Modelling Water Quality Using Soil and Water Assessment Tool (SWAT)

A Case Study in Lake Naivasha Basin, Kenya

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by

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Dedicated to:

To my daughter, Bezawit Berihun

Abstract

In this case study, nutrients were considered to be an important water quality concern in the Naivasha basin due to a high eutrophication problem of Lake Naivasha. Nitrogen and phosphorus are the two nutrients originating from inorganic and organic fertilizers that affect the lake water quality due to intensive agricultural farming and livestock grazing. Increased N and P fertilizer application on the land has enlarged N and P nutrient burdens to the lake through runoff and leaching.

The aim of this study was to identify the source of pollution, quantifying the nutrient loads to Lake Naivasha and testing the application of the Soil and Water Assessment Tool (SWAT) to model N and P transport processes under four different land management scenarios for the relatively wet year of 1998. The model was calibrated first using the observed flow data of rivers and next sediment was calibrated before nutrient calibration using a limited number of sediment data collected during field-work. Finally, calibration for nutrients was performed using the nutrient concentration data obtained from water quality analysis in the laboratory and during fieldwork. The sensitivity analysis of the model was undertaken for different parameters to identify the main sensitive parameters for non-point source pollution in this watershed. The main sensitive parameters for the water quality model were the nitrogen percolation coefficient (NPERCO), cover and management factor or cropping practices (USLE_C), phosphorus percolation coefficient (PPERCO), phosphorus soil partitioning coefficient (PHOSKD), average slope steepness (SLOPE), average slope length (SLSUBBSN), biological mixing efficiency (BIOMIX), support practice factor (USLE_P) and curve number (CN2). Among them the most sensitive parameter for the SWAT model was found to be the curve number (CN2) that with an increase of 26% variation of the parameter yields an increase in NO_3 and P concentration of 269.77% and 51.61% due to surface runoff, respectively.

The analysis result from the four land management scenarios showed significant differences in N and P with the introduction of grazing and fertilizer application. The first scenario was simulated for a land management practice without application of fertilizer and grazing activities, the second and the third scenario were simulated for fertilizer application and grazing activities, respectively. Finally, the fourth scenario was simulated for both fertilizer and grazing. For the second scenario analysis with the introduction of fertilizer application, the NO_3 and P yields in runoff were increased by 0.027 kg/ha/yr or 5.99% and 0.013 kg/ha/yr or 13.95%, respectively. NO_3 and P leached to the shallow aquifer increased by 411400 kg/yr or 48% and 11400 kg/yr or 10%, respectively. There was an increase of NO_3 and P yields in runoff with the introduction of fertilizer and grazing activities by 0.029 kg/ha/yr or 6.38% and 0.013 kg/ha/yr or 13.95%, respectively. NO_3 and P leached to the shallow aquifer were increased by 692900 kg/ha/yr or 75% and 44100 kg/ha/yr or 38%, respectively.

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Table of Contents

List of Tables

List of Figures

Acronyms

Abbreviations	Descriptions
SWAT	Soil and Water Assessment Tool
EC	Electrical conductivity
PH	pH of water
DO	Dissolved oxygen
Q_{surf}	Surface runoff generated on a given day (mm)
P	Rainfall (mm)
S	Retention parameter (mm)
CN	Curve number
CBOD	Carbonaceous biological oxygen demand
$Cbod_{surq}$	CBOD concentration in surface runoff (mg CBOD/L)
$OrgC_{surq}$	Organic carbon in surface runoff (kg orgC)
$area_{hru}$	Area of the hydrologic response unit
HRU	Hydrologic response unit
$OrgC_{surf}$	Percent organic carbon in the top 10 mm of soil (%)
sed	Sediment loading from the HRU (metric tons)
$\varepsilon_{c:sed}$	Carbon enrichment ratio
$conc_{sed,surq}$	Concentration of sediment in surface runoff (Mg sed/m^3)
OX_{surf}	Dissolved oxygen concentration in surface runoff (mg O_2/L)
Oxsat	the saturation oxygen concentration (mg O_2/L)
K_1	the CBOD deoxygenated rate (day^{-1})
t_{ov}	time of concentration for overland flow (hr)
$T_{wat,k}$	the water temperature in Kelvin (273.15+^{o}C)
$Conc_{NO3,mobile}$	the concentration of nitrate in the mobile water for a given layer (kg N/mm H_2O)
$NO3_{ly}$	the amount of nitrate in the layer (kg N/ha)
w_{mobile}	the amount of mobile water in the layer (mm H_2O)
θ_e	the fraction of porosity from which anions is excluded
SAT_{ly}	the saturated water content of the soil layer (mm H2O)
$Q_{lat, ly}$	the water discharged from the layer by lateral flow (mm H_2O)

$W_{perc, ly}$	the amount of water percolating to the underlying soil layer on a given day (mm H_2O)
$NO3_{surf}$	the nitrate removed in surface runoff (kg N/ha)
β_{NO3}	the nitrate percolation coefficient
$conc_{NO3,mobile}$	the concentration of nitrate in the mobile water for the top 10 mm of soil (Kg N/mm H_2O)
$orgN_{surf}$	the amount of organic nitrogen transported to the main channel in surface runoff (kg N/ha)
$\varepsilon_{N;sed}$	the nitrogen enrichment ratio
P_{surf}	the amount of soluble phosphorus lost in surface runoff (kg P/ha)
$P_{solution, surf}$	the amount of phosphorus in solution in the top 10 mm (kg P/ha)
ρ_b	the bulk density of the first soil layer (Mg/m^3)
$depth_{surf}$	the depth of the "surface" layer (10 mm)
$k_{d,surf}$	the phosphorus soil partitioning coefficient (m^3/Mg)
$sedP_{surf}$	the amount of phosphorus transported with sediment to the channel in surface runoff (kg P/ha)
$conc_{sedP}$	the concentration of phosphorus attached to sediment in the top 10 mm (g P/ metric ton soil)
$\varepsilon_{P:sed}$	the phosphorus enrichment ratio
D	depth of hole
K	saturated hydraulic conductivity (cm/day)
H	draw down depth of the water
R	radius of the hole
t	time
MS	mass of solid particle
VT	total volume of the soil
DAP	Di-ammonium phosphate
CAN	Calcium ammonium phosphate
N-P-K	Nitrogen-phosphorus-potassium
MAP	Mono ammonium phosphate
tDM/ha	ton dry matter per hectare
DM	dry matter
K_{USLE}	the soil erodibility factor
f_{csand}	a factor that gives low soil erodibility factors with high coarse-sand contents and high values for soils
f_{cl-si}	a factor that gives low soil erodibility factors with high clay to silt ratios

f_{orgc}	a factor that gives soil erodibility for soils with high organic carbon content
f_{hisand}	a factor that reduces soil erodibility for soils with extremely high sand contents
m_s	the percent sand content
m_{silt}	the percent silt content
m_c	the percent clay content
orgC	the percent organic carbon content of the layer (%)
OM	Organic carbon
$orgN_{hum, ly}$	the concentration of humic organic phosphorus in the layer (mg/kg)
$orgC_{ly}$	the amount of organic carbon in the layer (%)
$orgP_{hum, ly}$	the concentration of humic organic phosphorus in the layer (mg/kg)
DEM	Digital elevation model
UTM	Universal transverse mercator
NAIV	Naivasha
AGRC	wheat cropland
AGRR	maize cropland
CABG	cabbage and some vegetables land
FRSE	acacia wood and coniferous trees land
FRST	forest-mixed land
IRIL	irrigation land mainly flowers
IRRL	irrigation lands mainly maize, flowers and French beans
ONIO	onion farms
ORCD	orchard trees
PAST	pasture land
POTA	potato and vegetables land
RNGB	range grasses mixed with brush
RNGE	range grasses land
URHD	urban residential high density
URLD	urban residential low density
URMD	urban residential medium density
WATR	water land
WETL	wet lands-mixed
USLE-C	cover and management factor
NPERCO	nitrate percolation coefficient
PPERCO	phosphorus percolation coefficient
PHOSKD	phosphorus soil partitioning coefficient (m^3/Mg)

SOL-LABP	initial soluble P concentration in soil layer (mg/kg)
SOL-ORGN	initial organic nitrogen concentration in the soil layer (mg/kg)
SOL-ORGP	initial organic P concentration in soil layer (mg/kg)
ALPHA-BF	base flow Alpha factor
GWQMN	threshold depth of water in the shallow aquifer required for return flow to occur
GW-REVAP	ground water "revap" coefficient
SLOPE	average slope steepness (m/m)
SLSUBBSN	average slope length (m)
BIOMX	biological mixing efficiency
USLE-P	the support practice factor
CN2	initial SCS runoff curve number for moisture condition II
SOL-AWC	available water capacity of the soil layer (mm H_2O/mm soil)
MINP	mineral phosphorus transported into the reach during time step (kg P)
NO3-In	nitrate transported with water into the reach during time step (kg N)
NSURQ	nitrate in surface runoff (kg N/ha)
SOLP	soluble p yield (kg P/ha)

1. Introduction

Water is an essential requirement for all human activities such as for drinking, agriculture, and power generation. Fetter (1994) described the importance of water quality as, “The quality of water that we ingest as well as the quality of water in our lakes, streams, rivers, and oceans is a critical parameter in determining the overall quality of our lives”. Many lake ecosystems are endangered by man’s activities. The natural environment of a lake is affected due to improper land use, waste heat from power stations and pollution from fertilizers and pesticides applied by farmers for their cultivation.

Lake Naivasha is Kenya’s second largest freshwater, which is the main source of public water supply and irrigation for the people living on the lakeshore and for the nation of Kenya, and provides different social economic activities, such as horticulture, flower growing and geothermal power generation (Donia, 1998). The pollutant loading of the lake is coming from point and non point sources of pollution. The non point sources of pollution arise mainly from diffused sources that are normally associated with agricultural and human activities in the basin.

Studying the present water quality condition and predicting the future water quality of Lake Naivasha is becoming a very important issue to sustain the freshness of the water. Nutrients are becoming an important water quality concern in this case study due to the eutrophication of surface waters as well as imposing a significant health problem to human beings. Nitrogen and phosphorus are the two important nutrients originating largely from inorganic and organic fertilizers due to intensive agricultural farming and livestock grazing, and disinfectants.

Though some studies have been conducted to assess the quantity and quality of water in the lake, modelling the water quality of the basin is important for water quality assessment of Lake Naivasha in order to quantify the effect of nutrient enrichment and to identify the main source of pollution affecting the lake, which will help in developing monitoring techniques to limit the pollution risk of the lake.

Water quality and quantity are affected by the inherent spatial and time variability of the hydrological attributes of the basin around Lake Naivasha. A modern approach of determining spatial variability of water quality problems of non point source water pollution and erosion in a basin consists in linking distributed models to a geographic information system (Lenzi and Di Luzio, 1997).

SWAT (the Soil and Water Assessment Tool) is a physically based watershed model integrated into the Arc view geographic information system as an extension which allows to predict the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions (Neitsch, 2002).

This study aims to assess the feasibility of SWAT as a modelling tool in predicting the impact of land management practices on Lake Naivasha water quality and to quantify the solute concentration at the down stream of the rivers in the Lake Naivasha basin.

1.1. Problem Statement

Lake Naivasha is the only fresh water lake in the semiarid region of Kenya. This available natural resource of water supports a large and vitally important variety of economic activities such as fishery, recreation and irrigation. The intensive use of land and water in the watershed makes the lake environment susceptible to pollution hazards. It needs detailed study to analyse the main source of pollution in the basin and to assess the impact of different agricultural practices and other human activities on the water quality of the lake.

Some studies have been conducted around the lake (chemical runoff potential of agriculture by Mai van Trinh (2000) and about the fate of agrochemicals in the vadose zone environment by Anil Upendra de Silva (1998) to analyse the water quality of the lake and some models (Building a dynamic water quality assessment of the Lake Naivasha using Duflow modelling studio by Beltran (2001) and others) have been developed to predict the effect of different activities in the catchments. But the impact of different land management practices in the upper catchments and around the lake on sediment and agricultural chemical yields from the watershed have not been yet fully evaluated and quantified. The water quality problem of Lake Naivasha needs to be identified by considering the different impacts of human activities in the basin.

1.2. Research Objective

The objective of the research is to evaluate the use of the watershed scale model SWAT as a modelling tool in predicting the pollutant loads from agricultural chemicals and to assess the impact of land management practices on water quality of Lake Naivasha.

1.3. Specific Objectives

- To develop pollution source inventory mapping
- To explain and quantify the nutrient inputs that affect the lake water quality
- To determine the cause-effect relationships between land use and pollutant sources.

1.4. Research Questions

- Is there any spatial variation of water quality constituents along the Malewa river, if so why?
- Is SWAT a suitable modelling tool for water quality assessment of non-point pollution sources to the Lake Naivasha?
- Which areas are the major sources of nutrient input for Lake Naivasha in the watershed?

1.5. Hypothesis

- Higher concentration of nitrogen and phosphorus can be found at the down stream of the rivers that drain to the lake due to fertilizers applied by farmers for their cultivation in the basin.
- Agricultural lands produce much higher levels of nitrogen and phosphorus than other land surfaces such as forestlands.

1.6. Importance of the Study

Lake Naivasha is an important source of water for the public supply and irrigation to people living around the lake. The natural environment of the lake is affected by improper land use, waste heat from power stations and pollution from fertilizers and pesticides applied by farmers for their cultivation. A stream flowing to the lake carries sand, silt, clay, organic matter and other chemicals into the lake from the surrounding watershed. The lake has been polluted by sediment and nutrient-rich runoff flowing to the streams and then draining into the lake. The importance of the study is to identify major sources of nutrient enrichment for the lake, which helps in developing techniques to minimize and control pollutant flowing into the lake.

1.7. Methodology

The research methodology of this study is distributed in the following areas: Pre-fieldwork, fieldwork and post-fieldwork.

1.7.1. Pre-fieldwork

This stage includes problem identification and research objective formulation, literature review, data collection from previous studies and literature, analysis of available and required data, selection of sampling points and water quality parameters for SWAT input, and set-up of the model, as well as preparing measuring instruments for fieldwork.

1.7.2. Fieldwork

This phase includes insitu analysis of water samples for different parameters (EC, PH, DO); grab water samples collection and handling for the Malewa and Gilgil rivers and their tributaries to be analysed in the ITC laboratory; retrieval and verification of data such as rainfall and discharge; collecting information about fertilizers and pesticides quantity applied by each individual farmer; collecting soil samples for nutrient, bulk density and texture analysis; inverse auger test for selected sites to determine hydraulic conductivity; discharge measurement for Malewa , Gilgil and their tributaries; and ground truth point data collection of land cover for land use map delineation.

1.7.3. Post-fieldwork

This phase includes analysis of water quality parameters, i.e. nutrient, major cations and heavy metals; soil analysis for organic carbon, texture and extractable phosphorus in ITC laboratory; soil chemical analysis for NO_3, P_{alson}, NH_4-N and NO_3-N done by an external laboratory; data processing for model input; set-up of the model; model runs; model calibration; sensitivity analysis and pollution assessment. Finally, analysis result elaboration, conclusions and recommendations will be made for the study area. The research method is presented in a flow chart below in figure 1.

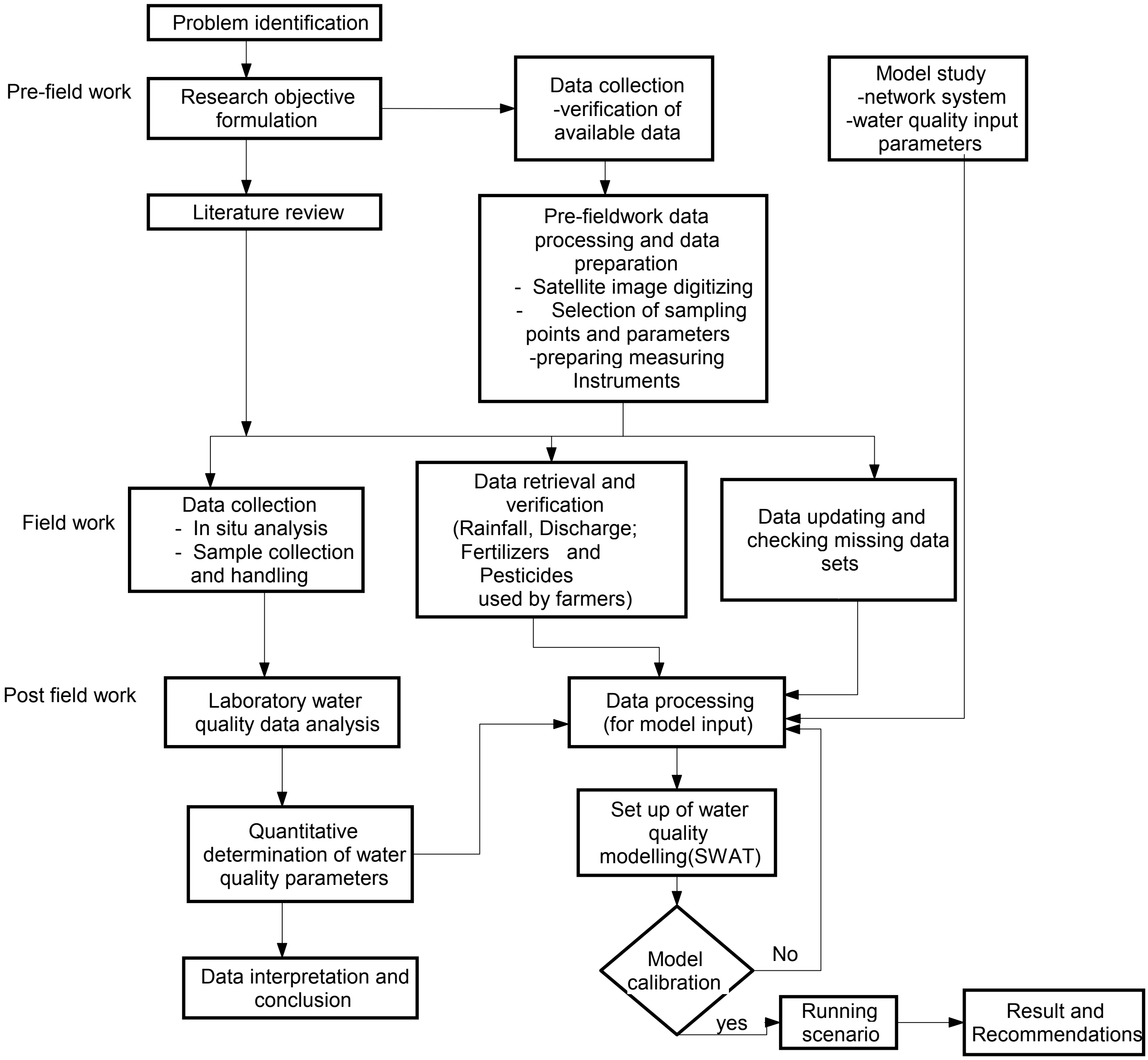

Figure 1: Research methodology flow chart

2. General Description of the Study Area

2.1. Location

Lake Naivasha basin is located at 00 46` to 00 52`S latitude and 36 15` to 36 25` longitude and UTM zone 37 with an altitude between 1900m and 3200m above sea level (Lukman, 2003). The Naivasha basin is bounded by the Aberdare Mountains to the east and the Mau escarpment to the west. The total area of the catchment is 3200 square kilometres (Donia, 1998). In the basin there are a substantial number of economic activities such as agricultural farms, flower plantations and fishing that provide huge employment opportunities for residents of Naivasha. Lake Naivasha dominates the Naivasha basin, with an elevation of 1885 mean above sea level and covers an area of 150 square kilometres and a mean depth of 4.7m (Nalugya, 2003).

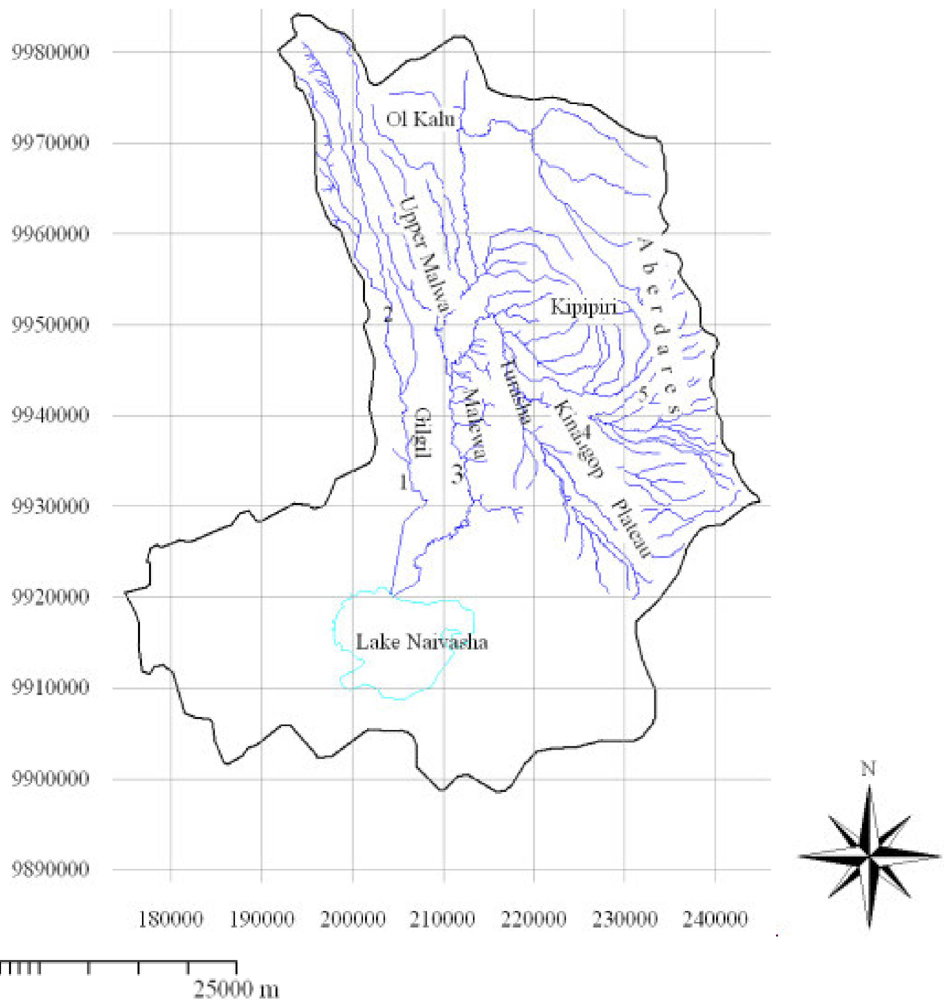

Figure 2.1: Geographical locations of Lake Naivasha and its catchment showing the principal rivers Malewa and Gilgil

2.2. Climate

The climatic conditions in the Naivasha basin are quite diverse, experiencing the semi-arid climate of the rift floor and the wet conditions of the upper catchment areas of the Abaredare ranges and the surrounding areas (Kitaka, 2000).

2.2.1. Temperature

The basin experiences cool conditions in the upper catchment and relatively higher temperatures near the lake. Air temperatures are moderate with monthly means varying from 15.9 to 18.5 ^{0}C (Pesantez, 2001). Generally as it is calculated by the Metrological Department in Nairobi, there is a decrease in temperature of 0.56 ^{0}C for every 100m increase in elevation.

2.2.2. Rainfall

The climate of Lake Naivasha basin is a typical equatorial climate with two rainy seasons followed by a dry season. The first rainy season is from March to May and the second rainy season is from October to December. The dry seasons are from December to February and from June to September (Lukman, 2003).

2.3. Hydrology

Lake Naivasha basin has numerous rivers and tributaries; three major rivers are Malewa, Gilgil and Karati. Malewa River, which drains the Kinangop plateau and wet highlands in the Abaredare range, contributes about 90% of the discharge to the lake. The river Malewa basin area is about 1600 square kilometres; Gilgil with a basin of 527 square kilometres and Karati area is about 150 square kilometres (Lukman, 2003). The river Karati and other streams flowing from the Mau escarpment and Eburu hills (120 km^2) are either dry or flow intermittently during the dry season. They contribute significantly to the lake hydrological equilibrium through seepage inflows (Kitaka (2000), Becht in press). As cited by Kitaka (2000), Becht (in press) estimated that the Malewa River contributed an average flow of $213.9*10^6$ m^3 to the lake for the period of 1935-1981.

2.4. Land Use

The major land use units in the Naivasha catchment can be categorized as agriculture, forest, natural vegetation (scrubs and range brush land), range land, pasture, settlement and water body. Most of the inhabitants of the Naivasha catchment are small scale mixed farmers in the upper catchment along the basin of Malewa and Gilgil Rivers. Maize is the main stable crop grown by almost all householders in the catchments, mainly in Turasha (see figure 2.2). The main vegetable types grown in the catchment are sweet potato, kale, carrot and cabbage. Though large farms allocate the lowest proportion of land to the cultivation of potato, potato is cultivated by over 50% of farmers in both small-scale and large-scale farms. Considerable land is allocated for pastureland in Turasha, upper Malewa and Gilgil river basins. Small-scale and large-scale farmers also grow pyrethrum on the Kipipiri range and wheat in Turasha and upper Malewa basin. There is intensive farming of onion in the Abaredare range. Extensive or range livestock production is mainly practiced in the drier parts of the catchment while intensive livestock production is practiced around the lake (Kitaka, 2000). The land cover of the Malewa and Gilgil river basins (see figure 2.1) can be described as follows in Table 2.1.

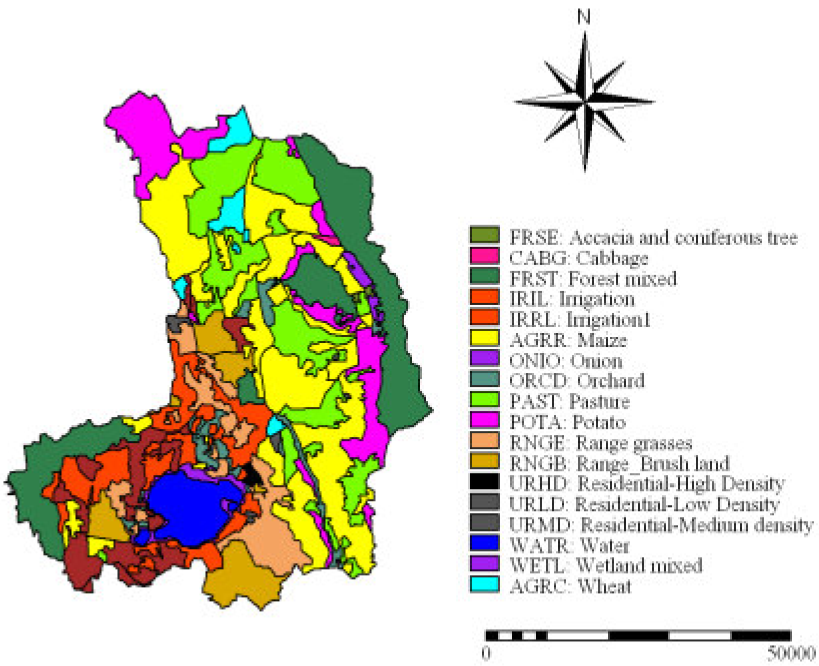

Figure 2.2: Land use map of Naivasha basin

Table 2.1: Land use pattern along Malewa and Gilgil river basins

Catchment name (Code)	Land use
Lower catchment of Gilgil (1)	Intensive live stock and game farming
Upper catchment of Gilgil (2 and above)	Small scale mixed farming Intensive live stock grazing
Lower catchment of Malewa (3)	Large scale and small scale farming Very intensive live stock farming
Upper Malewa catchment	Both small scale and large scale farming of wheat Arable small scale farming of vegetables, maize Very intensive live stock grazing
OL kalu	Small scale mixed farming; Very intensive grazing
Abaredare range (5)	Large scale farm size of onion and vegetables
Kipipiri range	Small scale mixed farming
Turasha basin(4)	Small scale mixed farming; Very intensive livestock grazing
Kinangop plateau	Small scale mixed farming; Intensive live stock grazing
Wanjohi river (7)	Small scale mixed farming mainly vegetables Intensive livestock grazing
Abaredare range of Turasha	Small scale mixed farming mainly vegetables

Note: codes are numbers, which are shown on figure 2.1 of the Malewa and Gilgil rivers basin map.

3. Literature Review

3.1. Overview of SWAT

SWAT is a physically based watershed model which allows predicting the impact of land management practices on water, sediment and agricultural chemical yields in a watershed with varying soils, land use and management conditions over a long period of time. Weather, soil properties, topography, vegetation, and land management practices are the most important inputs for SWAT to model hydrologic and water quality in a watershed (Neitsch, 2002).

SWAT allows a basin to be subdivided into sub-basins to evaluate hydrology, weather, sediment yield, nutrients, pesticides, soil temperature, crop growth and agricultural management practices (Francos, Bidoglio et al., 2001).

3.2. Hydrology

Since a hydrological component is fundamental for any watershed model, it will be developed based on the water balance equation using the input data sets of precipitation, evapo-transpiration, percolation, surface runoff and subsurface runoff for the soil subdivided into several columns (Krysanova, Muller-Wohlfeil et al., 1998).

3.3. Surface Runoff

Surface runoff occurs whenever the rate of water applied to the ground surface exceeds the rate of infiltration. The quantity of nitrogen, phosphorus and sediment loss from non-point sources can be determined by evaluating different components of surface runoff and their spatial and temporal variations in the catchment. When the rainfall intensity is greater than the rate at which it is able to infiltrate the soil, the water quality constituents will be transported towards streams and the lake due to runoff occurred by high rainfall intensity. The transportation of pollutants depends on the characteristics of the watershed which are important in determining the curve number index that expresses the catchment's responses to the rainfall event such as geology, soil type, vegetation cover, mean precipitation, drainage area and antecedent moisture condition (Gumbo, Munyamba et al., 2002).

The SCS curve number method is used to estimate the accumulated runoff for each sub basin. The amount of runoff under different watershed characteristics is defined as :(Neitsch, 2002)

$$Q_{surf} = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad 3.1$$

where

P	= rainfall (mm)
S	= retention parameter (mm)
Q_{surf}	= accumulated runoff (mm)

The retention parameter varies spatially due to changes in soil, land use, management and slope. The retention parameter is defined as (Neitsch, 2002):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad 3.2$$

where CN = the curve number for the decay. The SCS curve number is a function of the soil permeability, land use and antecedent soil water conditions.

Runoff depends on different factors such as soil type, rainfall duration, vegetation or land cover, slope, soil moisture content and management practices. Surface runoff is higher in clay and loam soil, which has lower soil permeability than sandy soil. The runoff volume in loam soil is much higher than in sandy loam soil. Runoff volume, sediment concentration and soil loss is 1.69, 2.14 and 2.74 times, respectively, higher in loam soil than in sandy loam soil (Trinh, 2000). This indicates nutrient transport is higher in low permeable soils and lower in sand soil and vegetation areas that have a low runoff volume. Quantifying the runoff volume is very important for a water quality analysis in order to collect quantitative information on potential chemical runoff from different land management practices in the catchment, which is the main source of pollutant load for streams and lake.

3.4. Water Quality Parameters

SWAT calculates the amount of algae, dissolved oxygen and carbonaceous biological oxygen demand entering the main channel with surface runoff.

3.4.1. Carbonaceous Biological Oxygen Demand

Carbonaceous biological oxygen demand (CBOD) defines the amount of oxygen required to decompose the organic matter transported in surface runoff. The SWAT loading function for the ultimate CBOD as cited by Neitsch (2002) is based on a relationship given by Thomann and Muller (1987):

$$cbod_{surq} = \frac{2.7 * orgC_{surq}}{Q_{surf} * area_{hru}} \qquad 3.3$$

where

$cbod_{surq}$ = the CBOD concentration in surface runoff (mg CBOD/L)

$orgC_{surq}$ = the organic carbon in surface runoff (kg orgC)

Q_{surf} = the surface runoff on a given day (mm)

$area_{hru}$ = the area of the hydrologic response unit (HRU) (km^2)

The amount of organic carbon in surface runoff can be calculated as:

$$orgC_{surq} = 1000 * \frac{orgC_{surf}}{100} * sed * \varepsilon_{c:sed} \qquad 3.4$$

where

$orgC_{surq}$ = the organic carbon in surface runoff (kg orgC)

$orgC_{surf}$ = the percent organic carbon in the top 10 mm of soil (%)

sed = the sediment loading from the HRU (metric tons)

$\varepsilon c : sed$ = the carbon enrichment ratio

The enrichment ratio (the ratio of the concentration of organic carbon transported with the sediment to the concentration in the soil surface layer) in SWAT is calculated by using the relationship described by Menzel (1980) for each storm event as follows (Neitsch, 2002):

$$\varepsilon c : sed = 0.78 * (conc_{sed,surq})^{-0.2468} \qquad 3.5$$

where

$conc_{sed,\ surq}$ = the concentration of sediment in surface runoff (Mg sed/m^3), and

The concentration of sediment in surface runoff is calculated as:

$$conc_{sed,surq} = \frac{sed}{10 * area_{hru} * Q_{surf}} \qquad 3.6$$

where

sed = the sediment yield on a given day (metric tons)

$area_{hru}$ = the HRU area (ha)

Q_{surf} = the amount of surface runoff on a given day (mm)

The smaller particles are more easily transported than coarser particles. As explained in section 3.3, due to higher runoff of smaller soil particles, the sediment load will contain a greater proportion of the organic carbon concentration in clay sized soil particles than that found in the soil surface layer (Neitsch, 2002).

3.4.2. Dissolved Oxygen

Dissolved gases (mainly oxygen and carbon dioxide) are present in both surface and ground waters. The concentration of dissolved oxygen is high if the water quality is good. Generally, surface water may be adversely impacted by human activities such as intensive livestock grazing and intensive farming. If organic matter, such as untreated human or animal waste, is placed in to the surface-water body, dissolved oxygen levels diminish as micro organisms grow, using the organic matter as an energy source and consuming oxygen in the process (Fetter, 1994).

In SWAT, to determine the dissolved oxygen concentration of surface runoff, the oxygen uptake by the oxygen demanding substances in runoff is subtracted from the saturation oxygen concentration. The dissolved oxygen concentration of surface runoff can be determined as (Neitsch, 2002):

$$Ox_{surf} = Ox_{sat} - k_1 * cbod_{surq} * \frac{t_{ov}}{24} \qquad 3.7$$

where

Ox_{surf} = the dissolved oxygen concentration in surface runoff (mg O_2/L)

Ox_{sat} = the saturation oxygen concentration (mg O_2/L)

K_1 = the CBOD deoxygenation rate (day^{-1}); for loadings from HRUs, SWAT assumes k_1=1.047 day^{-1}

$cbod_{surq}$ = the CBOD concentration in surface runoff (mg CBOD/L)

t_{ov} = time of concentration for overland flow (hr)

The oxygen saturation concentration can be calculated as:

$$Ox_{sat} = \exp[-139.34410 + \frac{1.575701*10^5}{T_{wat,k}} - \frac{6.642308*10^7}{(Twat,k)^2} + \frac{1.243800*10^{10}}{(T_{wat,k})^3} - \frac{8.621949*10^{11}}{(T_{wat,k})^4}] \quad 3.8$$

where

Ox_{sat} = the equilibrium saturation oxygen concentration at 1.00 atm (mg O_2/L)

$T_{wat,k}$ = the water temperature in Kelvin (273.15+^oC)

3.5. Nutrients

Nutrient enrichment in water bodies has started to be seen as a major problem due to different human activities experienced in the basin such as an increase of human settlement in the drainage basin, clearing of forest for farming, development of urban societies and with consequential disposal of industrial and agricultural wastes (Kitaka, 2000). The main nutrient sources are effluent discharges from domestic and industrial sources, and diffuse (or non-point) sources. The non-point sources are transported by surface runoff during the rainy season and by wind from the atmosphere.

The fate and transport of nutrients in a watershed depend on the transformations the compounds undergo in the soil environment (Neitsch, 2002). A certain portion of nutrients deposited in the sub-basin will be lost due to various processes such as conversion to nitrogen gas, an inert form of the nutrient, subsequently released to the atmosphere. The high concentration of nutrients, mainly nitrogen and phosphorus, increases the eutrophication in lakes and rivers. SWAT models the complete nutrient cycle for nitrogen and phosphorus as well as the degradation of any pesticides applied in a HRU.The transformation and movement of nitrogen and phosphorus within an HRU are simulated in SWAT based on the cycles shown in figures 3.1 and 3.2.

3.5.1. Nitrogen Cycle

There are three forms of nitrogen as it is described in figure 3.1: organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids, and mineral forms of nitrogen in solution (Neitsch, 2002). The main sources of nitrogen for soil nutrient are from fertilizer added for cultivation, manure or residue application, fixation by symbiotic or non-symbiotic bacteria, and rain.

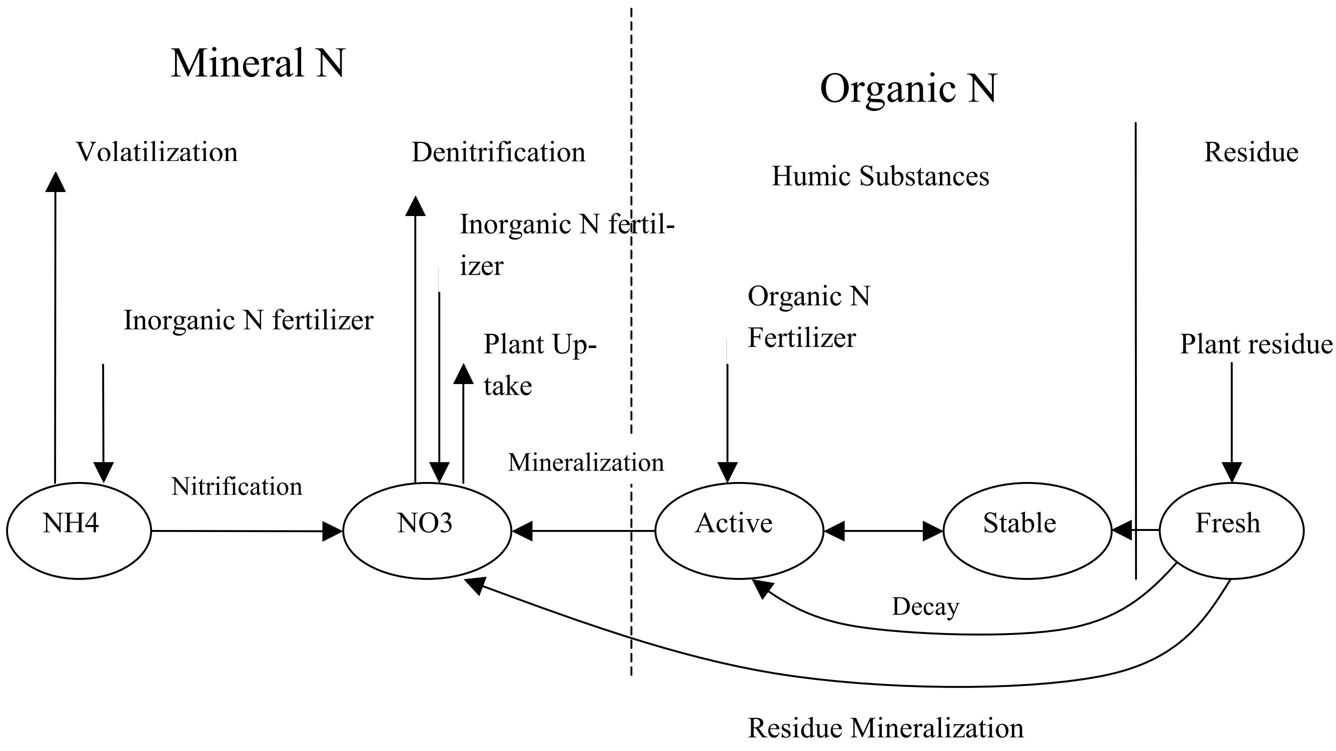

Figure 3.1: SWAT soil nitrogen and processes that move nitrogen in and out of pools (Neitsch, 2002).

The ability of nitrogen to vary its valence state makes it a highly mobile element. Predicting the movement of nitrogen between the different pools in the soil is critical to the successful management of this element in the environment (Neitsch, 2002). The organic and inorganic forms of N are input into the soil system via commercial fertilizers, livestock manure and plant residue.

3.5.2. Phosphorus Cycle

The three major forms of phosphorus in mineral soils that might be added to the soil by fertilizers, manure or residue application are organic phosphorus associated with humus, insoluble forms of mineral phosphorus, and plant-available phosphorus in soil solution (Neitsch, 2002).

SWAT monitors six different pools of phosphorus in the soil in which three pools are inorganic forms of phosphorus while the other three pools are organic forms of phosphorus (see figure 3.2).

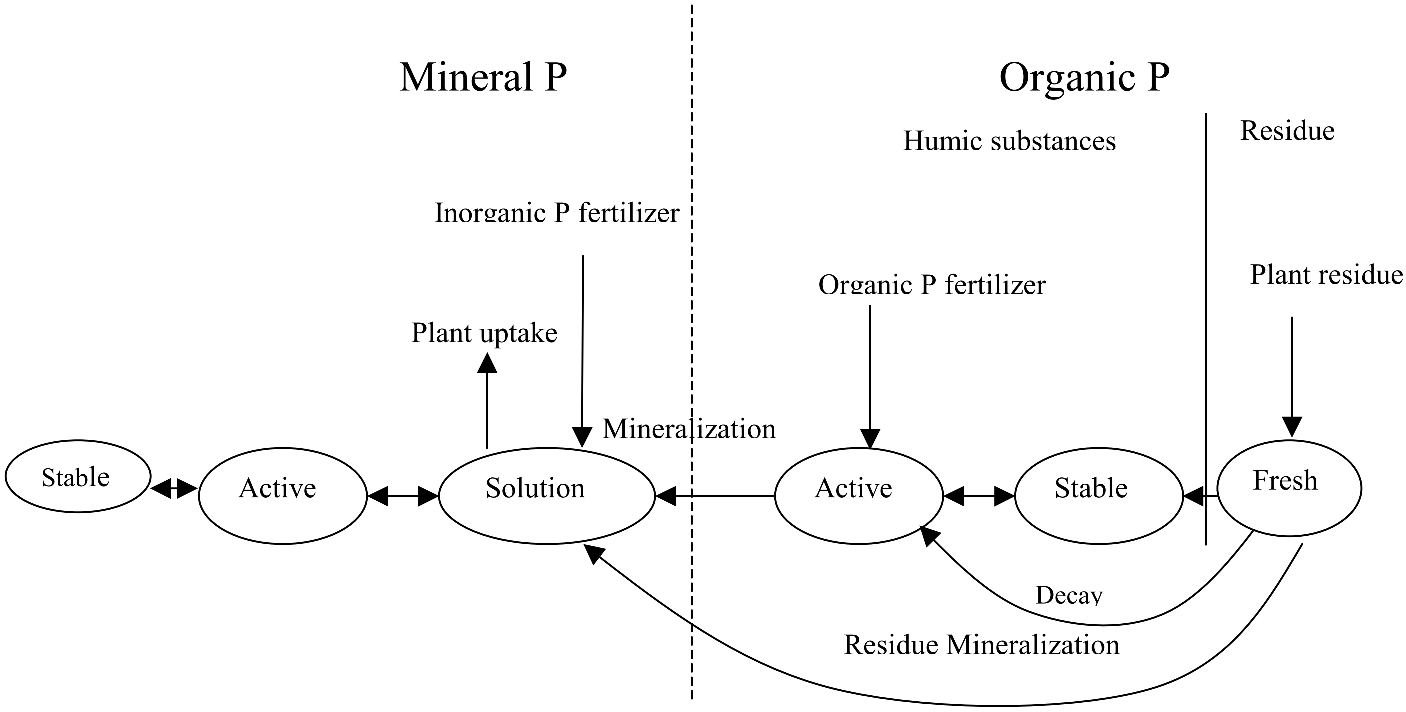

Figure 3.2: SWAT soil phosphorus and processes that move phosphorus in and out of pools (Neitsch, 2002).

3.5.3. Nitrate Movement

The nitrate in the soil may be transported with surface runoff, lateral flow or percolation. To calculate the amount of nitrate moved with water in SWAT, the concentration of nitrate in the mobile water is first calculated. This concentration is then multiplied by the volume of water moving in each pathway to obtain the mass of nitrate lost from the soil layer.

The concentration of nitrate in the mobile water fraction is calculated as:

$$Conc_{NO3,mobile} = \frac{NO3_{ly} * \exp\left[\frac{-w_{mobile}}{(1-\theta_e * SAT_{ly}}\right]}{w_{mobile}} \qquad 3.9$$

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

The amount of mobile water in the layer is the amount of water lost by surface runoff; lateral flow or percolation is calculated as:

$$W_{mobile} = Q_{surf} + Q_{lat,ly} + w_{perc,ly} \quad \text{for top 10 mm} \qquad 3.10$$

$$W_{mobile} = Q_{lat,ly} + w_{perc,ly} \quad \text{for lower soil layers} \qquad 3.11$$

where W_{mobile} is the amount of mobile water in the layer (mm H_2O), Q_{surf} is the surface runoff generated on a given day (mm H_2O), $Q_{lat,ly}$ is the water discharged from the layer by lateral flow (mm H_2O), and $w_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm H_2O). Finally, the nitrate removed in surface runoff from the top 10 mm of soil is calculated as:

$$NO3_{surf} = \beta_{NO3} * conc_{NO3,mobile} * Q_{surf} \qquad 3.12$$

where $NO3_{surf}$ is the nitrate removed in surface runoff (kg N/ha), β_{NO3} is the nitrate percolation coefficient, $conc_{NO3,mobile}$ is the concentration of nitrate in the mobile water for the top 10 mm of soil (kg N/mm H_2O), and Q_{surf} is the surface runoff generated on a given day (mm H_2O).

3.5.4. Organic N in Surface Runoff

The organic nitrogen attached to the soil particles via commercial fertilizer and livestock manure may be transported by surface runoff to the rivers and lake. As cited by Neitsch (2002), the amount of organic nitrogen transported with sediment to the stream is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1976).
SWAT calculates the movement of organic nitrogen in surface runoff as:

$$orgN_{surf} = 0.001 * conc_{orgN} * \frac{sed}{area_{hru}} * \varepsilon_{N:sed} \qquad 3.13$$

where $OrgN_{surf}$ is the amount of organic nitrogen transported to the main channel in surface runoff (kg N/ha), $conc_{orgN}$ is the concentration of organic nitrogen in the soil surface top 10 mm (g N/ metric ton soil), *Sed* is the sediment yield on a given day (metric tons), $Area_{hru}$ is the HRU area (ha), and $\varepsilon_{N:sed}$ is the nitrogen enrichment ratio.
The smaller particles are easily transported with surface runoff and the organic nitrogen in the soil is attached primarily to colloidal (clay) particles. Therefore, the sediment load will contain a greater concentration of organic nitrogen than found in the soil layer. SWAT calculates the enrichment ratio (or the ratio of the concentration of organic nitrogen transported with the sediment to the concentration in the soil surface) using a relationship described by Menzl (1980) cited by Neitsch (2002) in which the enrichment ratio is logarithmically related to sediment concentration. The equation used to calculate the nitrogen enrichment ratio, $\varepsilon_{N:sed}$ for each storm event is:

$$\varepsilon_{N:sed} = 0.78*(conc_{sed,surq})^{-0.2468} \qquad 3.14$$

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

$$conc_{sed,surq} = \frac{sed}{10 * area_{hru} * Q_{surf}} \qquad 3.15$$

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

3.5.5. Soluble Phosphorus Movement

The primary mechanism of phosphorus movement in the soil is by diffusion (Neitsch, 2002). Phosphorus has a lower mobility than nitrogen. Due to the low mobility of solution phosphorus, surface runoff will only partially interact with the solution P stored in the top 10 mm of the soil.

The amount of solution P transported in surface runoff is calculated as:

$$P_{surf} = \frac{P_{solution,surf} * Q_{surf}}{\rho_b * depth_{surf} * k_{d,surf}} \quad 3.16$$

where P_{surf} is the amount of soluble phosphorus lost in surface runoff (kg P/ha), $P_{solution,\ surf}$ is the amount of phosphorus in solution in the top 10 mm (kg P/ha), Q_{surf} is the amount of surface runoff on a given day (mm H_2O), ρ_b is the bulk density of the top 10 mm (Mg/m^3) (assumed to be equivalent to bulk density of first soil layer), $depth_{surf}$ is the depth of the "surface" layer (10 mm), and $k_{d,surf}$ is the phosphorus soil partitioning coefficient (m^3/Mg).The soil partition coefficient is the basic parameter in SWAT for the movement of phosphorus in the simulation process. The phosphorus-partitioning coefficient is the ratio of the soluble phosphorus concentration in the top 10 mm of soil to the concentration of soluble phosphorus in surface runoff (Neitsch, 2002).

3.5.6. Organic and Mineral P Attached to Sediment in Surface Runoff

Organic and mineral P attached to soil particles may be transported by surface runoff to the main channel. The amount of phosphorus transported with sediment to the stream is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) cited by Neitsch (2002).

$$sedP_{surf} = 0.001 * conc_{sedP} * \frac{sed}{area_{hru}} * \varepsilon_{P:sed} \quad 3.17$$

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

SWAT will calculate the enrichment ratio of phosphorus for each storm event by using the relationship described by Menzel (1980) in which the enrichment ratio is logarithmically related to sediment concentration. The equation used to calculate the phosphorus enrichment ratio, $\varepsilon_{P:sed}$, for each storm event is:

$$\varepsilon_{P:sed} = 0.78 * (conc_{sed,surq})^{-0.2468} \quad 3.18$$

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

The concentration of sediment in surface runoff is calculated as:

$$conc_{sed,surq} = \frac{sed}{10 * area_{hru} * Q_{surf}} \qquad 3.19$$

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

3.6. Previous Relevant Studies

Suangkiattikun (2003) used DUFLOW-modelling studio to analyse the solute balance of the lake in long-term and short-term periods. The final result of the model simulation showed a very good correlation between observed and simulated lake level with an R^2 = 0.923. Therefore, the model can explain 92% of the real situation of the lake level with a sum square difference of $155m^2$. According to his result in the water quality analysis, the Malewa water contains a predominance of bicarbonate. Sodium and calcium are the major cations. The result of the tributary's water analysis shows that almost all water quality parameters are high values indicating that the tributaries contain more solute than the main river. He noticed that the presence of carbonate and bicarbonate alkalinity in lake water mainly comes from the weathering process of laucustrine deposits. The level of nutrients during the study period in the lake is relatively higher than in the river. A decrease in nitrate has been observed in the upstream of the Malewa river and it gradually increased downstream and rapidly went up to the peak of 1.2 mg/l at the constructed dam for the pumping station of a private orchard spatially located after a workers` village that might have been polluted from the fertilizers used.

Donia (1998) used DMS for modelling the water flow and water quality of the major rivers (Malewa, Gilgil) flowing into Lake Naivasha. He made a spatial analysis of water quality by drawing the profile of different water quality parameters. He noticed that the overall conductivity increases gradually from 80 to 130 μs/cm when the Malewa River enters the swamp towards the lake. In general, most of the water quality parameters increase from upstream to down stream of the river. From the analysis of the Lake Naivasha profile, he concluded that the major problem of the lake water quality is its susceptibility to eutrophication due to substantial algal growth. The growth of algae is facilitated by the amount of nutrients supplied to the lake from the basin.

Several studies on the use of agrochemicals in the area have been carried out. The quality of ground water in the area is deteriorated by high nitrate levels from agriculture, which contribute to the reduction of potable water in the region (Morgan, 1998). Different mathematical modelling packages have been tested and used by Anil Upendra da Silva (1998) to simulate the fate of pesticides and fertilizers in the vadose zone. He explained that the potential risk of pesticides and fertilizers leaching was found to be relatively low due to relatively low rainfall and great soil depth where the experiments were undertaken. This indicates that the pollutant loading process is high in surface runoff due the soil depth and soil particle distribution in the basin.

The potential pollution of agrochemicals used around the lake has been identified and evaluated by Xu (1999). She analysed that water quality parameters measured from agricultural effluents discharging into the lake exceeded the discharge guidelines of Kenya. According to her analysis, the sandy loam area around the lake was the most susceptible soil for pesticide leaching.

4. Primary and Secondary Water Quality Data Collection and Analysis

4.1. Data Collection

4.1.1. Water Quality Survey and Samples Collection

A survey for the Malewa and Gilgil river catchments was done in the first week of the field work from 17 to 24 September 2003 to determine the proper location of a sampling scheme for SWAT water quality modelling based on the different crop management practices and drainage patterns of the two rivers` tributaries. Preliminary nutrient concentration analysis using reflectometer and EC measurement was done on site to identify the sources of pollution and determine the sampling location for outlet points of each sub basin in the watershed.

4.1.1.1. Sampling Schemes

Though the sampling scheme was designed in the phase of the pre-field work based on the drainage pattern of the two rivers` tributaries, the sampling scheme was modified during fieldwork depending on the existing conditions in the catchments such as different crop management practice, land cover, topographic nature which enables one to determine various process parameters occurring within the catchments. Based on different types of crop practices, drainage lines, pollution sources, outlets of the sub-catchments and accessibility of the proposed location, 17 water-sampling points were selected along the two rivers (see figure 4.1).

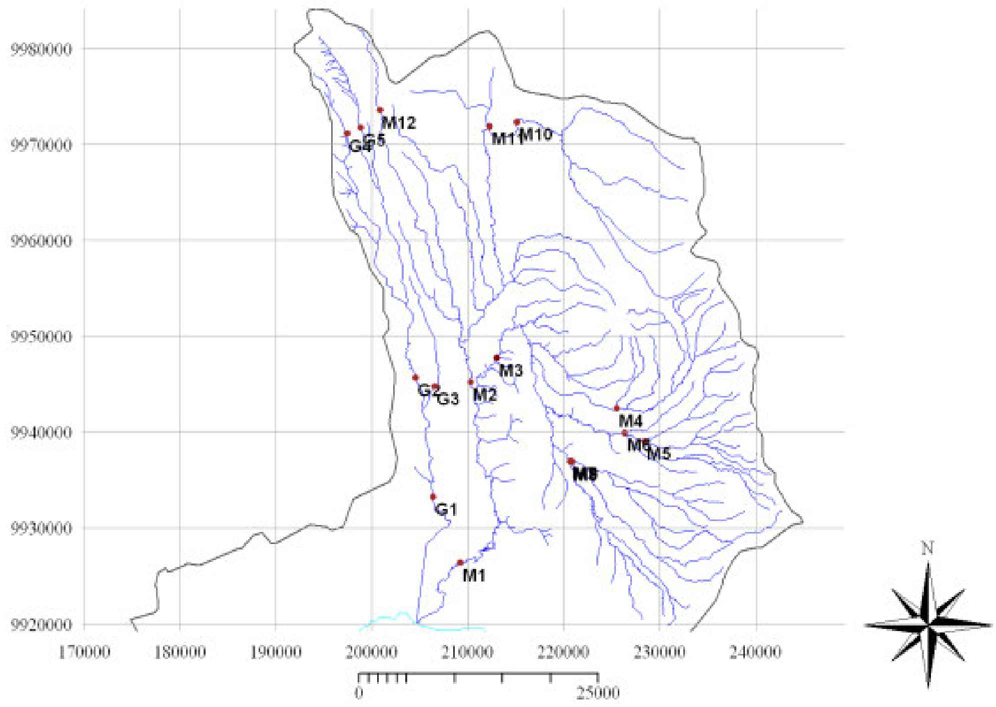

Figure 4.1: Naivasha catchment map showing the sampling points of the river Malewa and Gilgil

Note: M_i = Malewa River sampling points and G_i = Gilgil River sampling points

4.1.1.2. Sampling

Based on the sampling scheme, 17 water grab samples were collected with 250 ml and 100 ml plastic bottles for the analysis of nutrient and major cations of the Malewa and Gilgil rivers, respectively. Each sample was filtered through a 0.45 µm pore size filter disc and preserved with sulphuric acid to prevent microbial activity that can alter the chemical composition of a water sample for nitrogen and phosphorus analysis. A 100 ml polyethylene bottle for major cations was preserved with nitric acid to avoid the precipitation of carbonate and bicarbonate, which affect the content of dissolved cations. On site measurement was done simultaneously while collecting water for EC, pH and DO analysis. Samples were collected in the beginning of the day and during the time when there was no runoff from agricultural farms to avoid an anomalous result. The sampling location of each point is given in table 4.1.

Table 4.1: Locations of sampling points in Malewa (M) and Gilgil (G)

Sample ID	X-coordinates UTM	Y-coordinates UTM
M1	209181	9926382
M2	210221	9945252
M3	213000	9947748
M4	225456	9942510
M5	226310	9939928
M6	228368	9939068
M7	220584	9936958
M8	220770	9937000
M9	215051	9972308
M10	220750	9936876
M11	200821	9973590
M12	212205	9971874
G1	206385	9933252
G2	204513	9945704
G3	206538	9944804
G4	198832	9971748
G5	197430	9971180

4.1.2. Surface Runoff Samples

Surface runoff samples were collected at different randomly selected locations to identify the contribution of nutrient loads to the rivers from different land uses in the watershed and to compare the concentration of the nutrient load transported from each sub basin. Runoff samples were collected and analysed on site with a reflectometer to identify the area of high pollution sources and to determine the outlet location of the sub-basins. 11 water grab samples were collected with 250 ml polyethylene bottles to be analysed in the ITC laboratory for nutrient concentration using a spectrophotometer. The analysis results are given in section 4.2.1.1. The location of each sampling point is given in table 4.2.

Table 4.2: Locations of Surface Runoff Sampling Points

Sample ID	X-coordinates UTM	Y-coordinates UTM	Land use
SR1	234431	9947088	Onion area
SR2	234759	9949558	Onion and peas
SR3	234769	9949590	Onion farm
SR4	234398	9949936	Forest area and grass land
SR5	233126	9951460	Near maize area
SR6	229926	9940940	Mixed farm area (maize and grass land)
SR7	228489	9938850	Mixed farm (vegetables, maize, wheat)
SR8	220555	9934502	Sample in Turasha area, mixed farming
SR9	226312	9939634	Peas, beans, maize, grass land
SR10	220844	9937152	Turasha (pasture land)
SR11	223417	9945356	More maize and grass land

4.1.3. Soil Data

The data collected in the field were: saturated hydraulic conductivity and bulk density. Soil samples were taken at the surface of the soil (0-5 cm depth) for the determination of particle size, organic carbon, organic matter, and nutrient content of the soil. The samples were sent to a laboratory in the Netherlands for the analysis of NO_3 and P_{alson} concentration at the top 10 mm of soil for SWAT model input data.

4.1.3.1. Field Measurement of Parameters

During the soil investigation that has been carried out from the 16th September 2003 to 10th October 2003 in the Malewa and Gilgil river basins, disturbed soil samples were collected to mix the nutrient concentration of the 10 mm depth layer while undisturbed soil samples were collected for the bulk density determination using an 80 mm diameter ring.

4.1.3.1.1. Hydraulic Conductivity

Hydraulic conductivity (K) is one of the main parameters with respect to the flow of water in the soil zone that relates the soil water flow rate (flux density) to the hydraulic gradient. It helps to determine the ease of water movement through the soil and to quantify the nutrient transport due to surface runoff. This parameter was determined using the inverse auger-hole method. The value of K was determined for one layer of selected sites. A hole of certain radius r is augured down up to depth D until another new layer is encountered and the hole is filled with water, which is left to drain away freely. The hole is refilled with water several times until the soil around the hole is saturated over a considerable distance and the infiltration (rate) has attained a more or less constant value. After the last refilling of the hole, the draw down h` (t_i) of the water level is measured at each time step and recorded successively. Then, h (t_i) is obtained by subtraction from the total depth D. [h (t_i)+r/2] is plotted against time t on a semi log paper to obtain the slope s. The hydraulic conductivity is then calculated by the equation below. The results are given in table 4.3 and the graphs are given in the Appendix A-2.

$$K = 1.15r \, \frac{\log(h_0 + 0.5) - \log(h_t + 0.5r)}{t - t_0} \qquad 4.1$$

where K is the saturated hydraulic conductivity (cm/day), r is the radius of the hole (cm), h_0 is the height of the water column at time t_0 (cm), h_t is the height of the water column at time t (cm), and t is the time since the start of measuring (day).

Table 4.3: Hydraulic conductivity and soil types at the specified location

Depth range (in cm)	X-coordinates UTM	Y-coordinates UTM	Saturated hydraulic conductivity in cm/day
0-83	203574	9942250	82.8874
0-96	212050	9948958	18.1102
0-76	227127	9931062	7.733
0-120	230062	9941078	7.385

4.1.3.1.2. Bulk Density

The soil bulk density expresses the ratio of the mass of solid particles to the total volume of the soil i.e. ρ_b = MS/VT. The soil samples were collected at different locations to have a general overview of the catchments to prepare moist bulk density data for each sub-basin for SWAT input. In moist bulk density determinations, the moist soil are put in the oven overnight and the mass of the soil (oven dry weight) is measured .The total volume of the soil of undisturbed soil in the ring is calculated for each sample. The results are given in table 4.4. The calculation is given in Appendix A-3.

Table 4.4: Moist bulk densities

X-coordinates UTM	Y-coordinates UTM	Moist bulk density (g/cm3)	Soil types
227127	9931062	1.101	Clay
223634	9931294	1.203	Clay
229557	9940762	1.386	Silty loam
212050	9948958	1.284	Clay loam/clay
212036	9948960	1.335	Clay loam
203574	9942250	1.192	Silty clay loam
203591	9942244	1.243	Silty clay loam

4.1.4. Pollution Sources Identification and Assessment

Pollutants can be released into the environment as gases, dissolved substances or in the particulate form. The pollution sources of the rivers, which drain to Lake Naivasha, can be categorized as: non-point source pollution (agrochemical diffusion) and point sources (sewage, industrial, etc.). There is no clear-cut distinction between the two pollution sources, because a diffuse source on a region or even local scale may result from a large number of individual point sources (Mannaerts, lecture notes 3/1998). Mannaerts (lecture notes 3/1998) described that the major point sources of pollution to freshwater originate from the collection and discharge of domestic waste waters, industrial wastes or certain agricultural activities such as animal husbandry and most of other agricultural activities, such as pesticide spraying or fertilizer application, are considered as diffuse (or non-point) sources. Small-holders in the upper catchment and large-scale farms around Lake Naivasha have increased the non-point source pollution due to increased cropping intensity.

4.1.4.1. Agrochemical Application

There are several human activities, which have indirect and undesirable effects on the water bodies. The uncontrolled and excessive use of fertilizers and pesticides has long-term effects on ground and surface water quality.

4.1.4.1.1. Fertilizers

The fertilizer type and application amount is different for different farms due to soil condition, specific farm management and a farmer's daily income. In the upper catchment, the smallholders subsist on less than one hectare and apply mainly Di-ammonium phosphate (DAP), Calcium ammonium nitrate (CAN) and cattle manure. Interviews during fieldwork suggest that about 50% of the farmers apply the recommended fertilizer amount (see table 4.6) and the rest of the farmers apply either 50% of the recommended fertilizer amount or do not apply any at all. Instead cattle manure is used due to increasing cost of inorganic fertilizer. The regional experts from the Naivasha Division Office confirm this idea, as 50% of the smallholders do not apply inorganic fertilizers. Large size farms apply the recommended fertilizer amount per crop and use more than 8 types of fertilizers depending on the soil condition and specific farm management. The main type of fertilizers used around Lake Naivasha and the upper catchment are Di-ammonium phosphate, Calcium ammonium phosphate, N-P-K (15:15:30), Calcium nitrate, Ammonium sulphate, micro sol (MAP), Potassium nitrate and Urea (see Table 4.5). The fertilizer inventory in the upper catchment and riparian agricultural area taken from the Naivasha Division of the Nakuru District office is given in table 4.5.

Organic fertilizers particularly livestock manure are becoming highly valued and used by smallholder farmers in the Kenya high-lands and its importance is increasing as the cost of mineral fertilizers rises (Lekasi, 2001). The organic organization or Lekasi (2001) explained that sixty-seven percent of the farms in small, medium and large farms are using their own cattle manure for crop production. The organization found a relationship between ruminant livestock numbers and farm size: large farms had a higher density of sheep and goats per hectare than the small farms, where as the density of cattle, and as a result also total ruminants, is higher on small farms. He finally suggested that livestock numbers, especially cattle holdings, are apparently not constrained by farm size and indicated that smaller farms have higher manuring potential than larger farms. It is explained that the maximum theoretical production of manure (faeces only) is 0.8% of ruminants live weight DM daily. Therefore the estimated annual production of faeces/ha per year is as follows: small farms produce in average 8.2 tDM/ha, medium farms produce in average 3.6 tDM/ha and large farms produce about 2.2 tDM/ha. Based on this production, the organization estimates the theoretical nitrogen and phosphorus application rates to farm land from ruminant excreta produced on farms as shown in table 4.7. The average N and P content of cattle manure are estimated to be 14 g/kg and 5 g/kg DM, respectively (Lekasi, 2001). When smallholder farmers apply large amounts of manure for their intensive cropping, the nutrient input to the rivers and streams will increase and this results in eutrophication problems of lake water.

Table 4.5: Type of fertilizers used in the upper catchment and riparian agricultural area

Fertilizer type	Chemical formula	Total nitrogen (N) %	Available phosphoruric acid (P2O5) %	Water soluble potash (K2O)
Diammonium phosphate	$(NH_4)_2HPO_4$	17	47	
Calcium ammonium nitrate		17		
Tri-super phosphate			46	
Urea	$CO(NH_2)$	45		
N-P-K (20:10:10)		20	10	10
Potassium Nitrate	KNO_3	13		44
Potassium sulphate	K_2SO_4			51
Phosphoric acid	H_3PO_4		53	
Magnesium nitrate	$Mg\ (NO_3)_2$	19		

Table 4.6: Fertilizer inventory in the upper catchment and riparian area

Crop type	Diammonium phosphate (kg/ha)	Calcium ammonium nitrate (kg/ha)	Trisuper phosphate (kg/ha)	Urea (kg/ha)	Manure (kg/ha/ yr)	Potassium nitrate (kg/ha)	N-P-K (kg/ha)	Magnesium Nitrate (Kg/ha)	Phosphoric Acid (Kg/ha)
Maize	125	125							
Wheat	125								
Carrots	200	200							
Cabbage	200	200			50000				
Tomatoes	200	200							
Potato	225								
Bulp onion		300	225						
Mature Asparagus		82.5	82.5		70000				
*French bean	240	400		160		120	280		
*Rose		385		120		600	385	270	200

- Are data taken from Xu (1999)

Table 4.7: Theoretical N and P application rates to farmland from ruminant excreta produced on farms (Lekasi, 2001)

Farm size	Mean N application rates (kg/ha/yr)	Mean P application rates (kg/ha/yr)
Small	403	41
Medium	171	18
Large	108	11

4.1.4.1.2. Pesticides

Pesticides are a general name that includes herbicides, insecticides, fungicides, nematocides and rodenticides. The common types of pesticides applied in the study area are given below in table 4.8.

Table 4.8: Pesticides inventory in the upper catchment and riparian agricultural area

Pesticides Amount (trade name)	Maize	Wheat	Carrots	Cabbage	Tomato	Potato	Bulp onion	Mature asparagus
Dusting-buldock (kg/ha)	3							
Herbicide (buctril) (l/ha)		1.4						
Herbicide (apalon) (kg/ha)			2					
Furadan (kg/ha)				6				
Karate (l/ha)				2				
Fungicides (Ridomil) (kg/ha)					3			
Fungicides (Dithane M45 (kg/ha)					5			
Fungicides (Milraz) (kg/ha)						2		
Fungicides (Dithane M45) (kg/ha)						5		
Dithane M45 (kg/ha)							2.5	
Furadan (kg/ha)								6

4.1.4.2. Point Sources

Among the point pollution sources, sewage discharge and industrial effluents are the significant pollution sources, which will affect the quality of lake water as population pressure increases and industry grows fast. These sources are not included in this case study due to time constraints.

4.1.4.3. Livestock Grazing

As noted by Kitaka (2000), rivers and streams in the Naivasha basin are characterised by torrential flow with high turbid waters during the rainy season. This indicates that the Naivasha catchment experiences a high loss of nutrient-enriched soils from the upper catchment (small-scale intensive cropping farms and overgrazing areas) by surface runoff. The streams pass through areas of intensive human activities such as small scale farming of food crops and dairy farms are polluted by high ammonium-N concentrations, i.e. high organic inputs indicate that overgrazing in the study area has a great impact on the water quality of streams and the receiving lake water body of the Naivasha basin. She discovered that a high concentration of phosphorus is observed in rivers and streams when most of the livestock are frequently visiting the river. The cattle faeces are deposited at the bank of streams and rivers, and on the pastureland during watering and grazing, respectively, and are transported by surface runoff during the rainy season.

The daily production of livestock faeces and the nutrient content of dry waste matter in the central and eastern region of Kenya was analysed by Lekasi (2001) as given above in table 4.7. Therefore, as described above, this collected amount of livestock manure will be either applied on farms or deposited on pastureland during grazing and it will be transported by surface runoff to streams and the lake water body.

4.2. Laboratory Analysis

4.2.1. Laboratory Water Quality Analysis

Two types of water samples were analysed in the ITC laboratory to determine the nutrient and major cations concentration (in two rivers and the lake) and the nutrient loading due to surface runoff from different land uses in the basin. The analysis results and their description are given in the following sections.

4.2.1.1. Nutrient Analysis

There is a high variation of nutrient input into streams from different land uses as shown in table 4.9. The runoff that passes through intensive human activities, especially in small scale farming areas, was rich in nutrients concentration. The surface runoff which flows from the Abaredare range (SR1 and SR3) of small scale and medium farming contributes high nutrient input loads to the Mkungi River (M4) that might be due to fertilizers used for onion farms, vegetables and maize, and intensive livestock grazing.

Table 4.9: Malewa and Gilgil river basins surface runoff nutrient analysis results

Sample ID	NH3-N Mg/l	NH3 Mg/l	NH4+ Mg/l	NO_3-N mg/l	NO_3^- Mg/l	NO_2-N mg/l	NO_2^- Mg/l	$NaNO_2$ Mg/l	PO_4^{3-} Mg/l	P Mg/l	P_2O_5 Mg/l
SR1	0.59	0.72	0.76	2.2	9.5	0.004	0.012	0.019	0.17	0.06	0.13
SR2	1.58	1.93	2.04	6.2	27.6	0.005	0.015	0.023	0.2	0.06	0.15
SR3	1.48	1.79	1.9	6.2	27.6	0.005	0.017	0.026	0.28	0.09	0.21
SR4	0.58	0.7	0.74	3.6	16.1	0.008	0.03	0.045	0.11	0.04	0.08
SR5	1.03	1.25	1.32	4.3	18.9	0.004	0.014	0.022	0.31	0.1	0.23
SR6	0.49	0.6	0.63	4.8	21.1	0.005	0.017	0.025	0.82	0.27	0.61
SR7	0.89	1.08	1.14	4.1	18	0.005	0.015	0.023	0.35	0.12	0.27
SR8	0.81	0.99	1.05	2.7	12.1	0.004	0.013	0.02	0.56	0.18	0.41
SR9	1.91	2.33	2.46	6.8	29.9	0.004	0.014	0.021	0.43	0.14	0.32
SR10	0.66	0.81	0.86	5	22.2	0.02	0.065	0.098	0.38	0.12	0.28
SR11	1.38	1.68	1.78	4.6	20.2	0.004	0.012	0.018	2.42	0.79	1.81

SR refers to the surface runoff taken in the watershed located at different places (see table 4.2)

There was also a high concentration of NO_3-N in the Turasha tributary catchment (SR9), which drained from small-scale farms of peas, beans, maize, and grassland areas that contribute high nutrient input loads to the Turasha tributary (M7) (see figure 4.1). In this catchment the NH_3-N concentration was higher which supported the presence of intensive grazing indicating high organic input for the streams. Low NO_3-N concentration was observed in the analysis for the onion farm in the Abaredare area (SR1) that was collected after the rain stopped. This might be due to that the high load of nitrate was transported during rain events and the second main reason might be the time of concentration. The runoff collected after the rain stopped is the runoff drained from remote areas, in this case, from the forest area of the upper catchment. As it is shown in the figure 4.2 for SR2 and SR3, the samples were collected during storm events and the runoff comes from the nearby area, i.e. from the onion farmland concentrated with NO_3-N. The other nutrient load difference observed in surface runoff was for phosphorus. There was an increase in concentration in maize farm growing and grassland area as shown in figure 4.2 for SR6 and SR11. In the southern part of the Kipipiri Mountain, there is intensive maize farming as a result, the phosphorus concentration of the sample collected in this area (SR11) was high. This might be due to the intensive small-scale farming, mainly maize and live stock grazing, and medium scale farming experienced around the Kipipiri range. A low concentration of P was observed in surface runoff samples (SR4) collected in forest and pasture land areas in the Mkungi river basin. The low concentration of phosphorus observed here is mainly because the land use is well covered with forest in the uppermost catchment and pastureland in the nearby areas. The nutrient concentration in the two-headwater streams sampled (figure 4.1) depends on the land management practice experienced in the catchment.

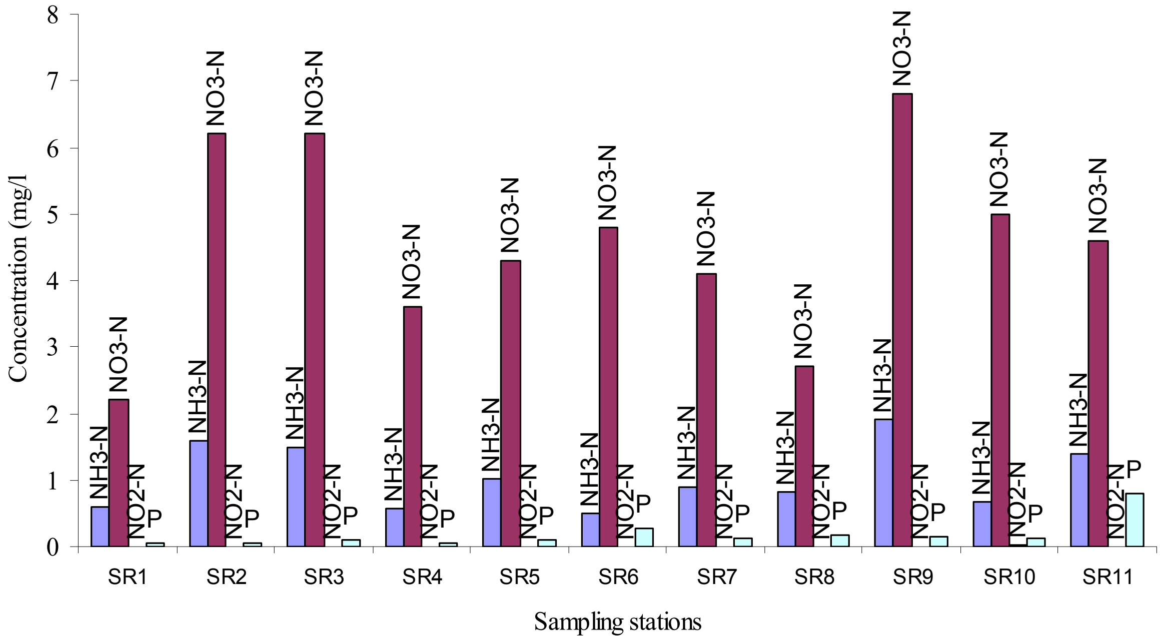

Figure 4.2: Surface runoff nutrient concentration from different land uses

The NO_3-N concentration in the Mkungi River (M4) was observed to be high (see figure 4.3). This stream passes through intensive human activities, mainly small scale farming of food crops such as maize, and medium scale farm of onion along the Abaredare range. The stream (M6) passes through pastureland and forestland including some mixed farming, which originates from the Abaredare area, has a low concentration of nitrate. This low concentration of nitrate may be due to low surface runoff and low nutrient input from fertilizer application. In case of NH_3-N, a high concentration was observed in the Wanjohi River (M10) due to intensive livestock grazing and watering of livestock. In the catchment of the Wanjohi River and its tributary from the Nyambugi area or Ol kalu area, there is an activity of watering large numbers of livestock and small scale farming (Kitaka, 2000). This results in a deposition of fresh cattle manure at the bank of the streams. The nutrient analysis result made with the instrument Spectrophotometer HACH DR/2010 is given in table 4.10. The major cations concentration analysed by Inductively Coupled Plasma (ICP) method in ITC and some water quality parameters made in the field are given in table 4.11. A high concentration of phosphorus was observed in Gilgil River at station G2 near to the Gilgil town (see figure 4.4). This might be due to the settling property of phosphorus attached with the sediment particles transported by erosion from upper catchment.

Table 4.10: Malewa and Gilgil rivers water quality from September 30 to October 8, 2003

Sample ID	NH_3-N Mg/l	NH_3 Mg/l	NH_4^+ Mg/l	NO_3-N mg/l	NO_3^- Mg/l	NO_2-N mg/l	NO_2^- Mg/l	$NaNO_2$ Mg/l	PO_4^{3-} Mg/l	P Mg/l	P_2O_5 Mg/l
M1	0.09	0.1	0.11	2.6	11.5	0.004	0.014	0.021	0.22	0.07	0.17
M2	0.32	0.39	0.41	2.5	11.1	0.005	0.016	0.023	0.09	0.03	0.07
M3	0.08	0.09	0.1	2.5	10.9	0.005	0.017	0.025	0.12	0.04	0.09
M4	0.17	0.21	0.22	3.8	16.8	0.023	0.075	0.113	0.12	0.04	0.09
M5	0.25	0.31	0.33	2.4	10.7	0.005	0.017	0.026	0.07	0.02	0.05
M6	0.13	0.16	0.17	2	9	0.004	0.015	0.022	0.1	0.03	0.07
M7	0.31	0.38	0.4	2.5	11.2	0.004	0.014	0.022	0.08	0.03	0.06
M8	0.34	0.41	0.43	2.5	11	0.005	0.018	0.026	0.05	0.02	0.04
M9	0.11	0.14	0.15	2.3	10.3	0.005	0.017	0.025	0.1	0.03	0.08
M10	0.48	0.58	0.61	2.4	10.8	0.005	0.018	0.026	0.03	0.01	0.02
M11	0.11	0.14	0.14	2.2	9.7	0.005	0.016	0.025	0.17	0.06	0.13
M12	0.19	0.23	0.24	2.4	10.5	0.078	0.257	0.386	0.22	0.07	0.17
G1	0.14	0.17	0.18	2.2	9.8	0.005	0.017	0.026	0.14	0.05	0.11
G2	0.19	0.23	0.25	2.1	9.3	0.007	0.023	0.034	2.49	0.81	1.86
G3	0.19	0.23	0.24	2	9.1	0.005	0.016	0.024	0.19	0.06	0.14
G4	0.09	0.1	0.11	2	8.9	0.004	0.014	0.021	0.07	0.02	0.05
G5	0.15	0.18	0.19	2.8	12.4	0.009	0.031	0.046	0.09	0.03	0.06

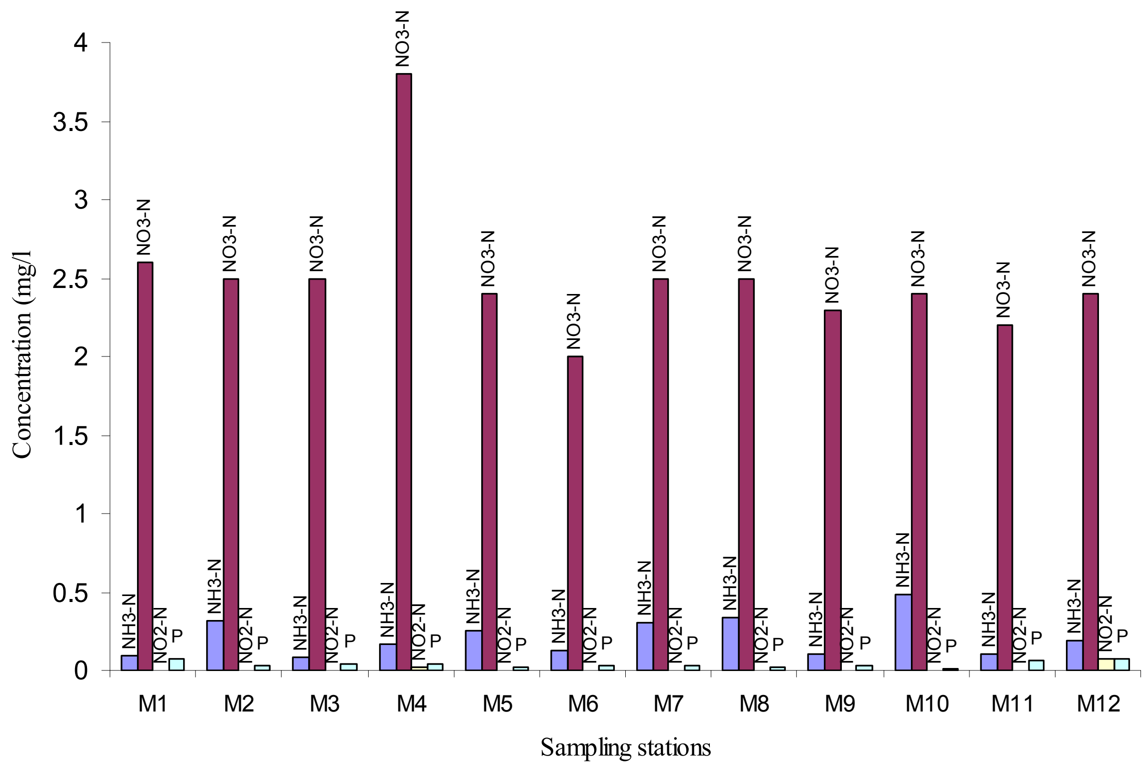

Figure 4.3: Nutrient concentration along the Malewa River

Generally, there is a trend of increase in both NO_3-N and P from upstream to downstream of the Malewa River.

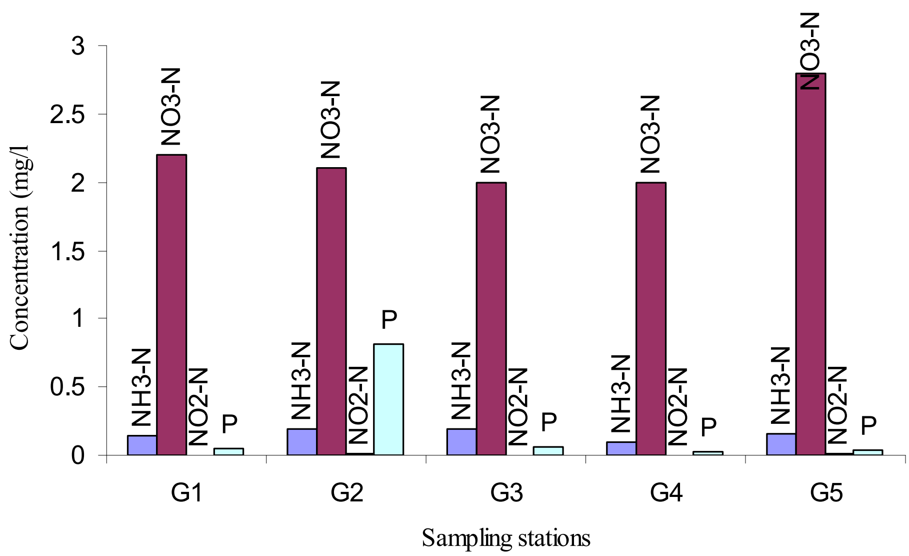

Figure 4.4: Nutrient concentration along the Gilgil River

Table 4.11: Major cations concentrations

Sample ID	Al mg/l	Ca mg/l	Fe mg/l	K mg/l	Mg mg/l	Mn mg/l	Na mg/l	DO mg/l	PH	EC µs/cm
G1	0.14	4.42	0.49	3.87	0.89	0.012	2.18	6.8	5.91	75.8
G2	0.14	3.88	0.51	3.41	0.92	0.042	2.01	7.27	5.85	69.7
G3	0.19	7.5	0.17	10.34	1.04	0.024	5.92	7.06	6.53	179.5
G4	0.05	1.87	0.2	2.09	0.47	0.027	1.15	7.67	6.3	41.2
G5	0.08	4.32	0.54	3.57	1	0.04	2.24	7.27	5.68	83.3
L1	0.18	20.23	0.12	18.34	5.84	0.005	7.5			
L2	0.43	22.52	0.37	21.89	7.34	0.049	9.7			
L3	0.56	19.34	0.53	18.13	5.47	0.094	6.34			
L4	0.5	15.27	0.54	1.57	4.9	0.062	6.04			
M1	0.53	6.72	0.62	3	1.96	0.239	1.27			75.3
M2	0.15	7.48	0.28	2.77	1.85	0.055	1.73	7.51	6.28	88.1
M3	0.12	7.64	0.18	2.55	2.15	0.02	1.17	7.82		79.4
M4	0.17	7.49	0.21	2.56	2	0.036	1.05	7.74	7.29	72.6
M5	0.2	5.82	0.31	2.72	1.34	0.057	1.3	7.42	6.14	65.5
M6	0.08	7.04	0.11	1.94	2.44	0.004	0.9	8.02	5.31	71.7
M7	0.23	11.73	0.25	0.72	3.16	0.09	1.44	7.5	6.08	104.4
M8	0.14	12.46	0.2	2.99	2.82	0.071	1.35	7.15	5.64	101.6
M9	0.14	8.04	0.42	5.21	2.23			7.26	5.94	89.1
M10	0.09	8.86	0.14	2.4	2.23	0.035	2.62	6.98	5.64	119.1
M12	0.43	17	0.32	14.63	0.52	0.122	2.77	5.95	6.16	117.9

4.2.2. Laboratory Soil Analysis

The soil is polluted when the most important nutrient constituents exist in abundance. This in excess quantity of nutrients will be transported to the rivers and lakes by storm-water runoff from different land uses. The main point sources of soil contamination might be from industrial and municipal waste dumps and landfill sites and from non-point sources (mainly agriculture and atmosphere). Therefore, determining the soil nutrient concentrations at different sites in the basin constitutes the basic data input parameters for setting the initial nutrient concentration in modelling the water quality of the basin. In most East African countries, soil erosion is the main problem which leads to soil nutrient depletion and results in increasing nutrient loadings to the rivers and lake by storm-water.

The soil texture, organic carbon content and extractable phosphorus analysis has been performed in ITC laboratory. The soil erodibility factor can be calculated by the equation developed by Williams (1995) as follows (Neitsch, 2002):

$$K_{USLE} = f_{csand} \cdot f_{cl\text{-}si} \cdot f_{orgc} \cdot f_{hisand} \quad 4.2$$

where f_{csand} is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand, $f_{cl\text{-}si}$ is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibilty for soils with high organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents.

The factors are calculated based on the soil particle analysis result obtained in the ITC laboratory using the following formulae:

$$f_{csand} = \left(0.2 + 0.3 * \exp\left[-0.256 * m_s\left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad 4.3$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad 4.4$$

$$f_{orgc} = \left(1 - \frac{0.25 * orgC}{orgC + \exp[3.72 - 2.95 * orgC]}\right) \quad 4.5$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 * \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad 4.6$$

where m_s is the percent sand content (0.05-2.00 mm diameter particle), m_{silt} is the percent silt content (0.002-0.05 mm diameter particle), m_c is the percent clay content (<0.002 mm diameter particles), and orgC is the percent organic carbon content of the layer (%).The organic matter can be calculated from organic carbon using the relationship by:

$$OM = 1.72 * orgC \quad 4.7$$

The concentration of humic organic nitrogen is calculated by assuming that the C: N ratio for humic materials is 14:1(Neitsch, 2002). Therefore, the concentration of humic nitrogen in a soil layer is given by:

$$orgN_{hum,ly} = 10^4 * \left(\frac{orgC_{ly}}{14}\right) \quad 4.8$$

where $orgN_{hum,\ ly}$ is the concentration of humic organic nitrogen in the layer (mg/kg or ppm), and $orgC_{ly}$ is the amount of organic carbon in the layer (%).The organic phosphorus level of the soil is calculated assuming that the N: P ratio for humic materials is 8:1 (Neitsch, 2002).

$$orgP_{hum,\ ly} = 0.125 * orgN_{hum,\ ly} \quad 4.9$$

where $orgP_{hum,\ ly}$ is the concentration of humic organic phosphorus in the layer (mg/kg)
The soil chemical, particle size laboratory analysis and calculation results are given in table 4.12.

Table 4.12: Soil particle size, organic carbon and soil nutrient analysis result

X-coordinate UTM	Y-coordinate UTM	Clay (%)	Silt (%)	Sand (%)	orgC (%)	OM (%)	$orgN_{hum, ly}$ (mg/kg)	$orgP_{hum, ly}$ (mg/kg)	Soil types
222306	9948922	31	31	38	1.9	3.2	1261	158	Clay loam
220183	9930610	63	20	16	4.9	8.4	3284	411	Clay
212566	9951038	40	31	29	2.6	4.5	1759	220	Clay loam/clay
234398	9949936	39	55	6	6.9	11.9	4621	578	Silty clay loam
221093	9930550	27	62	11	2.6	4.5	1768	221	Silty loam
234431	9947088	62	35	3	8.1	13.9	5395	674	Clay
234769	9949590	41	43	16	10.8	18.6	7214	902	Silty clay
201706	9973046	54	40	6	3.8	6.6	2551	319	Silty clay/clay
231553	9953324	52	32	16	8.4	14.5	5630	704	Clay
213811	9972396	51	44	5	3.2	5.5	2126	266	Silty clay
234759	9949558	43	51	6	9.2	15.8	6158	770	Silty clay
221083	9930450	32	60	7	11.6	23.2	7741.4	967.7	Silty clay loam
211244	9910256	17	43	40	1.4	2.8	950.1	118.8	Loam
210050	9906318	8	30	62	1.2	2.4	785.9	98.2	Sandy loam
213298	9917422	22	32	46	3.5	7.1	2357.6	294.7	Loam

4.3. Discharge Measurements

The rivers Malewa and Gilgil were flowing throughout the study time. There was a great variation in depth of flow in the rivers due to rainfall, which occurred in the upper catchment. In the beginning of the fieldwork, the depth of flow for the Gilgil River was 130 cm. After two weeks, during the time of discharge measurement and sampling, the depth of flow was 98 cm. The two rivers are the main tributaries of Lake Naivasha. The discharge of the two rivers and their tributaries were measured at each sampling point using a propeller current meter to determine the nutrient yields and loading from the catchment into the lake. From discharge measurements performed during the fieldwork, the Malewa and Gilgil Rivers contribute about 89.86% and 10.14% to the lake, respectively. The discharge measurement and its calculation are given in appendix A-1.

The nutrient load rate can be calculated as:

$$\underset{(Kg/day)}{\text{Nutrient rate}} = \underset{(L/sec)}{\text{discharge}} \times \underset{(mg/l)}{\text{nutrient concentration}} \times 0.0864 \qquad 4.10$$

where 0.0864 is a conversion factor from seconds to days and mg to kg

5. Model Implementation

Water quality modelling in this research study is based on different management practices in the study area such as fertilizer application and grazing operation. Delineating the watershed by integrating with Arc view starts the water quality modelling. In this chapter, integrating the DEM with soil and land use maps to create sub-basins that have similar or unique characteristics will do the watershed configuration process.

5.1. Water Quality Model Set-up

To analyse the impacts of different management practices and hydrologic conditions in the watershed for stream and lake quality, preparing input database information and loading this information in the model is the first and the main important step for any model. Input databases may be organized into metrological data, information for each hydrologic response unit, water quality parameters and different management practices.

The following steps were followed to set-up the model and load the input databases:

- Watershed delineation
- Land use and soil characterisation
- Climate data definition
- Editing input information

5.1.1. Watershed Delineation

5.1.1.1. DEM Set-up

In watershed delineation, the Digital Elevation Model (DEM), which provides topographic information in a basin, and a digitised stream network that were prepared by previous ITC students were used in this study. The DEM with a 20 meter-pixel size, prepared by Lukman (2003), was loaded to the system in an Arc info grid format. The DEM properties were set to verify the projection, and the horizontal and vertical units of measure as described in table 5.1. After the DEM was imported into SWAT, the masking polygon was created for the study area to focus only on the Lake Naivasha basin. Also a digitised stream network file to "burn" into the watershed was imported. Then the DEM was preprocessed.

Table 5.1: Coordinate system

Projection	Universal Transverse Mercator
Spheroid	Clarke 1880
Datum	Arc 1960
Zone	37
Central Meridian	39
Reference Latitude	0
Northing	10000000
Easting	500000
Scale factor	0.9996

5.1.1.2. Stream Definition

Based on the aim of the study, the details of the stream network, the size and number of sub-watersheds were determined by defining the threshold area or critical source area. It defined the minimum drainage area required to form the origin of stream. In a water quality study, setting minimum threshold area is advisable to identify the source of pollution depending on the crop and the drainage pattern in the study area. In this case study, the minimum threshold area was taken to be 10000 ha to form 33 sub basins.

5.1.1.3. Outlet and Inlet Definition

In this section the outlet points were added which helped to compare the measured and simulated flows and loads for some monitoring stations. For these outlet points, the coordinates of nutrient concentrations and flow measurement points were used to define the outlet point of each sub-basin.

5.1.1.4. Main Watershed Outlets Selection and Definition

It is convenient to select the most down-stream outlet of each target watershed to determine how much pollutant load is transported to the lake by specifying the main outlet point at the mouth of the Malewa and Gilgil rivers. After setting all parameters described above, a map of the watershed, sub-watershed, and stream network restricted to the watershed was obtained when the interface has completed the watershed delineation (see figure 5.1).

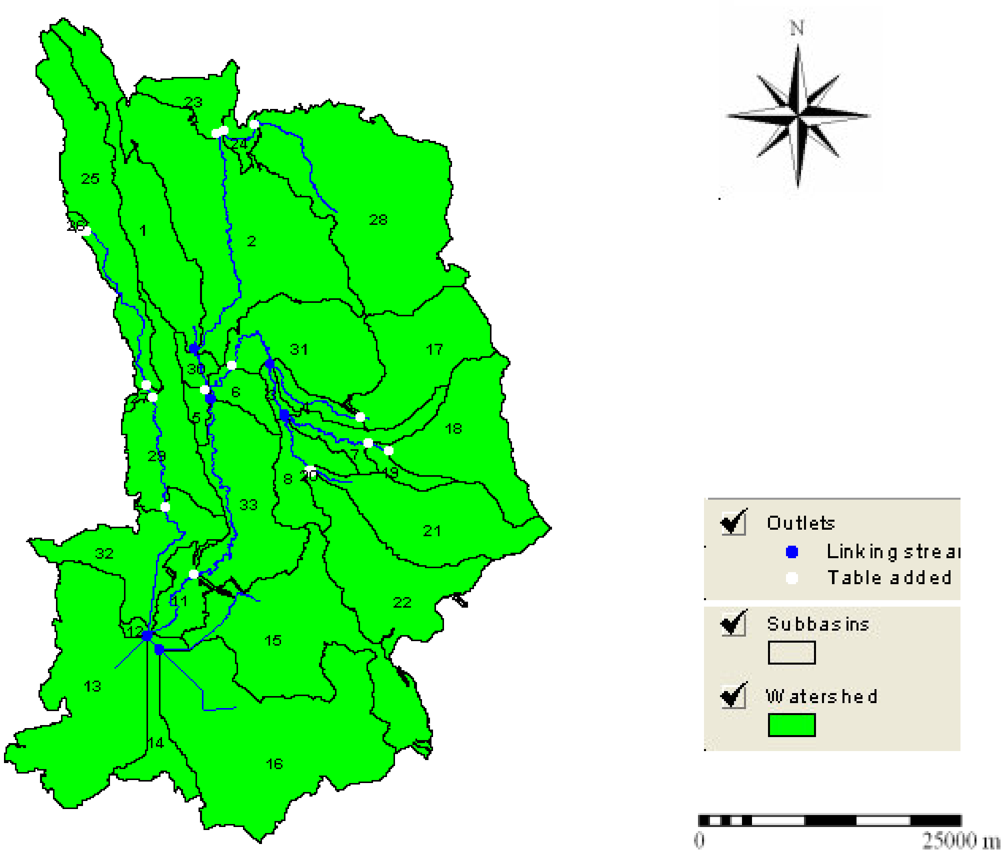

Figure 5.1: Sub-basin Delineation

5.1.2. Land Use and Soil Characterization

The movement of water depends on the soil type and vegetation cover. The amount of rain lost due to interception storage on the plants depends on the type of vegetation and has a significant effect on the infiltration capacity of the soil. Dense vegetation covers the soil from raindrop impact and reduces the problem of erosion. As vegetation coves decreases, the surface runoff increases result in increasing nutrient transportation to the streams.

The infiltration capacity of the soil depends, among others, on the porosity of the soil, which determines its storage capacity and affects the resistance of water to flow into deeper layers (Lukman, 2003). Since the soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soils. This indicates the surface runoff is higher in heavy clay or loamy soils which has low infiltration rates.

5.1.2.1. Land Use/Soil Definition and Overlay

5.1.2.1.1. Land Use

The land use for the study area was prepared based on the ground truth taken on field and the percentage of the land cover found in the area of study. About 18 different types of land use were delineated and used for SWAT input (see figure 5.2) based on the type and amount of fertilizer applied for each crop, which ease for editing SWAT input data.

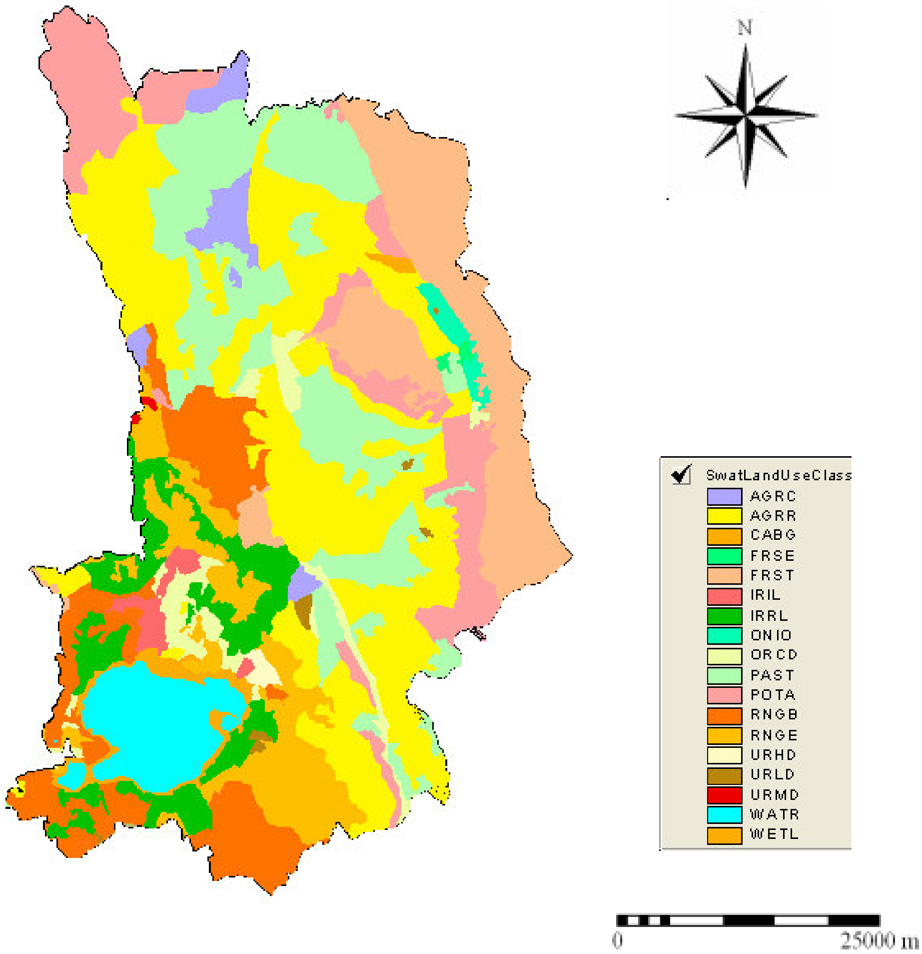

Figure 5.2: Land-use map

As shown in table 5.2, 26.2% of the watershed area is covered by the maize cropland, which is the main stable food in the region. In the region there is also a good and wide coverage of forest and brush around the periphery of the lake, along the rivers and in the Abaredare range (21.62%).

Table 5.2: Description of SWAT land use class codes and percent of area covered

Swat land use classes code	Description of land use code	% Watershed area
AGRC	Wheat crop land	2.17
AGRR	Maize crop land	26.20
CABG	Cabbage and some vegetables land	0.18
FRSE	Acacia wood and coniferous trees land	0.15
FRST	Forest - mixed land	12.55
IRIL	Irrigation land mainly flowers	6.26
IRRL	Irrigation lands mainly maize and flowers	0.95
ONIO	Onion farms	0.70
ORCD	Orchard trees	2.84
PAST	Pasture land	15.21
POTA	Potato and vegetables land	9.48
RNGB	Range grasses mixed with brush	9.07
RNGE	Range - grasses land	7.42
URHD	Urban residential-high density	0.26
URLD	Urban residential- low density	0.33
URMD	Urban residential -medium density	0.07
WATR	Water land	4.82
WETL	Wet lands- mixed	1.35

5.1.2.1.2. Soil

The soil texture in the watershed is mainly silty clay and clay in the upper catchment of the Malewa and Gilgil Rivers (see table 4.9 in section 4.2.2). The soil texture around the lake and lower catchment of the Gilgil and Malewa rivers is mainly loam and sandy loam soil.

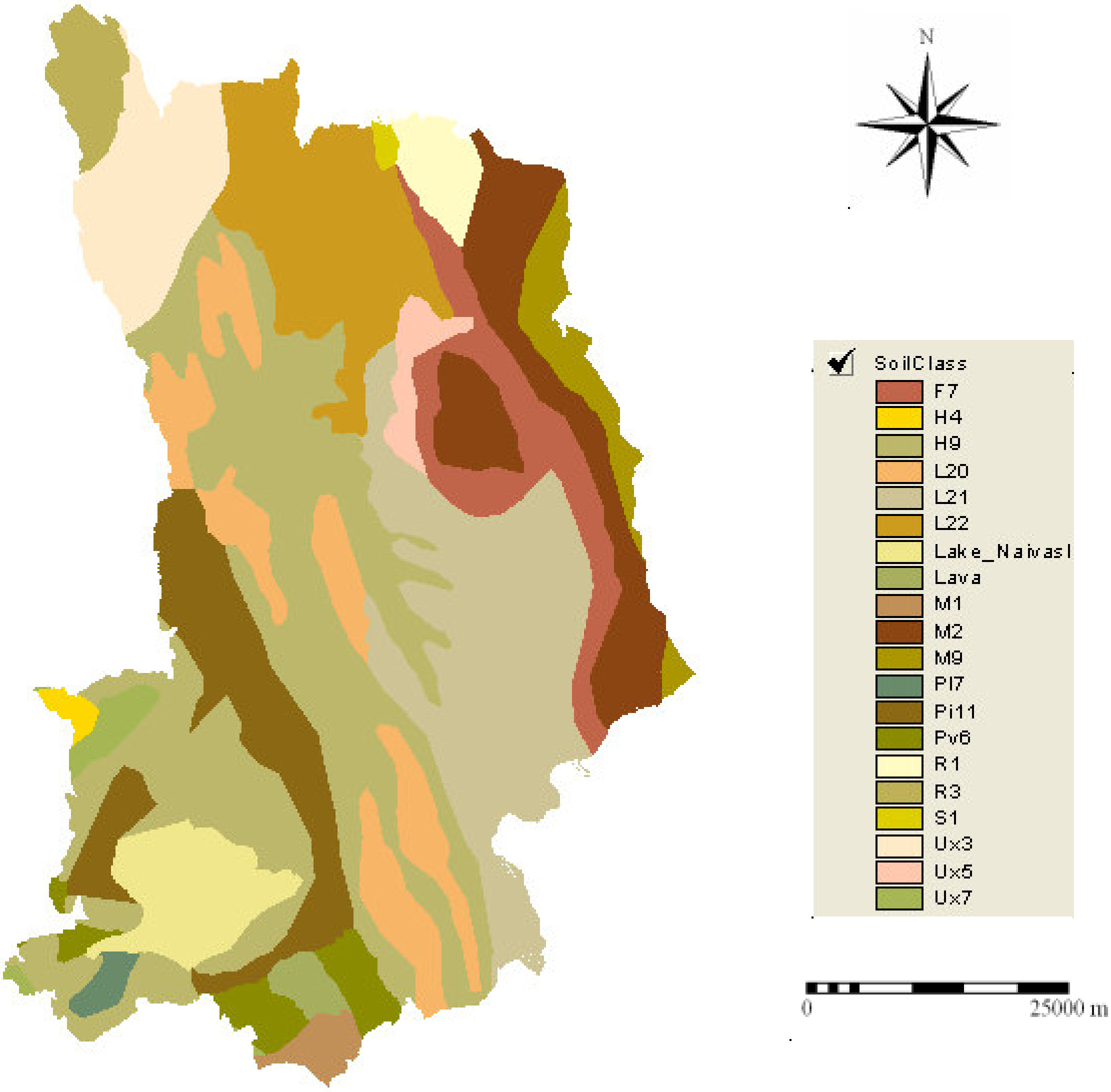

Figure 5.3: Soil map

5.1.2.2. Hydrologic Response Units Distribution (HRU)

Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils (Neitsch, 2002).

The load predictions will be good and accurate if each HRU is considered obtaining the total effect of different land cover/crops and soils. Since water quality depends on the total runoff in the watershed, detail consideration of each hydrologic condition of different land covers/crops and a soil is very important. The nutrient loading on the rivers and lake depends on the total runoff of the watershed. And the total runoff depends on the actual hydrologic condition of each land covers/crops and soil present in the watershed. In this case study, the threshold of 0% and 10% of land use and soil, respectively, is used to increase the accuracy of the load predictions and to provide a much better description of the water balance. Therefore, the impact of each type of land use is considered in this water quality modelling to apply to all nutrient inputs in the basin.

5.1.3. Climate Data

One of the main sets of input for simulating the watershed in SWAT is climate data. Climate inputs consist of precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity. The daily precipitation records for the period of 1935-2002 were used which was analysed by Lukman (2003) to develop the climate-input files required for the model. The remaining climate inputs were generated internally within SWAT using monthly climatic statistics provided for four stations located in the watershed. The four monitoring stations for precipitation within and surrounding the Lake Naivasha basin are given in table 5.3 below.

Table 5.3: Weather station spatial data (Lukman 2003)

Station ID	Station Name	X	Y	Elevation (m asl)
9036002	Naivasha DO	214315	9920714	1900
9036025	North Kinangop Forest Station	238582	9935474	2629
9036241	Geta Forest Station	207148	9948369	2591
9036264	North Kinangop Mawingo Scheme	223586	9944688	2484

5.1.4. Model Input Set-up

After simulating the climatic data, the next step was to set-up inputs required for running the SWAT model. These inputs were management data, soil data, soil chemical data and in-stream water quality parameters. The management data include fertilizer and pesticide application, tillage operation and management operations. Since most of the farmers did not apply the recommended amount of fertilizer for their cultivation, the fertilizer application data for SWAT input used were 75% of the actual recommended amount described in table 4.6, whereas, the pesticide rate used was as given in table 4.8. The fertilizer applied in the basin due to grazing was taken to be 5.5 tDM/ha/yr, which was nearly the average of the values given in section 4.1.4.1.1 for different farm size yearly production of manure. The soil (see table 4.12 and section 4.1.3.1), soil chemical (see table 4.12) and in-stream water quality parameters (see table 4.10 & 4.11) were the inputs used in SWAT to simulate the model.
Finally, the other key aspects of the SWAT simulation performed for the watershed are listed below:

- Output time step: daily
- Rainfall distribution: skewed normal
- Runoff generation: CN method
- Channel water routing: variable-storage method

5.2. Model Caliberation and Sensitivity Analysis

5.2.1. Model Calibration

Model calibration is necessary for the successful use of any hydrologic and water quality simulation. For better estimation of water quality parameters in the simulation model, the model was calibrated in three phases. The model was first calibrated for hydrology. After hydrologic calibration, the model was calibrated for sediment transport; then, the model was calibrated for nutrients. Model calibration was conducted for 24 years from 1980 to 2003. The first five years were used for priming the model. The model needs at least five years for better estimation of results through priming (Gitau, (2003, personal communication)). The hydrologic model calibration was performed for thirteen years from 1985 to 1997 by comparing the simulated discharge with the observed or measured discharge. In this calibration process, the model was calibrated by adjusting different parameters such as curve number, bration process, the model was calibrated by adjusting different parameters such as curve number, soil available water capacity and soil evaporation compensation factor and others until a good fitness between observed and simulated flow was obtained. The calibration result of this period was not having a good fit as it is shown in figure 5.4 for Malewa River at 2GB1 gage station. The reason for this was that the flow data was not reliable. As stated by Becht and Harper (2002) that the Naivasha flow data is considered to be unreliable after the mid 1970`s. After confirming the unreliability of the data, the model was calibrated for the period from 1965 to 1975 at the mouth of Malewa and Gilgil rivers. After several iterations of simulation process by adjusting the sensitive parameters, a good fit result was obtained as shown in figure 5.5. The resulting statistical goodness-of-fit was evaluated with the Nash-Sutcliffe coefficient (Strobl, 2002), R^2_{NS}= 0.492 and R^2 of the one-to-one line for the monthly stream flow was 0.489 (see figure 5.6). The "systematic" (RMSEs) and "unsystematic" (RMSEu) errors were checked for goodness-of-fit that RMSEs =2316523 is less than RMSEu =12150394. Therefore, with the statistical goodness-of-fit values obtained, the hydrologic calibration was deemed to be sufficient enough to proceed with the sediment and nutrient calibration.

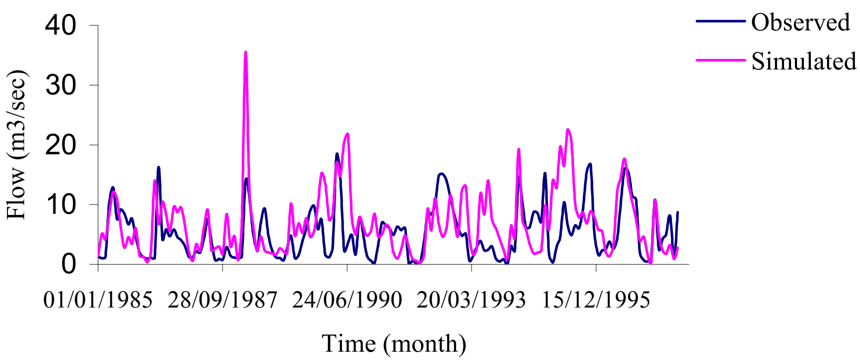

Figure 5.4: Comparison between the observed flow and simulated flow of the model

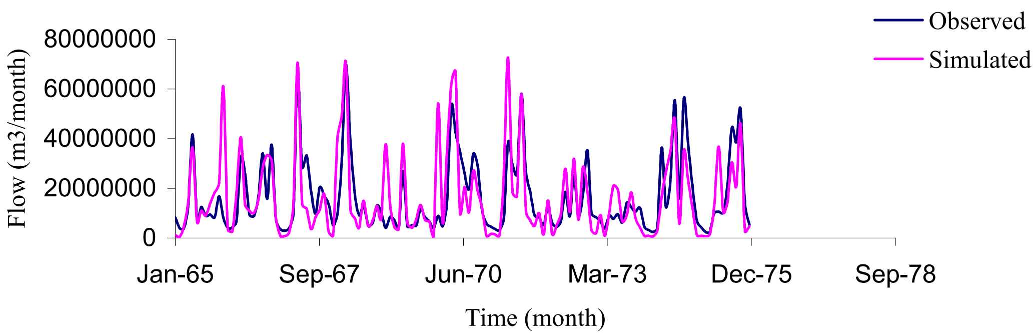

Figure 5.5: Comparison between the observed flow and simulated flow of the model

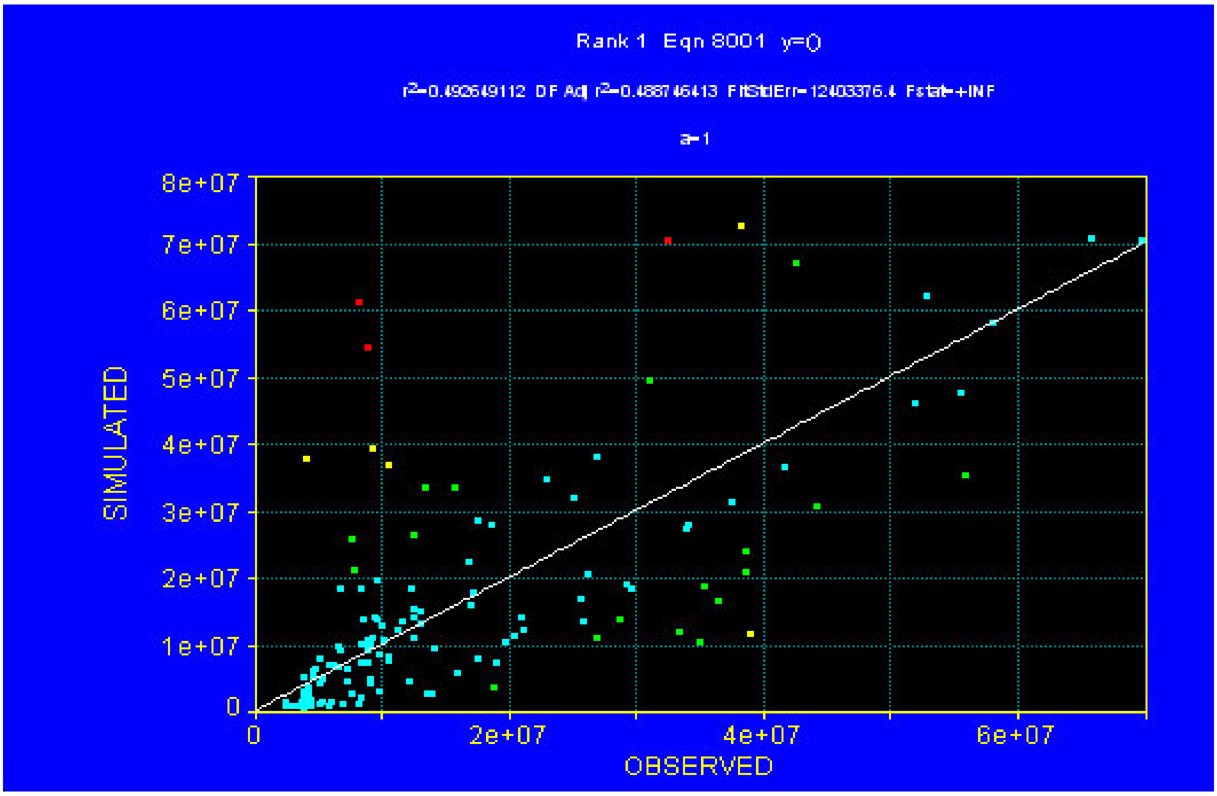

Figure 5.6: A linear regression of the simulated values against the observed values to the one-to-one line

In the second phase, the model was calibrated for sediment. From the model estimation result observed during sediment calibration, the SWAT model underestimated the sediment load. The observed sediment load was higher than the estimated value. All sediment calibration parameters were used to increase the sediment prediction. But it was not responding very much to increase the sediment estimation. This might indicate a SWAT limitation for sediment prediction. In the third phase, the model was calibrated for water quality (nutrient concentration). The load estimates for the period September 2003 to October 2003 were used to calibrate/adjust the SWAT model. These loads were compared with the data measured in this period during fieldwork. The calibration process was performed by verifying all initial concentrations of the nutrient and fertilizer application, then by altering the biological mixing efficiency and adjusting the nitrogen percolation coefficient, phosphorus percolation coefficient, phosphorus partitioning coefficient and other parameters mentioned in table 5.4. In the nutrient calibration process, since data collection for water quality was focused on an intensive field survey of short duration for discharge and quality parameters, the measured concentration value was only for one day for each point; and it was therefore difficult to make correlation graphs for nutrient calibration. Therefore, the simulated value was compared with the measured value, which was collected during fieldwork. Figure 5.7 and 5.8 shows the comparison of the estimated load and measured values. Stream loadings were calculated at each observation station by developing a relationship between flow and observed nutrient concentration. Loadings were developed for soluble phosphorus and nitrate to compare with the estimated load due to leaching.

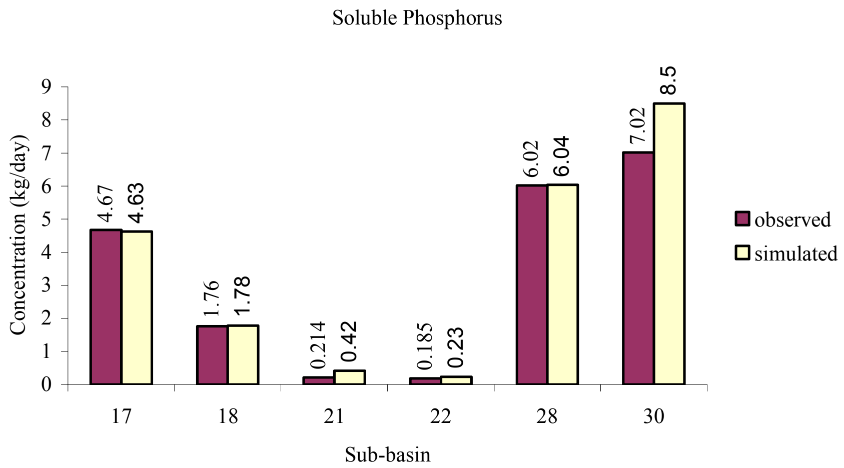

Figure 5.7: Comparison between observed and simulated soluble phosphorus concentration in streams.

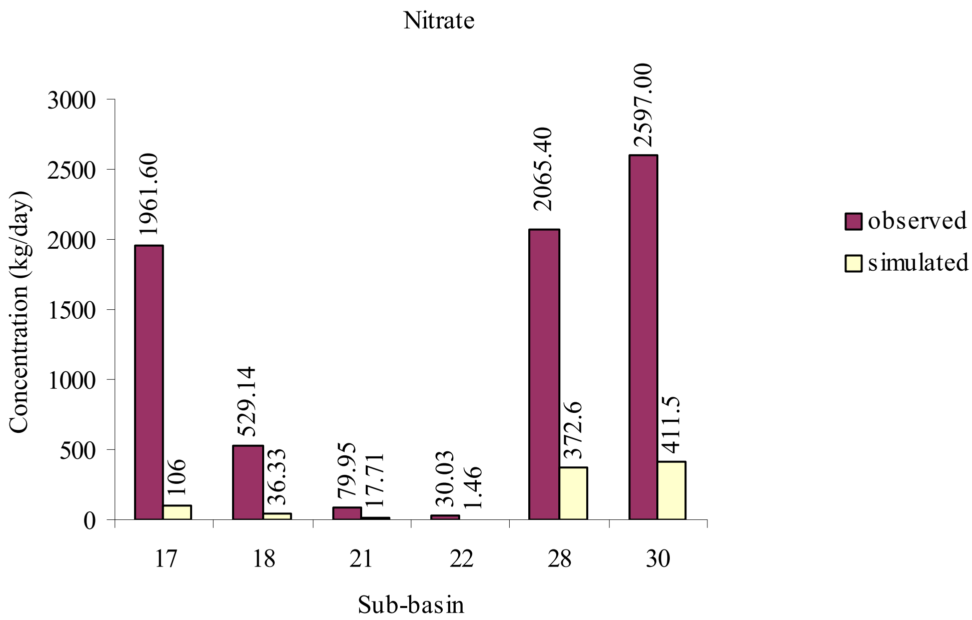

Figure 5.8: Comparison between observed and simulated concentration

As it is shown in figure 5.7, the correlation between the observed and simulated value of soluble phosphorus in the stream flow was good. Whereas, the nitrate in the simulated value was underestimated that might be due to the structural problem in the system, which uses different number of layers in calculating the mobile nitrate and the process of nitrate undergo to nitrite and other stable forms of nitrogen (see figure 5.8). For this model, only one layer was used to simplify the input data and because of the unavailability of data for different layers. The other problem was the sensitivity of the model for many parameters. Changing one parameter for phosphorus nutrient calibration would affect the nutrient level of nitrate, which was calibrated using sensitive parameters for nitrate.

5.2.2. Sensitivity Analysis

Sensitivity analysis is very important for a model to reduce the number of model parameters for calibration and to examine the more sensitive parameter, which in turn determines the main cause of water quality deterioration from different practices and physical conditions. The analysis was carried out using the calibrated model by changing one parameter at a time, while keeping the rest of the parameters constant. The parameter variation was made by applying ± 25% and ± 26% for some parameters as shown in table 5.4 and value changes for USLE_P, CN2 and SOL_AWC. In SWAT, CN2, SOL_AWC and USLE_P parameter variation are allowed to vary only by value. The results of this sensitivity analysis are discussed in section 5.3.1.

Table 5.4: Sensitivity analysis result of parameters for the SWAT model

Parameters	Parameter Variation	Flow Variation (%)	SURQ Variation (%)	NO3 Variation (%)	MinP Variation (%)	NSURQ Variation (%)	SOLP in runoff Variation (%)
USLE_C	25%	0	0	5.85	3.06	0	0
"	-25%	0	0	-6.94	-3.533	0	0
NPERCO	26%	0	0	13.605	-0.01257	26.047	0
"	-26%	0	0	-13.59	0.01257	-25.581	0
PPERCO	26%	0	0	-0.01452	0.33945	0	0.806
"	-26%	0	-0.002	0	0	0	0
PHOSKD	26%	0	0	0.13115	-9.3286	0	-12.5
"	-26%	0	0	-0.04356	26.1	0	34.677
SOL-LABP	26%	0	-0.009	-0.02904	10.636	0	10.081
"	-26%	0	0.0021	0.05805	-17.99	0.465	-21.371
SOL-ORGN	26%	0.269	0.569	15.478	-0.0629	8.837	0.403
"	-26%	0.05048	0.162	-13.649	0.2137	-7.907	0.403
SOL-ORGP	26%	0	-0.002	-0.0145	5.5318	0	1.613
"	-26%	0	0.002	0	-5.5318	0	-1.613
ALPHA-BF	26%	0	0	0	0	0	0
"	-26%	-0.01683	0	0	0	0	0
GWQMN	26%	-1.076	0	0	0	0	0
"	-26%	0	0	0	0	0	0
GW-REVAP	26%	-6.1922	0	0	-0.05	0	0
"	-26%	5.856	0	0	0.01257	0	0
SLOPE	26%	-1.74996	0.0121	13.1987	5.56	0	0
"	-26%	1.649	-0.018	-12.7922	-5.81	0.465	0
SLSUBBSN	25%	1.447	-0.0421	2.9185	2.4013	0.465	0
"	-25%	-1.447	0.053	-1.554	-3.1179	0	0
BIOMIX	26%	0	0	0	0	0	0
"	-26%	0.202	0.913	0.566	15.791	6.977	37.5
USLE-P	1.3	0	0	0	0	0	0
"	-1.3	0	0	-38.115	-18.996	0	0
CN2	8	9.1368	52.16	93.55	31	269.767	51.613
"	-8	-7.521	-39.451	-21.795	-28.2625	-57.209	-39.113
SOL-AWC	0.04	-3.85327	-7.693	-0.6098	-2.049	-6.512	-7.2589
"	-0.04	2.625	6.66	3.63	-7.8325	-17.209	6.452

Note: SURQ = surface runoff flow, NO3 = nitrate concentration in base flow, MinP = mineral phosphorus in base flow, NSURQ = NO3-N concentration in runoff and SOLP = soluble phosphorus in runoff

5.2.3. Scenario Development

Many different activities are carried out in the upper catchment, mainly dairy farming and crop cultivation to feed their families and to provide milk and different type of food crops for people living in towns and cities. Farming activities are increasing in the area due to the population pressure and depletion of soil fertility to produce the intended demand of food crop for the region and the country. To analyse the effect of these different human activities in the upper catchment of the basin on water quality in relation to demographic changes and management practices, we need to develop scenarios. Therefore, in order to use the model as a tool for analysing the effects of different activities in the study area, the following scenarios were considered.

- Management practice in the catchment for cultivation, i.e., application of fertilizer and pesticides
- Nutrient load effect due to intensive livestock grazing activities
- Nutrient load effect due to both grazing and fertilizer application

To determine the impact of theses practices on water quality, the model was first simulated for the scenario without the grazing activities and fertilizer application.

5.3. Result and Discussion

The developed model was run using the model input and physical parameters as described in section 5.1, and the model was simulated for sensitivity analysis and scenario development. The sensitivity analysis was performed for the main 27 SWAT parameters to determine the sensitivity of the model for each parameter and the sensitive parameters were selected (see table 5.4). After checking for sensitivity of the model, four different scenarios were simulated to analyse the effect of constituent loading in the catchment area to streams and lake. The results from sensitivity analysis and each scenario are as follows.

5.3.1. Sensitivity Analysis

Table 5.4 shows the parameter sensitivity that occurred at the outlet 11 of the watershed, i.e., at the mouth of Malewa River draining to the lake. The cover and management factor (USLE_C) is a sensitive parameter for the model in that the plant canopy affects erosion by reducing the effective rainfall energy of the intercepted raindrops. This indicates that the presence of a given percentage of residues on the soil surface during harvesting agricultural products helps in reducing the flow velocity and its nutrient transporting capacity. It obstructs the surface runoff flow occurred during high rainfall intensity. The analysis result shows that the nutrient concentration in the subsurface flow increases mainly NO_3-N when USLE_C increases due to its high mobility.

The other sensitive parameters in the model simulation were the support practice factor (USLE_P) and topographic factors (SLSUBBSN = slope length, SLOPE =Slope steepness). The movement and transport of nutrients are highly dependent on different support practices such as contour tillage, strip-cropping on contour and terrace systems. The proper implementation of contour tillage and planting reduces the problem of erosion and results in minimizing the movement of nutrients from cultivation land to streams. As it is shown in the analysis, increasing the efficiency of implementing these systems reduces the nutrient loading to the streams. Slope and length of slope parameters used in the calculation of the MUSLE topographic factor are also sensitive factors that can greatly affect the SWAT sediment yield prediction results in affecting the nutrient transport attached to the sediment particles.

There is a high sensitivity of the BIOMIX parameter. The redistribution of soil constituents as a result of the activity of biota in the soil increases when the biological mixing efficiency increases. The change of nutrient concentration in untilled areas like pasture land is observed to be significantly high in the system. The nutrient concentration, especially phosphorus, increases dramatically when the biological mixing efficiency decreases by 26%. This indicates that the movement of phosphorus is high via sediment transportation due to its attachment property to sediment particles. There is a high sensitivity of the model for phosphorus concentration due to change in phosphorus soil partitioning coefficient (m3/Mg). Since PHOSKD (phosphorus soil partitioning coefficient) is the ratio of the soluble phosphorus concentration in the surface 10 mm of soil to the concentration of soluble phosphorus in surface runoff, the phosphorus concentration is high when the coefficient is getting decreased. The primary mechanism of phosphorus movement in the soil is by diffusion (Neitsch, 2002). Due to the low mobility of solution phosphorus, surface runoff will only partially interact with the solution P stored in the top 10 mm of soil. As it is shown above in the sensitivity analysis result table 5.4, the soluble phosphorus in surface runoff due to PHOSKD is very high and more sensitive than phosphorus percolation coefficient.

The most sensitive parameter in the water quality model of SWAT is moisture condition II curve number (CN2). A small change of this parameter value will have a great change in hydrology and therefore in the nutrient loading. This indicates the movement of nutrient is basically depending on the hydrologic condition and hydrologic soil group that observed in cultivated agricultural land and uncultivated lands.

From the sensitive analysis result, the main sensitive parameters for the water quality model were NPERCO, USLE_C, PPERCO, PHOSKD, SLOPE, SLSUBBSN, BIOMIX, USLE_P and CN2.

5.3.2. Scenario Analysis

The water quality is mainly affected by different human daily activities experienced in the catchments. The improper management of cattle manures and fertilizer in dairy farming and intensive cropping, respectively, leads to deteriorate the quality of streams and lake making unfit for drinking and irrigation. The impact of different management practices was examined by applying different scenarios. The 1998 wet year period was used for each scenario comparison and the results of four scenarios are presented below.

5.3.2.1. Scenario 1: Nutrient Load without Fertilizer Application and Grazing Activities

The first scenario was simulated for the nutrient loading of streams without fertilizer application and any grazing activities. The result shows that the surface runoff concentration of nitrate is highest in sub-basins around the Kipipiri Mountain and Abaredare ranges. In those areas, the existing nutrients are high relatively, which might be due to the rapid decomposition of fresh organic matter. The existing nutrients that are found as organic material are recycled through the environment and transported to streams during periods when erosion occurs. As it is shown in the analysis result in section 4.2.2, the organic matter content of the soil in those areas was high. High nutrient load was observed in sub-basin 26, and in sub-basins 7, 10 and 20 around the Kipipiri area, which is covered by agricultural farmland (above 60%). Whereas sub basin 18, which consists of 56.56% forest, 37.57% cultivation land such as potato, maize and onion, 2.53% orchard trees and urban residential low density area, contributes low nitrate nutrient load to the streams. This might be due to that the nitrate was absorbed or held in place by the natural vegetation. Sub-basin 21 that has above 55% cropping land coverage is also contributing very low nutrient concentrations to river Turasha (see figure 5.9). This might be due to the topography of the area, which is nearly flat. The soluble phosphorus concentration yield in surface runoff is high in the large coverage of maize land use sub-basins such as sub-basin 4 (62.81%), 7 (91%), 9 (100%), 10 (100%), 19 (55.18%) and 20 (100%) (See figure 5.10). There is also a low nutrient load transport in phosphorus concentration in sub-basin 21 as nitrate concentration due to low susceptible nature of the land use to erosion, which has gentle slope. As it is explained in the previous sections, the movement of phosphorus is mainly associated with the movement of sediment particles due to high erosion. Erosion is high in cultivated and low in forest and undisturbed lands. The simulation result of the model from this scenario showed that the nutrient input loading to the lake from river Malewa and Gilgil Rivers due to surface runoff in NO_3 and P yield is 1.059 kg/ha/yr and 0.266 kg/ha/yr, respectively. The NO_3 and P leached to the shallow aquifer were 1539500 kg/yr and 230500 kg/yr, respectively.

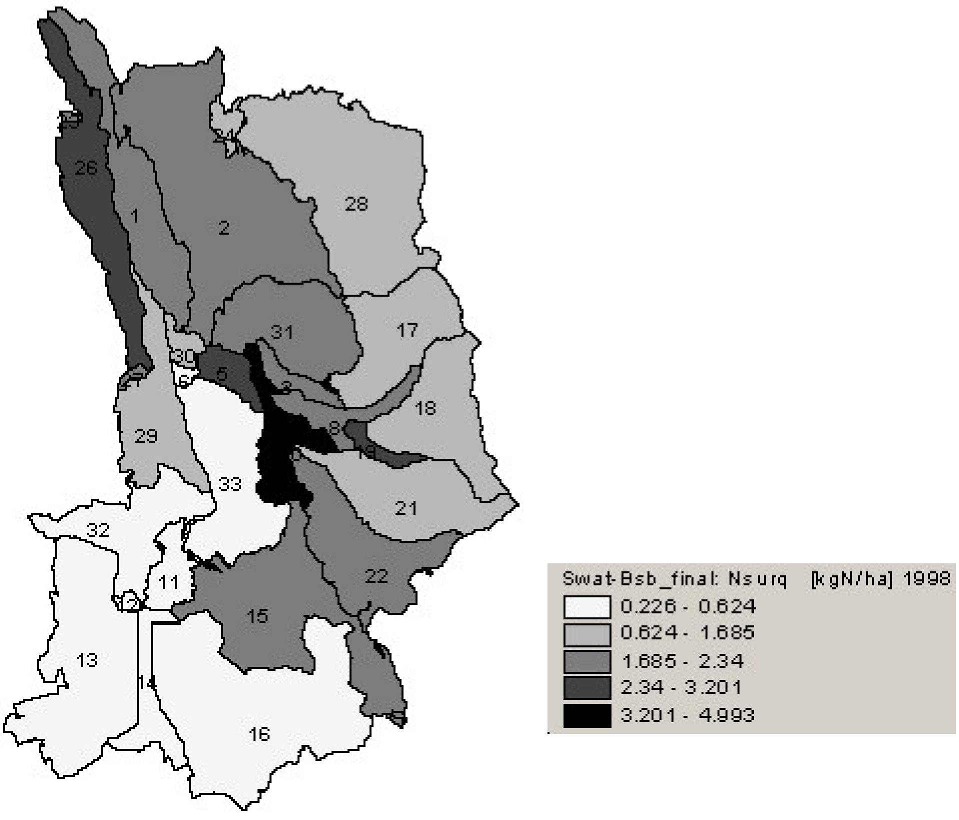

Figure 5.9: Map showing nitrate concentrations in surface runoff from each sub-basin with out fertilizer application and grazing activities (kg N/ha/yr)

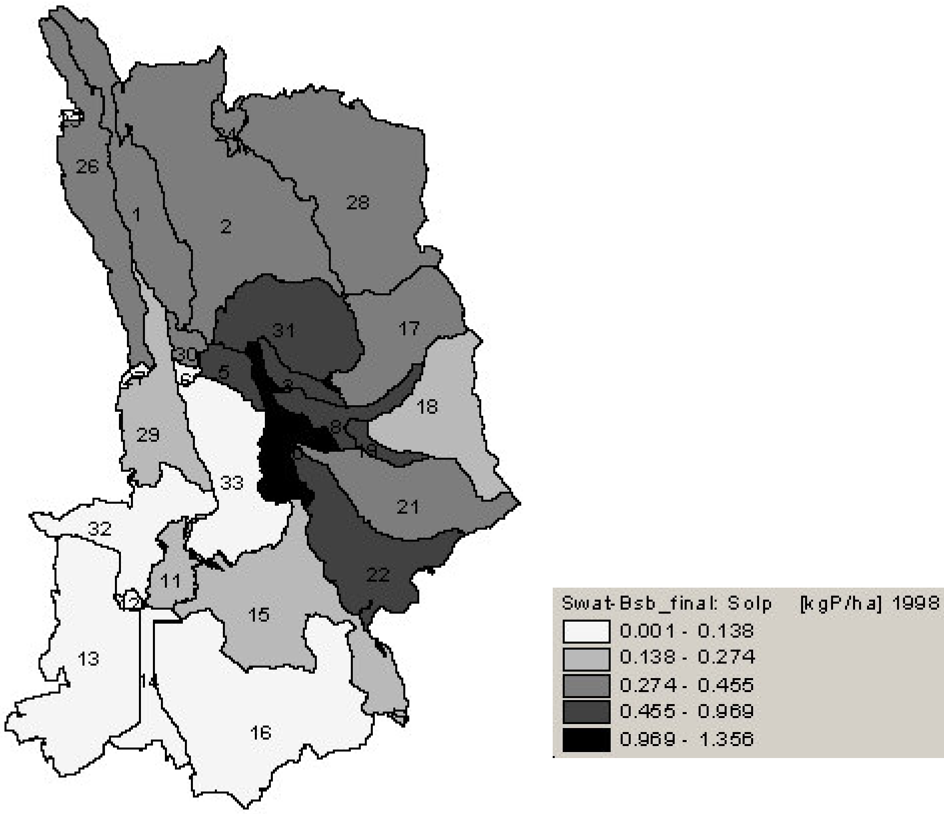

Figure 5.10: Map showing soluble phosphorus load from each sub-basin due to runoff with out fertilizer application and grazing activities (kg P/ha/yr)

5.3.2.2. Scenario 2: Nutrient Load with Fertilizer Application but without Grazing Activities

The second scenario was the application of fertilizer and pesticides on water quality in the upper catchment. The nutrient load input to the streams was simulated in the model by considering the actual fertilizer amount used by farmers for their intensive agricultural farming. In this case, the livestock grazing activity is excluded to quantify the effect of fertilizer management practice in intensive crop farming. There is an increase in nitrate and phosphorus nutrient loadings by 0.027 kg/ha/yr or 5.99% and 0.013 kg/ha/yr or 13.95% to streams, respectively, due to application of fertilizer with surface runoff at the mouth of Malewa and Gilgil rivers. A high concentration of nutrient load is transported from intensive farming of Malewa river catchment (see figure 5.11 and 5.12). A higher increase of nutrient concentration loadings was observed with surface runoff in Upper Malewa catchment (0.112 kg N/ha/yr) than Turasha river (0.054 kg N/ha/yr) catchment for nitrate in this scenario. There is also an increase in phosphorus concentration in Turasha and Upper Malewa rivers by 0.047 kg P/ha/yr and 0.032 kg P/ha/yr, respectively. The NO_3 and P leached to the shallow aquifer draining to streams then to lake were increased by 411400 kg/yr or 48% and 11400 kg/yr or 10% at the mouth of Malewa and Gilgil rivers, respectively.

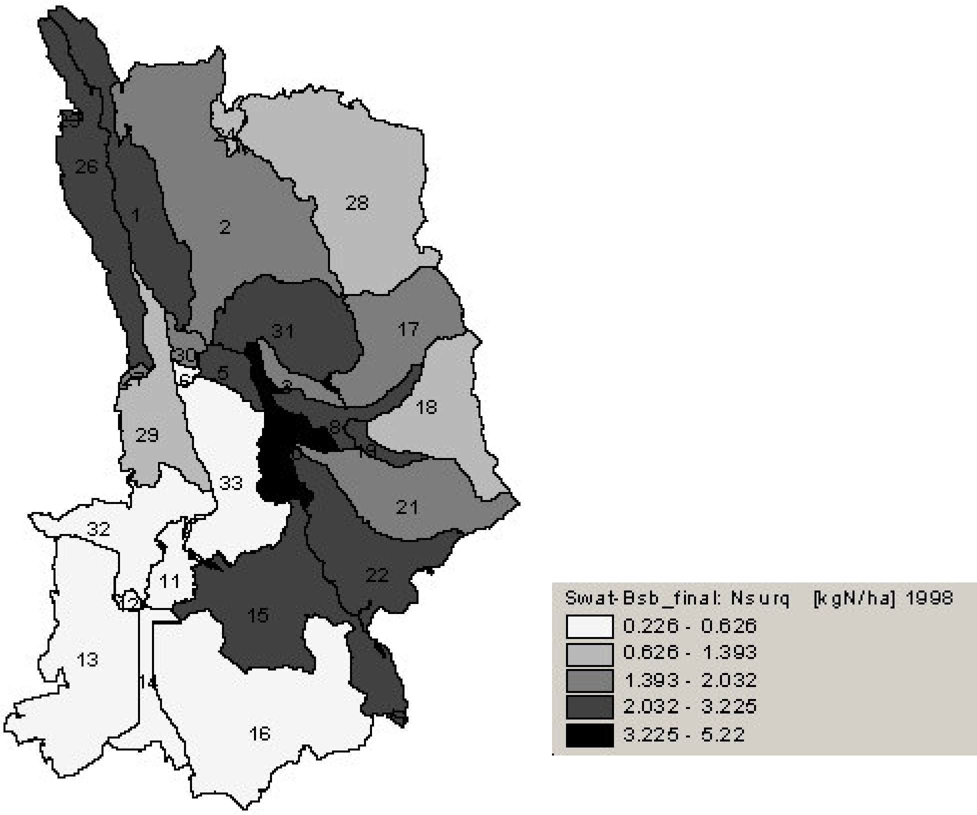

Figure 5.11: Map showing nitrate loads from each sub-basin due to runoff after fertilizer application (kg N/ha/yr)

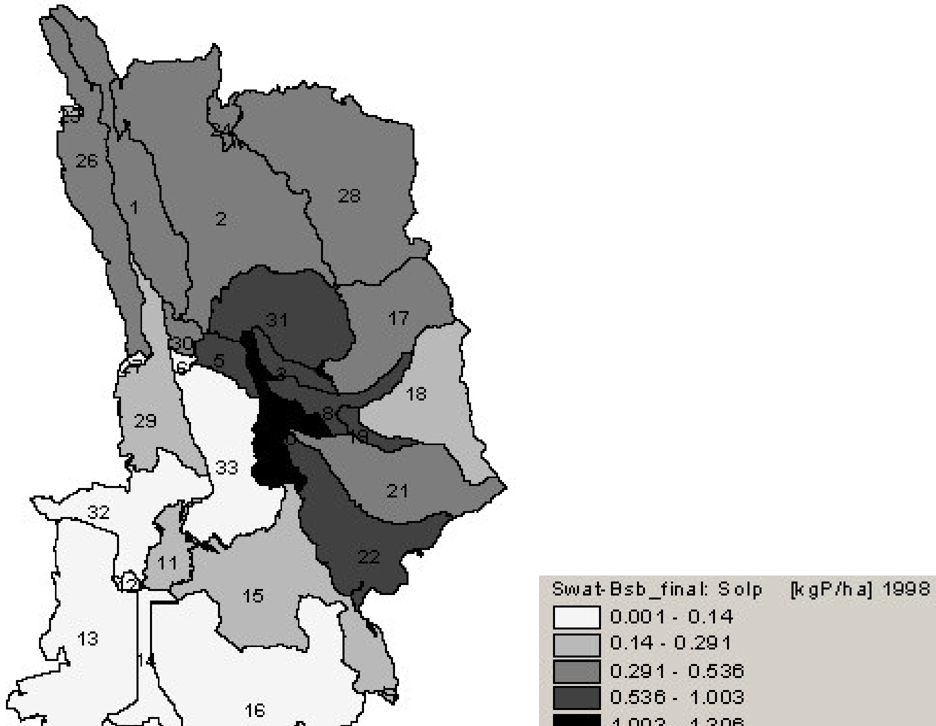

Figure 5.12: Map showing soluble phosphorus load from each sub-basin due to runoff after fertilizer application (kg P/ha/yr)

5.3.2.3. Scenario 3: Nutrient Load with Grazing Activities only

The third scenario was simulated for the effect due to intensive livestock grazing activities only. 15.21% of the catchment is covered by pastureland for livestock grazing (see table 5.2). There is an increase of 0.002 kg/ha/yr or 0.39% and 0 kg/ha/yr nutrient load input of nitrate and soluble phosphorus, respectively, to the Lake Naivasha at the mouth of Malewa and Gilgil rivers due to intensive livestock grazing activities by surface runoff in the basin. The concentration for this scenario was low that the comparison was made on sub-basin 11 and 32 at the mouth of the two rivers. The land uses in these sub-basins were irrigation and range brush land. As it is shown in figure 5.13 and 5.14 below, upper Malewa, Kipipiri and upper Gilgil river catchment, some part of South Kinangop (sub-basin 22), Ndunyu Njeru area (sub-basin 3,5,7,8&19) and livestock grazing around Naivasha town contribute high concentration of nitrate and phosphorus nutrient input to the lake for this scenario. The NO_3 and P leached to the shallow aquifer draining to streams then to lake were increased by 281500 kg/yr or 27% and 32700 kg/yr or 28% at the mouth of Malewa and Gilgil rivers, respectively.

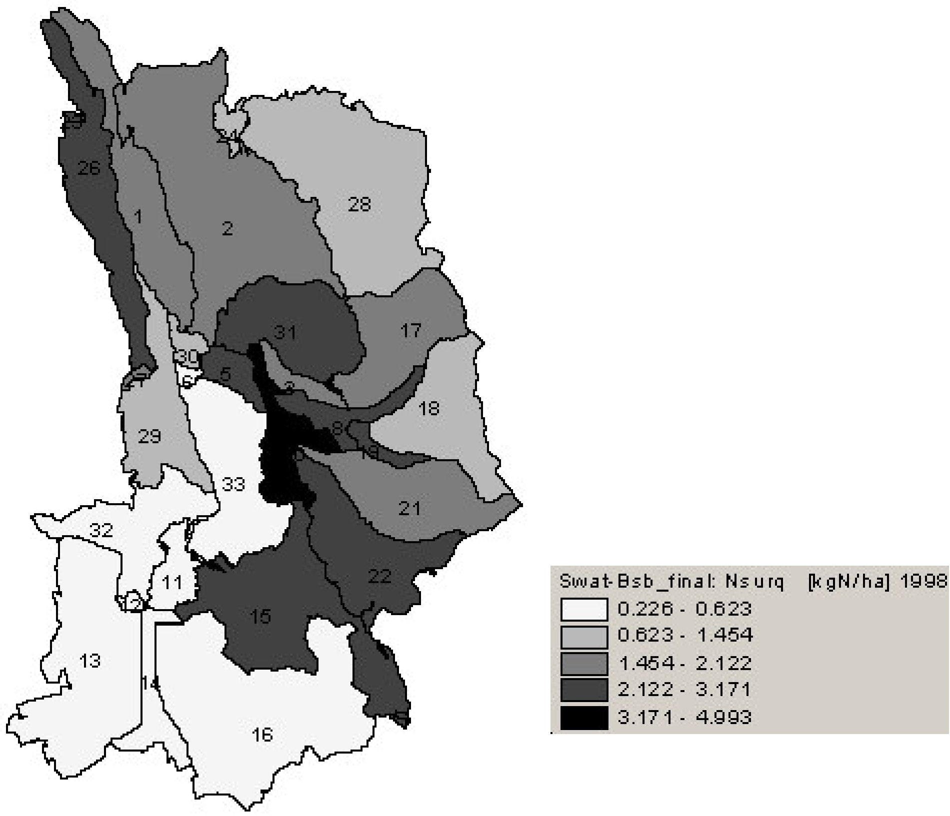

Figure 5.13:Map showing nitrate nutrient loads from each sub-basin due to runoff after grazing activities (kg N/ha/yr)

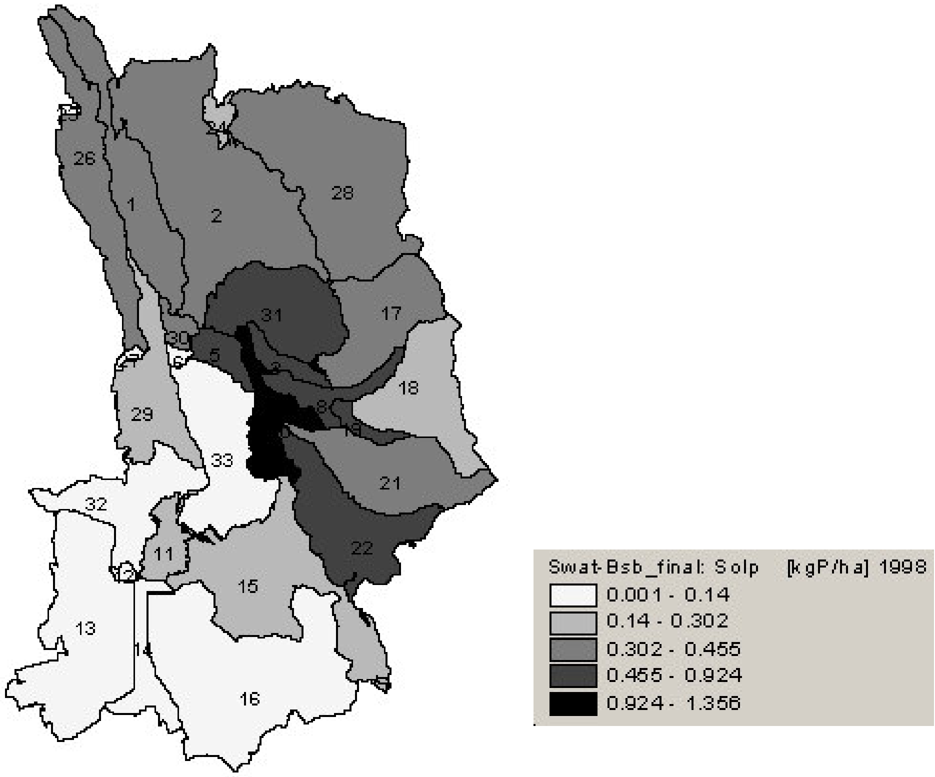

Figure 5.14: Map showing soluble phosphorus loading from each sub-basin due to runoff after grazing activities (kg P/ha/yr)

5.3.2.4. Scenario 4: Nutrient Load with Grazing and Fertilizer Application

The fourth scenario was simulated for the effect due to livestock grazing and fertilizer application. There is an increase of 0.029 or 6.38% and 0.013 or 13.95% nutrient load input of nitrate and soluble phosphorus, respectively, to the Lake Naivasha at the mouth of Malewa and Gilgil rivers due to this scenario by surface runoff in the basin. As it is shown in figure 5.15 and 5.16, high nutrient load is coming from Kipipiri area. In this area, there are some large-scale farms, and intensive livestock and cropping activities by small farm holders. There is also high NO_3 loading in the upper Malewa and Gilgil rivers catchment from intensive cropping activity of small farm holders. The NO_3 and P leached to the shallow aquifer draining to streams then to lake were increased by 692900 kg/yr or 75% and 44100 kg/yr or 38% at the mouth of Malewa and Gilgil rivers, respectively.

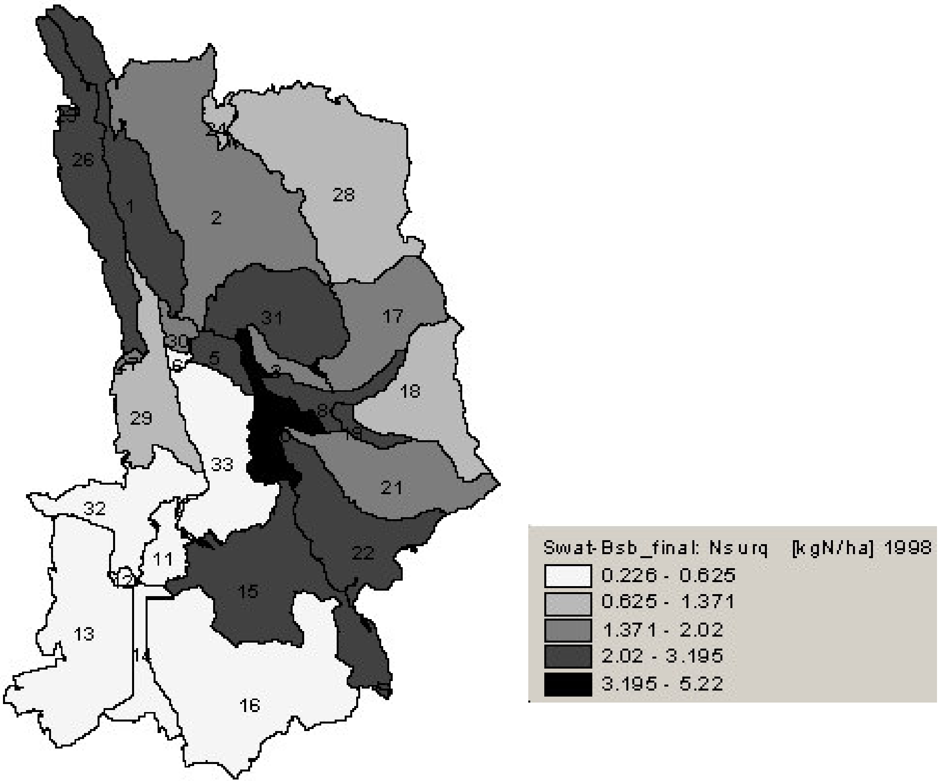

Figure 5.15: Map showing nitrate nutrient loads from each sub-basin due to runoff after fertilizer application and grazing activities (kg N/ha/yr)

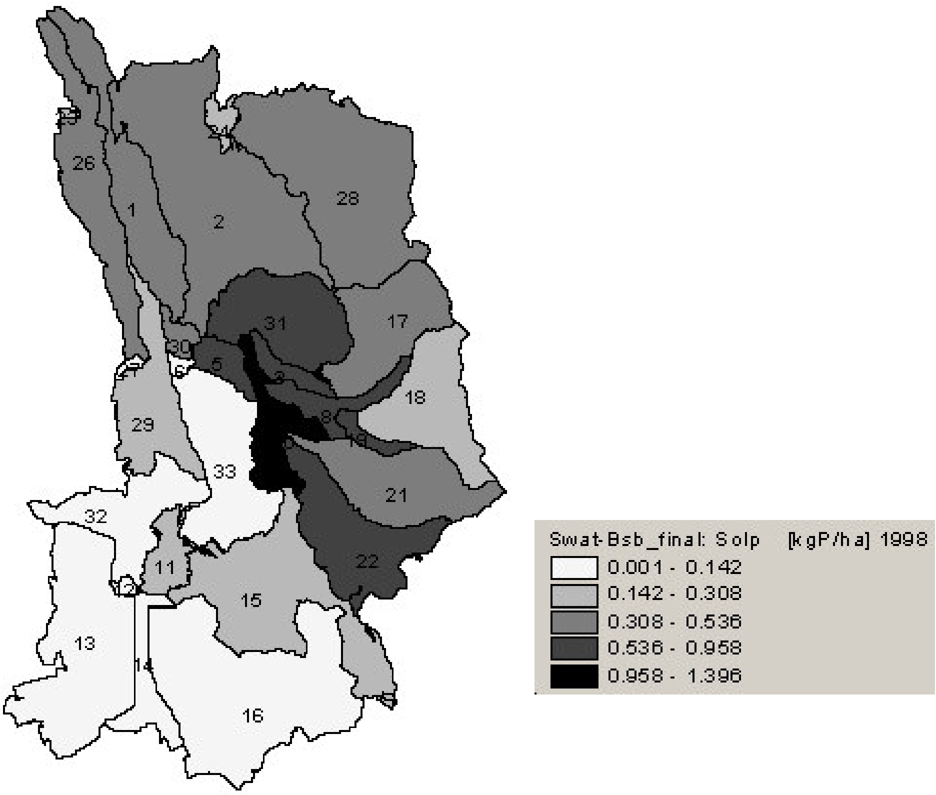

Figure 5.16: Map showing soluble phosphorus loading from each sub-basin due to runoff after fertilizer application and grazing activities (kg P/ha/yr)

5.3.2.5. Discussion of Scenario Results

Generally, the application of different management practices simulation results showed that the amount of nitrate and phosphorus transported by surface runoff in 1998 was increased by 1.084 kg/ha/yr and 0.279 kg/ha/yr, respectively, at the mouth of Malewa and Gilgil rivers. The NO_3 and P leached to the shallow aquifer and then to the lake were 1950900 kg/yr and 263200 kg/yr, respectively.

Table 5.5: Summary of all four-scenario results

	Scenario 1: No grazing activities or fertilization	Scenario 2: Fertilization application (Increase in % w.r.t scenario 1)	Scenario 3: Grazing activities (Increase in % w.r.t scenario 1)	Scenario 4: Fertilizer and grazing activities (Increase in % w.r.t scenario 1)	Units
NO3 yield in surface runoff	1.059	1.086 (5.99%)	1.061 (0.39%)	1.084 (6.38%)	Kg/ha/yr
P yield in surface runoff	0.266	0.279 (13.95%)	0.266 (0%)	0.279 (13.95%)	Kg/ha/yr
NO3 leached to shallow aquifer	1539.5	1950.9 (48%)	1821 (27%)	1857.9 (75%)	T/yr
P leached to shallow aquifer	230.5	241.9 (10%)	263.2 (28%)	239.9 (38%)	T/yr

The nutrient transportation by surface runoff around the lake was very low as compared to the upper catchment. This is due to the fact that the soil erosion is quite small in the riparian zone of the lake and the amount of chemicals entering the lake through surface runoff and soil erosion is negligible (Xu, 1999). The nitrate and phosphorus leached to the ground water then to the lake is higher in the riparian agricultural area than in the upper catchment. This is because pollutants move faster in the sandy loam soil than in the clay loam soil (Xu, 1999). This result was confirmed by SWAT that the NO_3 and phosphorus leached in the riparian area was higher than in the upper catchment.

In addition to the above scenarios described, the calibrated model was tested for the change of application rates. The predicted soluble phosphorus loading to the Lake Naivasha increased with increasing fertilizer application rates. Whereas the predicted nitrate loadings had no significant increase with increasing fertilizer application rates. The SWAT model underestimated sediment loading for the basin results in underestimating the sediment-bound-phosphorus concentration.

The fertilizer application was assumed to be once a year, because the main staple crop in the region is maize and it is cultivated only once a year. For vegetables it was not possible to get clear information of their cultivation system. It might be cultivated on the same plot land or on other cropland by using a crop rotation system.
Since the simulation was done on the assumption that the farmers cultivate their crop once a year, the simulated result showed that the nutrient leached from the riparian agriculture area has no significant difference from the upper catchment. But in reality, the farmers in riparian agriculture areas cultivate their crop thrice in a year. The nutrient leached to the shallow aquifer due to the application of fertil-

izer and pesticides thrice a year was tested for big farms around the lake in two ways. The first case was harvesting the same type of crop trice a year. The analysis result showed that the NO_3 load varies by a factor of 0.98 in the irrigation along Gilgil River, with no significant difference in the irrigation area along Malewa River and a decrease by a factor of 0.96 in the SULMAC farm area (sub-basin 14 and 16). It was also observed in the irrigation area with a little difference of phosphorus concentration by a factor from 1.004 to 1.0481. Even though the calibration was not performed for pesticide, it was observed that the pesticide leached to the shallow aquifer was 3186 kg/yr. A dramatic increase was observed in pesticide-leached concentration when farmers cultivate the same type of crop thrice a year, which would degrade the lake water quality. It was observed an increase of leached pesticide pollution by a factor from 1.3 to 11.8 in sub-basins around the lake. The second case was harvesting different type of crops (rotation). In this case, the NO_3 and P loads increased by a factor from 1.07 to 3.47 and 1.01 to 1.59, respectively, due to runoff. The NO_3 leached increased by a factor of 1.03, where as, the P has insignificant change in concentration. The pesticide leached to the shallow aquifer was increased by a factor from 1.26 to 9.0.

The yearly average nutrient load was calculated for the period from 1990 to 2003. The average nutrient load of NO_3 and phosphorus to the lake from the two rivers were 1776265 kg/yr and 82196.93 kg/year, respectively.

6. Conclusions and Recommendations

6.1. Conclusions

This study was aimed at evaluating the capability of SWAT in modelling the nutrient input loads to the streams and the lake, its application in the chemical pollution sources identification and the impact of different management practices in the Naivasha basin. The results obtained from this study support the conclusion listed below:

On the basis of the simulation result and on the field-collected nutrient data it was concluded that SWAT has a shortcoming in calibrating nutrients due to the sensitivity of the model to many parameters. Changing the sensitive parameters for phosphorus was affecting the calibrated nutrient NO_3 levels and it underestimated the NO_3 and sediment concentration transported in the streams.

In spite of this calibration problem and limitations, the model was used to identify the sources of major pollution to Lake Naivasha and to evaluate the impact of different land uses on water quality. Based on the modelling results it was concluded that the implementation of different management practices such as the application of agrochemicals and intensive live stock production in the upper catchment and around Lake Naivasha posed a potential risk to the lake water quality.

The SWAT model predicts a positive correlation between phosphorus loading to the lake and the fertilizer application rates in that an increase in phosphorus fertilizer application rates will result in increased loadings to Lake Naivasha.

On the basis of the simulation result of these scenarios, it can be concluded that improper management of animal waste from intensive livestock production would contribute a significant pollution load input to streams.

On the basis of the simulation result of different land uses in the basin, it can be concluded that pasture land around the creeks and croplands were the main land uses for the deterioration of lake water quality in the basin.

On the basis of the simulation result in the sub-basins, it can be concluded that the nutrient concentration increases downstream from a minimum NO_3 and phosphorus concentration of 20670 kg/yr and 2748kg/yr, respectively in sub-basin 18 in the upper catchment to 463900 kg/yr and 113800 kg/yr, respectively, at the downstream of Malewa catchment for the year 1998. This increase of nutrient is due to the practice of different agricultural activities along the river.

The application of two management scenarios resulted in the conclusion that the different agricultural practices experienced in the upper catchment of Malewa and Gilgil Rivers and south of Kipipiri agricultural farms were the main sources of pollution to Lake Naivasha with surface runoff. Higher nutrient concentration is leaching around the lake than in the upper catchment.

Generally, based on the total water quality model analysis result it can be concluded that the main nutrient load input to the lake due to surface runoff was the Upper catchment of Naivasha basin, whereas high pesticides and nutrient leaching were observed around the lake.

6.2. Recommendations

The model result indicates that the pollutant load coming from upper catchment due to intensive agricultural activities and livestock grazing can threaten the lake water quality. To reduce the burden of this nutrient pollution from these activities, the following points are recommended:

Because of population pressure and owning small pieces of plot land for farming in the developing countries, intensive livestock production schemes put more animals on smaller pieces of real estate. This accumulation of waste manure on small areas can cause a degradation of lake water quality. Through a series of follow-ups of experts to make the benefits of developing awareness of farmers, a good manure management practices should be practiced. Some of the points that must be practiced for good manure management are:

- Manure piles should be stored far from creeks or streams and should be protected from draining into streams.

- It is better to minimize animal tracking through creeks to avoid soil erosion that tracking animals through creeks will destroy plants and facilitate transportation of nutrients during periods of high rainfall events.

- As the model analysis result indicated and the analysis result done by Kitaka (2000) showed that watering of animals on rivers or streams will maximize deposit of manure on stream banks and streams itself. It is important to develop mechanism to minimize this problem such as use of pump to relocate from creek into trough and keep animals away from creeks or waterways by providing fencing.

- From the analysis result, it was shown that pasturelands were one of the main sources of nutrient loads next to agricultural lands. It is necessary to maintain an adequate pasture condition. Overstocking pasture and overgrazing activities should be reduced to maximize nutrient uptake by pasture plants and to reduce soil erosion.

- Conservation cropping systems should be practiced, mainly in the upper catchment. This would help to maximize nutrient uptake into plant matter and minimizes possible contamination of ground water.

Future Research
The following issues should be considered for further research and development.

- Sampling and analysis of different soil properties such as hydraulic conductivity, soil organic carbon, etc. at different soil layers for detail analysis of nutrient leaching.

- Since there is no water quality data for long time series, water quality analysis should be done at least for a month for SWAT model calibration.

- It is necessary to give attention for updating and selecting the reliable data, and arrange these reliable data with new Naivasha database file in order to minimize data pre-processing for future researchers.

- A detail analysis of manure production by farmers should be studied to estimate the actual application of animal waste on farms and on pasture land and its impact on water quality.

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APPENDICES

Appendix A: Field Data Calculations and Laboratory Analysis Procedures

Appendix A -1: Discharge Measurements

RIVER Malewa(upper)

Site: M2 UTMX 210216

Date/Time 06-Oct-03 UTMY 9945250

Vertical No.	Tape position (m)	Dis-tance from base (m)	Width (m)	Depth (cm)	current meter position 0.2 depth			average revolution	current meter position 0.6 depth			Average revolution
1	0.3	0	0.1	8	0	0	0	0	0	0	0	
2	0.5	0.2	0.35	10	21	23	23	23	-	-	-	
3	1	0.7	0.75	17	73	74	73	73	50	47	48	48
4	2	1.7	1	24	94	95	95	95	64	62	63	63
5	3	2.7	1	30	100	102	102	102	74	75	72	74
6	4	3.7	1	34	113	114	113	113	87	88	87	87
7	5	4.7	1	36	112	112	112	112	81	82	80	81
8	6	5.7	1	35	109	109	109	109	77	81	82	81
9	7	6.7	1	26	97	97	98	97	78	76	77	77
10	8	7.7	1	30	103	100	102	102	73	70	75	73
11	9	8.7	1	42	87	87	85	87	45	46	46	46
12	10	9.7	1	43	92	93	90	93	42	44	42	42
13	11	10.7	1	40	78	77	77	77	42	44	45	44
14	12	11.7	0.75	37	82	82	81	82	66	66	67	66
15	12.5	12.2	0.5	34	66	65	65	65	52	51	53	52
16	13	12.7	0.35	36	44	42	44	44	38	39	39	39
17	13.2	12.9	0.25	30	37	36	34	36	30	28	31	30
18	13.5	13.2	0.15	0	0	0	0	0	0	0	0	0

Flow measurement
X 210216
Y 9945250

Verti-cal No.	Tape position (m)	Dis-tance from base (m)	Width (m)	Depth (cm)	current meter position	Average revolution	n R/T	velocity m/sec	Average velocity m/sec	Area m^2	Dis-charge m^3/sec
1	0.3	0	0.1	8			0	0	0	0.01	0
2	0.5	0.2	0.35	10	0.2depth	23	0.77	0.202063	0.202	0.035	0.00707
3	1	0.7	0.75	17	0.2depth	73	2.43	0.610897			
					0.6depth	48	1.6	0.40648	0.509	0.128	0.06486
4	2	1.7	1	24	0.2depth	95	3.17	0.790783			
					0.6depth	63	2.1	0.52913	0.66	0.24	0.15839
5	3	2.7	1	30	0.2depth	102	3.4	0.84802			
					0.6depth	74	2.47	0.619073	0.734	0.3	0.22006
6	4	3.7	1	34	0.2depth	113	3.77	0.937963			
					0.6depth	87	2.9	0.72537	0.832	0.34	0.28277
7	5	4.7	1	36	0.2depth	112	3.73	0.929787			
					0.6depth	81	2.7	0.67631	0.803	0.36	0.2891
8	6	5.7	1	35	0.2depth	109	3.63	0.905257			
					0.6depth	81	2.7	0.67631	0.791	0.35	0.27677
9	7	6.7	1	26	0.2depth	97	3.23	0.807137			
					0.6depth	77	2.57	0.643603	0.725	0.26	0.1886
10	8	7.7	1	30	0.2depth	102	3.4	0.84802			
					0.6depth	73	2.43	0.610897	0.729	0.3	0.21884
11	9	8.7	1	42	0.2depth	87	2.9	0.72537			
					0.6depth	46	1.53	0.390127	0.558	0.42	0.23425
12	10	9.7	1	43	0.2depth	93	3.1	0.77443			
					0.6depth	42	1.4	0.35742	0.566	0.43	0.24335
13	11	10.7	1	40	0.2depth	77	2.57	0.643603			
					0.6depth	44	1.47	0.373773	0.509	0.4	0.20348
14	12	11.7	0.75	37	0.2depth	82	2.73	0.684487			
					0.6depth	66	2.2	0.55366	0.619	0.278	0.17179
15	12.5	12.2	0.5	34	0.2depth	65	2.17	0.545483			
					0.6depth	52	1.73	0.439187	0.492	0.17	0.0837
16	13	12.7	0.35	36	0.2depth	44	1.47	0.373773			
					0.6depth	39	1.3	0.33289	0.353	0.126	0.04452
17	13.2	12.9	0.25	30	0.2depth	36	1.2	0.30836			
					0.6depth	30	1	0.2593	0.284	0.075	0.02129
18	13.5	13.2	0.15	0						sum	**2.7088**

RIVER Turasha river(main)
Site: M3 UTM X 213000
Date/Time 06-Oct-03 UTMY 9947748

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Average revolution	Current meter position 0.6depth			Average revolution
1	4.1	0	0.1	17								
2	4.3	0.2	0.35	17	27	26	27	27				
3	4.8	0.7	0.65	17	64	66	66	66				
4	5.6	1.5	0.8	24	126	125	123	125	57	60	59	59
5	6.4	2.3	0.9	30	59	60	59	59	46	43	42	43
6	7.4	3.3	1	30	59	59	60	59	34	46	36	36
7	8.4	4.3	1	40	147	148	150	148	55	36	58	56
8	9.4	5.3	1	44	162	159	159	160	118	56	119	118
9	10.4	6.3	1	36	135	133	133	133	120	119	121	120
10	11.4	7.3	1	48	138	135	132	135	133	132	134	133
11	12.4	8.3	1	33	140	137	142	137	129	127	130	129
12	13.4	9.3	1	51	155	162	156	156	120	114	113	114
13	14.4	10.3	1	50	89	91	91	91	52	50	53	52
14	15.4	11.3	1	41	91	93	90	91	64	58	58	58
15	16.4	12.3	1	41	110	112	112	112	74	76	76	76
16	17.4	13.3	1	40	47	44	44	44	30	29	29	29
17	18.4	14.3	1.25	22	41	40	41	41	31	31	27	31
18	19.9	15.8	0.9	16	10	11	10	10				
19	20.2	16.1	0.15	5								

Flow measurement
X 213000
Y 9947748

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	meter position (m)	Average Revolution	n R/T	Velocity m/sec	average velocity m/sec	Area m^2	Discharge m^3/sec
	4.1	0	0.1	17						0.017	0
1	4.3	0.2	0.35	17	0.2depth	27	0.900	0.235	0.235	0.060	0.014
					0.6depth						
2	4.8	0.7	0.65	17	0.2depth	66	2.200	0.554	0.554	0.111	0.061
					0.6depth						
3	5.6	1.5	0.8	24	0.2depth	125	4.167	1.036			
					0.6depth	59	1.967	0.496	0.766	0.192	0.147
4	6.4	2.3	0.9	30	0.2depth	59	1.967	0.496			
					0.6depth	43	1.433	0.366	0.431	0.270	0.116
5	7.4	3.3	1	30	0.2depth	59	1.967	0.496			
					0.6depth	36	1.200	0.308	0.402	0.300	0.121
6	8.4	4.3	1	40	0.2depth	148	4.933	1.224			
					0.6depth	56	1.867	0.472	0.848	0.400	0.339
7	9.4	5.3	1	44	0.2depth	160	5.333	1.322			
					0.6depth	118	3.933	0.979	1.151	0.440	0.506
8	10.4	6.3	1	36	0.2depth	133	4.433	1.101			
					0.6depth	120	4.000	0.995	1.048	0.360	0.377
9	11.4	7.3	1	48	0.2depth	135	4.500	1.118			
					0.6depth	133	4.433	1.101	1.110	0.480	0.533
10	12.4	8.3	1	33	0.2depth	137	4.567	1.134			
					0.6depth	129	4.300	1.069	1.101	0.330	0.363
11	13.4	9.3	1	51	0.2depth	156	5.200	1.290			
					0.6depth	114	3.800	0.946	1.118	0.510	0.570
12	14.4	10.3	1	50	0.2depth	91	3.033	0.758			
					0.6depth	52	1.733	0.439	0.599	0.500	0.299
13	15.4	11.3	1	41	0.2depth	91	3.033	0.758			
					0.6depth	58	1.933	0.488	0.623	0.410	0.255
14	16.4	12.3	1	41	0.2depth	112	3.733	0.930			
					0.6depth	76	2.533	0.635	0.783	0.410	0.321
15	17.4	13.3	1	40	0.2depth	44	1.467	0.374			
					0.6depth	29	0.967	0.251	0.312	0.400	0.125
16	18.4	14.3	1.25	22	0.2depth	41	1.367	0.349			
					0.6depth	31	1.033	0.267	0.308	0.275	0.085
17	19.9	15.8	0.9	16	0.2depth	10	0.333	0.104	0.104	0.144	0.015
					0.6depth						
18	20.2	16.1	0.15	5	0.2depth					0.02	0.000
							sum				**4.249**

RIVER

Malewa(upper)	Mkungi		Photo no.	
Site:	M4		UTMX	225456
Date/Time	30-Sep-03		UTMY	9942510

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Average revolution	Current meter position 0.6depth			Average revolution
1	0.4	0	0.1	0	0	0	0	0	0	0	0	0
2	0.6	0.2	0.5	44	44	46	44	44	58	58	55	58
3	1.4	1	0.8	42	57	55	58	57	60	59	60	60
4	2.2	1.8	0.8	41	88	88	88	88	69	68	72	69
5	3	2.6	0.8	35	93	96	96	96	52	49	49	49
6	3.8	3.4	0.8	30	99	100	100	100	52	51	49	51
7	4.6	4.2	0.8	30	94	97	96	96	75	73	71	73
8	5.4	5	0.8	21	92	88	88	88	85	86	88	86
9	6.2	5.8	0.8	31	85	92	88	88	63	67	68	67
10	7	6.6	0.6	37	64	62	61	62	46	48	51	48
11	7.4	7	0.2	9								

Flow measurement

X 225456

Y 9942510

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position	Average revolution	n R/T	velocity m/sec	Average velocity m/sec	Area m^2	Discharge m^3/sec
1	0.4	0	0.1	0		0	0	0	0	0	0
2	0.6	0.2	0.5	44	0.2depth	44	1.467	0.374			
					0.6depth	58	1.933	0.488	0.431	0.22	0.095
3	1.4	1	0.8	42	0.2depth	57	1.900	0.480			
					0.6depth	60	2.000	0.505	0.492	0.336	0.165
4	2.2	1.8	0.8	41	0.2depth	88	2.933	0.734			
					0.6depth	69	2.300	0.578	0.656	0.328	0.215
5	3	2.6	0.8	35	0.2depth	96	3.200	0.799			
					0.6depth	49	1.633	0.415	0.607	0.28	0.170
6	3.8	3.4	0.8	30	0.2depth	100	3.333	0.832			
					0.6depth	51	1.700	0.431	0.631	0.24	0.152
7	4.6	4.2	0.8	30	0.2depth	96	3.200	0.799			
					0.6depth	73	2.433	0.611	0.705	0.24	0.169
8	5.4	5	0.8	21	0.2depth	88	2.933	0.734			
					0.6depth	86	2.867	0.717	0.725	0.168	0.122
9	6.2	5.8	0.8	31	0.2depth	88	2.933	0.734			
					0.6depth	67	2.233	0.562	0.648	0.248	0.161
10	7	6.6	0.6	37	0.2depth	62	2.067	0.521			
					0.6depth	48	1.600	0.406	0.464	0.222	0.103
11	7.4	7	0.2	9						0.074	0.000
										sum	**1.351**

RIVER Keja photo no.
Site: M6 UTMX 228368
Date/Time 30-Sep-03 UTMY 9939068

Vertical No.	Tape Position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Average revolution	Current meter position 0.6depth			Average revolution
1	0.2	0	0.1	0	0	0	0	0	0	0	0	
2	0.4	0.2	0.3	15	31	28	32	31	0	-	-	
3	0.8	0.6	0.3	34	78	78	68	78	26	30	33	30
4	1	0.8	0.35	60	88	89	89	89	46	49	51	49
5	1.5	1.3	0.5	73	94	92	92	92	70	72	72	72
6	2	1.8	0.5	36	80	83	78	80	82	80	81	81
7	2.5	2.3	0.7	31	74	74	74	74	56	55	60	46
8	3	2.8	0.45	16	33	32	33	33				
9	3.4	3.2	0.2	0								

Flow measurement
X 228368
Y 9939068

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position	Average revolution	n R/T	velocity m/sec	Average Velocity m/sec	area m^2	Discharge m^3/sec
1	0.2	0	0.1	0		0	0	0	0	0.015	0
2	0.4	0.2	0.3	15	0.2depth	31	1.033	0.267	0.263	0.045	0.012
					0.6depth						
3	0.8	0.6	0.3	34	0.2depth	78	2.600	0.652			
					0.6depth	30	1.000	0.259	0.456	0.102	0.046
4	1	0.8	0.35	60	0.2depth	89	2.967	0.742			
					0.6depth	49	1.633	0.415	0.578	0.21	0.121
5	1.5	1.3	0.5	73	0.2depth	92	3.067	0.766			
					0.6depth	72	2.400	0.603	0.684	0.365	0.250
6	2	1.8	0.5	36	0.2depth	80	2.667	0.668			
					0.6depth	81	2.700	0.676	0.672	0.18	0.121
7	2.5	2.3	0.7	31	0.2depth	74	2.467	0.619			
					0.6depth	46	1.533	0.390	0.505	0.217	0.109
8	3	2.8	0.45	16	0.2depth	33	1.100	0.284	0.284	0.072	0.020
9	3.4	3.2	0.2	0						0.032	0.000
										sum	**0.680**

RIVER:	Turasha-tributary	Photo Nr:	
Site:	M7	UTMX	220584
Date/Time:	06-Oct-03	UTMY	9936958

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Current position 0.6depth		
1	0.2	0	0.1	0	-	-	-	-	-	-
2	0.4	0.2	0.35	30	11	13	12		-	-
3	0.9	0.7	0.5	34	15	15	15	8	11	11
4	1.4	1.2	0.5	30	6	8	7			
5	1.9	1.7	0.5	20	13	13	13			
6	2.4	2.2	0.35	34	11	10	10			
7	2.6	2.4	0.35	32	9	10	10			
8	3.1	2.9	0.25	0	-					

Flow measurement
X 220584
Y 9936958

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position	Average revolution	n R/T	velocity m/sec	Area m^2	Average velocity m/sec	Discharge m^3/sec
1	0.2	0	0.1	0				0	0.03	0	0
2	0.4	0.2	0.35	30	0.2depth	12	0.4	0.118	0.105	0.118	0.012
3	0.9	0.7	0.5	34	0.2depth	15	0.5	0.141			
					0.6depth	11	0.3667	0.111	0.17	0.126	0.021
4	1.4	1.2	0.5	30	0.2depth	7	0.2333	0.082	0.15	0.082	0.012
5	1.9	1.7	0.5	20	0.2depth	13	0.4333	0.126	0.1	0.126	0.013
6	2.4	2.2	0.35	34	0.2depth	10	0.3333	0.104	0.119	0.104	0.012
7	2.6	2.4	0.35	32	0.2depth	10	0.3333	0.104	0.112	0.104	0.012
8	3.1	2.9	0.25	0					0.08	0	0
									sum		**0.083**

RIVER wanjohi river
Site: M10
Date/Time 01-Oct-03

Photo no.
UTMX 215051
UTMY 9972308

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Average revolution	Current meter position 0.6depth			average revolution
1	0.1	0	0.05	0	0	0	0	0	0	0	0	
2	0.2	0.1	0.3	15	65	68	66	66	-	-	-	
3	0.7	0.6	0.75	50	87	88	85	87	70	68	70	70
4	1.7	1.6	1	47	106	107	107	107	74	69	73	72
5	2.7	2.6	1	50	98	99	100	99	79	79	78	79
6	3.7	3.6	1	44	109	110	109	109	38	38	41	38
7	4.7	4.6	1	41	110	112	112	112	55	53	48	52
8	5.7	5.6	1	42	121	122	120	121	55	57	53	55
9	6.7	6.6	0.75	34	114	114	112	114	106	104	105	105
10	7.2	7.1	0.5	45	99	100	98	99	62	63	62	62
11	7.7	7.6	0.45	36	53	54	53	53				
12	8.1	8	0.3	20	27	28	27	27				
13	8.3	8.2	0.1	5								

Flow measurement

X 215051
Y 9972308

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position	Average revolution	n R/T	velocity m/sec	Average velocity m/sec	Area m^2	Discharge m^3/sec
1	0.1	0	0.05	0		0	0	0	0	0.008	0
2	0.2	0.1	0.3	15	0.2depth	66	2.2	0.55366	0.55366	0.045	0.0249147
					0.6depth						
3	0.7	0.6	0.75	50	0.2depth	87	2.9	0.72537			
					0.6depth	70	2.33	0.5863667	0.65587	0.375	0.2459506
4	1.7	1.6	1	47	0.2depth	107	3.57	0.8889033			
					0.6depth	72	2.4	0.60272	0.74581	0.47	0.3505315
5	2.7	2.6	1	50	0.2depth	99	3.3	0.82349			
					0.6depth	79	2.63	0.6599567	0.74172	0.5	0.3708617
6	3.7	3.6	1	44	0.2depth	109	3.63	0.9052567			
					0.6depth	38	1.27	0.3247133	0.61499	0.44	0.2705934
7	4.7	4.6	1	41	0.2depth	112	3.73	0.9297867			
					0.6depth	52	1.73	0.4391867	0.68449	0.41	0.2806395
8	5.7	5.6	1	42	0.2depth	121	4.03	1.0033767			
					0.6depth	55	1.83	0.4637167	0.73355	0.42	0.3080896
9	6.7	6.6	0.75	34	0.2depth	114	3.8	0.94614			
					0.6depth	105	3.5	0.87255	0.90935	0.255	0.231883
10	7.2	7.1	0.5	45	0.2depth	99	3.3	0.82349			
					0.6depth	62	2.07	0.5209533	0.67222	0.225	0.1512499
11	7.7	7.6	0.45	36	0.2depth	53	1.77	0.4473633	0.44484	0.162	0.0720641
					0.6depth		0	0.03			
12	8.1	8	0.3	20	0.2depth	27	0.9	0.23477	0.23477	0.06	0.0140862
13	8.3	8.2	0.1	5	0.2depth						
									sum		**2.32086**

RIVER Malewa tributary photo no.
Site: M11 UTMX 200821
Date/Time 01-Oct-03 UTMY 9973590

Vertical No.	Tape position (m)	Dis-tance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			Average revolu-tion	Current meter position 0.6depth			Average revolution
1	0	0	0.1	17	0	0	0	0	0	0	0	0
2	0.2	0.2	0.35	47	35	37	35	35	25	25	25	25
3	0.7	0.7	0.5	51	47	48	50	48	41	40	39	40
4	1.2	1.2	0.5	48	47	45	44	45	45	44	46	45
5	1.7	1.7	0.5	50	45	44	45	45	39	43	41	41
6	2.2	2.2	0.45	63	43	43	42	43	38	37	39	38
7	2.6	2.6	0.3	54	37	38	38	38	28	33	35	33
8	2.8	2.8	0.2	20	36	37	36	36	37	37	35	37
9	3	3	0.2	17	34	35	34	34				
10	3.2	3.2	0.1	7								

Flow measurement
X 200821
Y 9973590

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Currentr meter position	Average Revolution	n R/T	Velocity m/sec	Area m^2	Average velocity m/sec	Discharge m^3/sec
1	0	0	0.1	17			0	0	0.047	0	0
2	0.2	0.2	0.35	47	0.2deptth	35	1.1667	0.300			
					0.6depth	25	0.8333	0.218	0.165	0.259	0.043
3	0.7	0.7	0.5	51	0.2deptth	48	1.6	0.406			
					0.6depth	40	1.3333	0.341	0.255	0.374	0.095
4	1.2	1.2	0.5	48	0.2deptth	45	1.5	0.382			
					0.6depth	45	1.5	0.382	0.240	0.382	0.092
5	1.7	1.7	0.5	50	0.2deptth	45	1.5	0.382			
					0.6depth	41	1.3667	0.349	0.250	0.366	0.091
6	2.2	2.2	0.45	63	0.2deptth	43	1.4333	0.366			
					0.6depth	38	1.2667	0.325	0.284	0.345	0.098
7	2.6	2.6	0.3	54	0.2deptth	38	1.2667	0.325			
					0.6depth	33	1.1	0.284	0.162	0.304	0.049
8	2.8	2.8	0.2	20	0.2deptth	36	1.2	0.308			
					0.6depth	37	1.2333	0.317	0.040	0.312	0.012
9	3	3	0.2	17	0.2deptth	34	1.1333	0.292	0.034	0.292	0.010
					0.6depth						
10	3.2	3.2	0.1	7	0.2deptth				0.017	0	0
									sum		**0.491**

RIVER	near wanjohi draining from OlKalu area	Photo no.	
Site:	M12	UTMX	212205
Date/Time	01-Oct-03	UTMY	9971874

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			average revolution
1	0.1	0	0.1	5	0	0	0	0
2	0.3	0.2	0.2	16	51	52	53	52
3	0.5	0.4	0.15	18	74	75	76	75
4	0.6	0.5	0.1	16	80	79	78	79
5	0.7	0.6	0.1	14	62	64	66	64
6	0.8	0.7	0.15	10	32	33	33	33
7	1	0.9	0.1	0				

Flow measurement

X 212205

Y 9971874

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth	n R/T	velocity m/sec	Area m^2	Discharge m^3/sec
1	0.1	0	0.1	5	0	0	0.03	0.005	0.00015
2	0.3	0.2	0.2	16	52	1.73333	0.4392	0.032	0.014054
3	0.5	0.4	0.15	18	75	2.5	0.6273	0.027	0.0169358
4	0.6	0.5	0.1	16	79	2.63333	0.66	0.016	0.0105593
5	0.7	0.6	0.1	14	64	2.13333	0.5373	0.014	0.0075223
6	0.8	0.7	0.15	10	33	1.1	0.2838	0.015	0.0042575
7	1	0.9	0.1	0					
					sum				**0.053479**

RIVER Main Gilgil(lower catchment)
G1 UTMX 206385
Date/Time 06-Oct-03 UTMY 9933252

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position 0.2depth			average revolution	current meter position 0.6depth			average revolution
1	0.3	0	0.25	6	-	-	-		-	-	-	
2	0.8	0.5	0.5	15	23	22	21	22		-	-	
3	1.3	1	0.5	20	48	46	48	48	37	35	37	37
4	1.8	1.5	0.75	18	51	51	52	51	40	40	41	40
5	2.8	2.5	1	20	58	58	57	58	47	45	46	46
6	3.8	3.5	1	23	61	60	62	61	49	49	48	49
7	4.8	4.5	1	30	69	67	68	68	49	52	52	52
8	5.8	5.5	1	24	62	61	60	61	53	50	51	51
9	6.8	6.5	0.75	30	69	71	70	71	53	55	52	53
10	7.3	7	0.5	27	61	60	62	61	52	57	55	55
11	7.8	7.5	0.35	25	48	47	48	48	39	-	39	39
12	8	7.7	0.2	12	36	37	35	36	-	-	-	
13	8.2	7.9	0.1	6						-		

Flow measurement
X 206385
Y 9933252

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position	Average revolution	n R/T	velocity m/sec	Average veloc-ity m/sec	Area m^2	Discharge m^3/sec
1	0.3	0	0.25	6			0	0	0	0.0375	0
2	0.8	0.5	0.5	15	0.2depth	22	0.733	0.194	0.194	0.075	0.015
3	1.3	1	0.5	20	0.2depth	48	1.600	0.406			
					0.6depth	37	1.233	0.317	0.362	0.1	0.036
4	1.8	1.5	0.75	18	0.2depth	51	1.700	0.431			
					0.6depth	40	1.333	0.341	0.386	0.135	0.052
5	2.8	2.5	1	20	0.2depth	58	1.933	0.488			
					0.6depth	46	1.533	0.390	0.439	0.2	0.088
6	3.8	3.5	1	23	0.2depth	61	2.033	0.513			
					0.6depth	49	1.633	0.415	0.464	0.23	0.107
7	4.8	4.5	1	30	0.2depth	68	2.267	0.570			
					0.6depth	52	1.733	0.439	0.505	0.3	0.151
8	5.8	5.5	1	24	0.2depth	61	2.033	0.513			
					0.6depth	51	1.7	0.431	0.472	0.24	0.113
9	6.8	6.5	0.75	30	0.2depth	71	2.367	0.595			
					0.6depth	53	1.767	0.447	0.521	0.225	0.117
10	7.3	7	0.5	27	0.2depth	61	2.033	0.513			
					0.6depth	55	1.833	0.464	0.488	0.135	0.066
11	7.8	7.5	0.35	25	0.2depth	48	1.600	0.406			
					0.6depth	39	1.300	0.333	0.370	0.088	0.032
12	8	7.7	0.2	12	0.2depth	36	1.200	0.308	0.308	0.024	0.007
13	8.2	7.9	0.1	6	0.2depth				0	0.012	0.000
									sum		**0.785**

RIVER Main gilgil

Site: G2 UTMX 204513

Date/Time 02-Oct-03 UTMY 9945704

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position 0.2depth			Average revolution	current meter position 0.6depth			Average revolution
1	0.3	0	0.1	0	0	0	0	0	0	0	0	0
2	0.5	0.2	0.35	33	96	92	92	92	68	97	69	78
3	1	0.7	0.75	52	83	86	83	84	60	62	62	62
4	2	1.7	1	50	52	55	57	55	30	30	32	30
5	3	2.7	1	35	83	86	79	83	52	56	52	53
6	4	3.7	1	38	58	56	56	57	51	51	52	51
7	5	4.7	1	21	30	31	32	31	24	27	24	25
8	6	5.7	0.6	14	30	32	33	32				
9	6.2	5.9	0.1	10	9	8	7	8				
10	6.4	6.1	0.1	0								

Flow measurement

X 204513

Y 9945704

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position	average revolution	n R/T	Velocity m/sec	average velocity m/sec	Area m^2	Discharge m^3/sec
1	0.3	0	0.1	0		0	0	0		0	0
2	0.5	0.2	0.35	33	0.2depth	92	3.067	0.766			
					0.6depth	78	2.600	0.652	0.709	0.1155	0.082
3	1	0.7	0.75	52	0.2depth	84	2.800	0.701			
					0.6depth	62	2.067	0.521	0.611	0.39	0.238
4	2	1.7	1	50	0.2depth	55	1.833	0.464			
					0.6depth	30	1.000	0.259	0.362	0.5	0.181
5	3	2.7	1	35	0.2depth	83	2.767	0.693			
					0.6depth	53	1.767	0.447	0.570	0.35	0.200
6	4	3.7	1	38	0.2depth	57	1.900	0.480			
					0.6depth	51	1.700	0.431	0.349	0.38	0.133
7	5	4.7	1	21	0.2depth	31	1.033	0.267			
					0.6depth	25	0.833	0.218	0.243	0.21	0.051
8	6	5.7	0.6	14	0.2depth	32	1.067	0.276	0.085	0.084	0.007
					0.6depth		0.000	0.030			
9	6.2	5.9	0.1	10	0.2depth	8	0.267	0.089	0.043	0.01	0.000
					0.6depth		0				
11	6.4	6.1	0.1	0		0	0	0		0	0.000
									sum		**0.892**

River Little Gilgil

Site: G3 UTMX 206538

Date/Time: 02-Oct-03 UTMY 9944804

Vertical No.	Vertical Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			average revolution
1	0.2	0	0.15	14	0	0	0	0
2	0.5	0.3	0.25	20	21	20	21	21
3	0.7	0.5	0.2	19	27	26	27	27
4	0.9	0.7	0.15	15	30	30	30	30
5	1	0.8	0.1	14	26	28	28	28
6	1.1	0.9	0.15	10	20	21	19	20
7	1.3	1.1	0.1	0				

Flow measurement

Site: G3

X 206538

Y 9944804

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Average Revolution	Area (m^2)	n (R/T)	Average velocity m/sec	Discharge m^3/sec
1	0.2	0	0.15	14	0	0.021	0	0	0
2	0.5	0.3	0.25	20	21	0.05	0.7	0.186	0.009
3	0.7	0.5	0.2	19	27	0.038	0.9	0.235	0.009
4	0.9	0.7	0.15	15	30	0.0225	1	0.259	0.006
5	1	0.8	0.1	14	28	0.014	0.933	0.243	0.003
6	1.1	0.9	0.15	10	20	0.015	0.667	0.178	0.003
7	1.3	1.1	0.1	0	0	0.01			
							sum		**0.030**

RIVER	Gilgil tributary	Photo no.	
Site:	G4	UTMX	198832
Date/Time	01-Oct-03	UTMY	9971748

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	current meter position 0.2depth			Average revolution	Current meter position 0.6depth			Average revolution
1	0.1	0	0.05	42	0	0	0	0	0	0	0	0
2	0.2	0.1	0.3	40	53	52	52	52	44	43	43	43
3	0.7	0.6	0.5	34	86	86	88	86	45	44	42	44
4	1.2	1.1	0.5	30	98	101	102	101	59	61	60	61
5	1.7	1.6	0.35	21	80	80	78	80	20	20	19	20
6	1.9	1.8	0.3	19	32	33	33	33				
7	2.3	2.2	0.2	13								

Flow measurement

X 198832

Y 9971748

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position	Average revolution	n R/T	velocity m/sec	Average velocity m/sec	Area m^2	Discharge m^3/sec
1	0.1	0	0.05	42		0	0	0	0	0.02	0
2	0.2	0.1	0.3	40	0.2depth	52	1.733	0.439			
					0.6depth	43	1.433	0.366	0.402	0.12	0.048
3	0.7	0.6	0.5	34	0.2depth	86	2.867	0.717			
					0.6depth	44	1.467	0.374	0.545	0.17	0.093
4	1.2	1.1	0.5	30	0.2depth	101	3.367	0.840			
					0.6depth	61	2.033	0.513	0.676	0.15	0.101
5	1.7	1.6	0.35	21	0.2depth	80	2.667	0.668			
					0.6depth	20	0.667	0.178	0.423	0.0735	0.031
6	1.9	1.8	0.3	19	0.2depth	33	1.100	0.284	0.284	0.057	0.016
					0.6depth						
7	2.3	2.2	0.2	13	0.2depth		0	0		0.038	0
										sum	**0.290**

RIVER : Gilgil tributary
Site: G5 UTMX 197430
Date/Time 01-Oct-03 UTMY 9971180

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position 0.2depth			average revolution	Current meter position 0.6depth			Average revolution
1	0	0	0.05	0	0	0	0	0	0	0	0	
2	0.1	0.1	0.3	26	38	34	35	35	22	22	22	22
3	0.6	0.6	0.5	27	51	53	51	51	40	44	44	44
4	1.1	1.1	0.5	24	60	60	61	60	49	47	45	47
5	1.6	1.6	0.5	30	51	51	51	51	44	44	42	44
6	2.1	2.1	0.5	24	19	18	20	19				
7	2.4	2.4	0.25	24	27	28	28	28				
8	2.6	2.6	0.1	21	0	0	0	0				

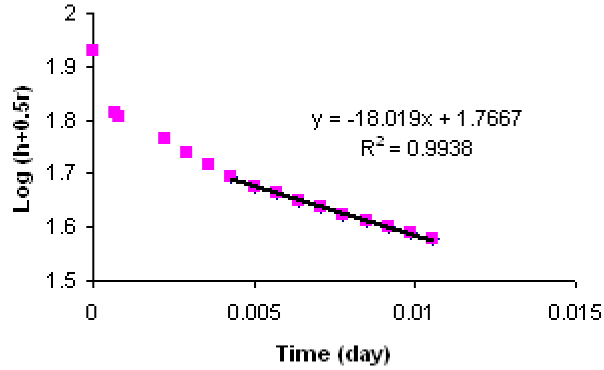
Flow measurement
X 197430
Y 9971180

Vertical No.	Tape position (m)	Distance from base (m)	Width (m)	Depth (cm)	Current meter position	Average revolution	n R/T	velocity m/sec	Average velocity m/sec	Area m^2	Discharge m^3/sec
1	0	0	0.05	0			0	0	0	0.013	0
2	0.1	0.1	0.3	26	0.2depth	35	1.167	0.300			
					0.6depth	22	0.733	0.194	0.247	0.078	0.019
3	0.6	0.6	0.5	27	0.2depth	51	1.700	0.431			
					0.6depth	44	1.467	0.374	0.402	0.135	0.054
4	1.1	1.1	0.5	24	0.2depth	60	2.000	0.505			
					0.6depth	47	1.567	0.398	0.451	0.12	0.054
5	1.6	1.6	0.5	30	0.2depth	51	1.700	0.431			
					0.6depth	44	1.467	0.374	0.402	0.15	0.060
6	2.1	2.1	0.5	24	0.2depth	19	0.633	0.170	0.166	0.12	0.020
7	2.4	2.4	0.25	24	0.2depth	28	0.933	0.243	0.238	0.06	0.014
8	2.6	2.6	0.1	21	0.2depth	0	0	0	0	0.024	0.000
								sum			**0.222**

Appendix A -2: Calculation of Hydraulic Conductivity by Inverse Auger Method

X	203574	
Y	9942250	
depth of hole	83	cm
diameter of the hole	8	cm
radius	4	cm

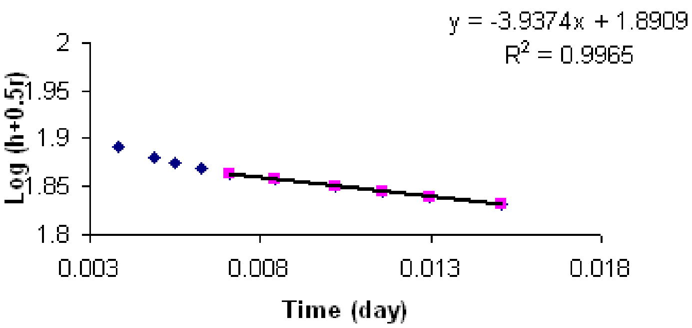
time sec	Time day	depth cm	h cm	h+0.5r cm	log(h+0.5r) cm
0	0	0	83	85	1.9294189
60	0.00069	20	63	65	1.8129134
72	0.00083	21	62	64	1.80618
192	0.00222	27	56	58	1.763428
252	0.00292	30	53	55	1.7403627
312	0.00361	33	50	52	1.7160033
372	0.00431	35.5	47.5	49.5	1.6946052
432	0.005	37.5	45.5	47.5	1.6766936
492	0.00569	39	44	46	1.6627578
552	0.00639	40.5	42.5	44.5	1.64836
612	0.00708	41.5	41.5	43.5	1.6384893
672	0.00778	43	40	42	1.6232493
732	0.00847	44.2	38.8	40.8	1.6106602
792	0.00917	45	38	40	1.60206
852	0.00986	46	37	39	1.5910646
912	0.01056	47	36	38	1.5797836



Hydraulic conductivity 82.8874 cm/day

X	212050	
Y	9948958	
depth of hole	96	cm
diameter of the hole	8	cm

Time sec	Time day	depth cm	h cm	(h+0.5r) cm	log(h+0.5r) cm
0	0	0	96	98	1.9912261
329	0.0038079	20	76	78	1.8920946
420	0.0048611	22	74	76	1.8808136
475	0.0054977	23	73	75	1.8750613
540	0.00625	24	72	74	1.8692317
615	0.0071181	25	71	73	1.8633229
730	0.0084491	26	70	72	1.8573325
880	0.0101852	27	69	71	1.8512583
1000	0.0115741	28	68	70	1.845098
1120	0.012963	29	67	69	1.8388491
1300	0.0150463	30	66	68	1.8325089

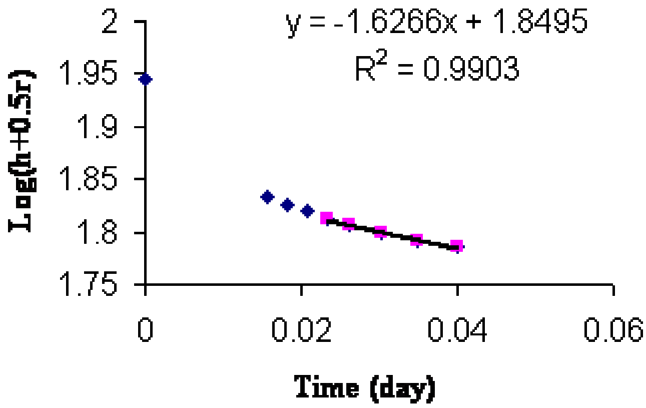


hydraulic conductivity 18.1102 cm/day

X 212022
Y 9948952
depth of hole 86 cm

diameter of hole 8 cm

Time sec	Time days	depth cm	H cm	(H+0.5r) cm	log(H+0.5r) cm
0	0	0	86	88	1.94448267
1360	0.0157	20	66	68	1.83250891
1570	0.0182	21	65	67	1.8260748
1795	0.0208	22	64	66	1.81954394
2020	0.0234	23	63	65	1.81291336
2260	0.0262	24	62	64	1.80617997
2620	0.0303	25	61	63	1.79934055
3004	0.0348	26	60	62	1.79239169
3460	0.04	27	59	61	1.78532984



hydraulic conductivity 7.48236 cm/day

Appendix A-3: Calculation of Soil Bulk Density

weight of cover 20 g
Length of the ring 5 cm
internal diameter of ring 5 cm
X-sectional area of the ring 19.62 cm2
Volume of soil 98.12 cm3

Coordinate X	Coordinate Y	Weight of box g	Original sample weight (cover+field_soil+ring) g	Dry sample weight (ring+box+dry_soil) g	weight of ring g	net dry weight g	dry bulk density g/cm3	wet weight g	wet bulk density g/cm3
227127	9931062	38	221	214	93	83	0.846	108	1.101
223634	9931294	37	234	226	96	93	0.948	118	1.203
229557	9940762	31	245	211	89	91	0.927	136	1.386
212050	9948958	76	242	276	96	104	1.060	126	1.284
212036	9948960	66	245	265	94	105	1.070	131	1.335
203574	9942250	30	230	222	93	99	1.009	117	1.192
203591	9942244	69	236	260	94	97	0.989	122	1.243

Appendix A-4: Procedures for Soil Analysis

A-4.I: Organic Carbon

A-4.I.1: Principle

The Walkley-Black procedure is followed. This involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid at about 125^{0}C. The residual dichromate is titrated against ferrous sulphate. To compensate for incomplete destruction an empirical correction factor of 1.3 is applied in the calculation of the result.

A-4.I.2: Procedure

- Grind approximately 5g fine earth to pass a 0.25mm sieve.

- Weigh 1 g of this material (accuracy 0.01g) into a 500 ml wide-mouth Erlenmeyer flask. Include a control sample.
- Add 10.00 ml dichromate solution. Include two blanks (Erlenmeyer flask without soil) to determine the molarity of the ferrous sulphate solution.
- Carefully add 20 ml sulphuric acid with a measuring cylinder, swirl the flask and allow to stand on a pad for 30 minutes (in fume cupboard)
- Add about 250 ml water and 10 ml of phosphoric acid with a measuring cylinder and allow to cool.
- Add 1 ml of indicator solution and titrate with ferrous sulphate solution while the mixture is being stirred. Near the end-point the brown color becomes purple or violent-blue and titration must be slow down. At the end-point of the color changes sharply to green. If more than 8 of the 10 ml dichromate added has been reduced then repeat the determination with less soil.

A-4.I.3: Calculation

Carbon content of the soil, %C = $M * \frac{V1 - V2}{s} * 0.39 * mcf$

Where: M = molaroty of ferrous sulphate solution (from blank titration)
V1 = ml Ferrous sulphate solution required for blank
V2 = ml Ferrous sulphate solution required for sample
S = weight of air dry sample in gram
0.39 = $3*10^{-3}*100\%*1.3$
mcf = Moisture correction factor

Multiplying with the empirical factor 2 does conversion of the % carbon to % organic matter.
%Organic matter = 2*%Carbon.

A-4.II: Phosphorus Soluble in Dilute Acid-Fluoride (Extraction According to Bray & Kurtz no. I)

A-4.II.1: Principle

The readily acid-soluble forms of P are extracted by a combination of HCl and NH_4F. Phosphate in the extract is determined calorimetrically with the blue ammonium molybdate method with ascorbic acid reducing agent.

A-4.II.2: Procedure

- Weigh 2 g fine earth (accuracy 0.01g) into a wide test tube (50 ml) or shaking bottle. Include two blanks and a control sample.
- Add 14.0 ml of extracting solution Bray I.
- Shake for 1 minute by hand and then immediately filter through a hardened filter (e.g. Whatman 42). In case the filtrate is turbid filter again through the same filter. Filtration procedure not to exceed 10 minutes.
- Pipette into (short) test tubes 1 ml of the standard series, the blanks and the sample extracts, 2 ml boric acid and 3 ml of the mixed reagent. Homogenise.

- Allow solutions to stand for at least 1 hour for the blue colour to develop its maximum
- Measure absorbance on spectrophotometer at 882 or 720 nm.

A-4.II.3: Calculation

$$P\ (\text{mg/kg soil}) = (a-b)*\frac{14}{1000}*\frac{1000}{s}*mcf = (a-b)*\frac{14}{s}*mcf$$

Where:

a = mg/l P in sample extract

b = ditto in blank

s = sample weight in gram

mcf = moisture correction factor

P_2O_5 can be calculated by:

$$P_2O_5 = 2.31 * P$$

A-4.III: Particle-Size Analysis

Particle size analysis is separation of the mineral part of the soil into various size fractions and determination of the proportion of these fractions. The analysis is applied to the fine earth (<2 mm) only.
Of paramount importance in this analysis is the pre-treatment of the sample aimed at complete dispersion of the primary particles. Therefore, cementing materials (usually of secondary origin) such as organic matter and calcium carbonates may have to be removed. N some cases also sesquioxides may need to be removed. It may be argued, however, that for agricultural purposes it is often not relevant or even fundamentally wrong to remove these components. For soil characterization purposes, in the ITC laboratory removal of organic matter by H_2O_2 and of carbonates by HCl is done for the preparation of separation fraction.
After shaking with a dispersing agent, sand is separated from clay and silt with a 50 μm sieve. The sand is fractioned by dry sieving; the clay and silt fractions are determined by the pipette method.

Appendix B: Soil chemical analysis result and SWAT Input Parameters

Appendix B-1: Soil chemical analysis result outside ITC

Coordinate X	Coordinate Y	P-Al mg P2O5 per 100g soil	Ammo-nium Kg N/ha	Nitrate N Kg N/ha	P2O5 mg/kg soil	P mg/kg soil	Density g/cm3	density kg/m3	Nitrate N mg/kg soil	Ammo-nium mg N/kg soil
222306	9948922	2	1	71	20	8.67	1.4	1386.0	20.5	0.3
212566	9951038	6	2	94	60	25.97	1.2	1243.3	30.2	0.6
234398	9949936	9	2	8	90	38.96	1.3	1335.0	2.4	0.6
234431	9947088	7	2	216	70	30.30	1.4	1386.0	62.3	0.6
234769	9949590	7	2	277	70	30.30	1.2	1243.3	89.1	0.6
201706	9973046	2	2	133	20	8.67	1.2	1202.5	44.2	0.7
231553	9953324	2	2	124	20	8.67	1.1	1100.6	45.1	0.7
213811	9972396	11	2	192	110	47.62	1.3	1284.1	59.8	0.6
234759	9949558	6	2	176	60	25.97	1.2	1243.3	56.6	0.6
221068	9930640	3	2	99	30	13	1.2	1192.4	33.2	0.7
211244	9910256	238	2	14	2380	1030.3	1.4	1386.0	4.0	0.6
210050	9906318	22	3	38	220	95.24	1.4	1386.0	11.0	0.9
213298	9917422	145	2	4	1450	627.7	1.2	1243.3	1.3	0.6

Appendix B-2: SWAT input parameters

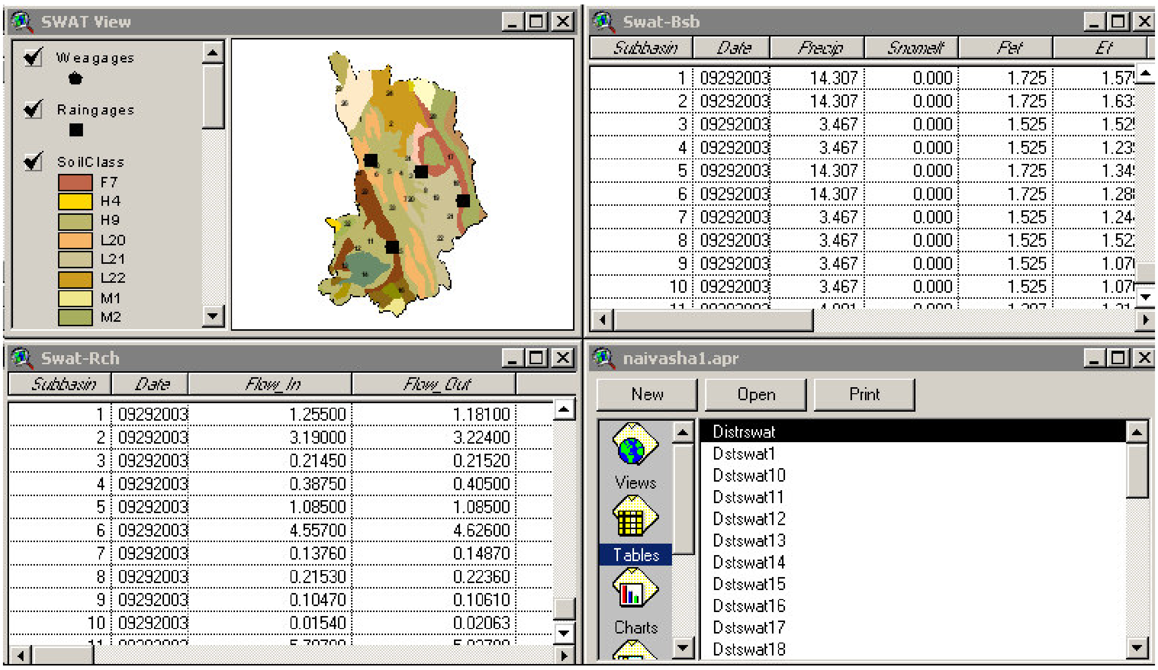
The following parameters are the parameters used for model calibration**.**

PARAMETRS	USED VALUES
NPERCO	1
PPERCO	10
PHOSKD	200
ALPHA_BF	1
GWQMN	1000
GW_REVAP	0.15
REVAPMN	0.5
SLOPE	0.084
SLSUBBSN	60.976
CH-COV	1
CH-EROD	0.6
CH-K2	100
BIOMIX	0.5
USLE_P	1
SOL-AWC	0.15

LAND USE	CN2
Maize land	70-78
Wheat land	72
Potato land	71-83
Flowring farm	65-72
Onion farm land	75-78
Cabage farm land	83
Spinach	60-70
Forest land	43-56
Pasture land	46-63
Orchard trees land	45-75
Range brush land	43-48
Range grass land	45
Wetland mixed	45-52
Urban residential low density	59-82
Urban residential medium density	82
Urban residential high density	63
Accacia and coniferrous trees	46

Appendix C: SWAT Output

Appendix C-1: SWAT Output Daily



RCH File

Swat-Rch

Subbasin	Date	Flow_In	Flow_Out	Evap	Tloss	Sed_In	Sed_Out
1	09302003	9.46900	9.48000	0.00003	0.03929	0.00001	0.000
2	09302003	21.64000	21.72000	0.00002	0.02836	2320.00000	57220.000
3	09302003	0.54970	0.55860	0.00001	0.01398	0.00002	1448.000
4	09302003	0.99170	0.88620	0.00011	0.14450	2944.00000	2123.000
5	09302003	4.02400	4.09600	0.00005	0.06139	6012.00000	13020.000
6	09302003	31.87000	31.96000	0.00002	0.02550	105500.00000	125000.000
7	09302003	0.37470	0.39730	0.00001	0.01681	336.20000	1049.000
8	09302003	0.53830	0.55430	0.00001	0.01411	1145.00000	1895.000
9	09302003	0.14270	0.14970	0.00002	0.02883	0.00137	188.700
10	09302003	0.01665	0.02043	0.00000	0.01665	0.00001	6.308
11	09302003	36.15000	36.22000	0.00005	0.02479	148900.00000	153400.000
12	09302003	1.11800	1.04900	0.00026	0.13380	1012.00000	2036.000
13	09302003	0.63930	0.68870	0.00003	0.01308	0.00002	0.000
14	09302003	0.38970	0.42960	0.00003	0.01648	0.00007	1012.000
15	09302003	0.02293	0.03015	0.00000	0.02293	0.00003	0.000
16	09302003	0.35730	0.35950	0.00003	0.01723	0.00002	0.000
17	09302003	0.51300	0.51600	0.00001	0.01443	0.00001	0.000
18	09302003	0.37800	0.39390	0.00001	0.01674	0.00047	0.000
19	09302003	0.43660	0.45370	0.00001	0.01558	0.00627	1145.000
20	09302003	0.17010	0.18310	0.00002	0.02598	195.00000	336.200
21	09302003	0.13080	0.14270	0.00002	0.03038	0.00137	0.001
22	09302003	0.04214	0.01665	0.00000	0.04214	0.00001	0.000

Swat-Rch

Sedconc	Orgn_In	Orgn_Out	Orgp_In	Orgp_Out	NO3_In	NO3_Out
0.00001	0.01223	53.66000	0.02446	11.94000	881.50000	868.0000
30490.00000	1220.00000	1068.00000	206.10000	163.10000	2724.00000	2782.0000
30000.00000	35.77000	41.26000	7.96400	8.29400	114.20000	112.2000
27720.00000	111.80000	86.66000	21.39000	14.72000	115.50000	103.3000
36800.00000	146.20000	152.80000	25.63000	25.57000	488.00000	496.5000
45280.00000	991.50000	857.30000	142.10000	112.80000	3827.00000	3995.0000
30560.00000	19.52000	40.82000	3.24400	7.77500	47.08000	47.4800
39560.00000	56.36000	70.98000	11.47000	13.62000	63.03000	61.0900
14590.00000	19.73000	16.41000	4.39700	3.15200	17.72000	18.5300
3573.00000	6.51600	6.44100	1.45400	1.24100	1.46400	1.5490
49040.00000	859.90000	724.40000	107.60000	83.01000	4513.00000	4712.0000
22470.00000	0.05936	0.04405	0.09338	0.05969	885.90000	830.8000
0.00037	0.02051	0.01749	0.04103	0.03012	539.60000	581.2000
27280.00000	0.04750	0.04143	0.08301	0.06237	276.40000	304.7000
0.01200	0.01964	0.02043	0.03927	0.03520	28.46000	37.4300
0.00077	0.02859	0.02276	0.05718	0.03922	237.40000	239.0000
0.00031	0.01106	35.76000	0.02212	7.96100	109.50000	106.0000
0.01378	0.03668	42.53000	0.02607	9.46400	38.63000	36.3300
29200.00000	42.54000	56.34000	9.46900	11.45000	45.67000	43.6400
21260.00000	22.85000	19.51000	4.39300	3.23400	20.10000	21.5400
0.11090	0.05361	19.73000	0.03137	4.39700	19.95000	17.7100
0.00551	0.01243	6.51600	0.02487	1.45400	8.13900	1.4630

Swat-Rch

NH4_In	NH4_Out	NO2_In	NO2_Out	Minp_In	Minp_Out	Chla_In
0.00000	0.10330	0.00000	0.00000	154.40000	151.40000	126.6000
455.40000	491.20000	73.88000	174.90000	698.90000	754.00000	234.2000
0.02530	6.02300	0.00000	0.00927	5.42700	6.90000	29.0600
22.90000	28.85000	4.71200	7.95400	22.15000	24.09000	20.0900
46.49000	53.80000	12.24000	18.77000	96.67000	102.90000	81.3500
530.30000	502.10000	197.10000	218.90000	968.60000	1007.00000	165.6000
7.35500	7.89500	1.86500	3.03900	10.63000	11.17000	54.4400
7.31800	15.00000	0.01132	1.67400	7.33800	9.85100	57.5000
0.03096	3.45000	0.00000	0.01170	0.41910	1.69500	0.0835
0.00861	1.35300	0.00000	0.00000	0.23210	0.72170	0.2146
721.50000	601.90000	238.10000	293.30000	1146.00000	1174.00000	101.1000
0.10600	0.10440	0.02419	0.03896	0.25600	0.26730	0.0000
0.00000	0.02913	0.00000	0.00000	0.04103	0.05887	0.0000
0.06089	0.07691	0.00000	0.02419	0.15290	0.19620	0.0000
0.00000	0.03310	0.00000	0.00000	0.03927	0.06870	0.0000
0.00000	0.02779	0.00000	0.00000	0.05718	0.07563	0.0000
0.00000	0.02530	0.00000	0.00000	5.49800	4.62600	83.9700
0.00000	0.03023	0.00000	0.00000	2.54000	1.78400	96.3500
0.03023	7.31800	0.00000	0.01132	3.20800	5.18900	48.5700
4.80300	7.35500	0.01170	1.86500	2.42100	3.87700	0.1209
0.00000	0.03096	0.00000	0.00000	1.19700	0.41750	45.5000
0.00000	0.00861	0.00000	0.00000	1.56400	0.23170	41.5800

Swat-Rch

Chla_Out	CBOD_In	CBOD_Out	Disox_In	Disox_Out	Solpst_In	Solpst_Out
64.60000	0.00000	0.00000	8304.00000	7374.00000	8066000.00000	7987000.0000
149.00000	0.00000	0.00000	55330.00000	0.00000	9019000.00000	8966000.0000
0.00000	0.00000	0.00000	5245.00000	0.00000	62220.00000	61790.0000
0.00000	0.00000	0.00000	24680.00000	0.00000	97150.00000	85220.0000
25.07000	0.00000	0.00000	62830.00000	0.00000	192200.00000	193000.0000
114.50000	0.00000	0.00000	889300.00000	0.00000	16860000.00000	16770000.0000
0.00000	0.00000	0.00000	173.20000	6980.00000	9349.00000	9624.0000
0.00000	0.00000	0.00000	73.84000	17670.00000	87000.00000	87520.0000
0.00000	0.00000	0.00000	1967.00000	0.00000	8004.00000	7863.0000
0.00000	0.00000	0.00000	0.00013	792.00000	1214.00000	1326.0000
74.75000	0.00000	0.00000	1397000.00000	0.00000	16850000.00000	16730000.0000
0.00000	0.00000	0.00000	26630.00000	0.00000	33070.00000	30450.0000
0.00000	0.00000	0.00000	0.00000	26630.00000	0.00000	0.0000
0.00000	0.00000	0.00000	15070.00000	0.00000	30880.00000	33070.0000
0.00000	0.00000	0.00000	0.00000	1166.00000	3357.00000	3914.0000
0.00000	0.00000	0.00000	0.00000	13900.00000	27640.00000	26970.0000
0.00000	0.00000	0.00000	323.10000	5224.00000	63350.00000	62220.0000
0.00000	0.00000	0.00000	228.80000	4084.00000	63070.00000	63800.0000
0.00000	0.00000	0.00000	4122.00000	0.00000	72710.00000	73560.0000
0.00000	0.00000	0.00000	792.00000	0.00000	9189.00000	9349.0000
0.00000	0.00000	0.00000	69.82000	1967.00000	7876.00000	8004.0000
0.00000	0.00000	0.00000	35.86000	0.00000	3466.00000	1214.0000

Swat-Rch

Sorpst_In	Sorpst_Out	Reactpst	Volpst	Settlpst	Resusp_Pst	Diffusepst
0.00000	0.00000	56470.00000	28930.00000	0.00000	2.07700	2880.0000
0.00000	0.00000	63130.00000	17660.00000	0.00000	0.51690	1762.0000
0.00000	0.00000	435.50000	890.00000	0.00000	0.99090	86.7400
0.00000	0.00000	680.00000	1014.00000	0.00000	1.41100	98.8900
0.00000	0.00000	1346.00000	1173.00000	0.00000	0.82270	115.8000
0.00000	0.00000	118000.00000	24610.00000	0.00000	0.61040	2457.0000
0.00000	0.00000	65.44000	192.20000	0.00000	1.51200	17.3200
0.00000	0.00000	609.00000	1269.00000	0.00000	2.18700	122.9000
0.00000	0.00000	56.03000	419.80000	0.00000	3.54600	36.2800
0.00000	0.00000	8.49500	120.50000	0.00000	3.28400	7.6610
0.00000	0.00000	117900.00000	22340.00000	0.00000	0.58990	2230.0000
0.00000	0.00000	231.50000	334.90000	0.00000	0.48930	32.6600
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000
0.00000	0.00000	216.20000	611.70000	0.00000	1.70500	58.2600
0.00000	0.00000	23.50000	333.30000	0.00000	3.37100	26.7300
0.00000	0.00000	193.50000	594.90000	0.00000	2.10200	56.1100
0.00000	0.00000	443.40000	967.10000	0.00000	1.15500	94.0700
0.00000	0.00000	441.50000	1286.00000	0.00000	3.33100	122.7000
0.00000	0.00000	509.00000	1292.00000	0.00000	2.78200	124.2000
0.00000	0.00000	64.32000	405.70000	0.00000	3.54800	35.2700
0.00000	0.00000	55.13000	450.00000	0.00000	4.25600	38.2300
0.00000	0.00000	24.27000	344.20000	0.00000	2.83100	28.2300

Swat-Rch

Reacbedpst	Burypst	Bed_Pst	Bactp_Out	Bactlp_Out	Cmetal#1	Cmetal#2
268.50000	383.60000	5102.00000	0.00000	0.00000	0.00000	0.0000
143.40000	204.80000	2724.00000	0.00001	0.00001	0.00000	0.0000
20.05000	28.64000	381.00000	0.00000	0.00000	0.00000	0.0000
35.88000	51.26000	681.70000	0.00002	0.00002	0.00000	0.0000
36.60000	52.28000	695.30000	0.00003	0.00003	0.00000	0.0000
211.50000	302.20000	4019.00000	0.00001	0.00001	0.00000	0.0000
17.78000	25.40000	337.80000	0.00001	0.00001	0.00000	0.0000
40.37000	57.67000	767.00000	0.00001	0.00001	0.00000	0.0000
17.19000	24.56000	326.70000	0.00000	0.00000	0.00000	0.0000
7.86700	11.24000	149.50000	0.00000	0.00000	0.00000	0.0000
207.10000	295.90000	3935.00000	0.00004	0.00004	0.00000	0.0000
12.70000	18.14000	241.20000	0.00001	0.00001	0.00000	0.0000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000
22.58000	32.26000	429.00000	0.00001	0.00001	0.00000	0.0000
8.95600	12.79000	170.20000	0.00000	0.00000	0.00000	0.0000
25.15000	35.93000	477.90000	0.00000	0.00000	0.00000	0.0000
21.87000	31.24000	415.50000	0.00000	0.00000	0.00000	0.0000
43.42000	62.03000	825.10000	0.00000	0.00000	0.00000	0.0000
41.93000	59.90000	796.60000	0.00000	0.00000	0.00000	0.0000
20.10000	28.72000	381.90000	0.00001	0.00001	0.00000	0.0000
18.85000	26.92000	358.10000	0.00000	0.00000	0.00000	0.0000
7.79100	11.13000	148.00000	0.00000	0.00000	0.00000	0.0000

BSB File

Swat-Bsb

Subbasin	Date	Precip	Snomelt	Pet	Et	Sw	Perc	Surq	Gw_q	Wyld	Syld
1	09302003	29.736	0.000	2.125	1.900	260.016	13.514	6.642	0.000	6.688	0.000
2	09302003	29.736	0.000	2.125	2.000	429.798	14.290	5.635	0.000	5.670	0.000
3	09302003	11.084	0.000	1.902	1.902	528.687	4.845	0.091	0.000	0.151	0.000
4	09302003	11.084	0.000	1.902	1.521	245.933	3.778	0.240	0.000	0.424	0.000
5	09302003	29.736	0.000	2.125	1.646	279.957	9.936	6.856	0.000	7.056	0.000
6	09302003	29.736	0.000	2.125	1.590	543.309	16.902	0.001	0.000	0.039	0.000
7	09302003	11.084	0.000	1.902	1.528	253.190	3.861	0.345	0.000	0.350	0.000
8	09302003	11.084	0.000	1.902	1.898	528.789	4.803	0.190	0.000	0.199	0.000
9	09302003	11.084	0.000	1.902	1.295	79.647	4.005	0.000	0.000	0.002	0.000
10	09302003	11.084	0.000	1.902	1.295	79.634	4.002	0.000	0.000	0.005	0.000
11	09302003	0.000	0.000	4.762	3.613	343.080	0.175	0.000	0.000	0.001	0.000
12	09302003	0.000	0.000	4.762	2.251	205.681	0.000	0.000	0.000	0.000	0.000
13	09302003	0.000	0.000	4.762	2.574	379.726	0.012	0.000	0.000	0.269	0.000
14	09302003	0.000	0.000	4.762	1.695	216.624	0.000	0.000	0.000	0.000	0.000
15	09302003	0.000	0.000	4.762	2.173	275.629	0.596	0.000	0.000	0.010	0.000
16	09302003	0.000	0.000	4.762	2.490	349.722	0.551	0.000	0.000	0.108	0.000
17	09302003	11.084	0.000	1.902	1.855	532.575	2.425	0.207	0.000	0.401	0.000
18	09302003	8.233	0.000	1.946	1.942	526.273	4.394	0.130	0.000	0.285	0.000
19	09302003	11.084	0.000	1.902	1.898	529.748	4.192	0.263	0.000	0.268	0.000
20	09302003	11.084	0.000	1.902	1.295	79.643	4.004	0.000	0.000	0.003	0.000
21	09302003	8.233	0.000	1.946	1.945	529.217	4.464	0.020	0.000	0.094	0.000
22	09302003	8.233	0.000	1.946	1.877	480.670	4.526	0.024	0.000	0.029	0.000

Swat-Bsb

Et	Sw	Perc	Surq	Gw_q	Wyld	Syld	Orgn	Orgp	Nsurq	Solp	Sedp
1.900	260.016	13.514	6.642	0.000	6.688	0.000	0.000	0.000	0.071	0.013	0.000
2.000	429.798	14.290	5.635	0.000	5.670	0.000	0.000	0.000	0.074	0.015	0.000
1.902	528.687	4.845	0.091	0.000	0.151	0.000	0.000	0.000	0.001	0.000	0.000
1.521	245.933	3.778	0.240	0.000	0.424	0.000	0.000	0.000	0.005	0.001	0.000
1.646	279.957	9.936	6.856	0.000	7.056	0.000	0.000	0.000	0.074	0.022	0.000
1.590	543.309	16.902	0.001	0.000	0.039	0.000	0.000	0.000	0.002	0.001	0.000
1.528	253.190	3.861	0.345	0.000	0.350	0.000	0.000	0.000	0.005	0.001	0.000
1.898	528.789	4.803	0.190	0.000	0.199	0.000	0.000	0.000	0.004	0.001	0.000
1.295	79.647	4.005	0.000	0.000	0.002	0.000	0.000	0.000	0.005	0.001	0.000
1.295	79.634	4.002	0.000	0.000	0.005	0.000	0.000	0.000	0.005	0.001	0.000
3.613	343.080	0.175	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2.251	205.681	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.574	379.726	0.012	0.000	0.000	0.269	0.000	0.000	0.000	0.000	0.000	0.000
1.695	216.624	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.173	275.629	0.596	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000
2.490	349.722	0.551	0.000	0.000	0.108	0.000	0.000	0.000	0.000	0.000	0.000
1.855	532.575	2.425	0.207	0.000	0.401	0.000	0.000	0.000	0.002	0.000	0.000
1.942	526.273	4.394	0.130	0.000	0.285	0.000	0.000	0.000	0.002	0.000	0.000
1.898	529.748	4.192	0.263	0.000	0.268	0.000	0.000	0.000	0.006	0.001	0.000
1.295	79.643	4.004	0.000	0.000	0.003	0.000	0.000	0.000	0.005	0.001	0.000
1.945	529.217	4.464	0.020	0.000	0.094	0.000	0.000	0.000	0.000	0.000	0.000
1.877	480.670	4.526	0.024	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000

Appendix C-2: SWAT Output Yearly

BSB File

	SUBBASIN	DATE	PRECIP	SNOMELT	PET	ET	SW	PERC	SURQ	GW_Q	WYLD
596	1	1998	1602.000	0.000	1101.971	677.250	256.797	727.009	162.262	450.201	62
597	2	1998	1602.000	0.000	1101.971	710.178	426.873	711.648	141.982	432.990	58
598	3	1998	1803.000	0.000	1041.334	762.969	473.183	895.016	140.424	713.886	89
599	4	1998	1803.000	0.000	1041.334	565.877	190.533	866.127	280.500	687.849	108
600	5	1998	1602.000	0.000	1101.971	623.873	275.217	716.142	172.377	465.065	68
601	6	1998	1602.000	0.000	1101.971	860.828	538.383	692.823	15.733	405.395	43
602	7	1998	1803.000	0.000	1041.334	531.035	203.571	974.499	323.380	818.672	114
603	8	1998	1803.000	0.000	1041.334	720.068	477.656	928.377	181.318	771.511	96
604	9	1998	1803.000	0.000	1041.334	469.915	30.902	1003.668	22.011	1055.269	107
605	10	1998	1803.000	0.000	1041.334	469.898	30.886	1002.365	18.052	1053.888	107
606	11	1998	725.000	0.000	1274.578	675.017	206.228	234.156	50.861	0.000	5
607	12	1998	725.000	0.000	1274.578	464.395	177.187	0.000	19.462	0.000	33
608	13	1998	725.000	0.000	1274.578	626.865	258.527	129.648	40.641	0.000	16
609	14	1998	725.000	0.000	1274.578	473.318	197.872	0.000	34.432	0.000	34
610	15	1998	725.000	0.000	1274.578	628.753	213.865	204.675	54.939	0.000	5
611	16	1998	725.000	0.000	1274.578	632.442	235.204	197.020	41.133	0.000	8
612	17	1998	1803.000	0.000	1041.334	788.709	490.076	754.372	154.158	258.113	56
613	18	1998	1467.000	0.000	1032.872	810.898	487.852	500.344	127.891	223.891	41
614	19	1998	1803.000	0.000	1041.334	653.587	477.881	901.742	263.947	754.249	102
615	20	1998	1803.000	0.000	1041.334	469.914	30.897	1003.248	17.455	1054.824	107
616	21	1998	1467.000	0.000	1032.872	756.465	494.222	569.065	140.355	411.137	58
617	22	1998	1467.000	0.000	1032.872	670.088	447.499	628.140	191.602	538.852	73

	PERC	SURQ	GW_Q	WYLD	SYLD	ORGN	ORGP	NSURQ	SOLP	SEDP
596	727.009	162.262	450.201	625.581	0.000	0.000	0.000	2.260	0.454	0.001
597	711.648	141.982	432.990	585.580	0.000	0.000	0.000	2.003	0.439	0.001
598	895.016	140.424	713.886	896.800	0.000	0.000	0.000	1.863	0.655	0.001
599	866.127	280.500	687.849	1080.900	0.000	0.000	0.000	4.058	1.132	0.001
600	716.142	172.377	465.065	686.458	0.000	0.000	0.000	2.973	0.709	0.001
601	692.823	15.733	405.395	433.271	0.000	0.000	0.000	0.252	0.099	0.001
602	974.499	323.380	818.672	1144.672	0.000	0.000	0.000	4.564	1.271	0.001
603	928.377	181.318	771.511	960.211	0.000	0.001	0.001	2.251	0.708	0.001
604	1003.668	22.011	1055.269	1078.246	0.000	0.000	0.000	5.220	1.396	0.001
605	1002.365	18.052	1053.888	1074.379	0.001	0.000	0.000	5.217	1.395	0.001
606	234.156	50.861	0.000	51.322	0.000	0.000	0.000	0.625	0.194	0.001
607	0.000	19.462	0.000	339.794	0.000	0.000	0.000	0.226	0.001	0.001
608	129.648	40.641	0.000	160.546	0.000	0.000	0.000	0.439	0.023	0.001
609	0.000	34.432	0.000	340.070	0.000	0.000	0.000	0.426	0.004	0.001
610	204.675	54.939	0.000	59.427	0.002	0.041	0.004	2.267	0.218	0.001
611	197.020	41.133	0.000	80.747	0.000	0.001	0.000	0.541	0.089	0.001
612	754.372	154.158	258.113	561.013	0.001	0.016	0.002	1.689	0.432	0.002
613	500.344	127.891	223.891	418.397	0.001	0.013	0.001	1.371	0.248	0.002
614	901.742	263.947	754.249	1022.393	0.001	0.001	0.001	3.195	0.958	0.001
615	1003.248	17.455	1054.824	1073.685	0.000	0.000	0.000	5.219	1.396	0.001
616	569.065	140.355	411.137	585.067	0.000	0.001	0.000	1.592	0.411	0.001
617	628.140	191.602	538.852	733.077	0.000	0.000	0.000	2.239	0.600	0.001

RCH File

SUBBASIN	DATE	FLOW_IN	FLOW_OUT	EVAP	TLOSS	SED_IN	SED_OUT	SEDCONC	ORGN
1	1998	2.42600	2.42300	0.00009	0.07520	0.00255	0.00255	0.00008	
2	1998	10.28000	10.28000	0.00006	0.04897	4190000.00000	11390000.00000	35230.00000	
3	1998	2.51500	2.51500	0.00009	0.07271	6.78600	2245000.00000	25830.00000	
4	1998	10.26000	10.26000	0.00007	0.05807	12620000.00000	14680000.00000	41550.00000	
5	1998	16.01000	16.00000	0.00005	0.04586	21370000.00000	23660000.00000	44990.00000	
6	1998	13.01000	13.02000	0.00005	0.04377	16800000.00000	19030000.00000	46360.00000	
7	1998	6.88500	6.88500	0.00007	0.05904	6711000.00000	9107000.00000	36660.00000	
8	1998	3.09200	3.09400	0.00008	0.07051	1775000.00000	3515000.00000	31820.00000	
9	1998	2.23700	2.23900	0.00007	0.05867	0.37800	2045000.00000	22840.00000	
10	1998	2.92500	2.92600	0.00007	0.05459	0.00322	2702000.00000	23930.00000	
11	1998	29.24000	29.24000	0.00004	0.03074	44680000.00000	45540000.00000	49330.00000	
12	1998	2.66000	2.66200	0.00007	0.05325	1419000.00000	2988000.00000	22100.00000	
13	1998	1.04400	1.04600	0.00004	0.04101	0.62570	0.62570	0.00763	
14	1998	1.56500	1.56600	0.00004	0.03917	33.45000	1419000.00000	15860.00000	
15	1998	0.37020	0.36990	0.00001	0.02389	31.65000	31.65000	2.17300	
16	1998	0.73200	0.73170	0.00003	0.03680	1.79600	1.79600	0.03244	
17	1998	1.96700	1.96700	0.00009	0.07142	6.78500	6.78500	0.01055	
18	1998	1.52300	1.52500	0.00007	0.06230	5.77000	5.77000	0.01787	
19	1998	1.97200	1.97500	0.00007	0.05999	6.82200	1775000.00000	25390.00000	
20	1998	5.16600	5.16600	0.00007	0.05319	4746000.00000	6711000.00000	34760.00000	
21	1998	2.23500	2.23700	0.00007	0.06008	0.37760	0.37760	0.00797	
22	1998	2.92400	2.92500	0.00006	0.05416	0.00290	0.00290	0.00034	

ORGN_IN	ORGN_OUT	ORGP_IN	ORGP_OUT	NO3_IN	NO3_OUT	NH4_IN	NH4_OUT
4.46400	3675.00000	8.92700	821.80000	29690.00000	29090.00000	0.00000	18.760
202500.00000	166100.00000	18040.00000	13750.00000	148300.00000	148200.00000	87550.00000	87790.000
6711.00000	8788.00000	1486.00000	1773.00000	35120.00000	34460.00000	48.25000	1242.000
22400.00000	22480.00000	4193.00000	3898.00000	105800.00000	105600.00000	5761.00000	7526.000
36660.00000	38360.00000	6504.00000	6493.00000	189500.00000	190100.00000	12340.00000	14880.000
139100.00000	113100.00000	11160.00000	8435.00000	212100.00000	222800.00000	82170.00000	94570.000
8449.00000	11110.00000	1535.00000	2026.00000	70290.00000	69280.00000	2656.00000	3281.000
8960.00000	11290.00000	1826.00000	2167.00000	32960.00000	32080.00000	1168.00000	2480.000
3964.00000	4460.00000	885.50000	890.20000	21990.00000	21610.00000	20.11000	733.500
3315.00000	4171.00000	742.30000	843.90000	27890.00000	27360.00000	21.05000	618.500
129700.00000	110400.00000	12510.00000	10360.00000	463800.00000	463900.00000	92400.00000	112400.000
10940.00000	10770.00000	2174.00000	1937.00000	881300.00000	882000.00000	1674.00000	2924.000
8.32800	2094.00000	15.35000	482.00000	163500.00000	175000.00000	0.00000	21.750
8675.00000	8849.00000	1855.00000	1691.00000	666100.00000	662900.00000	160.40000	1652.000
804.90000	5261.00000	79.28000	1082.00000	50310.00000	42420.00000	0.00000	147.500
14.57000	3413.00000	22.16000	769.90000	75960.00000	74020.00000	0.00000	12.940
172.10000	6711.00000	35.22000	1485.00000	31230.00000	30380.00000	0.00000	48.250
148.40000	6311.00000	31.60000	1398.00000	21190.00000	20670.00000	0.00000	40.380
6313.00000	8957.00000	1399.00000	1822.00000	25120.00000	24330.00000	40.38000	1168.000
8631.00000	8448.00000	1734.00000	1532.00000	48980.00000	48550.00000	1352.00000	2656.000
13.93000	3964.00000	10.57000	885.50000	22510.00000	21980.00000	0.00000	20.110
4.53800	3315.00000	9.07600	742.30000	28470.00000	27890.00000	0.00000	21.050

NO2_IN	NO2_OUT	MINP_IN	MINP_OUT	CHLA_IN	CHLA_OUT	CBOD_IN	CBOD_O
0.00000	0.00000	5556.00000	5426.00000	9176.00000	2427.00000	0.00000	0.
1859.00000	35680.00000	41250.00000	46190.00000	19040.00000	10900.00000	0.00000	0.
0.00000	15.05000	5871.00000	6144.00000	8013.00000	2724.00000	0.00000	0.
1252.00000	2343.00000	27300.00000	28270.00000	11420.00000	6955.00000	0.00000	0.
3488.00000	4920.00000	44530.00000	46010.00000	22690.00000	14410.00000	0.00000	0.
37520.00000	37300.00000	56110.00000	59030.00000	10090.00000	6849.00000	0.00000	0.
223.80000	992.30000	18960.00000	19160.00000	10090.00000	4983.00000	0.00000	0.
10.01000	259.70000	6897.00000	7219.00000	9700.00000	3025.00000	0.00000	0.
0.00000	7.56900	4843.00000	5011.00000	3115.00000	1179.00000	0.00000	0.
0.00000	7.75400	7430.00000	7536.00000	3583.00000	1569.00000	0.00000	0.
47150.00000	47440.00000	110700.00000	113800.00000	20140.00000	14330.00000	0.00000	0.
61.70000	709.20000	7737.00000	8329.00000	5048.00000	3211.00000	0.00000	0.
0.00000	0.00000	485.70000	491.20000	4622.00000	1413.00000	0.00000	0.
0.00000	61.70000	6748.00000	7245.00000	4697.00000	2765.00000	0.00000	0.
0.00000	0.00000	4298.00000	4225.00000	10560.00000	1683.00000	0.00000	0.
0.00000	0.00000	2554.00000	2505.00000	7555.00000	1654.00000	0.00000	0.
0.00000	0.00000	4782.00000	4607.00000	14680.00000	3199.00000	5747.00000	0.
0.00000	0.00000	2858.00000	2748.00000	13740.00000	2170.00000	4244.00000	0.
0.00000	10.01000	4068.00000	4298.00000	9081.00000	2097.00000	0.00000	0.
15.32000	223.80000	12550.00000	12940.00000	3829.00000	2141.00000	0.00000	0.
0.00000	0.00000	4958.00000	4841.00000	8941.00000	2076.00000	35.57000	0.
0.00000	0.00000	7555.00000	7430.00000	7541.00000	2545.00000	0.00000	0.

CBOD_OUT	DISOX_IN	DISOX_OUT	SOLPST_IN	SOLPST_OUT	SORPST_IN	SORPST_OUT
0.00000	344900.00000	19870000.00000	306800000.00000	304500000.00000	0.00000	0.00000
0.00000	18810000.00000	91040000.00000	455000000.00000	451400000.00000	0.00000	0.00000
0.00000	14330000.00000	5509000.00000	201900000.00000	199900000.00000	0.00000	0.00000
0.00000	45200000.00000	14770000.00000	543100000.00000	538500000.00000	0.00000	0.00000
0.00000	167900000.00000	42170000.00000	844000000.00000	837100000.00000	0.00000	0.00000
0.00000	5622000.00000	174300000.00000	749800000.00000	743800000.00000	0.00000	0.00000
0.00000	58900000.00000	14720000.00000	283300000.00000	280900000.00000	0.00000	0.00000
0.00000	4876000.00000	30430000.00000	264300000.00000	262200000.00000	0.00000	0.00000
0.00000	18950000.00000	3329000.00000	138800000.00000	137600000.00000	0.00000	0.00000
0.00000	23440000.00000	6264000.00000	149400000.00000	148100000.00000	0.00000	0.00000
0.00000	6113000.00000	406600000.00000	1568000000.00000	1556000000.00000	0.00000	0.00000
0.00000	13910000.00000	0.00000	87460000.00000	86770000.00000	0.00000	0.00000
0.00000	180400.00000	6734000.00000	0.00000	0.00000	0.00000	0.00000
0.00000	3834000.00000	7172000.00000	88360000.00000	87460000.00000	0.00000	0.00000
0.00000	107400.00000	352900.00000	29650000.00000	29050000.00000	0.00000	0.00000
0.00000	154200.00000	3417000.00000	60360000.00000	59310000.00000	0.00000	0.00000
0.00000	308900.00000	14270000.00000	204200000.00000	201900000.00000	0.00000	0.00000
0.00000	238300.00000	11260000.00000	239000000.00000	236800000.00000	0.00000	0.00000
0.00000	11330000.00000	4751000.00000	248700000.00000	246600000.00000	0.00000	0.00000
0.00000	9593000.00000	58630000.00000	285700000.00000	283300000.00000	0.00000	0.00000
0.00000	294800.00000	18950000.00000	140000000.00000	138800000.00000	0.00000	0.00000
0.00000	420000.00000	23440000.00000	150700000.00000	149400000.00000	0.00000	0.00000

REACTPST	VOLPST	SETTLPST	RESUSP_PST	DIFFUSEPST	REACBEDPST	BURYPST	BED_PST
2148000.00000	1009000.00000	0.00000	1038.00000	99370.00000	40340.00000	57620.00000	684.700
3185000.00000	722800.00000	0.00000	382.40000	71730.00000	29290.00000	41850.00000	355.200
1413000.00000	723100.00000	0.00000	855.50000	71100.00000	28950.00000	41360.00000	17.920
3801000.00000	822400.00000	0.00000	392.90000	81670.00000	33450.00000	47790.00000	62.980
5908000.00000	1031000.00000	0.00000	372.70000	102600.00000	42100.00000	60140.00000	53.110
5249000.00000	955800.00000	0.00000	417.00000	94990.00000	38820.00000	55450.00000	545.300
1983000.00000	531400.00000	0.00000	321.50000	52680.00000	21550.00000	30790.00000	40.010
1850000.00000	1001000.00000	0.00000	1000.00000	98580.00000	40170.00000	57390.00000	61.880
971700.00000	554200.00000	0.00000	816.60000	54220.00000	21970.00000	31390.00000	49.430
1046000.00000	459900.00000	0.00000	548.50000	45210.00000	18380.00000	26260.00000	34.730
10980000.00000	1363000.00000	0.00000	326.90000	135800.00000	55640.00000	79480.00000	523.600
612200.00000	262500.00000	0.00000	934.10000	24780.00000	9832.00000	14050.00000	40.310
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.000
618500.00000	435700.00000	0.00000	2265.00000	39940.00000	15540.00000	22210.00000	33.820
207000.00000	235100.00000	0.00000	5447.00000	17380.00000	70600.00000	22480.00000	4846.000
422400.00000	520000.00000	0.00000	4876.00000	45430.00000	29890.00000	34500.00000	411.600
1429000.00000	826500.00000	0.00000	1097.00000	81080.00000	32970.00000	47100.00000	22.100
1673000.00000	1166000.00000	0.00000	1933.00000	113700.00000	45970.00000	65680.00000	115.800
1741000.00000	1099000.00000	0.00000	1384.00000	107800.00000	43810.00000	62580.00000	90.530
2000000.00000	614200.00000	0.00000	540.90000	60640.00000	24730.00000	35320.00000	62.620
980100.00000	563600.00000	0.00000	852.20000	55090.00000	22320.00000	31880.00000	59.750
1055000.00000	464400.00000	0.00000	552.30000	45660.00000	18570.00000	26520.00000	34.110

BACTP_OUT	BACTLP_OUT	CMETAL_1	CMETAL_2	CMETAL_3
0.00073	0.00073	0.00000	0.00000	0.00000
0.00217	0.00217	0.00000	0.00000	0.00000
0.00146	0.00146	0.00000	0.00000	0.00000
0.00700	0.00700	0.00000	0.00000	0.00000
0.00992	0.00992	0.00000	0.00000	0.00000
0.00436	0.00436	0.00000	0.00000	0.00000
0.00410	0.00410	0.00000	0.00000	0.00000
0.00218	0.00218	0.00000	0.00000	0.00000
0.00136	0.00136	0.00000	0.00000	0.00000
0.00137	0.00137	0.00000	0.00000	0.00000
0.01571	0.01571	0.00000	0.00000	0.00000
0.00365	0.00365	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00219	0.00219	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00145	0.00145	0.00000	0.00000	0.00000
0.00338	0.00338	0.00000	0.00000	0.00000
0.00073	0.00073	0.00000	0.00000	0.00000
0.00072	0.00072	0.00000	0.00000	0.00000