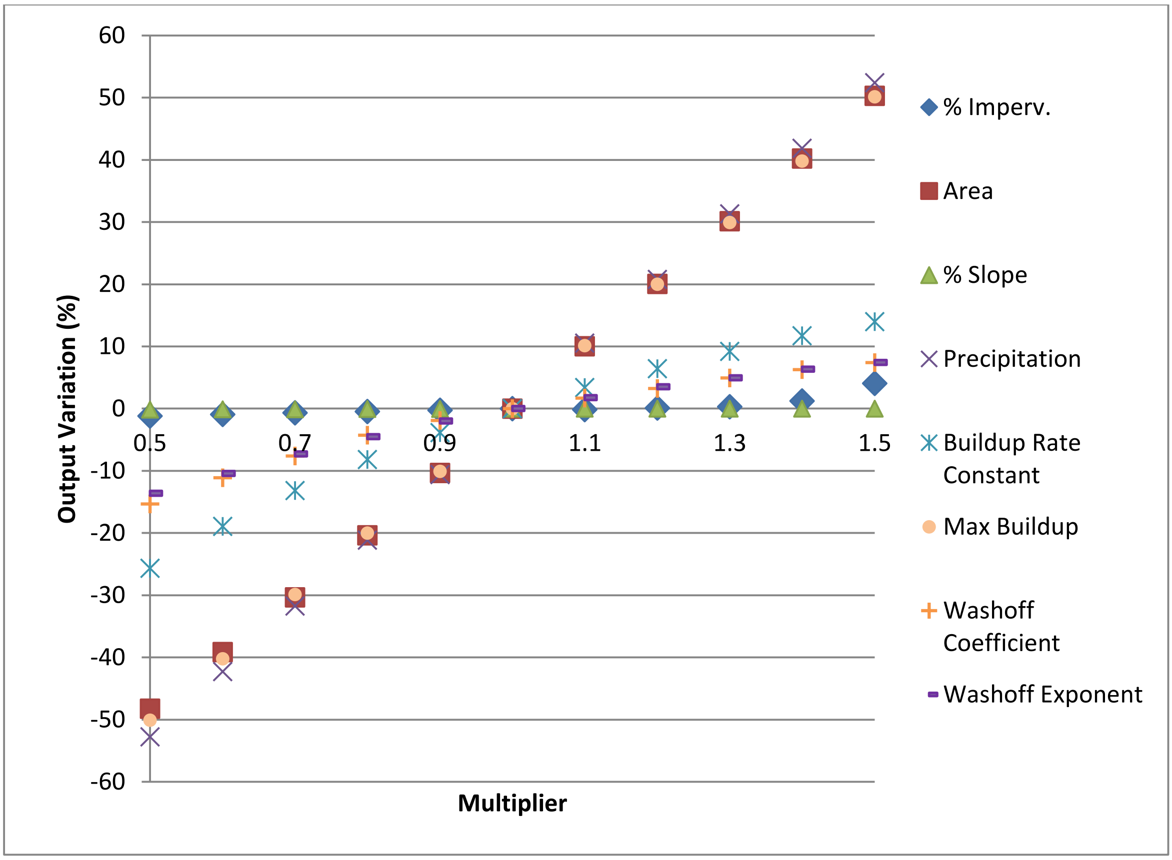


Figure 4.19. Parametric sensitivities (Output Variation vs Multiplier).

All the parameters and sensitivity of SWMM to changes in those are demonstrated in Figure 4.20. by considering their ratio of variations (ROV). The parameters are classified according to their importance ranking and a subjective sensitivity class is assigned to each assessed parameter, which is provided in Table 4.9. Sensitivity analysis results are consistent with previous published literature (Nearing et al., 1990; El-Hassanin et al., 1993).

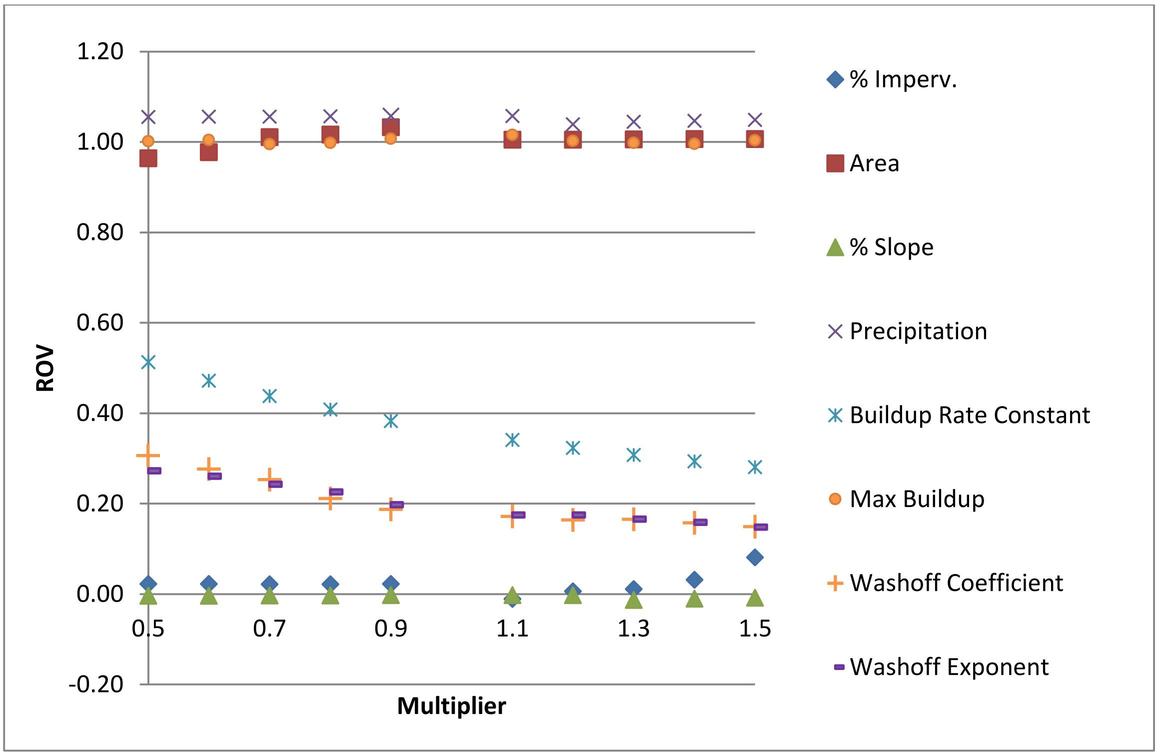


Figure 4.20. Parametric sensitivities (Ratio of Variation vs Multiplier).

Table 4.9. Parameter sensitivity classification and ranking.

Parameter	Sensitivity Class	Sensitivity Rank
Precipitation	Very High	1
Area	Very High	2
Maximum Buildup	Very High	2
Buildup Rate Constant	High	4
Washoff Coefficient	Medium	5
Washoff Exponent	Medium	6
% Imperviousness	Low	7
% Slope	Low	8

The results of the sensitivity analysis reveal that precipitation and area are the most significant parameters affecting model outputs. Therefore, extreme caution should be taken in the determination of these particular parameters. In this study, the precipitation values were directly obtained from real data and catchment/subcatchment areas were automatically derived by the GIS supported SWMM program. The average slope values were assumed as lumped parameters, because slope values were initially determined in the GIS, based on the 51 catchments delineated by the “Basin” tool of the program; however, these catchments were further delineated as 499 subcathments in the SWMM environment to increase the sensitivity of the simulations. Any problems that can be attributed to this lumped assumption of the slope parameter will be hampered by the fact that percent slope is the least significant parameter amongst the model parameters assessed for their sensitivities.

5. CONCLUSION AND RECOMMENDATIONS

The aim of the study presented here was to develop a catchment hydrology model for the Marmara Region and to observe the washoff and total loads of nutrients and heavy metals to receiving waters from the catchments that have different land use percentages. For this purpose, GIS was used to supply maps with spatial data regarding catchment's topographical features, land use characteristics and SWMM's input parameter requirements. The GIS based maps were then incorporated to the modelling environment, SWMM, for the simulations of runoff and pollutant load.

Rainfall-runoff model illustrates that high rainfall events and high imperviousness values that are associated with different land use characteristics contribute to runoff production in catchments. Washoff and pollutant mass loading results reveal that nitrogen load in runoff are higher than the other contaminants significantly and zinc has the largest loading values amongst other heavy metals. Although soil partition coefficient value of copper is lower than the other metals, it has the lowest loading values as a result of the low concentrations in soil. The regression lines indicate the positive linear relationship between load and runoff. The influence of different land use percentages on pollutant loading was examined by choosing catchments 45 and 47, which have 34.1% and 10 % residential areas and 27.1% and 9.8% imperviousness values, respectively. Load of nutrients and heavy metals increased in catchment 45, which demonstrates the importance of imperviousness on water quality. The effect of rainfall intensity on each contaminant load was also investigated for the wettest and driest periods corresponding to the years 1997 and 1977, respectively. The results indicate a significant correlation between rainfall and pollutant loading.

A one-at-a-time sensitivity analysis procedure was carried out to determine the sensitivity ranking of parameters affecting SWMM's simulation results. According to the analysis results, the most significant parameters include rainfall, area, and maximum buildup of contaminants. The model is also quite sensitive to changes in buildup rate constant, while exponential washoff functions has an average influence. On the other hand, % imperviousness and % slope have the lowest influence on model outputs.

Data gathering and harmonization are one of the most challenging steps towards developing distributed catchment models due to the spatial variability of data. This study suggests that GIS incorporated SWMM modeling approach is an efficient tool in catchment modeling in terms of the derivation of input parameters for catchment hydrology, determination of the effect of meteorological and land use changes on runoff production, and associated pollutant load to receiving waters. Therefore, SWMM integrated with GIS has the potential to evaluate the storm rainfall and pollution prevention planning. Further research may focus on developing catchment hydrology and runoff quality models in a more distributed manner to account for the rather high spatio-temporal variability of catchments. Thus, more comprehensive evaluation and management mechanism for catchments can be undertaken and pollutant prevention programs in receiving waters can be developed.

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APPENDIX A: SWMM INPUT PARAMETERS

Table A.1. Characteristics of the subcatchments in the study area and calculation of the % imperviousness.

Sub. #	Subcatchment Area (ha)	Commercial Area		Residential Area		Rural Area		% IMP= *(%Com*0,95)+*(%Res*0,75)+*(%Rural.*0,02))	Catchment #	% Slope
		ha	%	ha	%	ha	%			
153	11070.57	0.00	0.0	2586	23.4	8484.57	76.6	**19.052**	31	4.641
154	3500.66	0.00	0.0	0	0.0	3500.66	100.0	**2.000**		
155	13371.45	0.00	0.0	5309	39.7	8062.45	60.3	**30.984**		
156	16208.19	0.00	0.0	3758	23.2	12450.19	76.8	**18.926**		
157	13683.77	0.00	0.0	4049	29.6	9634.77	70.4	**23.601**		
159	17835.23	0.00	0.0	3997	22.4	13838.23	77.6	**18.360**	30	5.694
160	18979.08	0.00	0.0	4130	21.8	14849.08	78.2	**17.885**		
161	9788.65	0.00	0.0	3030	31.0	6758.65	69.0	**24.597**		
183	7695.73	0.00	0.0	4140	53.8	3555.73	46.2	**41.271**	29	5.948
184	7156.11	0.00	0.0	2000	27.9	5156.11	72.1	**22.402**		
185	5762.1	0.00	0.0	720	12.5	5042.1	87.5	**11.122**		
186	11372.74	759.37	6.7	3113	27.4	7500.369	66.0	**28.192**		
187	16691.09	468.14	2.8	2405	14.4	13817.955	82.8	**15.127**		
188	9601.38	0.00	0.0	1802	18.8	7799.38	81.2	**15.701**		
189	24265.99	607.00	2.5	5580	23.0	18078.99	74.5	**21.113**	28	5.156
190	18057.06	0.00	0.0	1822	10.1	16235.06	89.9	**9.366**		
191	11314.25	0.00	0.0	1533	13.5	9781.25	86.5	**11.891**		
192	16426.7	0.00	0.0	2780	16.9	13646.7	83.1	**14.354**		
193	18992.96	0.00	0.0	3100	16.3	15892.96	83.7	**13.915**		
194	14288.42	0.00	0.0	5200	36.4	9088.42	63.6	**28.567**		
195	13952.21	0.00	0.0	3987	28.6	9965.21	71.4	**22.861**		
196	14400.04	0.00	0.0	2359	16.4	12041.04	83.6	**13.959**		
197	10722.74	2771.00	25.8	3323	31.0	4628.74	43.2	**48.656**		
198	12048.78	2620.00	21.7	2058	17.1	7370.78	61.2	**34.692**		
199	19723.14	0.00	0.0	3600	18.3	16123.14	81.7	**15.324**		
200	11178.47	0.00	0.0	1988	17.8	9190.47	82.2	**14.982**		

201	9773.46	0.00	0.0	1592	16.3	8181.46	83.7	**13.891**	28	5.156
202	7002.06	0.00	0.0	0	0.0	7002.06	100.0	**2.000**		
203	10828.47	0.00	0.0	1557	14.4	9271.47	85.6	**12.496**	25	3.492
204	13044.71	1711.00	13.1	2922	22.4	8411.71	64.5	**30.550**		
205	7955.19	0.00	0.0	1776	22.3	6179.19	77.7	**18.297**		
206	16758.07	0.00	0.0	2963	17.7	13795.07	82.3	**14.907**	27	4.942
207	16665.63	0.00	0.0	3539	21.2	13126.63	78.8	**17.502**		
208	10099.08	0.00	0.0	1904	18.9	8195.08	81.1	**15.763**		
209	11326.06	0.00	0.0	1555	13.7	9771.06	86.3	**12.022**		
210	13382.39	0.00	0.0	3146	23.5	10236.39	76.5	**19.161**	26	12.264
211	16065.41	0.00	0.0	1627	10.1	14438.41	89.9	**9.393**		
212	19086.1	0.00	0.0	3379	17.7	15707.1	82.3	**14.924**		
213	10057.38	0.00	0.0	690	6.9	9367.38	93.1	**7.008**		
214	12693.32	0.00	0.0	4518	35.6	8175.32	64.4	**27.983**	34	7.476
215	19607.68	0.00	0.0	4089	20.9	15518.68	79.1	**17.223**		
216	13247.09	0.00	0.0	1998	15.1	11249.09	84.9	**13.010**		
217	18414.57	0.00	0.0	4061	22.1	14353.57	77.9	**18.099**		
218	7798.54	0.00	0.0	1561	20.0	6237.54	80.0	**16.612**		
219	14515.72	0.00	0.0	4074	28.1	10441.72	71.9	**22.488**		
220	15963.95	0.00	0.0	5034	31.5	10929.95	68.5	**25.019**		
221	13698.12	0.00	0.0	1686	12.3	12012.12	87.7	**10.985**	32	4.939
222	17385.23	1951.97	11.2	2703	15.5	12730.265	73.2	**23.792**		
223	16424.84	0.00	0.0	2369	14.4	14055.84	85.6	**12.529**		
224	17980.57	0.00	0.0	5753	32.0	12227.57	68.0	**25.357**		
226	10250.44	0.00	0.0	1133	11.1	9117.44	88.9	**10.069**		
227	14548.49	3559.00	24.5	2732	18.8	8257.49	56.8	**38.459**		
228	14739.55	0.00	0.0	4671	31.7	10068.55	68.3	**25.134**		
229	14132.37	4477.00	31.7	4798	34.0	4857.37	34.4	**56.245**		
230	14324.14	0.00	0.0	2784	19.4	11540.14	80.6	**16.188**		

231	11161.62	0.00	0.0	3250	29.1	7911.62	70.9	**23.256**	32	4.939
232	15142.25	0.00	0.0	5108	33.7	10034.25	66.3	**26.625**		
233	14273.7	0.00	0.0	2469	17.3	11804.7	82.7	**14.627**		
234	19534.8	0.00	0.0	6200	31.7	13334.8	68.3	**25.169**		
235	14403.47	0.00	0.0	5783	40.2	8620.47	59.8	**31.310**		
236	14377.79	0.00	0.0	6109	42.5	8268.79	57.5	**33.017**		
237	8589.29	0.00	0.0	3600	41.9	4989.29	58.1	**32.596**		
238	15020.12	0.00	0.0	2130	14.2	12890.12	85.8	**12.352**		
239	4847.19	0.00	0.0	326	6.7	4521.19	93.3	**6.910**		
240	5501.36	0.00	0.0	2681	48.7	2820.36	51.3	**37.575**		
241	10482.2	0.00	0.0	0	0.0	10482.2	100.0	**2.000**	33	6.822
242	18865.72	0.00	0.0	4300	22.8	14565.72	77.2	**18.639**		
243	8690.34	0.00	0.0	0	0.0	8690.34	100.0	**2.000**		
244	14827.45	269.00	1.8	1078	7.3	13480.45	90.9	**8.995**		
245	14211.01	658.00	4.6	8000	56.3	5553.01	39.1	**47.401**		
246	9999.8	0.00	0.0	3200	32.0	6799.8	68.0	**25.360**		
247	12085.27	0.00	0.0	4200	34.8	7885.27	65.2	**27.370**		
248	12973.85	0.00	0.0	4450	34.3	8523.85	65.7	**27.039**		
249	16467.97	0.00	0.0	3200	19.4	13267.97	80.6	**16.185**		
250	8841.71	0.00	0.0	1500	17.0	7341.71	83.0	**14.384**		
251	11102.85	0.00	0.0	2600	23.4	8502.85	76.6	**19.095**		
252	13682.84	0.00	0.0	5000	36.5	8682.84	63.5	**28.676**		
253	19125.76	0.00	0.0	5200	27.2	13925.76	72.8	**21.848**		
254	25741.23	0.00	0.0	8000	31.1	17741.23	68.9	**24.687**		
255	13607.27	0.00	0.0	4900	36.0	8707.27	64.0	**28.287**	3	6.670
256	9339.18	0.00	0.0	3800	40.7	5539.18	59.3	**31.703**		
257	13790.19	0.00	0.0	5000	36.3	8790.19	63.7	**28.468**		
258	11605.1	0.00	0.0	3800	32.7	7805.1	67.3	**25.903**		
259	14327.46	0.00	0.0	7300	51.0	7027.46	49.0	**39.194**		

260	5975	3045.63	51.0	2540	42.5	389.366	6.5	**80.437**		
261	14771.89	1812.45	12.3	2400	16.2	10559.441	71.5	**25.271**		
262	13458.47	0.00	0.0	3246	24.1	10212.47	75.9	**19.607**		
263	13458.47	0.00	0.0	5400	40.1	8058.47	59.9	**31.290**		
264	7881.64	0.00	0.0	2000	25.4	5881.64	74.6	**20.524**		
265	8177.82	0.00	0.0	0	0.0	8177.82	100.0	**2.000**		
266	9364.6	0.00	0.0	1015	10.8	8349.6	89.2	**9.912**		
267	5436.85	0.00	0.0	1071	19.7	4365.85	80.3	**16.380**		
268	4772.33	0.00	0.0	750	15.7	4022.33	84.3	**13.472**		
269	5402.03	0.00	0.0	2200	40.7	3202.03	59.3	**31.730**		
270	14291.85	1217.38	8.5	4400	30.8	8674.474	60.7	**32.396**		
271	13722.21	0.00	0.0	4096	29.8	9626.21	70.2	**23.790**		
272	14508.75	1594.34	11.0	3001	20.7	9913.415	68.3	**27.319**		
273	14586.55	0.00	0.0	4300	29.5	10286.55	70.5	**23.520**		
274	13725.32	0.00	0.0	5500	40.1	8225.32	59.9	**31.253**	3	6.670
275	14028.11	0.00	0.0	2200	15.7	11828.11	84.3	**13.448**		
276	14312.08	0.00	0.0	4700	32.8	9612.08	67.2	**25.973**		
277	13810.4	0.00	0.0	5200	37.7	8610.4	62.3	**29.487**		
278	13617.9	0.00	0.0	4070	29.9	9547.9	70.1	**23.818**		
279	14067.8	0.00	0.0	4320	30.7	9747.8	69.3	**24.417**		
280	13681.84	0.00	0.0	1100	8.0	12581.84	92.0	**7.869**		
281	13957.73	0.00	0.0	1800	12.9	12157.73	87.1	**11.414**		
282	13940.83	0.00	0.0	4000	28.7	9940.83	71.3	**22.946**		
283	13896.99	0.00	0.0	4333	31.2	9563.99	68.8	**24.761**		
284	13920.37	1421.56	10.2	5000	35.9	7498.812	53.9	**37.718**		
285	13574.88	872.43	6.4	4000	29.5	8702.453	64.1	**29.487**		
286	13574.88	0.00	0.0	2150	15.8	11424.88	84.2	**13.562**		
287	14049.15	0.00	0.0	1120	8.0	12929.15	92.0	**7.820**		
288	12152.25	0.00	0.0	4200	34.6	7952.25	65.4	**27.230**		

289	14247.57	0.00	0.0	2865	20.1	11382.57	79.9	**16.679**		
290	14567.15	995.25	6.8	3000	20.6	10571.898	72.6	**23.388**		
291	14240.28	1546.15	10.9	4250	29.8	8444.135	59.3	**33.884**		
292	14334.07	1839.05	12.8	5850	40.8	6645.021	46.4	**43.724**		
293	14020.95	0.00	0.0	3150	22.5	10870.95	77.5	**18.400**		
294	14420.66	0.00	0.0	3900	27.0	10520.66	73.0	**21.743**		
295	14154.49	0.00	0.0	5130	36.2	9024.49	63.8	**28.457**		
296	18874.85	0.00	0.0	2530	13.4	16344.85	86.6	**11.785**		
297	13898.61	0.00	0.0	2980	21.4	10918.61	78.6	**17.652**		
298	14126.75	0.00	0.0	3680	26.0	10446.75	74.0	**21.016**		
299	13510.13	1028.69	7.6	4900	36.3	7581.437	56.1	**35.558**		
300	13896.9	1088.38	7.8	3814	27.4	8994.522	64.7	**29.318**		
301	13569.17	0.00	0.0	2300	17.0	11269.17	83.0	**14.374**		
302	14122.75	0.00	0.0	1424	10.1	12698.75	89.9	**9.361**		
303	14159.22	0.00	0.0	1980	14.0	12179.22	86.0	**12.208**	3	6.670
304	2813.88	0.00	0.0	470	16.7	2343.88	83.3	**14.193**		
305	3785.06	660.91	17.5	690	18.2	2434.15	64.3	**31.546**		
306	21030.03	3523.39	16.8	7100	33.8	10406.643	49.5	**42.227**		
307	14263.57	933.40	6.5	6650	46.6	6680.174	46.8	**42.120**		
308	14192.3	3577.93	25.2	5900	41.6	4714.37	33.2	**55.793**		
309	13557.11	0.00	0.0	4500	33.2	9057.11	66.8	**26.231**		
310	13868.8	0.00	0.0	5470	39.4	8398.8	60.6	**30.792**		
312	14088.71	0.00	0.0	1900	13.5	12188.71	86.5	**11.845**		
313	14192.3	933.43	6.6	2900	20.4	10358.866	73.0	**23.033**		
314	12878.04	4779.01	37.1	1470	11.4	6629.027	51.5	**44.845**		
315	14549.35	0.00	0.0	2750	18.9	11799.35	81.1	**15.798**		
316	14191.72	0.00	0.0	2566	18.1	11625.72	81.9	**15.199**		
317	14507.26	0.00	0.0	3142	21.7	11365.26	78.3	**17.810**		
318	14369.71	0.00	0.0	2548	17.7	11821.71	82.3	**14.944**		

319	20595.42	1986.54	9.6	3547	17.2	15061.878	73.1	**23.543**	3	6.670
320	14049.05	0.00	0.0	1800	12.8	12249.05	87.2	**11.353**		
321	14049.96	0.00	0.0	2208	15.7	11841.96	84.3	**13.472**		
322	22114.42	0.00	0.0	7399	33.5	14715.42	66.5	**26.424**		
323	18042.2	0.00	0.0	4308	23.9	13734.2	76.1	**19.430**		
324	21754.27	0.00	0.0	6650	30.6	15104.27	69.4	**24.315**		
325	14180.33	0.00	0.0	2510	17.7	11670.33	82.3	**14.921**		
326	13599.98	0.00	0.0	4142	30.5	9457.98	69.5	**24.233**		
327	9348.15	0.00	0.0	2190	23.4	7158.15	76.6	**19.102**		
328	12918.66	0.00	0.0	940	7.3	11978.66	92.7	**7.312**		
329	7682.53	0.00	0.0	0	0.0	7682.53	100.0	**2.000**		
330	11237.68	0.00	0.0	495	4.4	10742.68	95.6	**5.216**		
331	14033.73	0.00	0.0	933	6.6	13100.73	93.4	**6.853**		
332	14613.96	0.00	0.0	4060	27.8	10553.96	72.2	**22.281**		
333	14309.7	0.00	0.0	3134	21.9	11175.7	78.1	**17.988**		
334	13639.66	0.00	0.0	930	6.8	12709.66	93.2	**6.977**		
335	13811.34	0.00	0.0	3070	22.2	10741.34	77.8	**18.227**		
336	13469.73	0.00	0.0	2555	19.0	10914.73	81.0	**15.847**		
337	13596.05	0.00	0.0	1460	10.7	12136.05	89.3	**9.839**		
338	14177.04	1298.00	9.2	970	6.8	11909.038	84.0	**15.509**		
339	14421.58	1303.78	9.0	2794	19.4	10323.804	71.6	**24.550**		
340	15207.2	0.00	0.0	2750	18.1	12457.2	81.9	**15.201**		
341	9420.05	0.00	0.0	195	2.1	9225.05	97.9	**3.511**		
342	14087.09	0.00	0.0	3800	27.0	10287.09	73.0	**21.692**		
343	14005.41	0.00	0.0	2100	15.0	11905.41	85.0	**12.946**		
344	13895.41	0.00	0.0	1500	10.8	12395.41	89.2	**9.880**		
345	14702.99	1178.57	8.0	2700	18.4	10824.425	73.6	**22.860**		
346	14024.88	0.00	0.0	2080	14.8	11944.88	85.2	**12.826**		
347	13370.94	1553.29	11.6	1870	14.0	9947.654	74.4	**23.013**		

348	14265.37	0.00	0.0	3500	24.5	10765.37	75.5	**19.911**	3	6.670
349	14306.55	0.00	0.0	3732	26.1	10574.55	73.9	**21.043**		
350	14105.93	2568.85	18.2	3500	24.8	8037.079	57.0	**37.049**		
351	14683.56	0.00	0.0	5000	34.1	9683.56	65.9	**26.858**		
352	13745.65	0.00	0.0	3750	27.3	9995.65	72.7	**21.915**		
353	13530.5	0.00	0.0	3300	24.4	10230.5	75.6	**19.804**		
354	14551	0.00	0.0	3800	26.1	10751	73.9	**21.064**		
355	14819.58	0.00	0.0	4300	29.0	10519.58	71.0	**23.181**		
356	11640.8	0.00	0.0	2600	22.3	9040.8	77.7	**18.305**		
357	7431.62	0.00	0.0	1050	14.1	6381.62	85.9	**12.314**		
358	9193.44	0.00	0.0	1842	20.0	7351.44	80.0	**16.626**		
359	14531.41	0.00	0.0	4500	31.0	10031.41	69.0	**24.606**		
360	14343.65	0.00	0.0	3600	25.1	10743.65	74.9	**20.322**		
361	14001.43	805.01	5.7	2830	20.2	10366.419	74.0	**22.102**		
362	14184.21	0.00	0.0	4000	28.2	10184.21	71.8	**22.586**		
363	14160.84	3036.34	21.4	6530	46.1	4594.502	32.4	**55.603**		
364	14831.03	0.00	0.0	5000	33.7	9831.03	66.3	**26.611**		
365	14311.44	702.64	4.9	4300	30.0	9308.799	65.0	**28.499**		
366	15100.5	528.20	3.5	3114	20.6	11458.304	75.9	**20.307**		
367	20961.96	0.00	0.0	5500	26.2	15461.96	73.8	**21.154**		
368	20961.96	0.00	0.0	4985	23.8	15976.96	76.2	**19.360**		
369	14288.68	692.59	4.8	5900	41.3	7696.09	53.9	**36.651**		
370	14307.39	0.00	0.0	3600	25.2	10707.39	74.8	**20.368**		
371	14840.71	1380.17	9.3	3240	21.8	10220.545	68.9	**26.586**		
372	13186.58	0.00	0.0	2000	15.2	11186.58	84.8	**13.072**		
373	16468.89	0.00	0.0	3400	20.6	13068.89	79.4	**17.071**		
374	13875.04	0.00	0.0	3930	28.3	9945.04	71.7	**22.677**		
375	13724.67	0.00	0.0	4700	34.2	9024.67	65.8	**26.999**		
376	10669.61	847.31	7.9	3400	31.9	6422.296	60.2	**32.648**		

377	18924.41	0.00	0.0	5000	26.4	13924.41	73.6	**21.287**	3	6.670
378	11571.1	0.00	0.0	1152	10.0	10419.1	90.0	**9.268**		
379	12247.84	0.00	0.0	4600	37.6	7647.84	62.4	**29.417**		
380	12225.65	0.00	0.0	4500	36.8	7725.65	63.2	**28.870**		
381	12225.65	0.00	0.0	4670	38.2	7555.65	61.8	**29.885**		
382	8180.47	834.94	10.2	2860	35.0	4485.531	54.8	**37.014**	35	7.552
383	7818.93	0.00	0.0	1900	24.3	5918.93	75.7	**19.739**		
384	5577.56	0.00	0.0	705	12.6	4872.56	87.4	**11.227**		
385	6929.2	0.00	0.0	560	8.1	6369.2	91.9	**7.900**		
386	9364.6	0.00	0.0	336	3.6	9028.6	96.4	**4.619**		
387	5330.92	0.00	0.0	219	4.1	5111.92	95.9	**4.999**		
388	4986.92	0.00	0.0	709	14.2	4277.92	85.8	**12.379**		
389	3471.47	0.00	0.0	1520	43.8	1951.47	56.2	**33.963**	50	8.099
390	2631.44	0.00	0.0	826	31.4	1805.44	68.6	**24.914**		
392	12751.52	0.00	0.0	3400	26.7	9351.52	73.3	**21.464**		
393	17560.64	0.00	0.0	2925	16.7	14635.64	83.3	**14.159**	51	10.261
394	7112.12	0.00	0.0	567	8.0	6545.12	92.0	**7.820**	2	7.845
395	13172.84	0.00	0.0	2926	22.2	10246.84	77.8	**18.215**		
396	16121.57	0.00	0.0	3162	19.6	12959.57	80.4	**16.318**		
397	13806.81	0.00	0.0	6570	47.6	7236.81	52.4	**36.737**		
398	9467.77	0.00	0.0	1632	17.2	7835.77	82.8	**14.583**		
399	14252.99	0.00	0.0	5895	41.4	8357.99	58.6	**32.193**		
400	19458.94	0.00	0.0	2805	14.4	16653.94	85.6	**12.523**		
401	21210.87	0.00	0.0	8018	37.8	13192.87	62.2	**29.595**		
402	14596.4	0.00	0.0	6425	44.0	8171.4	56.0	**34.133**		
403	14251.53	0.00	0.0	7427	52.1	6824.53	47.9	**40.043**		
404	17820.49	0.00	0.0	7387	41.5	10433.49	58.5	**32.260**		
405	11871.73	0.00	0.0	5883	49.6	5988.73	50.4	**38.175**		
406	13452.72	0.00	0.0	6398	47.6	7054.72	52.4	**36.718**		

407	13664.56	0.00	0.0	7633	55.9	6031.56	44.1	**42.778**		
408	9635.57	0.00	0.0	2604	27.0	7031.57	73.0	**21.728**		
409	13071.47	0.00	0.0	1844	14.1	11227.47	85.9	**12.298**		
410	11791.75	0.00	0.0	1292	11.0	10499.75	89.0	**9.998**		
411	14912.81	0.00	0.0	4032	27.0	10880.81	73.0	**21.737**		
412	14396.84	0.00	0.0	1444	10.0	12952.84	90.0	**9.322**		
413	20064.14	0.00	0.0	4620	23.0	15444.14	77.0	**18.809**		
414	16878.03	484.00	2.9	4273	25.3	12121.03	71.8	**23.148**		
415	13644.9	661.00	4.8	1254	9.2	11729.9	86.0	**13.214**		
416	9312	0.00	0.0	1540	16.5	7772	83.5	**14.073**		
417	13718.97	0.00	0.0	4171	30.4	9547.97	69.6	**24.194**		
418	14044.29	571.00	4.1	3677	26.2	9796.29	69.8	**24.894**		
419	13797.69	129.00	0.9	5727	41.5	7941.69	57.6	**33.170**		
420	13337.75	509.00	3.8	4746	35.6	8082.75	60.6	**31.525**		
421	14921.7	201.00	1.3	805	5.4	13915.7	93.3	**7.191**	2	7.845
422	14431.55	0.00	0.0	2522	17.5	11909.55	82.5	**14.757**		
423	14215.22	0.00	0.0	2286	16.1	11929.22	83.9	**13.739**		
424	13950.48	0.00	0.0	2790	20.0	11160.48	80.0	**16.599**		
425	13973.15	0.00	0.0	1765	12.6	12208.15	87.4	**11.221**		
426	9349.72	0.00	0.0	1450	15.5	7899.72	84.5	**13.321**		
427	20396.99	305.31	1.5	5300	26.0	14791.684	72.5	**22.361**		
428	19525.45	1479.88	7.6	5056	25.9	12989.57	66.5	**27.952**		
429	11850.58	0.00	0.0	2800	23.6	9050.58	76.4	**19.248**		
430	11847.54	0.00	0.0	3954	33.4	7893.54	66.6	**26.363**		
431	14964.14	1238.26	8.3	4500	30.1	9225.88	61.7	**31.648**		
432	14826.51	0.00	0.0	4780	32.2	10046.51	67.8	**25.535**		
433	14221.22	0.00	0.0	4590	32.3	9631.22	67.7	**25.561**		
434	13625.28	0.00	0.0	2550	18.7	11075.28	81.3	**15.662**		
435	13113.8	862.19	6.6	2023	15.4	10228.611	78.0	**19.376**		

438	14725.12	0.00	0.0	4240	28.8	10485.12	71.2	**23.020**	2	7.845
439	15014.1	938.33	6.2	3360	22.4	10715.766	71.4	**24.149**		
440	11296.89	1720.87	15.2	1130	10.0	8446.025	74.8	**23.469**		
441	19440.75	0.00	0.0	1917	9.9	17523.75	90.1	**9.198**		
442	20705.56	0.00	0.0	3400	16.4	17305.56	83.6	**13.987**		
443	22117.07	3720.31	16.8	5500	24.9	12896.757	58.3	**35.797**		
444	12823.31	2282.24	17.8	1500	11.7	9041.066	70.5	**27.091**		
445	13897.48	0.00	0.0	5677	40.8	8220.48	59.2	**31.820**		
446	14345.37	0.00	0.0	5468	38.1	8877.37	61.9	**29.825**		
447	14298.43	491.59	3.4	3057	21.4	10749.844	75.2	**20.805**		
448	14130.52	0.00	0.0	5367	38.0	8763.52	62.0	**29.727**		
449	14160.82	0.00	0.0	2357	16.6	11803.82	83.4	**14.150**		
450	14154.76	0.00	0.0	2035	14.4	12119.76	85.6	**12.495**		
451	14490.5	0.00	0.0	2164	14.9	12326.5	85.1	**12.902**		
452	11965.52	0.00	0.0	1127	9.4	10838.52	90.6	**8.876**		
453	14584.4	0.00	0.0	2206	15.1	12378.4	84.9	**13.042**		
454	18820.47	2625.52	14.0	5162	27.4	11032.948	58.6	**34.996**		
455	18820.47	8152.61	43.3	3574	19.0	7093.865	37.7	**56.148**		
456	6428.5	0.00	0.0	3818.5	59.4	2610	40.6	**45.362**	1	2.042
457	19601.01	0.00	0.0	1105	5.6	18496.01	94.4	**6.115**		
458	22582.6	0.00	0.0	1035	4.6	21547.6	95.4	**5.346**		
459	20751.69	68.00	0.3	657	3.2	20026.69	96.5	**4.616**		
460	19814.88	161.00	0.8	2093	10.6	17560.88	88.6	**10.466**		
461	12632.43	0.00	0.0	924	7.3	11708.43	92.7	**7.340**		
462	13988.47	0.00	0.0	2193	15.7	11795.47	84.3	**13.444**		
463	14129.62	0.00	0.0	1495	10.6	12634.62	89.4	**9.724**		
464	14322.16	0.00	0.0	1173	8.2	13149.16	91.8	**7.979**		
465	13325.41	0.00	0.0	2520	18.9	10805.41	81.1	**15.805**		
466	9990.05	0.00	0.0	189	1.9	9801.05	98.1	**3.381**		

471	3917.16	0.00	0.0	611	15.6	3306.16	84.4	**13.387**		
472	16566.24	0.00	0.0	1425	8.6	15141.24	91.4	**8.279**		
473	14467.62	0.00	0.0	2292	15.8	12175.62	84.2	**13.565**		
474	14074.02	0.00	0.0	3438	24.4	10636.02	75.6	**19.832**		
475	14279.51	0.00	0.0	4267	29.9	10012.51	70.1	**23.814**		
476	14275.04	0.00	0.0	1986	13.9	12289.04	86.1	**12.156**		
477	15092.21	0.00	0.0	3056	20.2	12036.21	79.8	**16.782**		
478	14561.75	0.00	0.0	3362	23.1	11199.75	76.9	**18.854**		
479	15237.63	0.00	0.0	2674	17.5	12563.63	82.5	**14.811**		
480	25564.33	0.00	0.0	4584	17.9	20980.33	82.1	**15.090**		
481	15156.32	0.00	0.0	3247	21.4	11909.32	78.6	**17.639**		
482	23814.73	0.00	0.0	6417	26.9	17397.73	73.1	**21.670**		
483	13928.69	0.00	0.0	1834	13.2	12094.69	86.8	**11.612**		
484	13902.99	0.00	0.0	2865	20.6	11037.99	79.4	**17.043**		
485	14749.96	0.00	0.0	2865	19.4	11884.96	80.6	**16.179**	1	2.042
486	14523.23	0.00	0.0	2292	15.8	12231.23	84.2	**13.521**		
487	9714.95	0.00	0.0	1146	11.8	8568.95	88.2	**10.611**		
488	15237.69	0.00	0.0	1719	11.3	13518.69	88.7	**10.235**		
489	14476.13	0.00	0.0	2368.4	16.4	12107.73	83.6	**13.943**		
490	13629.21	0.00	0.0	3056	22.4	10573.21	77.6	**18.368**		
491	13651.39	0.00	0.0	1146	8.4	12505.39	91.6	**8.128**		
492	13531.34	0.00	0.0	2101	15.5	11430.34	84.5	**13.335**		
493	13728.72	0.00	0.0	2483	18.1	11245.72	81.9	**15.203**		
494	13800.76	0.00	0.0	1528	11.1	12272.76	88.9	**10.082**		
495	14120.73	0.00	0.0	2904	20.6	11216.73	79.4	**17.013**		
496	15444.32	0.00	0.0	2101	13.6	13343.32	86.4	**11.931**		
499	1084.98	0.00	0.0	132	12.2	952.98	87.8	**10.881**		
500	7884.97	0.00	0.0	2292	29.1	5592.97	70.9	**23.220**		
501	15040.84	0.00	0.0	2674	17.8	12366.84	82.2	**14.978**		

502	14539.46	0.00	0.0	2101	14.5	12438.46	85.5	**12.549**		
503	14632.71	0.00	0.0	3820	26.1	10812.71	73.9	**21.057**		
504	14264.74	0.00	0.0	3514	24.6	10750.74	75.4	**19.983**		
505	14976.74	0.00	0.0	2101	14.0	12875.74	86.0	**12.241**		
506	15174.11	0.00	0.0	3438	22.7	11736.11	77.3	**18.540**		
507	23835.76	467.00	2.0	2865	12.0	20503.76	86.0	**12.597**		
508	13707.4	882.00	6.4	2292	16.7	10533.4	76.8	**20.190**		
509	18963.55	594.00	3.1	2106	11.1	16263.55	85.8	**13.020**		
510	15120.77	0.00	0.0	2865	18.9	12255.77	81.1	**15.832**		
511	15995.46	0.00	0.0	1960	12.3	14035.46	87.7	**10.945**		
512	18699.63	1795.00	9.6	6249	33.4	10655.63	57.0	**35.322**		
513	14563.43	0.00	0.0	2101	14.4	12462.43	85.6	**12.531**		
514	14800.72	0.00	0.0	1146	7.7	13654.72	92.3	**8.039**		
515	24163.83	0.00	0.0	2101	8.7	22062.83	91.3	**8.347**		
516	12232.61	0.00	0.0	2292	18.7	9940.61	81.3	**15.678**	1	2.042
517	13600.73	0.00	0.0	2636	19.4	10964.73	80.6	**16.148**		
518	13712.68	0.00	0.0	2292	16.7	11420.68	83.3	**14.202**		
519	14107.37	0.00	0.0	1051	7.5	13056.37	92.5	**7.439**		
520	13566	0.00	0.0	2865	21.1	10701	78.9	**17.417**		
521	13774.03	0.00	0.0	1910	13.9	11864.03	86.1	**12.123**		
522	13101.97	0.00	0.0	3247	24.8	9854.97	75.2	**20.091**		
523	13654.04	0.00	0.0	2674	19.6	10980.04	80.4	**16.296**		
524	14067.3	0.00	0.0	1910	13.6	12157.3	86.4	**11.912**		
525	14243.39	0.00	0.0	955	6.7	13288.39	93.3	**6.895**		
526	3009.64	0.00	0.0	1068	35.5	1941.64	64.5	**27.905**		
529	5133.28	0.00	0.0	471	9.2	4662.28	90.8	**8.698**		
531	13536.59	0.00	0.0	2674	19.8	10862.59	80.2	**16.420**		
532	14414.12	0.00	0.0	2101	14.6	12313.12	85.4	**12.640**		
533	14918.08	0.00	0.0	2865	19.2	12053.08	80.8	**16.020**		

534	14915.52	0.00	0.0	2292	15.4	12623.52	84.6	**13.218**		
535	15197.99	0.00	0.0	2292	15.1	12905.99	84.9	**13.009**		
536	14517.98	0.00	0.0	2101	14.5	12416.98	85.5	**12.564**		
537	14040.81	0.00	0.0	2105	15.0	11935.81	85.0	**12.944**		
538	15360.76	0.00	0.0	1719	11.2	13641.76	88.8	**10.169**		
539	22097.06	665.00	3.0	2101	9.5	19331.06	87.5	**11.740**		
540	14352.73	0.00	0.0	4286	29.9	10066.73	70.1	**23.799**		
541	14128.8	0.00	0.0	1528	10.8	12600.8	89.2	**9.895**		
542	13739.35	0.00	0.0	2292	16.7	11447.35	83.3	**14.178**		
543	14720.75	0.00	0.0	1910	13.0	12810.75	87.0	**11.472**		
544	14880.86	0.00	0.0	1146	7.7	13734.86	92.3	**7.622**		
545	13725.99	0.00	0.0	764	5.6	12961.99	94.4	**6.063**		
546	14790.03	0.00	0.0	1528	10.3	13262.03	89.7	**9.542**		
547	14598.15	223.00	1.5	2292	15.7	12083.15	82.8	**14.882**		
548	15955.4	264.00	1.7	1910	12.0	13781.4	86.4	**12.278**	1	2.042
549	12805.97	727.00	5.7	764	6.0	11314.97	88.4	**11.635**		
550	23587.74	0.00	0.0	3056	13.0	20531.74	87.0	**11.458**		
551	13365.92	0.00	0.0	1146	8.6	12219.92	91.4	**8.259**		
552	14229.96	0.00	0.0	1910	13.4	12319.96	86.6	**11.798**		
553	13908.03	0.00	0.0	955	6.9	12953.03	93.1	**7.013**		
554	13551.96	0.00	0.0	1528	11.3	12023.96	88.7	**10.231**		
555	14065.62	0.00	0.0	2865	20.4	11200.62	79.6	**16.869**		
556	14437.78	0.00	0.0	3629	25.1	10808.78	74.9	**20.349**		
557	14468.55	0.00	0.0	2292	15.8	12176.55	84.2	**13.564**		
560	15843.42	0.00	0.0	2674	16.9	13169.42	83.1	**14.321**		
561	10015.91	0.00	0.0	2865	28.6	7150.91	71.4	**22.881**		
562	20676.5	0.00	0.0	4393	21.2	16283.5	78.8	**17.510**		
563	22571.14	0.00	0.0	2292	10.2	20279.14	89.8	**9.413**		
564	14911.5	0.00	0.0	1528	10.2	13383.5	89.8	**9.480**		

565	14897.74	0.00	0.0	1337	9.0	13560.74	91.0	**8.551**	1	2.042
566	15737.79	0.00	0.0	2674	17.0	13063.79	83.0	**14.403**		
567	14126.83	437.00	3.1	1069	7.6	12620.83	89.3	**10.401**		
568	13966.21	0.00	0.0	1146	8.2	12820.21	91.8	**7.990**	23	4.431
569	22154.88	0.00	0.0	1757	7.9	20397.88	92.1	**7.789**		
571	10875.56	0.00	0.0	330	3.0	10545.56	97.0	**4.215**		
574	9150.84	0.00	0.0	479	5.2	8671.84	94.8	**5.821**		
575	20777.13	0.00	0.0	1034	5.0	19743.13	95.0	**5.633**		
576	16964.17	0.00	0.0	189	1.1	16775.17	98.9	**2.813**		
577	23775.14	0.00	0.0	840	3.5	22935.14	96.5	**4.579**		
578	16168.34	2359.00	14.6	499	3.1	13310.34	82.3	**17.822**		
579	26064.73	0.00	0.0	1146	4.4	24918.73	95.6	**5.210**	24	3.219
580	9563.14	0.00	0.0	70	0.7	9493.14	99.3	**2.534**		
581	18029.09	386.00	2.1	1948	10.8	15695.09	87.1	**11.879**		
582	16551.1	800.00	4.8	399	2.4	15352.1	92.8	**8.255**	4	4.133
583	10941.91	1619.00	14.8	507	4.6	8815.91	80.6	**19.375**		
584	14004.54	0.00	0.0	497	3.5	13507.54	96.5	**4.768**	5	2.409
585	11226.48	0.00	0.0	573	5.1	10653.48	94.9	**5.981**		
586	18579.88	0.00	0.0	1910	10.3	16669.88	89.7	**10.018**		
587	13442.68	0.00	0.0	1528	11.4	11914.68	88.6	**10.866**		
588	15599.59	0.00	0.0	610	3.9	14989.59	96.1	**5.050**		
589	10456.43	0.00	0.0	1451	13.9	9005.43	86.1	**12.824**		
590	15721.43	2228.00	14.2	1910	12.1	11583.43	73.7	**24.656**	6	2.501
591	9932.25	0.00	0.0	1604	16.1	8328.25	83.9	**14.597**		
592	6826.63	0.00	0.0	5473	80.2	1353.63	19.8	**64.534**	7	2.415
593	19920.29	0.00	0.0	4924	24.7	14996.29	75.3	**21.280**		
594	12124.51	0.00	0.0	1307	10.8	10817.51	89.2	**10.408**		
595	5101.4	0.00	0.0	5101.4	100.0	0	0.0	**80.000**		
598	11007.57	0.00	0.0	1719	15.6	9288.57	84.4	**14.181**	8	2.270

599	12980.03	0.00	0.0	1451	11.2	11529.03	88.8	**10.719**	8	2.270
600	8660.13	233.00	2.7	3218	37.2	5209.13	60.2	**33.486**		
601	14411.92	0.00	0.0	12855.92	89.2	1556	10.8	**71.579**		
602	9394.41	0.00	0.0	2642	28.1	6752.41	71.9	**23.936**		
603	22209.6	0.00	0.0	3056	13.8	19153.6	86.2	**12.733**	9	2.676
604	11953.91	0.00	0.0	2196	18.4	9757.91	81.6	**16.329**		
605	10034.57	0.00	0.0	1337	13.3	8697.57	86.7	**12.393**		
608	16147.88	0.00	0.0	819	5.1	15328.88	94.9	**5.956**		
609	9181.6	0.00	0.0	572	6.2	8609.6	93.8	**6.859**		
610	7303.93	0.00	0.0	487	6.7	6816.93	93.3	**7.201**	10	2.212
611	5389.43	0.00	0.0	289	5.4	5100.43	94.6	**6.183**		
612	12625.1	0.00	0.0	238	1.9	12387.1	98.1	**3.470**		
613	12048.17	0.00	0.0	764	6.3	11284.17	93.7	**6.946**		
614	14765.52	0.00	0.0	791	5.4	13974.52	94.6	**6.179**		
615	10434.16	0.00	0.0	219	2.1	10215.16	97.9	**3.532**		
616	14765.52	0.00	0.0	1230	8.3	13535.52	91.7	**8.081**		
617	14694.99	0.00	0.0	1146	7.8	13548.99	92.2	**7.693**		
618	8909.51	0.00	0.0	242	2.7	8667.51	97.3	**3.983**		
619	7739.22	0.00	0.0	573	7.4	7166.22	92.6	**7.405**	11	2.197
620	7794.75	250.00	3.2	764	9.8	6780.75	87.0	**12.138**		
621	4635.68	0.00	0.0	382	8.2	4253.68	91.8	**8.016**		
622	2865.18	262.00	9.1	137	4.8	2466.18	86.1	**13.995**		
623	22992.76	0.00	0.0	2483	10.8	20509.76	89.2	**9.883**	12	3.959
624	19743.01	483.00	2.4	1260	6.4	18000.01	91.2	**8.934**		
625	13581.97	0.00	0.0	2689	19.8	10892.97	80.2	**16.453**	13	4.212
626	20228.54	0.00	0.0	1120	5.5	19108.54	94.5	**6.042**		
627	25612.25	0.00	0.0	2210	8.6	23402.25	91.4	**8.299**		
628	20143.36	0.00	0.0	2996	14.9	17147.36	85.1	**12.858**		
629	10771.91	135.00	1.3	1095	10.2	9541.91	88.6	**10.586**	16	1.577

630	22977.63	0.00	0.0	3822	16.6	19155.63	83.4	**14.143**	15	2.205
631	18627.2	0.00	0.0	2820	15.1	15807.2	84.9	**13.052**	14	4.113
632	8066.33	0.00	0.0	1325	16.4	6741.33	83.6	**13.991**		
633	14422.9	0.00	0.0	2293	15.9	12129.9	84.1	**13.606**	21	4.660
634	9231.27	0.00	0.0	1015	11.0	8216.27	89.0	**10.027**	22	3.208
635	10756.85	875.84	8.1	824	7.7	9057.006	84.2	**15.164**	21	4.660
636	5426.72	0.00	0.0	1001	18.4	4425.72	81.6	**15.465**	20	2.192
637	11844.3	0.00	0.0	2466	20.8	9378.3	79.2	**17.199**	19	3.728
638	20552.07	0.00	0.0	5030	24.5	15522.07	75.5	**19.866**		
639	22811.97	0.00	0.0	4292	18.8	18519.97	81.2	**15.735**	18	3.473
640	15000.98	0.00	0.0	7133	47.6	7867.98	52.4	**36.712**		
641	16083.32	0.00	0.0	1386	8.6	14697.32	91.4	**8.291**	17	8.277
642	17809.79	0.00	0.0	960	5.4	16849.79	94.6	**5.935**		
643	11800.2	0.00	0.0	2893	24.5	8907.2	75.5	**21.123**	48	2.805
644	13396.97	0.00	0.0	10729	80.1	2667.97	19.9	**64.467**		
645	18783.73	0.00	0.0	1520	8.1	17263.73	91.9	**8.312**	47	2.764
646	14527.54	0.00	0.0	4424	30.5	10103.54	69.5	**25.753**		
647	16611.53	0.00	0.0	760	4.6	15851.53	95.4	**5.569**		
648	15555.62	0.00	0.0	1011	6.5	14544.62	93.5	**7.069**		
649	21748.54	0.00	0.0	988	4.5	20760.54	95.5	**5.543**		
650	12407.48	0.00	0.0	11618.48	93.6	789	6.4	**75.040**	49	3.206
651	13365.07	0.00	0.0	7231	54.1	6134.07	45.9	**44.201**		
652	17002.21	462.00	2.7	237	1.4	16303.21	95.9	**5.614**	46	2.739
653	18062.71	0.00	0.0	1904	10.5	16158.71	89.5	**10.222**		
654	18504.46	0.00	0.0	4913	26.6	13591.46	73.4	**22.709**		
655	18831.47	0.00	0.0	3179	16.9	15652.47	83.1	**15.167**		
656	12114.37	0.00	0.0	3854	31.8	8260.37	68.2	**26.814**	45	3.859
657	15819.02	0.00	0.0	1168	7.4	14651.02	92.6	**7.390**		
658	14685.03	0.00	0.0	7121	48.5	7564.03	51.5	**37.399**		

659	23974.08	0.00	0.0	11664	48.7	12310.08	51.3	**37.516**	45	3.859
660	16119.45	0.00	0.0	4411	27.4	11708.45	72.6	**21.976**		
661	19047.66	0.00	0.0	2831	14.9	16216.66	85.1	**12.850**	44	2.519
662	15439.34	173.00	1.1	5157	33.4	10109.34	65.5	**27.425**		
663	17548.31	137.00	0.8	1215	6.9	16196.31	92.3	**7.780**		
664	11566.41	0.00	0.0	1360	11.8	10206.41	88.2	**10.583**		
665	14477.51	0.00	0.0	5302	36.6	9175.51	63.4	**28.734**		
666	14175.61	0.00	0.0	7800	55.0	6375.61	45.0	**42.168**		
667	14487.25	0.00	0.0	7042	48.6	7445.25	51.4	**37.484**		
668	13494.12	0.00	0.0	6132	45.4	7362.12	54.6	**35.173**		
669	17683.18	747.00	4.2	4641	26.2	12295.18	69.5	**25.088**	43	4.835
670	22003.94	0.00	0.0	6190	28.1	15813.94	71.9	**22.536**		
671	10311.92	461.00	4.5	2804	27.2	7046.92	68.3	**26.008**	42	8.706
672	16239.36	435.00	2.7	2131	13.1	13673.36	84.2	**14.071**		
673	23991.08	0.00	0.0	3588	15.0	20403.08	85.0	**12.918**		
674	20489.23	1171.00	5.7	2559	12.5	16759.23	81.8	**16.432**		
675	15113.2	0.00	0.0	1353	9.0	13760.2	91.0	**8.535**		
676	7746.24	445.00	5.7	1540	19.9	5761.24	74.4	**21.855**	41	10.226
677	17487.31	0.00	0.0	6853	39.2	10634.31	60.8	**30.608**		
678	5684.97	0.00	0.0	1977	34.8	3707.97	65.2	**27.386**		
679	11265.05	0.00	0.0	7165	63.6	4100.05	36.4	**48.431**	40	6.902
680	11261.55	0.00	0.0	5875	52.2	5386.55	47.8	**40.083**		
681	10550.54	262.00	2.5	3210	30.4	7078.54	67.1	**26.520**		
682	12322.9	380.00	3.1	3132	25.4	8810.9	71.5	**23.422**		
683	12789.52	697.00	5.4	1097	8.6	10995.52	86.0	**13.330**	39	8.502
684	15055.35	0.00	0.0	2687	17.8	12368.35	82.2	**15.029**		
685	24952.95	0.00	0.0	10605	42.5	14347.95	57.5	**33.025**		
686	17913.42	0.00	0.0	7844	43.8	10069.42	56.2	**33.966**	38	8.622
687	8589.62	0.00	0.0	1527	17.8	7062.62	82.2	**14.977**		

688	12012.24	0.00	0.0	3216	26.8	8796.24	73.2	**21.544**	37	8.753
689	23904.59	0.00	0.0	8000	33.5	15904.59	66.5	**26.430**		
690	29691.68	0.00	0.0	4663	15.7	25028.68	84.3	**13.464**		
691	25666.42	0.00	0.0	2986	11.6	22680.42	88.4	**10.493**		
693	20071	555.46	2.8	3004	15.0	16511.536	82.3	**15.500**		
694	11616.96	0.00	0.0	2047	17.6	9569.96	82.4	**14.863**		
695	20242.45	0.00	0.0	5400	26.7	14842.45	73.3	**21.474**		
696	7142.77	708.36	9.9	1655	23.2	4779.41	66.9	**28.137**	36	8.753
697	7307.16	0.00	0.0	1870	25.6	5437.16	74.4	**20.682**		

*U.S. EPA, 2009

APPENDIX B: EVENT MEAN CONCENTRATIONS (EMCs) IN RUNOFF WATER

Table B.1. Predicted EMCs of nutrients in runoff water.

Sample ID[1]	Sampling Date[1]	Region[1]	Texture (%)[1]			Soil Type[2]	Density of Fresh Soil[3] $(g/cm^3)=\rho_{soil}$	pH values[1]	Foc (%)[1]	K	α	β	V (mm)	TN		TP	
			Clay	Sand	Silt									N0[1] (g/kg)	Nr (mg/L)	P0[1] (g/kg)	Pr (mg/L)
E1-1	June 2006	Doğanpınar/Bandırma	39.44	22.00	38.56	Clay Loam	1.45	6.46	1.83	0.074	0.155	0.518	18.78	2.70	5.391	0.78	1.734
E1-2	Oct 2006	Doğanpınar/Bandırma	39.44	22.00	38.56	Clay Loam	1.45	6.49	3.36	0.113	0.213	0.401	62.31	19.50	20.190	11.94	12.363
E2-1	June 2006	Doğanpınar/Bandırma	37.44	20.00	42.56	Silty Clay Loam	1.50	6.44	2.12	0.085	0.172	0.476	62.31	1.88	1.485	0.67	0.529
E2-2	Oct 2006	Doğanpınar/Bandırma	37.44	20.00	42.56	Silty Clay Loam	1.50	6.52	2.47	0.094	0.186	0.447	62.31	15.00	13.198	7.37	6.484
E3	Oct 2006	Doğanpınar/Bandırma	41.44	20.00	38.56	Clay	1.40	6.75	3.16	0.105	0.201	0.420	62.31	15.00	13.736	3.59	3.287
K1-1	June 2006	Karacabey	15.44	23.64	60.92	Silt Loam	1.50	6.63	1.09	0.099	0.193	0.434	126.22	1.65	0.754	0.24	0.110
K1-2	Oct 2006	Karacabey	15.44	23.64	60.92	Silt Loam	1.50	7.31	1.38	0.117	0.219	0.393	126.22	10.50	5.774	3.65	2.007
K2-1	June 2006	Karacabey	19.44	24.00	56.56	Silt Loam	1.50	7.23	1.11	0.085	0.173	0.475	126.22	1.58	0.619	0.23	0.090
K2-2	Oct 2006	Karacabey	19.44	24.00	56.56	Silt Loam	1.50	7.33	1.38	0.099	0.194	0.433	126.22	10.50	4.815	3.03	1.390
F1-1	June 2006	Görükle/Bursa	33.44	18.00	48.56	Silty Clay Loam	1.50	6.37	1.88	0.084	0.171	0.478	147.14	0.83	0.276	0.41	0.136
F1-2	June 2006	Görükle/Bursa	33.44	18.00	48.56	Silty Clay Loam	1.50	6.8	3.56	0.132	0.240	0.366	147.14	24.00	13.140	17.49	9.576
F2-1	June 2006	Görükle/Bursa	41.44	20.00	38.56	Clay	1.40	6.46	1.64	0.066	0.142	0.553	147.14	0.30	0.075	0.05	0.012
F2-2	Oct 2006	Görükle/Bursa	41.44	20.00	38.56	Clay	1.40	5.27	2.47	0.088	0.177	0.466	147.14	13.50	4.366	2.87	0.928
T1-1	June 2006	Zeytinbağı	25.44	21.64	52.92	Silt Loam	1.50	6.44	1.01	0.066	0.143	0.553	125.34	0.90	0.282	0.29	0.091
T1-2	Oct 2006	Zeytinbağı	25.44	21.64	52.92	Silt Loam	1.50	6.94	2.47	0.124	0.228	0.380	125.34	13.50	8.012	7.31	4.338
T2-1	June 2006	Zeytinbağı	25.44	28.00	46.56	Loam	1.50	6.8	1.78	0.098	0.192	0.436	125.34	1.13	0.516	0.24	0.110
T2-2	Oct 2006	Zeytinbağı	25.44	28.00	46.56	Loam	1.50	6.79	7.51	0.269	0.410	0.238	125.34	36.00	68.567	10.31	19.637
İ1	Oct 2006	Inegöl	11.44	24.00	64.56	Silt Loam	1.50	6.53	9.09	0.537	0.690	0.157	129.83	36.00	300.821	73.42	613.508
İ2	Oct 2006	Inegöl	11.44	18.00	70.56	Silt Loam	1.50	7.27	3.95	0.300	0.445	0.223	129.83	12.00	27.080	13.46	30.375
O1	Oct 2006	Orhangazi	43.44	24.00	32.56	Clay	1.40	6.89	2.67	0.090	0.180	0.460	105.31	13.50	6.234	4.11	1.898
O2	Oct 2006	Orhangazi	23.44	24.00	52.56	Silt Loam	1.50	7.07	4.45	0.198	0.325	0.287	105.31	19.50	26.303	3.72	5.018
D1	December 2006	Babaeski	10.85	11.17	77.98	Silt Loam	1.50	6.93	2.42	0.221	0.354	0.268	112.07	4.13	6.268	2.50	3.794
D2	December 2006	Babaeski	10.19	13.66	76.15	Silt Loam	1.50	6.91	4.40	0.351	0.501	0.203	112.07	3.45	12.333	1.20	4.290

M1	December 2006	Malkara	1.80	49.22	48.98	Sandy Loam	1.55	6.9	3.71	1.044	1.140	0.106	125.74	3.90	286.857	1.46	107.387
M2	December 2006	Malkara	9.51	39.56	50.93	Silt Loam	1.50	6.94	3.90	0.338	0.487	0.208	125.74	4.05	11.973	4.80	14.191
B1	Jan 2007	Balçık	15.83	11.05	73.12	Silt Loam	1.50	6.99	3.20	0.206	0.336	0.279	131.96	3.00	3.460	4.20	4.844
B2	Jan 2007	Balçık	3.71	64.15	32.14	Sandy Loam	1.55	6.72	3.41	0.594	0.745	0.148	131.96	3.75	41.858	3.50	39.068
B3	Jan 2007	Balçık	22.05	21.32	56.63	Silt Loam	1.50	6.54	1.66	0.104	0.200	0.423	131.96	2.85	1.307	1.40	0.642
KA1	Jan 2007	Kandıra	23.34	34.95	41.71	Loam	1.50	5.99	2.12	0.118	0.221	0.391	183.03	2.55	0.980	0.80	0.307
KA2	Jan 2007	Kandıra	8.02	40.88	51.10	Silt Loam	1.50	6.47	8.14	0.637	0.785	0.142	183.03	7.20	68.199	5.80	54.938

(1) Balcıoğlu et al., 2007; (2) USDA NRCS, 2011; (3) USDA NRCS, 2012

Table B.2. Predicted heavy metal concentrations in pore water and EMCs in runoff water.

Sample ID[(1)]	Sampling Date[(1)]	Region[(1)]	Texture (%)[(1)]			Soil Type[(2)]	Density of Fresh Soil[(3)] $(g/cm^3)=\rho_{soil}$	pH values[(1)]	Weight of Fresh Soil Sample[(1)] (g)	Volume of Fresh Soil Sample (cm3)	$F_{watersoil}$[(1)] (% kg)	Weight of Soil Water (g)	Volume of Soil Water (cm^3)	$F_{watersoil}$ (m^3/m^3)	$F_{solidsoil}$ (m^3/m^3)	ρ_{solid} (kg/m^3)
			Clay	Sand	Silt											
E1-1	June 2006	Doğanpınar/Bandırma	39.44	22.00	38.56	Clay Loam	1.45	6.46	20	13.793103	19.38	3.876	3.876	0.28101	0.71899	1625.878
E1-2	Oct 2006	Doğanpınar/Bandırma	39.44	22.00	38.56	Clay Loam	1.45	6.49	20	13.793103	17.49	3.498	3.498	0.253605	0.746395	1602.8979
E2-1	June 2006	Doğanpınar/Bandırma	37.44	20.00	42.56	Silty Clay Loam	1.50	6.44	20	13.333333	19.73	3.946	3.946	0.29595	0.70405	1710.1768
E2-2	Oct 2006	Doğanpınar/Bandırma	37.44	20.00	42.56	Silty Clay Loam	1.50	6.52	20	13.333333	19.09	3.818	3.818	0.28635	0.71365	1700.6236
E3	Oct 2006	Doğanpınar/Bandırma	41.44	20.00	38.56	Clay	1.40	6.75	20	14.285714	20.66	4.132	4.132	0.28924	0.71076	1562.7779
K1-1	June 2006	Karacabey	15.44	23.64	60.92	Silt Loam	1.50	6.63	20	13.333333	4.2	0.84	0.84	0.063	0.937	1533.6179
K1-2	Oct 2006	Karacabey	15.44	23.64	60.92	Silt Loam	1.50	7.31	20	13.333333	12.47	2.494	2.494	0.18705	0.81295	1615.044
K2-1	June 2006	Karacabey	19.44	24.00	56.56	Silt Loam	1.50	7.23	20	13.333333	11.83	2.366	2.366	0.17745	0.82255	1607.8658
K2-2	Oct 2006	Karacabey	19.44	24.00	56.56	Silt Loam	1.50	7.33	20	13.333333	13.75	2.75	2.75	0.20625	0.79375	1629.9213
F1-1	June 2006	Görükle/Bursa	33.44	18.00	48.56	Silty Clay Loam	1.50	6.37	20	13.333333	24.51	4.902	4.902	0.36765	0.63235	1790.7014
F1-2	June 2006	Görükle/Bursa	33.44	18.00	48.56	Silty Clay Loam	1.50	6.8	20	13.333333	27.89	5.578	5.578	0.41835	0.58165	1859.6235
F2-1	June 2006	Görükle/Bursa	41.44	20.00	38.56	Clay	1.40	6.46	20	14.285714	20.67	4.134	4.134	0.28938	0.71062	1562.8887

F2-2	Oct 2006	Görükle/Bursa	41.44	20.00	38.56	Clay	1.40	5.27	20	14.285714	25.16	5.032	5.032	0.35224	0.64776	1617.5127
T1-1	June 2006	Zeytinbağı	25.44	21.64	52.92	Silt Loam	1.50	6.44	20	13.333333	10.29	2.058	2.058	0.15435	0.84565	1591.2612
T1-2	Oct 2006	Zeytinbağı	25.44	21.64	52.92	Silt Loam	1.50	6.94	20	13.333333	11.5	2.3	2.3	0.1725	0.8275	1604.2296
T2-1	June 2006	Zeytinbağı	25.44	28.00	46.56	Loam	1.50	6.8	20	13.333333	13.01	2.602	2.602	0.19515	0.80485	1621.2338
T2-2	Oct 2006	Zeytinbağı	25.44	28.00	46.56	Loam	1.50	6.79	20	13.333333	21.52	4.304	4.304	0.3228	0.6772	1738.3343
İ1	Oct 2006	Inegöl	11.44	24.00	64.56	Silt Loam	1.50	6.53	20	13.333333	32.95	6.59	6.59	0.49425	0.50575	1988.6307
İ2	Oct 2006	Inegöl	11.44	18.00	70.56	Silt Loam	1.50	7.27	20	13.333333	9.55	1.91	1.91	0.14325	0.85675	1583.6008
O1	Oct 2006	Orhangazi	43.44	24.00	32.56	Clay	1.40	6.89	20	14.285714	23.95	4.79	4.79	0.3353	0.6647	1601.7752
O2	Oct 2006	Orhangazi	23.44	24.00	52.56	Silt Loam	1.50	7.07	20	13.333333	26.85	5.37	5.37	0.40275	0.59725	1837.1704
D1	December 2006	Babaeski	10.85	11.17	77.98	Silt Loam	1.50	6.93	20	13.333333	9.6	1.92	1.92	0.144	0.856	1584.1121
D2	December 2006	Babaeski	10.19	13.66	76.15	Silt Loam	1.50	6.91	20	13.333333	11.6	2.32	2.32	0.174	0.826	1605.3269
M1	December 2006	Malkara	1.80	49.22	48.98	Sandy Loam	1.55	6.9	20	12.903226	23.4	4.68	4.68	0.3627	0.6373	1863.0158
M2	December 2006	Malkara	9.51	39.56	50.93	Silt Loam	1.50	6.94	20	13.333333	21.1	4.22	4.22	0.3165	0.6835	1731.5289
B1	Jan 2007	Balçık	15.83	11.05	73.12	Silt Loam	1.50	6.99	20	13.333333	13.73	2.746	2.746	0.20595	0.79405	1629.6833
B2	Jan 2007	Balçık	3.71	64.15	32.14	Sandy Loam	1.55	6.72	20	12.903226	14.25	2.85	2.85	0.220875	0.779125	1705.9201
B3	Jan 2007	Balçık	22.05	21.32	56.63	Silt Loam	1.50	6.54	20	13.333333	16.25	3.25	3.25	0.24375	0.75625	1661.157
KA1	Jan 2007	Kandıra	23.34	34.95	41.71	Loam	1.50	5.99	20.5871	13.724733	24.97	5.1405989	5.1405989	0.37455	0.62545	1799.4244
KA2	Jan 2007	Kandıra	8.02	40.88	51.10	Silt Loam	1.50	6.47	22.0826	14.721733	35.29	7.7929495	7.7929495	0.52935	0.47065	2062.3606

(1) Balcıoğlu et al., 2007; (2) USDA NRCS, 2011; (3) USDA NRCS, 2012

…Continued

Sample ID[1]	Sampling Date[1]	Region[1]	Cu					Ni					Zn				
			$Cu^{(1)}$ (g/kg)	$Kp_{soil}^{(4)}$ (dm^3/kg)	$K_{soil-water}$	$PEC_{porewater}$ (mg/L)	PEC_r (mg/L)	$Ni^{(1)}$ (g/kg)	$Kp_{soil}^{(4)}$ (dm^3/kg)	$K_{soil-water}$	$PEC_{porewater}$ (mg/L)	PEC_r (mg/L)	$Zn^{(1)}$ (g/kg)	$Kp_{soil}^{(4)}$ (dm^3/kg)	$K_{soil-water}$	$PEC_{porewater}$ (mg/L)	PEC_r (mg/L)
E1-1	June 2006	Doğanpınar/Bandırma	0.013	316.227	369.947	0.0510	0.0051	0.022	794.328	928.842	0.0343	0.0034	0.041	501.187	586.164	0.1014	0.0101
E1-2	Oct 2006	Doğanpınar/Bandırma	0.015	316.227	378.586	0.0575	0.0057	0.016	794.328	950.584	0.0244	0.0024	0.037	501.187	599.871	0.0894	0.0089
E2-1	June 2006	Doğanpınar/Bandırma	0.019	316.227	381.049	0.0748	0.0075	0.014	794.328	956.707	0.0220	0.0022	0.036	501.187	603.750	0.0894	0.0089
E2-2	Oct 2006	Doğanpınar/Bandırma	0.006	316.227	384.075	0.0234	0.0023	0.015	794.328	964.323	0.0233	0.0023	0.027	501.187	608.552	0.0666	0.0067
E3	Oct 2006	Doğanpınar/Bandırma	0.01	316.227	351.542	0.0398	0.0040	0.019	794.328	882.597	0.0301	0.0030	0.019	501.187	556.988	0.0478	0.0048
K1-1	June 2006	Karacabey	0.011	316.227	454.481	0.0363	0.0036	0.098	794.328	1141.512	0.1288	0.0129	0.034	501.187	720.269	0.0708	0.0071
K1-2	Oct 2006	Karacabey	0.008	316.227	415.377	0.0289	0.0029	0.085	794.328	1043.100	0.1222	0.0122	0.025	501.187	658.221	0.0570	0.0057
K2-1	June 2006	Karacabey	0.017	316.227	418.403	0.0609	0.0061	0.124	794.328	1050.716	0.1770	0.0177	0.04	501.187	663.022	0.0905	0.0090
K2-2	Oct 2006	Karacabey	0.001	316.227	409.325	0.0037	0.0004	0.099	794.328	1027.868	0.1445	0.0144	0.025	501.187	648.617	0.0578	0.0058
F1-1	June 2006	Görükle/Bursa	0.017	316.227	358.447	0.0711	0.0071	0.037	794.328	899.825	0.0617	0.0062	0.034	501.187	567.887	0.0898	0.0090
F1-2	June 2006	Görükle/Bursa	0.014	316.227	342.465	0.0613	0.0061	0.049	794.328	859.603	0.0855	0.0086	0.049	501.187	542.527	0.1355	0.0135
F2-1	June 2006	Görükle/Bursa	0.009	316.227	351.497	0.0358	0.0036	0.07	794.328	882.486	0.1110	0.0111	0.022	501.187	556.918	0.0553	0.0055
F2-2	Oct 2006	Görükle/Bursa	0.014	316.227	331.682	0.0591	0.0059	0.073	794.328	832.617	0.1227	0.0123	0.02	501.187	525.476	0.0533	0.0053
T1-1	June 2006	Zeytinbağı	0.02	316.227	425.685	0.0705	0.0070	0.009	794.328	1069.042	0.0126	0.0013	0.026	501.187	674.577	0.0578	0.0058
T1-2	Oct 2006	Zeytinbağı	0.02	316.227	419.964	0.0714	0.0071	0.009	794.328	1054.643	0.0128	0.0013	0.024	501.187	665.498	0.0541	0.0054
T2-1	June 2006	Zeytinbağı	0.025	316.227	412.824	0.0908	0.0091	0.273	794.328	1036.674	0.3950	**0.0395**	0.032	501.187	654.169	0.0734	0.0073
T2-2	Oct 2006	Zeytinbağı	0.017	316.227	372.585	0.0684	0.0068	0.213	794.328	935.406	0.3416	0.0342	0.038	501.187	590.320	0.0966	0.0097
İ1	Oct 2006	Inegöl	0.044	316.227	318.540	0.2072	0.0207	0.06	794.328	799.390	0.1126	0.0113	0.119	501.187	504.563	0.3538	0.0354
İ2	Oct 2006	Inegöl	0.012	316.227	429.184	0.0419	0.0042	0.016	794.328	1077.848	0.0223	0.0022	0.03	501.187	680.129	0.0662	0.0066
O1	Oct 2006	Orhangazi	0.025	316.227	337.022	0.1039	0.0104	0.027	794.328	846.056	0.0447	0.0045	0.039	501.187	533.949	0.1023	0.0102
O2	Oct 2006	Orhangazi	0.045	316.227	347.383	0.1943	0.0194	0.021	794.328	871.979	0.0361	0.0036	0.034	501.187	550.330	0.0927	0.0093
D1	December 2006	Babaeski	0.001	316.227	428.948	0.0035	0.0003	0.0003	794.328	1077.253	0.0004	0.0000	0.068	501.187	679.754	0.1501	0.0150
D2	December 2006	Babaeski	0.013	316.227	419.491	0.0465	0.0046	0.005	794.328	1053.453	0.0071	0.0007	0.032	501.187	664.748	0.0722	0.0072

M1	December 2006	Malkara	0.03	316.227	375.819	0.1237	0.0124	0.108	794.328	943.468	0.1774	0.0177	0.067	501.187	595.422	0.1744	0.0174
M2	December 2006	Malkara	0.062	316.227	374.571	0.2483	**0.0248**	0.093	794.328	940.404	0.1483	**0.0148**	0.158	501.187	593.471	0.3993	0.0399
B1	Jan 2007	Balçık	0.024	316.227	409.419	0.0879	0.0088	0.0034	794.328	1028.106	0.0050	0.0005	0.0938	501.187	648.767	0.2169	**0.0217**
B2	Jan 2007	Balçık	0.017	316.227	420.526	0.0627	0.0063	0.006	794.328	1055.982	0.0088	0.0009	0.0884	501.187	666.361	0.2056	0.0206
B3	Jan 2007	Balçık	0.028	316.227	397.504	0.1057	0.0106	0.0104	794.328	998.118	0.0156	0.0016	0.0807	501.187	629.860	0.1922	0.0192
KA1	Jan 2007	Kandıra	0.036	316.227	356.272	0.1516	0.0152	0.009	794.328	894.351	0.0151	0.0015	0.187	501.187	564.435	0.4970	**0.0497**
KA2	Jan 2007	Kandıra	0.028	316.227	307.475	0.1366	**0.0137**	0.04	794.328	771.544	0.0778	0.0078	0.044	501.187	487.007	0.1355	0.0136

(1) Balcıoğlu et al., 2007; (4)U.S. EPA, 2005