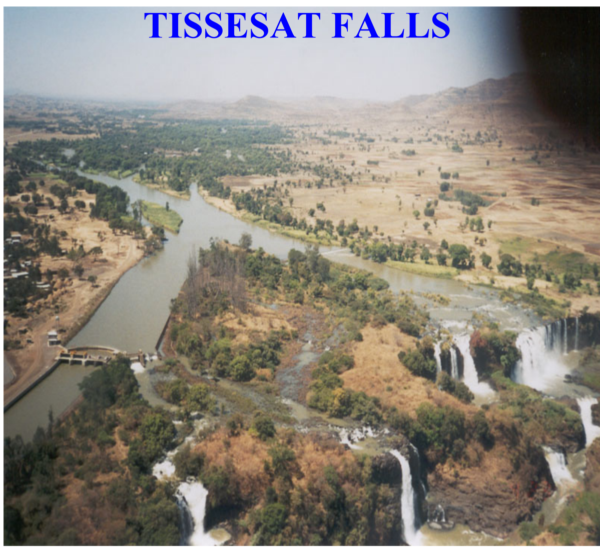
DEVELOPMENT OF RAINFALL-RUNOFF-SEDIMENT DISCHARGE RELATIONSHIP IN BLUE NILE BASIN



M.Sc Thesis

By

Fikadu Fetene Worku

ARBA MINCH UNIVERSITY SCHOOL OF GRADUATE STUDIES

ARBA MINCH, ETHIOPIA

October, 2008

DEVELOPMENT OF RAINFALL-RUNOFF-SEDIMENT DISCHARGE RELATIONSHIP IN BLUE NILE BASIN

Master of Science Thesis

By

Fikadu Fetene Worku

Thesis submitted to Arba Minch University, School of Graduate Studies as partial fulfillment of the requirements for the degree of Master of Science in Hydraulic/Hydropower Engineering.

Supervisor: Dr. Ing. Seleshi Bekele (IWMI, Ethiopia)

Co Supervisor: Dr. Ing. Nigusie Teklie (AMU, Ethiopia)

AMU

October 2008

Acknowledgement

The Mercy and Glory of God is helped me to complete my work and in all my life, great, great thanks to Almighty God.

I would like to pass my sincere thanks to Nile Basin Initiative, Applied Training Program office who awarded me the fund to follow my study and Dr. Semu Ayalewu who arranged every thing for me to attend my study here. Similarly, great appreciation for International Water Management Institute (IWMI) who granted me part of my research work.

My greatest gratitude goes to my advisor Dr. Ing. Seleshi Bekele who gave me the chance to do my thesis on this area together with him and contributing great effort to bring this paper to come true by sacrificing his valuable time and advising me the direction and the way. I have enormous thanks for Dr. Ing. Nigusie Teklie who encouraged me to proceed my thesis work on this title from his experience on the topic and guide me the way.

I would like to express my heartfelt gratitude to those who have input in my work, especially Ato Kassa Tadele, who scarify his time patiently to solve the trouble of my work and encouraged me when I lost hope. Like wise, great appreciation for my friends who morally and kindly support me during my thesis work. I would never forget the encouragement, consideration of my best friend Fiseha Behulu, who distance never barrier him to motivate me during my study from abroad.

My grand appreciation directed to all my friends of Mahibere Kidusan who support me in moral and idea in their prayer.

My utmost praise for my family who encouraged me in my life to be here and their prayer helps me to be a man.

Abstract

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 7^0 45'-12^0 45' N and 34^0 05'-39^0 45' E.

From its geographic location, the Blue Nile region is the main contributor to Nile flood flows.

In Ethiopia only it comprises 18 percent of the total surface area of the country (199,812 km^2 out of 1.1Mkm^2) with mean annual discharge of 48.5 Km^3.

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. Many farmers in Ethiopia's highlands cultivate sloped or hilly land, causing topsoil to wash away.

The objective of this study was to determine rainfall, runoff and sediment yield relationship in Blue Nile basins and specifically to analysis spatiotemporal distribution of sediments in the Blue Nile catchment; moreover, to identify susceptible regions for erosion and deposition.

To analysis this, SWAT model was applied with methodology of collecting hydro metrological data, sediment data, topographic, land use and soil map data and by overlying mechanism, the model run.

SWAT was successfully calibrated and validated for measured stream flow at Bahirdar, at near Kessie and at Sudan Border for flow gauging stations and for measured sediment yield at Gilgel Abbay, Addis Zemen and near Kessie gauging stations in the Blue Nile Basin. The model performance evaluation statistics (Nash–Sutcliffe model efficiency (E_{NS}), coefficient of determination (r^2)) are in the acceptable rang, (r^2 in the range of 0.71 to 0.91 and E_{NS} in the range of 0.65 to 0.90).

From the model simulated result, it was found that the Guder, N.Gojam and Jemma sub basins are the severely eroded area with 34% of sediment yield of the Blue Nile are from these sub basins. Similarly, the Dinder, Beshilo and Rahad sub basins cover only 7% of sediment yield of the basin.

The annual average sediment yield for the whole Blue Nile is 4.26 t/ha/yr and total 91.3 Million tones eroded from the whole Blue Nile Basin in Ethiopia.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

List of symbols

μm	micro meter
D	Diameter
Km^2	Square kilometer
SWAT	Soil and Water Assessment Tool
N	North direction
E	east direction
Km	kilometer
M	meter unit
Km^3	cubic kilometer
Mkm^2	Million square kilometer
Bm3	Billion cubic meter
mm	millimeter unit
^0c	degree centigrade
HEC-HMS	Hydrologic Engineering Center, Hydrological Model Simulation
MOWBAL	Monthly Water Balance Model
USLE	Universal Soil Loss Equation,
RUSLE	Revised Universal Soil Loss Equation,
MUSLE	Modified Universal Soil Losses Equation,
KINEROS	Kinematics Runoff and Erosion Model,
WEPP	Water Erosion Prediction Project
ARS	Agricultural Research Service
USDA	United States of department of Agriculture
GIS	Geographic Information System
ET	Evapotranspiration
HRU	Hydrological Response Unit
SCS	Soil Conservation Service
H_2O	water
NRCS	Natural Resource Conservation Service
PET	Potential Evapotranspiration
mg/L	milligram per liter
AMU	Arba Minch University
SGS	school of graduate studies

DEM	Digital Elevation Model
m.a.s.l	mean above see level
PET	potential evaporation
t/ha/yr	tones per hectare per year
SW	shallow water flow (mm)
Precip	precipitation (mm)
Perc	percolation (mm)
SWR_Q	surface runoff (mm)
GW_Q	Ground water flow (mm)

1. INTRODUCTION

1.1 Background

Although sampling to assess transport of water quality constituents in runoff has been conducted for many years, relatively little information is available on the uncertainty of measured data. The need to understand uncertainty in measured water quality data has recently increased because of the adverse impact of diffuse or non point-source pollution on rivers, lakes, and coastal waters (USEPA, 2000) and the intensified disputes regarding relative contributions of diffuse and point-source pollution (e.g., McFarland and Hauck, 2001). The issue of uncertainty is particularly important in water quality modeling because models are increasingly used to guide decisions regarding water resource policy, management, and regulation (Beck, 1987; Sharpley et al., 2002). It is important that decision makers appreciate the uncertainty in measured water quality data and its effect on model output. The scientific community, however, has not compiled an adequate understanding on the uncertainty of measured runoff water quality data and has not adequately described the effects of uncertainty on water quality management.

The quantification of individual components of the hydrologic cycle, especially at catchment scale is a crucial step in integrated watershed management. In addition to data scarcity, now a day the challenging task that hydrologists, water resource managers and professionals who are dealing with hydrologic aspects of water face is the accuracy of methods to estimate the components.

In fact, one of the evidence attached to our real world systems (that consist of various geographic phenomena) is the spatial and temporal variability of any process within the system. Data capturing and analysis of a hydrologic system seeks an advanced tool to account for this variability.

Establishing a relationship among hydrological components is the central focus of hydrological modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. As the computing capabilities are increasing, the use of these models to simulate a catchment became a standard. Models are generally used as utility in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (intervention of watershed conservation practices).

Compared to humid, climate hydrological studies are often hindered in semi-arid and arid areas by the limited availability of relevant data and information. The main reasons for this are: 1) Quite a lot of river basins are un-gauged, 2) unavailability of high resolution spatial and temporal data like digital elevation model, soil properties, land use, and climate data of the basins. Moreover in gauged river basins, finding all the information essential for understanding the hydrological process is difficult due to the limited range of measurement techniques in space and time (Beven, 1999). For such conditions, hydrological models provide an alternative solution. There are two basic advantages using hydrological models instead of relying only on collected data. In the first place models can be used to understand the processes that are difficult to measure due to the complexity of temporal and/or spatial scale and inaccessibility. Secondly, a model can be used to study the effect of changes in land cover, water management or climate (Kite and Droogers, 2001).

Sediment is a fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from round to angular.

Once the sediment particles are detached, they may either be transported by gravity, wind or/ and water.

When the transporting agent is water, it is called fluvial or marine sediment transport. The process of moving and removing from their original sources or resting place is called erosion. In a channel the water flow erodes the available material in the banks and/ or the streams bed until the flow is loaded with as much as sediment particles as the energy of the stream will allow it to carry. Usually, three modes of particle motion are distinguished: rolling and/ or sliding particle motion, saltating or hopping particle motion and suspended particle motion (Leo C. van Rijn, Jan 1993).

Sediments are all the basin rock and soil particles water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. The finer the particles and/ or the stronger the flow turbulence, the greater is the transport in suspension.

Sediment transport by flowing water is strongly linked to surface soil erosion due to rain on a given catchments. Water seeping in to the ground can contribute to landslides (subsurface erosion) which may become major sources of sediments for rivers.

The whole process can be seen as a continuous cycle of: Soil erosion= detachment + transport + deposition.

Soil erosion and sediment yield strongly depend on the local climatic (rainfall), soil type, land use, slope of the catchments, and vegetation condition, etc. There is no universal formula for sediment yield, depending on the local condition and data, regional formula have been developed (Leo C. van Rijn, Jan 1993).

Sediment transport deals with flow of water and sediment particles. Therefore, properties and theories of both water flow and sedimentation are important. Sediment is transported in water bodies as suspended load and bed load. Bed load is defined as the sediment load which moves along the bed. Suspended load is defined as the sediment load which moves in suspension and occupies the entire flow depth above the bed load layer. According to the mechanism of suspension the suspended sediment may belong to the bed material load and the wash load. Wash load is defined as the transport of material finer than the bed material. The discharge of the wash load through a reach depends only on the rate with which these particles become available in the catchment area and not on the transport capacity of flow. Usually a diameter D with 50 μm< D < 70 μm is taken as a practical distinction between wash load and bed material load (Jansen, et al., 1979). The distinction between bed load and suspended load can not be defined sharply. Not only the grain size but also the flow conditions characterize the distinction (Jansen, et al., 1979).

1.2 Problem Statement and Justification

Some of the studies that have been conducted in the past are highly dependent on the ground based observations that leads to further error in their outputs. However, for organizations and/or professionals working on the hydrological events and watershed management, a proper and accurate quantification of the components of the hydrologic cycle is essential; so that a proper decision support system can be built at basin scale. The difficulty is to quantify the individual components of the hydrologic cycle specifically the rainfall and flood to get the tool for the purpose of flood erosion and sediment transport.

The Blue Nile river basin is the largest river basin in Ethiopia discharges maximum outflow to the main Nile basin, but has data scarcity to quantify exactly the discharge outflow and sediment yield and transported from the basin.

The Blue Nile basin is characterized by arid climatic conditions and erratic rainfall (seasonal), and often hit by recurring flood and serious sediment discharge that eroded the high mountainous area of Ethiopia and affects the land use and different reservoirs of lowland of Ethiopia, Sudan and Egypt by deposition. Recurrent flood events cause serious economic, life, social and environmental problems and devastating particularly the agricultural economy and life of the residence.

Flood discharge, and sediment carried assessment and monitoring for the basin using conventional methods which rely on the availability of weather data, field measurement are tedious, costly and time consuming. On the other hand, these weather data and field data are often incomplete and limited in the basin and will be.

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. Many farmers in Ethiopia’s highlands cultivate sloped or hilly land, causing topsoil to wash away during the torrential rains of the rainy season. The rains also leach the highland soils of much fertility. In most of part of Ethiopia the high intensity rainfall occurs during the time where the cultivated land will have low cover, which can reduce the impact of the high intensity raindrop and the high runoff which can be slowed by soil cover.

With the fast growing population and the density of livestock in the basin, there is pressure on the land resources, resulting in even forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation. High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation &maintenance and shortening lifespan of water resources infrastructure.

Specifically, the problems and constraints in the study area lack of sediment data, difficulty of gathering this data, variation of land management due to highly increasing deforestation for search of agricultural land and climate change makes the things difficult and this study with little effort and cost, continuously can predict sediment yield in the basin and sediment transported with streams flow.

1.3 Objective of the study

The objective of this study was to determine rainfall, runoff and sediment yield relationship in Blue Nile basins.
The specific objectives of the studies are:

1. determination of spatiotemporal distribution of sediments in the Blue Nile basin,
2. to evaluate applicability of SWAT model in predicting sediment yield and concentration in the Blue Nile basin,
3. To analyze the lag time of Hydrograph, LAG and lag time of sediment graph, LAGs.
4. Identify sensitive regions for erosion and deposition.

1.4 Description of the Study Area

1.4.1 LOCATION

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 7^0 45'-12^0 45' N and 34^0 05'-39^0 45' E. The study area covers about 199,812 square kilometers with a total perimeter of 2440 Km.

From its geographic location, the Blue Nile region is the main contributor to Nile flood flows. A schematic of the area of interest for this study with corresponding rain gauge stations is shown in figure 1 for illustration. Most of the important tributaries of the Blue Nile are located in the Ethiopian highlands (North western part of the country) with elevation ranging from about 300 to 4200m above mean sea level. According to recent study by Conway (2000), in Ethiopia only it comprises 17.1 percent of the total surface area of the country excluding Dindar and Rahad sub basins (176 000km^2, out of 1.1Mkm^2) with mean annual discharge of 48.5 Km^3. The source of the Blue Nile is a small spring at a height of 2,900 m and at about 100 km south of Lake Tana (Volume III of Nile Basin, Hurst, 1950). Most of the Ethiopian Plateau country is hilly with grassy downs, swamps valleys, and scattered trees. The high country is cut up by deep ravines or canyons in which the rivers flow. In some places the Blue Nile flows in a channel that is about 1,200 m below the level of the country on either side. Numerous rock-outcrops occur in the river bed, the last of which are a few kilometers south of Roseires, some 1,000 km from its source beyond Tana and known as the Damazin Rapids. The Blue Nile emerges from the Plateau close to the western border of

Ethiopia, where it runs north-west and enters the Sudan at an altitude of 490 m. Just before crossing the frontier, the river enters the clay plain, through which it flows to Khartoum. At this point, the Blue Nile joins the White Nile to form the main stem of the Nile River. The area bounded of these two rivers is known as the Gezira Plain. The Rahad and Dinder main tributaries rivers of Nile meet with Nile River in Sudan (Conway 2000).

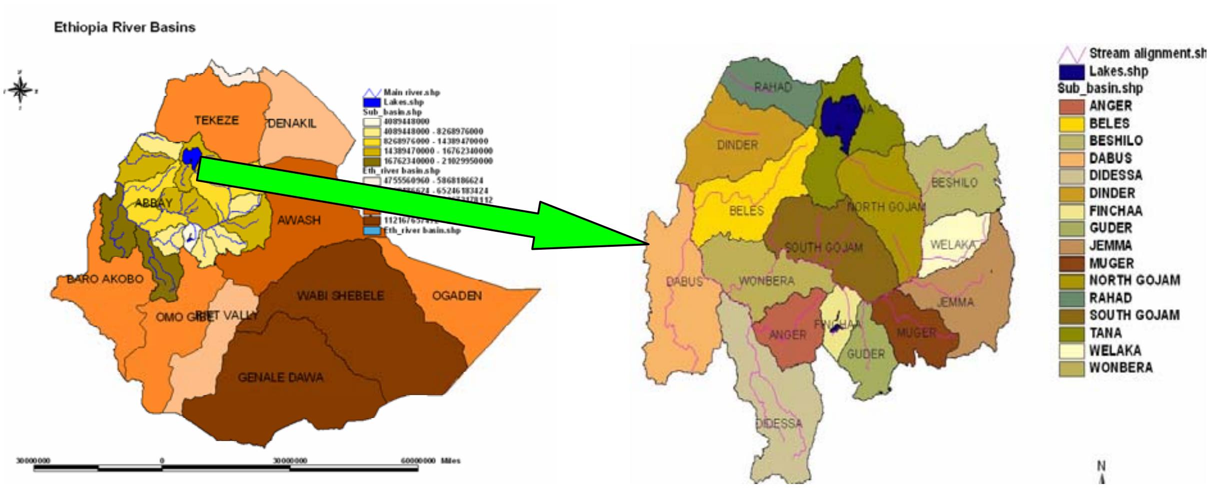


Figure 1.1 Ethiopian Major River Basins and sub basins of Blue Nile basin

(Source: Ministry of Water Resources)

1.4.2 TOPOGRAPHY

Blue Nile is characterized by highly varying topography, altitude ranges from 344m downstream up to 4261m in the highlands of Upper Blue Nile, and flat (plain) topography in the lower Blue Nile at the border of Sudan and ragged mountainous in the Ethiopian highlands (Simen Mountainous).

1.4.3 CLIMATE AND HYDROLOGY

The climate of the Abbay basin is humid to sub-humid in the highlands and semi-arid to arid in the Sudan border. The annual rainfall over the basin decreases from the south west (>2000 mm) to the north east (around 1000 mm), with about 70 per cent occurring between June and September (Conway, 2000). Conway (1997) explained that the Blue Nile is characterized by severe seasonality with average annual flow of about 50 km^3 measured at the basin outlet at El Diem station near the Sudan-Ethiopia border. More than 80% of this flow occurs during the flood season between July and September, while only 4% of that flow occurs during the driest period January-April. In the basin, annual mean PE and rainfall range, with increasing elevation, from 800mm to 2220mm and 924mm to 1845mm, respectively.

Climate in the highlands is strongly influenced by the effects of elevation, which makes the basin ideal for estimating climate variables based on empirical relationships with elevations. The climate is generally temperate at higher elevations and tropical at lower elevations. The traditional classification of climate in the basin uses elevation as a controlling factor and recognized the following three regions:

1. The *Kolla* zone below 1800m has mean annual temperatures in the range 20-28^{o}C
2. The *Woina Dega* zone between 1800-2400m has mean annual temperatures in the range 16-20^{o}C; and
3. The *Dega* zone above 2400 has mean annual temperatures in the range 6-16^{o}C

According to the amount of rainfall received in the area the upper Blue Nile basin will have different number of seasons.

Two Seasons*:* The western half of Ethiopia has two distinct seasons (wet from June-September and dry from November-February), with the rainfall peak occurring from July to August.

Three Seasons*:* The central and most of the eastern part of the country have two rainy periods and one dry period. These season are known locally as the main Kiremt rains (June - September), small Belg rains, (February-May), and dry Bega season (October-January).

1.4.4 LAND USE

The land use of the study area can be categorized mainly as agricultural, forest, bush, bare-land, savanna, and water bodies. The information contained in the land use map tells how the different uses of the surface are distributed inside the area under study. It can be seen from land use map, that the basin is mainly occupied by Savanna with more than 67% of the basin area. There is also a 20% of the area covered by dry land, cropland and pasture. The rest is mainly woodland and grassland.

1.4.5 SOIL TYPE

The Upper Blue Nile basin is mainly formed from clay and clay-loam soil type, but the riverbed has a loam and sandy-loam type of soil. 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 the water to flow into deep layers. Since the soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soil. This shows that, surface runoff is higher in heavy clay and loamy which has low infiltration rate. As a result of this fact annual surface runoff from Upper Blue Nile basin in Ethiopia is 54.4 BM^3. Throughout the basin the soils are generally vetisols or latosols. The drainage system is well defined; the gradient of most tributaries is steep. Flood water quickly collect in the drainage channels (Hurst et al., 1959) and the loss to overflowing on flood plains or to evaporation is small over much of the basin. Because of the sparse growth of trees, steep slopes, and the shallow and often denuded soil, runoff is rapid and a relatively small amount of rainfall is retained deep percolation or absorption.

As Blue Nile is of international interest especially in recent years many researchers and scholars have carried out many researches on Blue Nile basins from inside and outside the country in different aspects. Blue Nile is the most complicated and unexploited basins in the world, due to its topographic difficulty, fluctuating rainfall and flow, and steep slopes.

1.5 Organization of the Thesis

This thesis is arranged to have six chapters dealing with specific portion of the paper including introduction as the general overview of the study, study area, problem statement and objective of the study.

The second chapter comprises of literature review of the study direction to give the general concepts of the approach of the water sector today and this paper specifically. In this portion it tried to give highlight of the relation of rainfall runoff and sediment with different approaches, empirical, physical, hydrological and model approach. Finally the model which has been applied in this study, SWAT was dealt in detail.

In the next chapter, chapter there the availability of the required data, data collected from different sources and its analysis has been incorporated in short.

Materials required and Methodology followed for the study has been discussed in the fourth chapter in detail and procedurally.

The portion of results and discussion the calibration and validation results of flow and sediment of SWAT model has carried out and the rainfall runoff and sediment relation has been dealt in detail for the gauged and comparison of discharge with measured one and sediment yield at different catchments and total basin figured.

Finally, summary of the work, conclusion and recommendation from the observed results has been incorporated in the paper with references and appendices are attached at the end.

2. LITERATURE REVIEW

2.1 Concepts and Practices of Rainfall-Runoff-Sediment Relationship

Mankind has always been anxious to comprehend and subsequently control the processes of the hydrologic cycle. Many hydrologic phenomena are extremely complex, and thus, they may never be fully understood.

During the past, the processes of the hydrologic cycle were only conceptualized, and causes and effects were just described in relatively simple relations. For example, in ancient Roman times, watercourses were constructed without preceding sound (theoretical) scientific research, yet the construction lasted for ages. Nowadays, however, the state of knowledge and technology makes it possible to even understand rather complex processes of the hydrologic cycle by means of executing a *model* on the computer. Anderson & Woessner, 1992 attempted to define in such away that *model is a simplified representation of a complex system.* The purpose of model is to replace reality, enabling measuring and experimenting in a cheap and quick way, when real experiments are impossible, too expensive, or too time-consuming (Eppink, 1993).

A hydrological system is defined as a set of physical, chemical and/or biological processes acting upon input variables to convert them into output variables (Dooge, 1968**).** In this definition a variable is understood to be a characteristic of the system, which may be measured, assuming different values when measured at different times. A parameter is a quantity characterizing the hydrological system and which is usually assumed to remain constant in time.

Hydrological modeling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling, (Lenhart *et al.* 2002).

There are many classification schemes of hydrologic models, based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle (source: *(Cunderlik 2003)*.

Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow.

Soil erosion models can be separated into models simulating a single hill slope or a single field and models simulating a watershed. Based on their sources of pollutions model can be divided into point sources and non-point sources model. Point sources of pollution are those sources emitted to catchments at a specific point. Common point sources include municipal and industrial pollutants discharged directly to a stream. No point sources are those sources discharged to a catchment in a way that they depend upon the vagaries of the hydrologic cycle to transport them to the stream system. Nutrients, pesticides, salts, bacteria, heavy loads of organic matter, and sediments are considered no point source pollutants (DeCoursey, 1985). No point source pollution is a 'source –transport' problem in which the hydrological cycle provides the transport processes to move the pollutants from the source to groundwater, a stream, or a reservoir. The mode of transport is the flow of water across the soil surface and in stream channels and reservoirs or the flow of water through the soil profile.

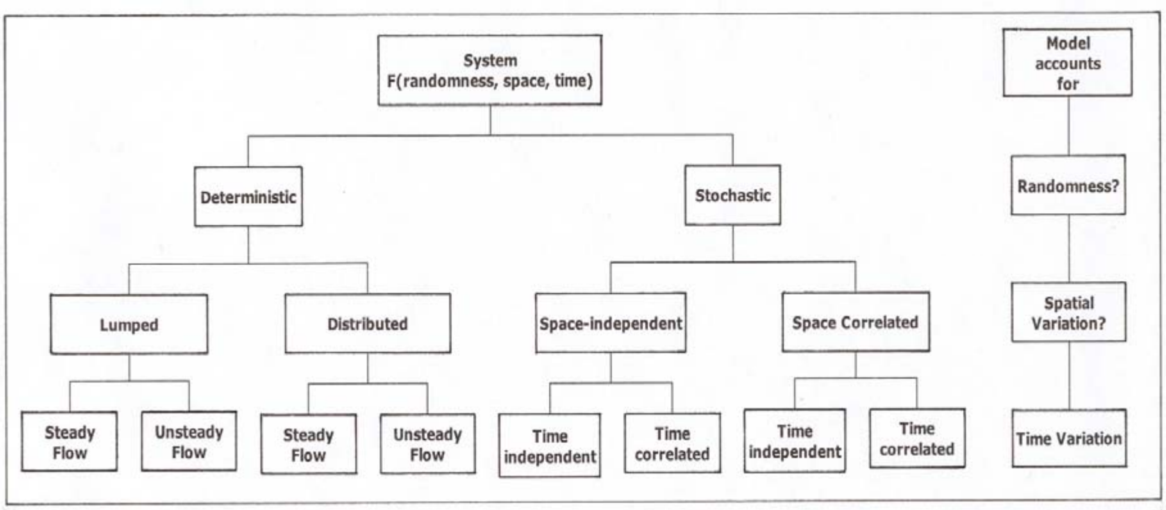


Figure 2.1 Classification of models (Chow et al., 1988)

Determination of accurate runoff rate or volume from the watershed is a difficult task, because runoff is dependant upon several factors related to watershed and atmosphere, prediction of which is not so easy. However, some common runoff estimation methods are Rainfall-Runoff Correlation, Empirical Methods, Rational Method, Infiltration Indices method, Hydrograph Method and using different models now a days, like HEC-HMS, MOWBAL, SWAT model and others.

Several models are available for predicting erosion too, including the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Losses Equation (MUSLE), Kinematics Runoff and Erosion Model (KINEROS), and Water Erosion Prediction Project (WEPP). .

2.1.1 RAINFALL-RUNOFF-SEDIMENT RELATIONS

SWAT is the acronym for **S**oil and **W**ater **A**ssessment **T**ool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA, Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.

To satisfy this objective, the model

- *Is physically based*: rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data.

- *Uses readily available inputs*: while SWAT can be used to study more specialized processes such as sediment transport, the minimum data required to make a run are commonly available from government agencies.

- . *is computationally efficient*: simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.

- *Enables users to study long-term impacts*: many of the problems currently addressed by users involve the gradual buildup of pollutants and the impact on downstream water bodies. To study these types of problems, results are needed from runs with output spanning several decades.
- *Capability for application to large-scale catchments* (>100 km2).
- *Capability for interface with a Geographic Information System* (GIS).

- *Input data requirements* that allow the model to be applied in a wide variety of Ethiopian situations. (Done by few researchers and applicable and gave good results).
- *A model that could be made available as part of a freely accessible package*.

SWAT is a continuous time model, i.e. a long-term yield model; it is not designed to simulate detailed, single-event flood routing. Generally, physically based models are used to simulate a wide range of complex aspects, (Lenhart *et al.* 2002).

2.2 Development of SWAT Model

SWAT incorporates features of several ARS models and is a direct outgrowth of the SWRRB1 model (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). Specific models that contributed significantly to the development of SWAT were CREAMS2 (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS3 (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987), and EPIC4 (Erosion-Productivity Impact Calculator) (Williams et al., 1984).

Development of SWRRB began with modification of the daily rainfall hydrology model from CREAMS.

The major changes made to the CREAMS hydrology model were:

a) The model was expanded to allow simultaneous computations on several sub basins to predict basin water yield;
b) A groundwater or return flow component was added;
c) A reservoir storage component was added to calculate the effect of farm ponds and reservoirs on water and sediment yield;
d) A weather simulation model incorporating data for rainfall, solar radiation, and temperature was added to facilitate long-term simulations and provide temporally and spatially representative weather;
e) The method for predicting the peak runoff rates was improved;
f) The EPIC crop growth model was added to account for annual variation in growth
g) A simple flood routing component was added;
h) Sediment transport components were added to simulate sediment movement through ponds, reservoirs, streams and valleys; and

i) Calculation of transmission losses was incorporated.

Table 2.1 SWAT description

SWAT DESCRIPTION	Performance
Model components/capabilities	Hydrology weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, agricultural management, channel and reservoir routing, water transfer and part of the USEPA BASINS modeling system with user interface and ArcView GIS platform.
Temporal scale	Long term; daily steps
Watersheds representation	Sub-basins, grouped based on climate, Hydrologic Response Units (lumped area with same cover, soil, and management), ponds, ground water and main channel.
Rainfall excess on overland /water balance	Daily water budget; precipitation, runoff, ET, percolation, and return flow from subsurface and ground water flow.
Runoff on overland	Runoff volume using curve number and flow peak using modified Rational formula.
Runoff in channel	Routing based on variable storage coefficient method and flow using Manning's equation adjusted for transmission losses, evaporation, diversions, and return flow
Overland sediment	Sediment yield based on Modified Universal Soil Losses Equation (MUSLE) expressed in terms of runoff volume, peak flow and USLE factors

Source: (Borah and Bera, 2003).

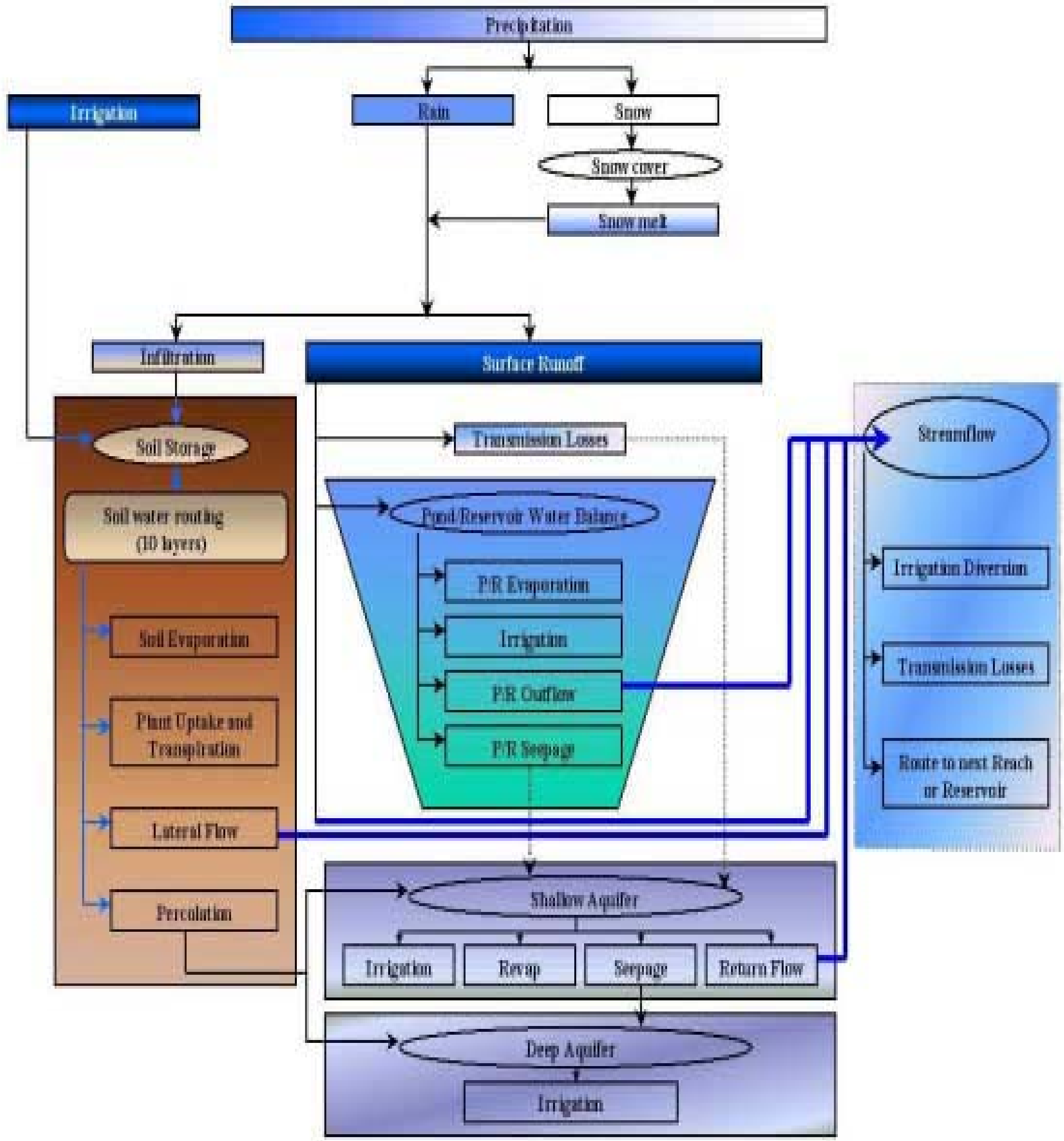


Figure 2.2 over view of SWAT hydrologic component (Arnold et.al, 1998)

No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed. To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed.

Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle, depicted in Figure 2.2. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin.

The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet.

The main components of water balance are discussed below but the detail description of the hydrologic cycle could be seen in (Arnold, Srinivasan, Muttiah and Williams et.al, 1998, Neitsch, Arnold, Kiniry and Williams, et.al, 2005).

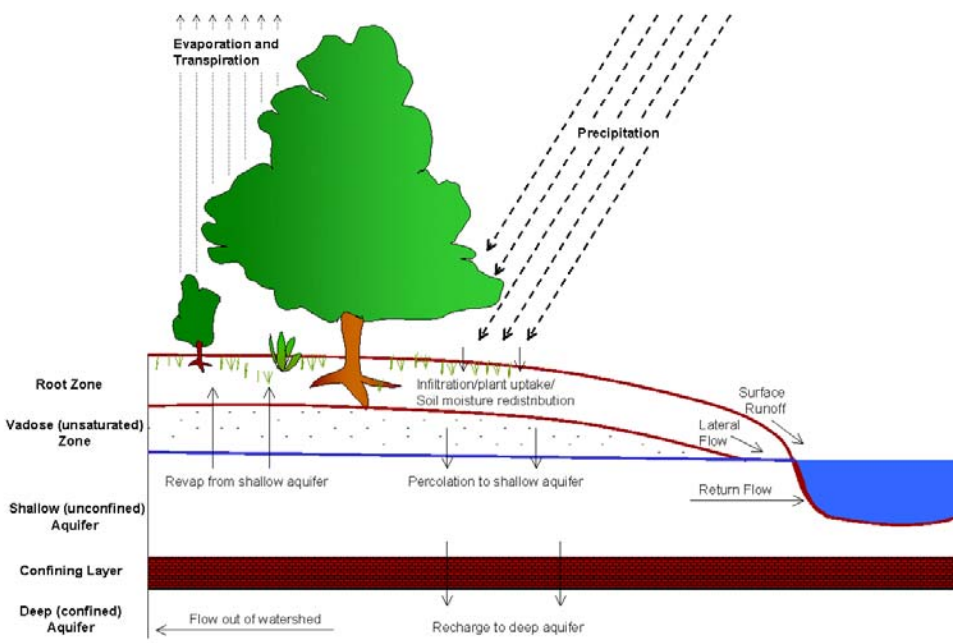


Figure 2.3 Schematic representation of the hydrologic cycle.

2.2.1 LAND PHASE OF THE HYDROLOGIC CYCLE

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

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

Where: SW_t -is the final soil water content (mm H2O), SW_0 -is the initial soil water content on day i (mm H2O), t -is the time (days), R_{day} -is the amount of precipitation on day i (mm H2O), Q_{surf} -is the amount of surface runoff on day i (mm H2O), E_a -is the amount of evapotranspiration on day i (mm H2O), W_{seep} -is the amount of water entering the vadose zone from the soil profile on day *i*(mm H2O), and Q_{gw} -is the amount of return flow on day *i* (mm H2O).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

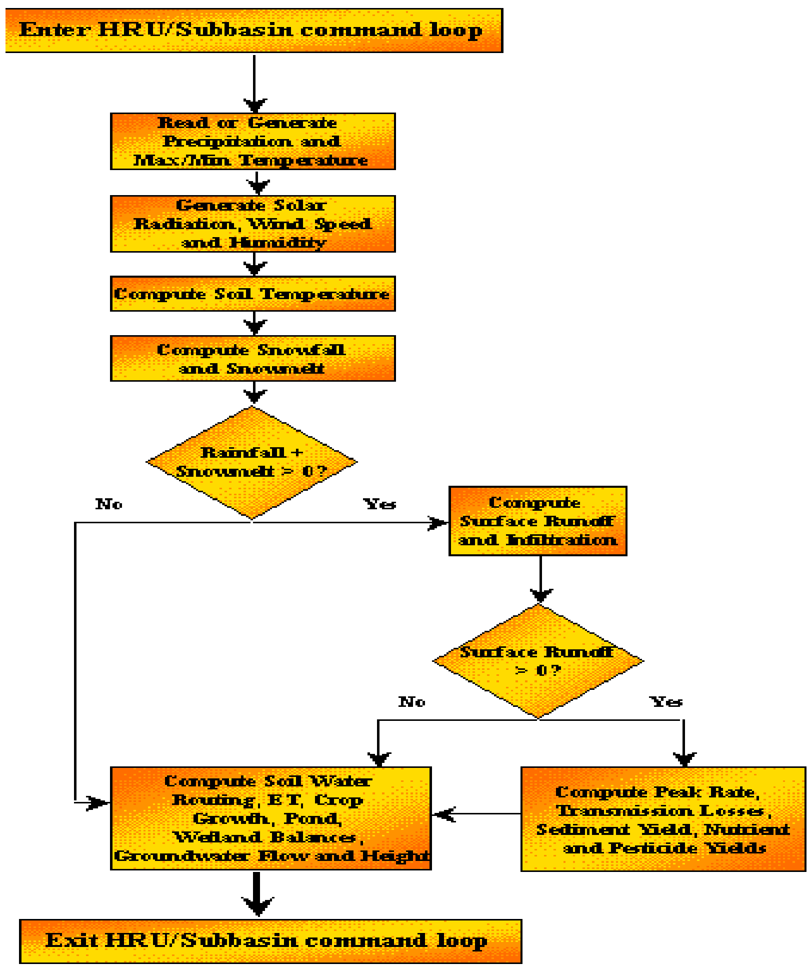


Figure 2.4: HRU/Sub basin command loop

The different inputs and processes involved in this phase of the hydrologic cycle are summarized in the following sections.

The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. The model allows values for daily precipitation, maximum/minimum air temperatures, solar radiation, wind speed and relative humidity to be input from records of observed data or generated during the simulation.

2.2.1.1 Weather Generator

For missing data and shortage of daily data, it is generated from average monthly values. The model generates a set of weather data for each sub basin. The values for any one sub basin will be generated independently and there will be no spatial correlation of generated values between the different sub basins. This are generation of precipitation, temperature, wind speed, solar radiation and relative humidity of a given station in the basin

SWAT uses a model developed by Nicks (1974) to generate daily precipitation for simulations which do not read in measured data. This precipitation model is also used to fill in missing data in the measured records. The precipitation generator uses a first-order Markov chain model to define a day as wet or dry by comparing a random number (0.0-1.0) generated by the model to monthly wet dry probabilities input by the user. If the day is classified as wet, the amount of precipitation is generated from a skewed distribution or a modified exponential distribution.

Maximum and minimum air temperatures and solar radiation are generated from a normal distribution. A continuity equation is incorporated into the generator to account for temperature and radiation variations caused by dry vs. rainy conditions.

2.2.2 HYDROLOGY

As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapo transpired or it may slowly make its way to the surface water system via underground paths. The potential pathways of water movement simulated by SWAT in the HRU are illustrated in Figure 2.4.

2.2.2.1 Surface Runoff

Surface runoff, or overland flow, is flow that occurs along a sloping surface. Using daily or sub daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU.

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter. When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will commence.

Surface Runoff Volume is computed using a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911). In the curve number method, the curve number varies non-linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation.

The Green & Ampt method requires sub daily precipitation data and calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity. Water that does not infiltrate becomes surface runoff. SWAT includes a provision for estimating runoff from frozen soil where a soil is defined as frozen if the temperature in the first soil layer is less than 0°C. The model increases runoff for frozen soils but still allows significant infiltration when the frozen soils are dry.

The SCS curve number equation is (SCS, 1972):

$$\mathbf{Q_{surf}} = \frac{(\mathbf{R_{day}} - \mathbf{I_a})^2}{(\mathbf{R} - \mathbf{I_a} + \mathbf{S})} \qquad (2.5)$$

Where: Q_{surf}: is the accumulated runoff or rainfall excess (mm H2O), R_{day} is the rainfall depth for the day (mm H2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and S is the retention parameter (mm H2O).

The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \quad (2.6)$$

Where, CN- is the curve number for the day.

The initial abstractions, *Ia*, is commonly approximated as 0.2*S* and equation 2.6 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (2.7)$$

Runoff will only occur when $R_{day} > I_a$. A graphical solution of equation 2.7 for different curve number values is presented in Figure 2.5

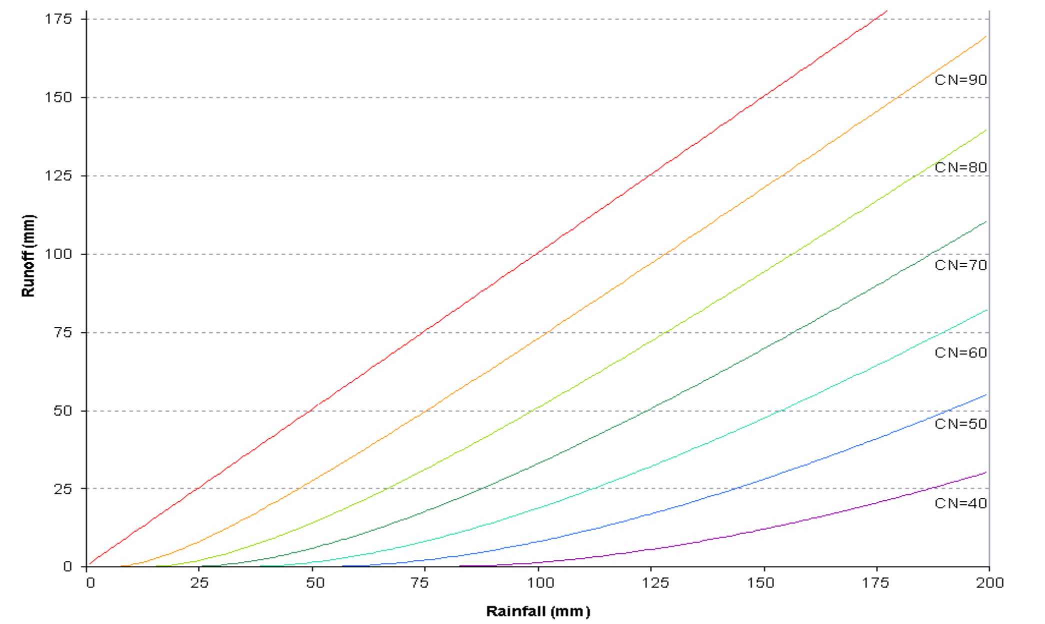


Figure 2.5: Relationship of runoff to rainfall in SCS curve number method

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method.

The rational formula is:

$$q_{peak} = \frac{C \cdot i \cdot Area}{3.6} \quad (2.8)$$

Where: q_{peak}: is the peak runoff rate (m3/s), *C:* is the runoff coefficient, *i-* is the rainfall intensity (mm/hr), *Area-* is the sub basin area (km^2) and 3.6 is a unit conversion factor.

2.2.3 ROUTING PHASE OF THE HYDROLOGIC CYCLE

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure similar to that of HYMO (Williams and Hann, 1972). In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and streambed. Figure 2.6 illustrates the different stream processes modeled by SWAT.

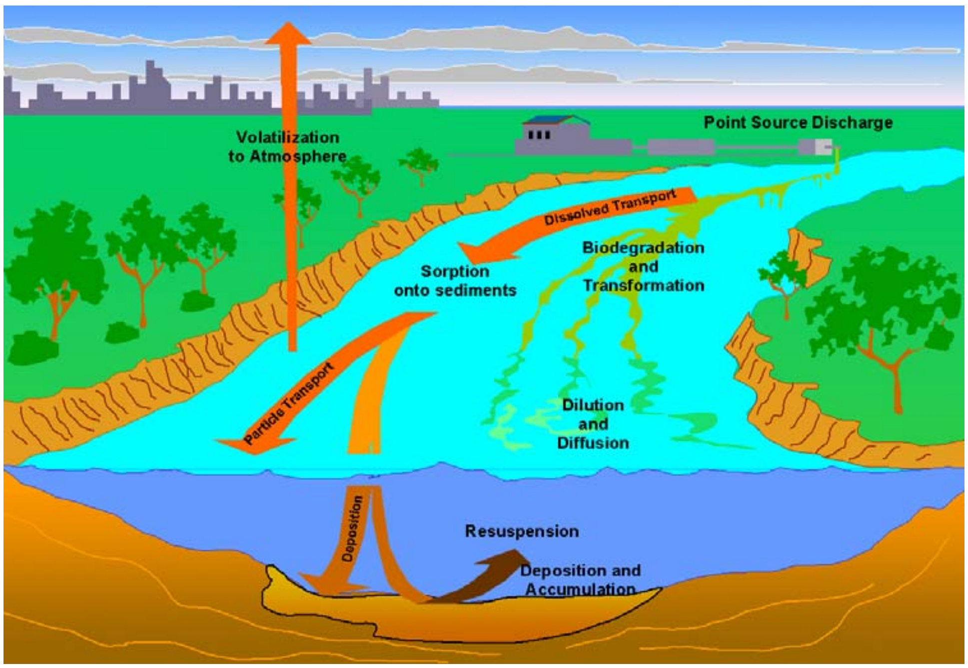


Figure 2.6 : In stream processes modeled by SWAT

2.2.3.1 Routing In the Main Channel or Reach

Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals.

Flood Routing: As water flows downstream, a portion may be lost due to evaporation and transmission through the bed of the channel. Another potential loss is removal of water from the channel for agricultural or human use. Flow may be supplemented by the fall of rain directly on the channel and/or addition of water from point source discharges. Flow is routed through the channel using a *variable storage* coefficient method developed by Williams (1969) or the *Muskingum routing method*.

Sediment Routing: The transport of sediment in the channel is controlled by the simultaneous operation of two processes, deposition and degradation. Previous versions of SWAT used stream power to estimate deposition/degradation in the channels (Arnold et al, 1995). Bagnold (1977) defined stream power as the product of water density, flow rate and water surface slope. Williams (1980) used Bagnold's definition of stream power to develop a method for determining degradation as a function of channel slope and velocity. In this version of SWAT, the equations have been simplified and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. Available stream power is used to re entrain loose and deposited material until all of the material is removed. Excess stream power causes bed degradation. Bed degradation is adjusted for stream bed erodibility and cover.

The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom and diversions.

2.2.3.2 Soil Hydrologic Groups

The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS Soil Survey Staff (1996) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to seasonally high water table, saturated hydraulic conductivity, and depth to a very slowly permeable layer. Soil may be placed in one of four groups, A, B, C, and D, or three dual classes, A/D, B/D, and C/D.
Definitions of the classes are:
A: (Low runoff potential): The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D: (High runoff potential): The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Dual hydrologic groups are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the un drained. Only soils that are rated D in their natural condition are assigned to dual classes.

Mein and Larson (1973) developed a methodology for determining ponding time with infiltration using the Green & Ampt equation. The Green-Ampt Mein-Larson excess rainfall method was incorporated into SWAT to provide an alternative option for determining surface runoff. This method requires sub-daily precipitation data supplied by the user.

Time of Concentration: The time of concentration is the amount of time from the beginning of a rainfall event until the entire sub basin area is contributing to flow at the outlet. In other words, the time of concentration is the time for a drop of water to flow from the remotest point in the sub basin to the sub basin outlet. The time of concentration is calculated by summing the overland flow time (the time it takes for flow from the remotest point in the sub basin to reach the channel) and the channel flow time (the time it takes for flow in the upstream channels to reach the outlet):

$$t_{conc} = t_{ov} + t_{ch} \qquad (2.9)$$

Where: t_{conc} -is the time of concentration for a sub basin (hr), t_{ov} -is the time of concentration for overland flow (hr), and t_{ch} -is the time of concentration for channel flow (hr).

The overland flow time of concentration, ***tov***, can be computed using the equation

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \qquad (2.10)$$

Where: $\boldsymbol{L_{slp}}$ -is the sub basin slope length (m), $\boldsymbol{v_{ov}}$ -is the overland flow velocity (m/s) and 3600 is a unit conversion factor.

The overland flow velocity can be estimated from Manning's equation by considering a strip 1 meter wide down the sloping surface:

$$V_{ov} = \frac{q_{ov}^{\;0.4} * Slp^{0.3}}{n^{0.6}} \qquad (2.11)$$

Where: q_{ov} is the average overland flow rate (m3 s-1), *slp* is the average slope in the sub basin (m/m), and n is Manning's roughness coefficient for the sub basin.

Assuming an average flow rate of 6.35mm/hr and converting units

$$V_{ov} = \frac{0.005 * L_{slp}^{\;0.4} * Slp^{0.3}}{n^{0.6}} \qquad (2.12)$$

From the above two equation we will get:

$$t_{ov} = \frac{L_{slp}^{\;0.6} * n^{0.6}}{18 * Slp^{0.3}} \qquad (2.13)$$

The channel flow time of concentration, *tch*, can be computed using the equation:

$$t_{ch} = \frac{L_c}{3.6 * V_c} \qquad (2.14)$$

Where: $\boldsymbol{L_c}$- is the average flow channel length for the sub basin (km), $\boldsymbol{v_c}$ -is the average channel velocity (m/s), and 3.6 is a unit conversion factor.

The average channel flow length can be estimated using the equation

$$L_c = \sqrt{L * L_{cen}} \qquad 2.15)$$

where: ***L***- is the channel length from the most distant point to the sub basin outlet (km), and $\boldsymbol{L_{cen}}$ -is the distance along the channel to the sub basin centroid (km).

Assuming, Lcen = 0.5**L*, the average channel flow length is: $L_c = 0.71 * L$

The average velocity can be estimated from Manning's equation assuming a trapezoidal channel with 2:1 side slopes and a 10:1 bottom width-depth ratio.

$$V_c = \frac{0.489 * q_{ch}^{0.25} * slp_{ch}^{0.375}}{n^{0.75}} \qquad (2.16)$$

Where: v_c -is the average channel velocity (m/s), q_{ch} is the average channel flow rate (m^3/s), slp_{ch}- is the channel slope (m/m), and *n* is Manning's roughness coefficient for the channel.

To express the average channel flow rate in units of mm/hr, the following expression is used:

$$q_{ch} = \frac{q^{*}_{ch} * Area}{3.6} \tag{2.17}$$

Where: q^*_{ch} -is the average channel flow rate (mm/ hr), Area is the sub basin area (km^2), and 3.6 is a unit conversion factor.

The average channel flow rate is related to the unit source area flow rate (unit source area =1 ha)

$$q_{ch}* = q_o* \, (100 \;\; Area)^{-0.5} \tag{2.18}$$

Where: q_0* -is the unit source area flow rate (mm/ hr), and 100 is a unit conversion factor.

Assuming the unit source area flow rate is 6.35 mm/hr and substituting equations 2.18 and 2.17 into 2.16 gives

$$V_c = \frac{0.317 * Area^{0.125} * slp_{ch}^{0.375}}{n^{0.75}} \tag{2.19}$$

Substituting equations 2.15 and 2.19 into 2.14 gives

$$t_{ch} = \frac{0.62 * L_c * n^{0.75}}{Area^{0.125} * slp_{ch}^{0.375}} \tag{2.20}$$

Runoff Coefficient: The runoff coefficient is the ratio of the inflow rate, i * *Area,* to the peak discharge rate, q_{peak}. The coefficient will vary from storm to storm and is calculated with the equation:

$$C = \frac{Q_{surf}}{R_{day}} \tag{2.21}$$

Where: Q_{surf} is the surface runoff (mm H2O) and R_{day} is the rainfall for the day (mm H2O).

Rainfall Intensity: The rainfall intensity is the average rainfall rate during the time of concentration. Based on this definition, it can be calculated with the equation:

$$i = \frac{R_{tc}}{t_{conc}} \tag{2.22}$$

Where: $\boldsymbol{i}$ is the rainfall intensity (mm/hr), $\boldsymbol{R_{tc}}$ is the amount of rain falling during the time of concentration (mm H_2O), and $\boldsymbol{t_{conc}}$ is the time of concentration for the sub basin (hr).

An analysis of rainfall data collected by Hershfield (1961) for different durations and frequencies showed that the amount of rain falling during the time of concentration was proportional to the amount of rain falling during the 24-hr period.

$$R_{tc} = \alpha_{tc} * R_{day} \quad (2.23)$$

For short duration storms, all or most of the rain will fall during the time of concentration, causing α_{tc} to approach its upper limit of 1.0. The minimum value of α_{tc} would be seen in storms of uniform intensity ($i_{24} = i$). This minimum value can be defined by substituting the products of time and rainfall intensity into equation 2.23.

$$\alpha_{tc,\min} = \frac{R_{tc}}{R_{day}} = \frac{i * t_{conc}}{i_{24} * 24} = \frac{t_{conc}}{24} \quad (2.24)$$

SWAT estimates the fraction of rain falling in the time of concentration as a function of the fraction of daily rain falling in the half-hour of highest intensity rainfall.

$$\alpha_{tc} = 1 - \exp\left[2 * t_{conc} * \ln\left(1 - \alpha_{0.5}\right)\right] \quad (2.25)$$

Where: $\alpha_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall, and t_{conc} is the time of concentration for the sub basin (hr).

The modified rational formula used to estimate peak flow rate is obtained by substituting equations 2.25, 2.21, and 2.19 into equation 2.18

$$q_{peak} = \frac{\alpha_{tc} * Q_{surf} * Area}{3.6 * t_{conc}} \quad (2.26)$$

Surface Runoff Lag: In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated. SWAT incorporates a surface runoff storage feature to lag a portion of the surface runoff release to the main channel. Once surface runoff is calculated with the curve number or Green & Ampt method, the amount of surface runoff released to the main channel is calculated:

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1}) * \left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \quad (2.27)$$

Where: Q_{surf} is the amount of surface runoff discharged to the main channel on a given day (mm H2O), Q'_{surf} is the amount of surface runoff generated in the sub basin on a given day (mm H2O), $Q_{stor,i-1}$ is the surface runoff stored or lagged from the previous day (mm H2O), *Surlag*- is the surface runoff lag coefficient, and t_{conc} is the time of concentration for the sub basin (hrs).

Note that for a given time of concentration, as *surlag* decreases in value more water is held in storage. The delay in release of surface runoff will smooth the stream flow hydrograph simulated in the reach.

Potential Evapotranspiration (PET): The model provides three methods for estimating potential evapotranspiration are also provided: Priestly-Taylor (Priestley and Taylor, 1972), Penman-Monteith (Monteith, 1965), and Hargreaves (Hargreaves and Riley, 1985). The Penman-Monteith method requires solar radiation, air temperature, wind speed and relative humidity. Priestley-Taylor method requires solar radiation, air temperature and relative humidity; where as Hargreve method requires air temperature only.

Priestley and Taylor (1972) used the following equation to estimate PET:

$$\lambda E_o = \alpha_{pet} * \frac{\Delta}{\Delta + \gamma}(H_{net} - G) \tag{2.28}$$

Where: λ is the latent heat of vaporization (MJ/kg), E_o is the potential evapotranspiration (mm/day), α_{pet} is a coefficient, (α_{pet} = 1.28 when the general surroundings are wet or under humid condition), Δ is slope of saturation vapour pressure-temperature curve *de/dT* (kPa/°C), γ is the psychrometric constant (kPa/°C), H_{net} is the net radiation (MJ/m^2day), and G is the heat flux density to the ground (MJ/m^2day).

The Hargreaves method (Hargreaves *et al.* 1985) of PET determination is based on the following equation:

$$\lambda E_o = 0.0023 * H_o * (T_{\max} - T_{\min})^{0.5} * (\bar{T}_{av} + 17.8) \tag{2.29}$$

Where: λ is the latent heat of vaporization (MJ/kg), E_o is the potential evapotranspiration (mm/day), H_0 is the extraterrestrial radiation (MJ/m^2day), T_{max} is the maximum air temperature for a given day (°C), T_{min} is the minimum air temperature for a given day (°C), and T_{av} is the mean air temperature for a given day (°C).

Percolation: Percolation is the downward movement of water in the soil. The percolation is calculated for each soil layer. The percolation component uses a storage routing technique combined with crack flow model to predict flow in each soil layer. The volume of water available for percolation in the soil layer is calculated using equations:

$$SW_{ly.excess} = SW_{ly} - FC_{ly} \qquad \text{if } SW_{ly} > FC_{ly}$$

$$SW_{ly,excess} = 0 \qquad \text{if } SW_{ly} \le FC_{ly} \tag{2.30}$$

Where: $SW_{ly,excess}$ is the drainable volume of water in the soil layers in a given day (mm), SW_{ly} is the water content of the soil layer in a given day (mm), and FC_{ly} is the water content of the soil layer at field capacity (mm). The amount of water that moves from one layer to the other calculated using the storage routing technique as:

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right) \tag{2.31}$$

Where: $w_{ly,excess}$ is the amount of water percolating to the underlying soil layer on a given day (mm), $SW_{ly,excess}$ is the drainable volume of water in the soil layers in a given day (mm), Δt is the length of the time step (hrs), and $TTperc$ is the travel time for percolation (hrs). The travel time for percolation computed for each soil layer using the linear storage equation:

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}} \tag{2.32}$$

Where: TT_{perc} is the travel time for percolation (hrs), SAT_{ly} is the amount of water when the soil layer is completely saturated (mm), FC_{ly} is the water content of the soil layer at field capacity (mm) and K_{sat} is the saturated hydraulic conductivity of the soil layer (mmh^{-1}).

Groundwater: SWAT assumes two layers of aquifers while simulating the groundwater balance; namely a shallow-unconfined aquifer, and a deep-confined aquifer. The unconfined shallow aquifer is contributes to flow in the main channel or reach of the sub basin, whereas the deep confined aquifer assumed to contribute to stream flows outside the watershed (Arnold *et al.* 1993).

The water balance for a shallow aquifer in SWAT is calculated as:

$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg} - Q_{gw} - w_{revap} - w_{deep} - w_{pump,sh} \tag{2.33}$$

Where: $aq_{sh,i}$ is the amount of water stored in the shallow aquifer on day i (mm), $aq_{sh,i-1}$ is the amount of water stored in the shallow aquifer on day i-1 (mm), w_{rchrg} is the amount of recharge entering the aquifer on day i (mm), Q_{gw} is the groundwater flow, base flow, into the main channel on day i (mm), w_{revap} is the amount of water moving into the soil zone in response to water deficiencies on day i (mm), w_{deep} is the amount of water percolating from the shallow aquifer into the deep aquifer on day i (mm), and $w_{pump,sh}$ is the amount of water removed from the shallow aquifer by pumping on day i (mm).

Base flow occurs only when the amount of water stored in the shallow aquifer exceeds a threshold volume of water. Similarly, deep percolation happens only when the amount of water stored in the shallow aquifer exceeds a threshold value.

2.2.4 EROSION

Transport of sediment, nutrients and pesticides from land areas to water bodies is a consequence of weathering that acts on landforms. Soil and water conservation planning requires knowledge of the relations between factors that cause loss of soil and water and those that help to reduce such losses.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

***MUSLE*:** The modified universal soil loss equation (Williams, 1995) is:

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \qquad (2.34)$$

Where: *sed*- is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H2O/ha), q_{peak} is the peak runoff rate (m3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m2 hr/(m3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor; LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor.

2.2.4.1 Soil Erodibility Factor

Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself. Wischmeier and Smith (1978) define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.1-m (72.6-ft) long, with a uniform length-wise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow is defined as land that has been tilled and kept free of vegetation for more than 2 years. The units for the USLE soil erodibility factor in MUSLE are numerically equivalent to the traditional English units of 0.01 (ton acre hr)/ (acre ft-ton inch).

Wischmeier and Smith (1978) noted that a soil type usually becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or clay fraction.

Direct measurement of the erodibility factor is time consuming and costly. Wischmeier et al. (1971) developed a general equation to calculate the soil erodibility factor when the silt and very fine sand content makes up less than 70% of the soil particle size distribution.

$$K_{USLE} = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM) + 3.25 \cdot (C_{soilstr} - 2) + 2.5 \cdot (C_{perm} - 3)}{100} \qquad (2.35)$$

Where: *M*- is the particle-size parameter, *OM*- is the percent organic matter (%), $C_{soilstr}$ is the soil structure code used in soil classification, and c_{perm} is the profile permeability class.

The particle-size parameter, *M*, is calculated

$$M = (m_{silt} + m_{vfs}) \cdot (100 - m_c) \qquad (2.36)$$

Where: m_{silt} is the percent silt content (0.002-0.05 mm diameter particles), m_{vfs} is the percent very fine sand content (0.05-0.10 mm diameter particles), and m_c is the percent clay content (< 0.002 mm diameter particles).

The percent organic matter content, *OM*, of a layer can be calculated:

$$OM = 1.72 * orgC \qquad (2.37)$$

Where**:** orgC is the percent organic carbon content of the layer (%).

2.2.4.2 Cover and Management Factor

The USLE cover and management factor, *CUSLE*, is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). The plant canopy affects erosion by reducing the effective rainfall energy of intercepted raindrops. Water drops falling from the canopy may regain appreciable velocity but it will be less than the terminal velocity of free-falling raindrops. The average fall height of drops from the canopy and the density of the canopy will determine the reduction in rainfall energy expended at the soil surface. A given percentage of residues on the soil surface are more effective that the same percentage of canopy cover.

Residue intercepts falling raindrops so near the surface that drops regain no fall velocity. Residue also obstructs runoff flow, reducing its velocity and transport capacity. Because plant cover varies during the growth cycle of the plant, SWAT updates C_{USLE} daily using the equation:

$$C_{USLE} = \exp\left(\left[\ln(0.8) - \ln\left(C_{USLE,mn}\right)\right] \cdot \exp\left[-0.00115 \cdot rsd_{surf}\right] + \ln\left[C_{USLE,mn}\right]\right) \qquad (2.38)$$

Where: $C_{USLE,,mn}$ is the minimum value for the cover and management factor for the land cover, and rsd_{surf} is the amount of residue on the soil surface (kg/ha).

The minimum C factor ($C_{USLE,\ ,mn}$) can be estimated from a known average annual C factor ($C_{USLE,aa}$) using the following equation (Arnold and Williams, 1995):

$$C_{USLE,mn} = 1.463 \ln\left[C_{USLE,aa}\right] + 0.1034 \qquad (2.39)$$

Topographic Factor: The topographic factor, LS_{USLE}, is the expected ratio of soil loss per unit area from a field slope to that from a 22.1-m length of uniform 9 percent slope under otherwise identical conditions. The topographic factor is calculated:

$$LS_{USLE} = \left(\frac{L_{hill}}{22.1}\right)^{m} \cdot \left(65.41 \cdot \sin^2\left(\alpha_{hill}\right) + 4.56 \cdot \sin \alpha_{hill} + 0.065\right) \qquad (2.40)$$

Where: $\boldsymbol{L_{hill}}$ is the slope length (m), $\boldsymbol{m}$ is the exponential term, and $\boldsymbol{\alpha_{hill}}$ is the angle of the slope.

The exponential term, *m*, is calculated:

$$m = 0.6 \cdot \left(1 - \exp\left[-35.835 \cdot slp\right]\right) \qquad (2.41)$$

Where: *slp* is the slope of the HRU expressed as rise over run (m/m).

The relationship between α_{hill} and *slp* is:

$$slp = \tan(\alpha_{hill}) \qquad (2.42)$$

Coarse Fragment Factor: The coarse fragment factor is calculated:

$$CFRG = \exp(-0.053 * rock) \qquad (2.43)$$

Where: *rock* is the percent rock in the first soil layer (%).

2.2.4.3 Sediment Lag in Surface Runoff

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated. SWAT incorporates a surface runoff storage feature to lag a portion of the surface runoff release to the main channel. Sediment in the surface runoff is lagged as well.

Once the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated:

$$sed = \left(sed' + sed_{stor,i-1}\right)\cdot\left(1-\exp\left[\frac{-surlag}{t_{conc}}\right]\right) \tag{2.44}$$

Where: *sed* is the amount of sediment discharged to the main channel on a given day (metric tons), *sed'* is the amount of sediment load generated in the HRU on a given day (metric tons), $sed_{stor,i-1}$ is the sediment stored or lagged from the previous day (metric tons), *surlag* is the surface runoff lag coefficient, and t_{conc} is the time of concentration for the HRU (hrs).

Note that for a given time of concentration, as *surlag* decreases in value more sediment is held in storage.

2.2.4.4 Sediment in Lateral & Groundwater Flow

SWAT allows the lateral and groundwater flow to contribute sediment to the main channel. The amount of sediment contributed by lateral and groundwater flow is calculated:

$$sed_{lat} = \frac{\left(Q_{lat} + Q_{gw}\right)\cdot area_{hru}\cdot conc_{sed}}{1000} \tag{2.45}$$

Where: sed_{lat} is the sediment loading in lateral and groundwater flow (metric tons), Q_{lat} is the lateral flow for a given day (mm H2O), Q_{gw} is the groundwater flow for a given day (mm H2O), $area_{hru}$ is the area of the HRU (km^2), and $conc_{sed}$ is the concentration of sediment in lateral and groundwater flow (mg/L).

2.2.5 CHANNEL WATER BALANCE

Water storage in the reach at the end of the time step is calculated:

$$V_{stored,2} = V_{stored,1} + V_{in} - V_{out} - tloss - E_{ch} + div + V_{bnk} \tag{2.46}$$

Where: $V_{stored,2}$ is the volume of water in the reach at the end of the time step (m^3 H_2O), $V_{stored,1}$ is the volume of water in the reach at the beginning of the time step (m^3 H_2O), V_{in} is the volume of water flowing into the reach during the time step (m^3 H_2O), $V_{out}t$ is the volume of water flowing out of the reach during the time step (m^3 H_2O), t_{loss} is the volume of water lost from the reach via transmission through the bed (m^3 H_2O), E_{ch} is the evaporation from the reach for the day (m^3 H_2O), d_{iv} is the volume of water added or removed from the reach for the day through diversions (m^3 H_2O), and V_{bnk} is the volume of water added to the reach via return flow from bank storage (m^3 H_2O).

SWAT treats the volume of outflow calculated with variable storage routing equation:

$$V_{out,2} = SC \cdot \left(V_{in} + V_{stored,1}\right) \tag{2.47}$$

Or Muskingum routing equation:

$$V_{out,2} = C_1 \cdot V_{in,2} + C_2 \cdot V_{in,1} + C_3 \cdot V_{out,1} \tag{2.48}$$

As the net amount of water removed from the reach, as transmission losses, evaporation and other water losses for the reach segment are calculated; the amount of outflow to the next reach segment is reduced by the amount of the loss.

When outflow and all losses are summed, the total amount will equal the value obtained from 2.47.

2.2.6 Sediment Channel Routing

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach. SWAT will compute deposition and degradation using the same channel dimensions for the entire simulation.

The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity.

The peak channel velocity, $\boldsymbol{v}_{ch,pk}$, is calculated:

$$v_{ch,pk} = \frac{q_{ch,pk}}{A_{ch}} \tag{2.49}$$

Where $q_{ch,pk}$ is the peak flow rate (m^3/s) and A_{ch} is the cross-sectional area of flow in the channel (m^2). The peak flow rate is defined as:

$$q_{ch,pk} = prf \cdot q_{ch} \tag{2.50}$$

Where, prf is the peak rate adjustment factor, and *qch* is the average rate of flow (m^3/s).

The maximum amount of sediment that can be transported from a reach segment is calculated:

$$conc_{sed,ch,mx} = c_{sp} \cdot v_{ch,pk}^{\ spexp} \tag{2.51}$$

Where: $conc_{sed,,ch,,mx}$ is the maximum concentration of sediment that can be transported by the water (ton/m3 or kg/L), C_{sp} is a coefficient defined by the user, $V_{ch,pk}$ is the peak channel velocity (m/s), and *spexp* is an exponent defined by the user.

The exponent, *spexp*, normally varies between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation (Arnold et al., 1995). The maximum concentration of sediment calculated with equation 2.49 is compared to the concentration of sediment in the reach at the beginning of the time step, $conc_{sed,\ ch,,i.}$ If $Conc_{sed,\ ch,\ i} > conc_{sed,\ ch,\ mx}$ deposition is the dominant process in the reach segment and the net amount of sediment deposited is calculated:

$$sed_{dep} = \left(conc_{sed,ch,i} - conc_{sed,ch,mx}\right) \cdot V_{ch} \tag{2.52}$$

Where: sed_{dep} is the amount of sediment deposited in the reach segment (metric tons), $conc_{sed,ch,i}$ is the initial sediment concentration in the reach (kg/L or ton/m3), $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/L or ton/m3), and V_{ch} is the volume of water in the reach segment (m^3 H_2O).

If $conc_{sed,\ ch,\ i} < conc_{,sed,\ ch,\ mx}$ degradation is the dominant process in the reach segment and the net amount of sediment reentrained is calculated:

$$sed_{deg} = \left(conc_{sed,ch,mx} - conc_{sed,ch,i}\right) \cdot V_{ch} \cdot K_{CH} \cdot C_{CH} \tag{2.53}$$

Where: sed_{deg} is the amount of sediment re entrained in the reach segment (metric tons), K_{CH} is the channel erodibility factor (cm/hr/Pa), and C_{CH} is the channel cover factor.

Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach is determined:

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg} \tag{2.54}$$

Where: sed_{ch} is the amount of suspended sediment in the reach (metric tons), $sed_{ch,I}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons), sed_{dep} is the amount of sediment deposited in the reach segment (metric tons), and sed_{deg} is the amount of sediment re entrained in the reach segment (metric tons).

The amount of sediment transported out of the reach is calculated:

$$sed_{out} = sed_{ch} \cdot \frac{V_{out}}{V_{ch}} \tag{2.55}$$

Where: sed_{out} is the amount of sediment transported out of the reach (metric tons), sed_{ch} is the amount of suspended sediment in the reach (metric tons), V_{out} is the volume of outflow during the time step (m^3 H_2O), and V_{ch} is the volume of water in the reach segment (m^3 H_2O).

2.2.6.1 Channel Erodibility Factor

The channel erodibility factor is conceptually similar to the soil erodibility factor used in the USLE equation. Channel erodibility is a function of properties of the bed or bank materials. Channel erodibility can be measured with a submerged vertical jet device.

The basic premise of the test is that erosion of a vegetated or bare channel and local scour beneath an impinging jet are the result of hydraulic stresses, boundary geometry, and the properties of the material being eroded. *Hanson (1990)* developed a method for determining the erodibility coefficient of channels *in situ* with the submerged vertical jet. *Allen et al. (1999)* utilized this method to determine channel erodibility factors for thirty sites in Texas.

The channel erodibility coefficient is calculated:

$$K_{CH} = 0.003 \cdot \exp[385 \cdot J_i] \tag{2.56}$$

Where: K_{CH} is the channel erodibility coefficient (cm/h/Pa) and J_i is the jet index.

In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility.

2.2.6.2 Channel Cover Factor

The channel cover factor, C_{CH}, is defined as the ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface.

3. DATA AVAILABILITY AND ANALYSIS

3.1 General

The aim of this chapter is to collect all available data of hydrological, metrological, topography, soil data, land use/cover and etc to assure the required objectives. The SWAT model is one of data intensive model as input and in counter gives a lot of results.

3.2 DEM data

The Digital Elevation Model of 90m by 90m resolution of different type has been taken from AMU, SGS data base. The DEM was in the format of STRM and this was processed on 3 DEM, Global Mapper software's and imported to ArcView GIS environment.

Figure 3.1Topographic view of DEM map

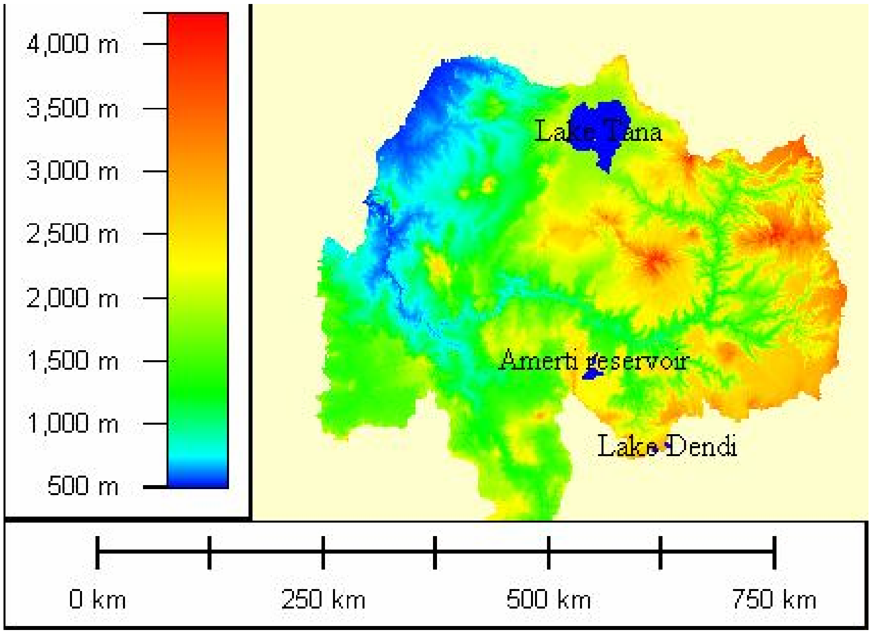


Figure 3.2 Unprocessed DEM of Blue Nile

3.3 Hydrological data

Daily flow data is required for SWAT simulated result calibration and validation. This data were also collected from AMU, SGS data base. Depending on the extent of calibration and validation, three site flow data were collected and arranged as per the requirement of SWAT model. These sites are at Bahirdar flow station (11.60^{0}N, 37.40^{0}E), near Kessie flow station (11.06^{0}N, 38.183^{0}E) and at the Sudan border flow station (11.233^{0}N, 34.983^{0}E). These sites were selected due to long year and reliable data availability and also strategically sites for representing the sub-basins upstream of them. And they represent upper Blue Nile, middle Blue Nile and lower Blue Nile.

3.4 Sediment data

There are few sites which has measured suspended sediment data in Blue Nile which is not long year recorded data. So, it is generated by regression analysis arranged as per the SWAT model and used for calibration at three sites (at Addis Zemen, at Gilgel Abbay, and at Kessie station). But for final verification of representing sediment yield and concentration on all sub basins, different historical data and studies has been looked.

To generate this sediment data for calibration, depending on short time data a rating curve of sediment load versus discharge was derived. The dry season curve and the wet season curve are developed separately. Then, suspended sediment data were derived by using long year flow data on a specific site that expected to have similar catchments (in the same watershed).

3.5 Climate data

The climate data is among the most prerequisite parameter of SWAT model. This data was collected from Ethiopian Metrological Service Agency.

In Blue Nile basin around 164 metrological stations (D.Tesfahun, 2006). But only some of them have long year data. It is uncommon to see fully recorded stations. Compared to other basin in Ethiopia, it is well equipped and established more than any other basins. The stations and their location are looked on appendix 1 and 2.

3.5.1 RAINFALL DATA

The SWAT model requires daily rainfall data arranged vertically parallel to time series. So, among 164 stations, 74 of them have good daily data, still a lot of missed data filled with -99 (data generating code in SWAT). The station distribution is uneven, very densely in Tana sub-basin, few in North Gojem, S.Gojam, and scarce in others. Moreover, Rihad and Dinder sub-basins have only one station each. In figure 3.3 a rainfall data distribution is located.

3.5.2 TEMPERATURE DATA

For generating of evaporation and evapotranspiration, temperature data is required for SWAT Model on this study. The maximum and minimum daily temperature is arranged downward parallel to corresponding date of record. Like other climate data even more than precipitation data is hard to get continuously recorded many years' data in the basin. Twenty (20) stations data have been collected and analyzed, the missing data again assigned -99, to generate it. These are also located on figure3.3.

3.5.3 WIND SPEED, RELATIVE HUMIDITY AND SUNSHINE HOURS

These are also the vital parameters for SWAT model to generate weather. Since, very few stations have daily data of wind speed, relative humidity and solar radiation; it is preferred to generate this data by SWAT model weather generator mechanism. But for the option of weather generating data base, monthly data of twelve stations are collected.

The weather generator first independently generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently. For the sake of data generation, weather parameters were developed by using the weather parameter calculator WXPARM (Williams, 1991) and dew point temperature calculator DEW02 (Liersch, 2003), which were downloaded from the SWAT website (http://www.brc.tamus.edu/swat/soft_links.html). The WXPARM program reads daily values of solar radiation (calculated from daily sunshine hours), maximum and minimum temperatures, precipitation, relative humidity, and wind speed data. It then calculates monthly daily averages and standard deviations of all variables as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month. The DEW02 programs reads daily values of relative humidity, and maximum and minimum temperature values and calculates monthly average dew point temperatures. The weather generator parameters used and their values are shown in Appendix 3.

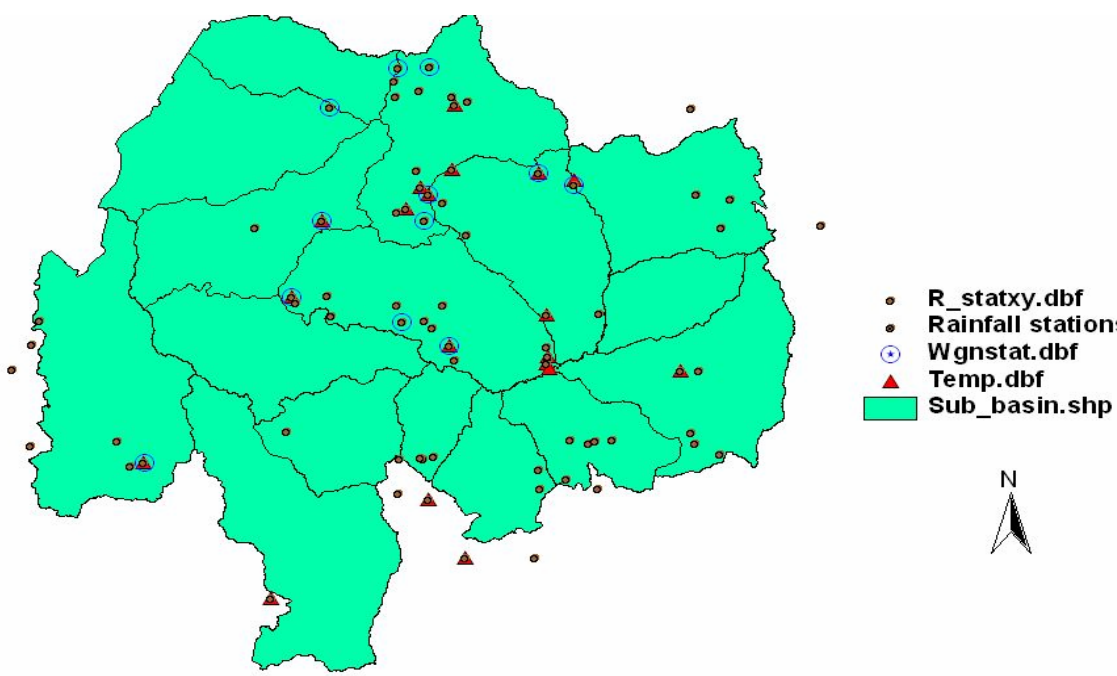


Figure 3.3Climate stations and weather generating stations in the catchment of the Blue Nile

4. MATERIALS AND METHODS

4.1 Materials for the study

As far as this study about flood discharge estimation from rainfall and determining sediment carrying capacity, is concerned, the material for hydro-metrological data, sediment data, land use/cover data, soil type and soil physical properties data, topographic data and other data collections were take place.

Topographic map of the area is required to determine the area of catchments in the watershed, the site of gauging stations and related information about the watershed. DEM of the basin is required to determine the stream flow direction, to delineate the area of each basin and to determine the outlet of the basins.

Soil type map is required to know the infiltration capacity and to determine the effective runoff of the catchments, soil erosion etc, soil erodibility etc.

Land use map is required for understanding of the catchments type whether it is prone to erosion or not and required for SWAT model to determine Manning's coefficient, erodibility factor and runoff coefficient.

4.2 Methodology

The methodology for this study was break down into Data collection and data processing, running model and model result interpretation.

The conceptual frame work serves to describe the over all research steps describing the methodology applied to carry out the research .In general the remotely sensed data, Land sat images, ASTER images and SRTM data are collected, processed and verified for accuracy by ground truth to extract useful information like land cover maps, soil type, soil physical and mechanical properties and catchments boundary of the study area. At the same time the necessary hydro-metrological data, daily rainfall, daily maximum and minimum temperatures, daily humidity, sunshine hours, wind speed and observed river discharge and sediment load/concentration at different stations in the basins are collected and processed to make the data ready for use in the models. Once the model is parameterized by converting the results of data analysis into model parameters, then model sensitivity analysis, calibration, validation and simulation for different parameter changing are conducted ending up on some conclusions and recommendations. The conceptual frame work, figure: 4.1 indicate the general outline of the modelling approaches.

The next step in the methodology will be simulation of sub-basin/Hydrological response unit (HRU) area rainfall, flood discharge (runoff) and sediment load/concentration by using SWAT MODEL. Then relate rainfall versus effective runoff that is a cause for sediment transport. Again determine how much sediment is transported with a given storm runoff and determine their relation.

Finally correlate a rainfall on a given Sub-basin will produce an effective runoff that initiates sediment of a given amount on sub basins.

The applied methodology comprises five phases;

1) Preparation
2) Data acquisition
3) Modeling and data analyzing
4) Calibration, Validation, evaluation, and
5) Reporting.

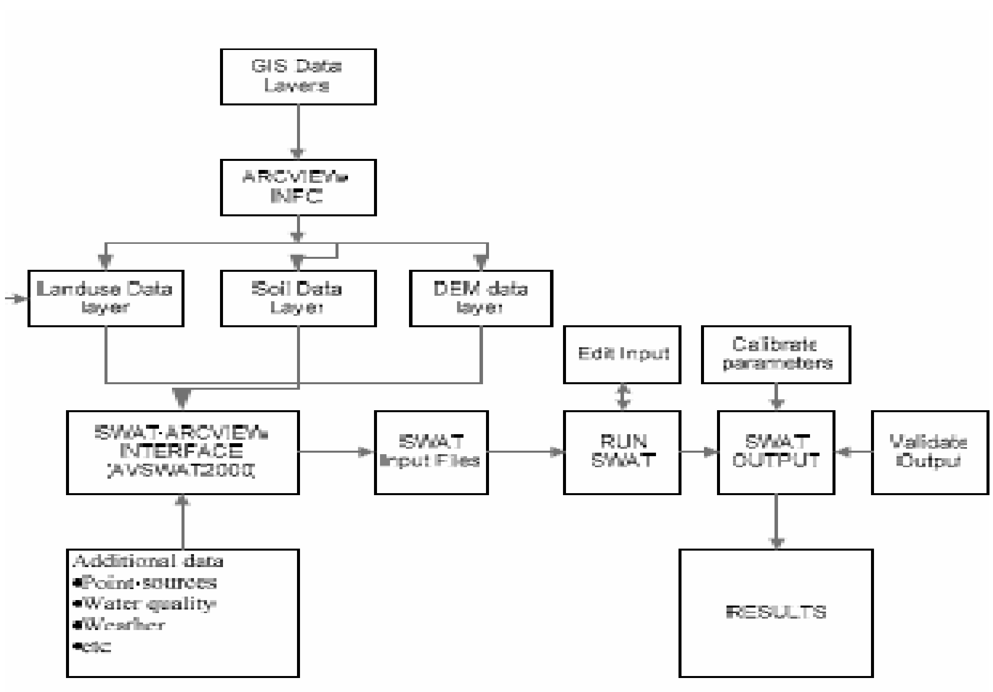


Figure 4.1The general layout of Simulation diagram of SWAT model

4.3 Hydrological Model SWAT

Major hydrological processes that can be simulated by the model include evapotranspiration (ET), surface runoff, infiltration, percolation, shallow aquifers and deep aquifers flow, and channel routing (Figure 2.6) (Arnold et al., 1998). The simulation of the processes can be done in four subsystems: surface soil, intermediate zone, shallow and deep aquifers, and open channels. Stream flow in a main channel is determined by three sources: surface runoff, lateral flow and base flow from the shallow aquifers. In SWAT, the impacts of spatial variations in topography, land use, soil and other watershed characteristics on hydrology are considered in subdivisions. There are two-level scales of subdivisions: (1) a basin is divided into a number of sub-basins based upon drainage areas of the tributaries, and (2) each sub-basin is further divided into a number of hydrologic response units (HRUs) based on land cover and soil type. Each HRU is assumed to be spatially uniform in terms of land use, soil, topography and climate.

4.3.1 HYDROLOGICAL WATER BALANCE

The fundamental hydrology of a watershed in SWAT based on the following the water balance equation mentioned in Literature review (equation 2.1)

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right)$$

(Variables are as defined above, equation 2.1)

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various land cover and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance. (Arnold et al. 1999)

4.3.2 MODEL INPUTS

Inputs including basin area and main channel length were determined by AVSWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland Manning’s n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics.

Measured daily rainfall, temperature, solar radiation, wind speed and relative humidity for the study area were used in the model. Missed data for daily rainfall, temperature, solar radiation, wind speed and relative humidity were estimated using the weather generator in SWAT by generating code "-99". The weather generator parameters used and their values are shown in Appendix 3.

An ArcView GIS interface (AVSWAT) is available to generate model inputs from GIS data (DiLuzio et al. 2001). AVSWAT processes mapped land use and soils data as well as a Digital Elevation Model (DEM) to create a set of default model input files.

SWAT requires specific information about watershed characteristics such as topography, land use /cover, soil types, weather data and management practices. The model uses a two-level discrimination schemes; firs basin and sub-basin delineation is performed based on topographic information, followed by further discrimination in to HRUs using land use and soil type consideration in order to represent heterogeneous watershed properties. Climate inputs are required since they control water balance that drives all the processes simulated in the watershed. Management practice of a watershed is needed because it greatly influences the sediment transported from basins.

4.3.3 DIGITAL ELEVATION MODEL (DEM)

Topography was defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A digital elevation model is needed for raster-based hydrological analysis in a GIS. A 90m by 90m resolution of DEM was obtained from AMU, School of graduate studies office. This DEM is in the form of STRM and processed by Global Mapper software and exported to ArcView GIS environment with the projection defined in Table 4.1. The DEM top map of Blue Nile is as shown below (figure 4.2).

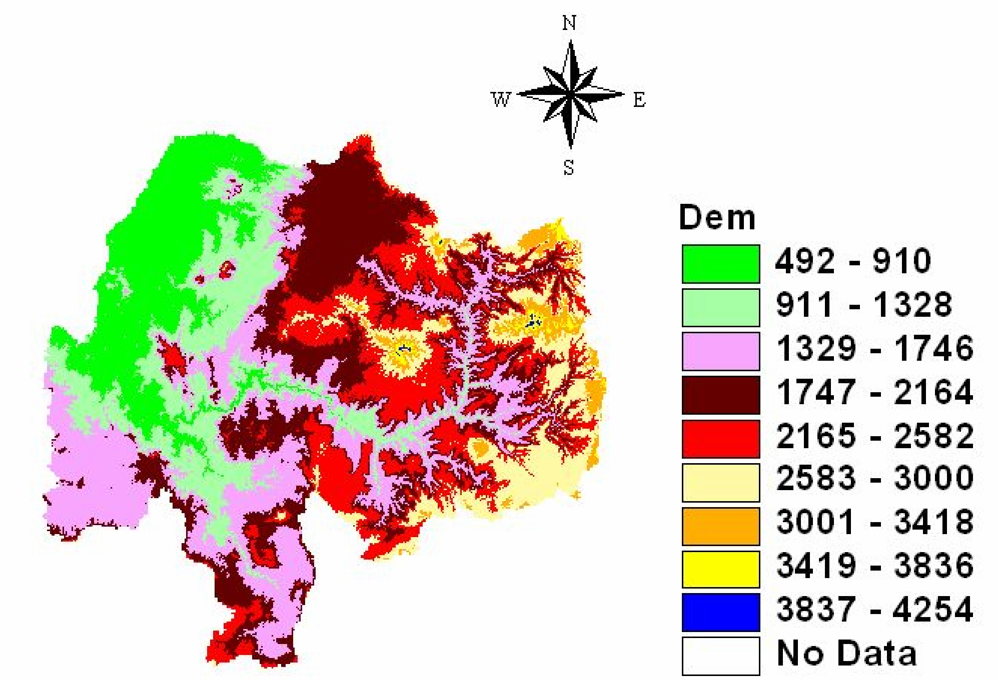


Figure 4.2 Digital Elevation Model (DEM) of the Blue Nile Basin (meter above see level (m.a.s.l))

Table 4.1Projection of map for Blue Nile Ethiopia, I have used

Projection	Custom Transverse Mercator
Spheroid	WGS-84
Datum	GCS
Zone	37
Central Meridian	39
Reference Latitude	0
False Northing	0
False Easting	500000
Scale factor	0.9996

(Source: From Internet)

4.3.4 LAND USE/COVER MAP

Land cover and soil are one of greatly influencing the hydrological properties of a watershed that of five main input datasets required by SWAT to help describe a sub-basin or HRU. Once watershed topographic parameters have been computed for each sub basin, the interface uses land cover and soils data to generate multiple hydrologic response units (HRUs) within each sub basin by GIS overlay process to assign soil parameters and SCS curve numbers. HRUs are lumped land areas within the sub watershed that are comprised of distinctive land cover, soil, and management combinations (Neitsch et al., 2002). Such subdivision of sub-basins in to HRUs enables the SWAT model to reflect the spatial variations of the hydrologic conditions for different land cover and soil distributions within the sub-basins.

The land use map was obtained from IWMI (international water management Institute) in the format of shape. In addition further physical properties of different land cover parameters were collected from Abbay River basin Integrated Development master plan projects, 1998. The remaining parameters not defined by user would be assigned by the model itself as default value from data base of USA land cover. But later some of them were changed during calibration time.

This land classification is as FAO's classification; hence it is required to convert to format as required by SWAT model.

SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces. Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model. Information collected from Master Plan of Abbay basin was used in renaming the land uses of the study area as the following table (table 4.2). This SWAT classification is as follows:

Table 4.2 Land classification as per FAO and SWAT

S.No.	Original Land Cover	Area (Km2)	% of watershed	Redefined SWAT classification	SWAT code
1	Agriculture	39878.43	19.96	Agricultural close grown	AGRC
2	Agro-pastoral	55614.08	27.83	Agricultural Generic	AGRL
3	Agro-sylvicultural	15597.41	7.81	Forest mixed	FRST
4	Marsh	648.29	0.32	Summer Pasture	SPAS
5	Pastoral	14589.23	7.30	pastoral	PAST
6	State Farm	968.33	0.48	Agricultural Row crops	AGRR
7	Sylvicultural	7297.63	3.65	Forest Deciduous	FRSD
8	Sylvo-pastoral	17417.92	8.72	Corn	CORN
9	Traditional	43492.05	21.77	Range Brush	RNGB
10	Unused	700.83	0.35	wetlands, non forested	WETN
11	Urban	104.11	0.05	Residential-Med/Low Density	URML
12	Water	3503	1.75	water land	WATR
	Total	199810.98			

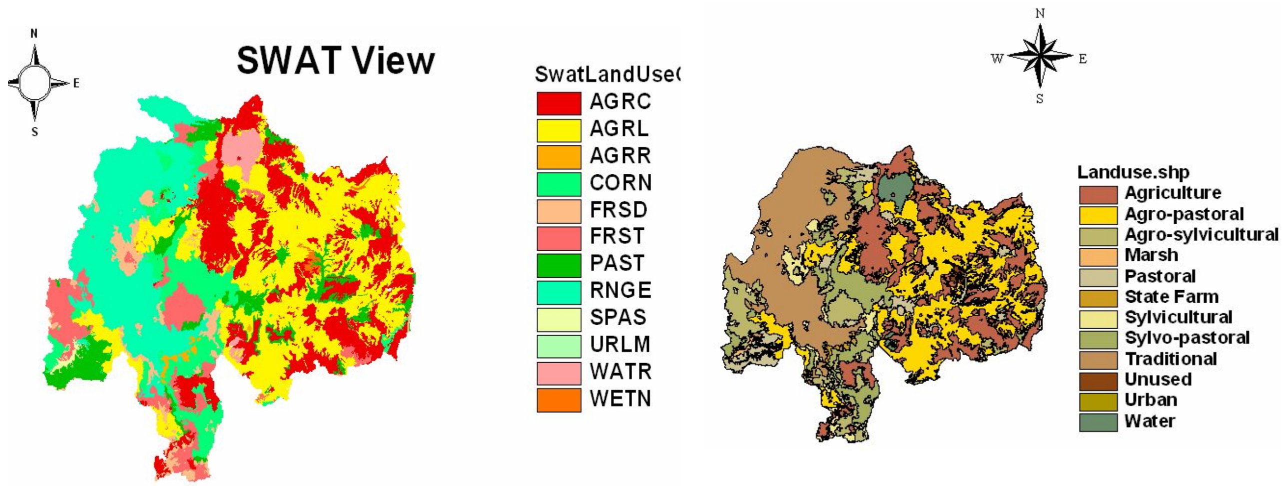


Figure 4.3a) SWAT land use/cover classification b) FAO land use/cover classification

4.3.5 SOIL MAP

Soil data is also one of the major inputs for SWAT modeling with intensive physio-chemical properties.

The soil map of Blue Nile was obtained from IWMI office in the shape format. But the SWAT interface parameters were collected from Abbay River basin Integrated development master plan project, September 1998. The value of different soil parameters, which were extracted from the above soil data sources, and the estimated soil parameters for the SWAT data required are listed in Appendix 5.

In order to integrate the soil map within the SWAT model, it is necessary to make a User Soil Database, which contains textural properties and physicochemical properties for each soil layers. In this database all the soil in the area are represented, and coupled with its characteristics (Appendix: 6)

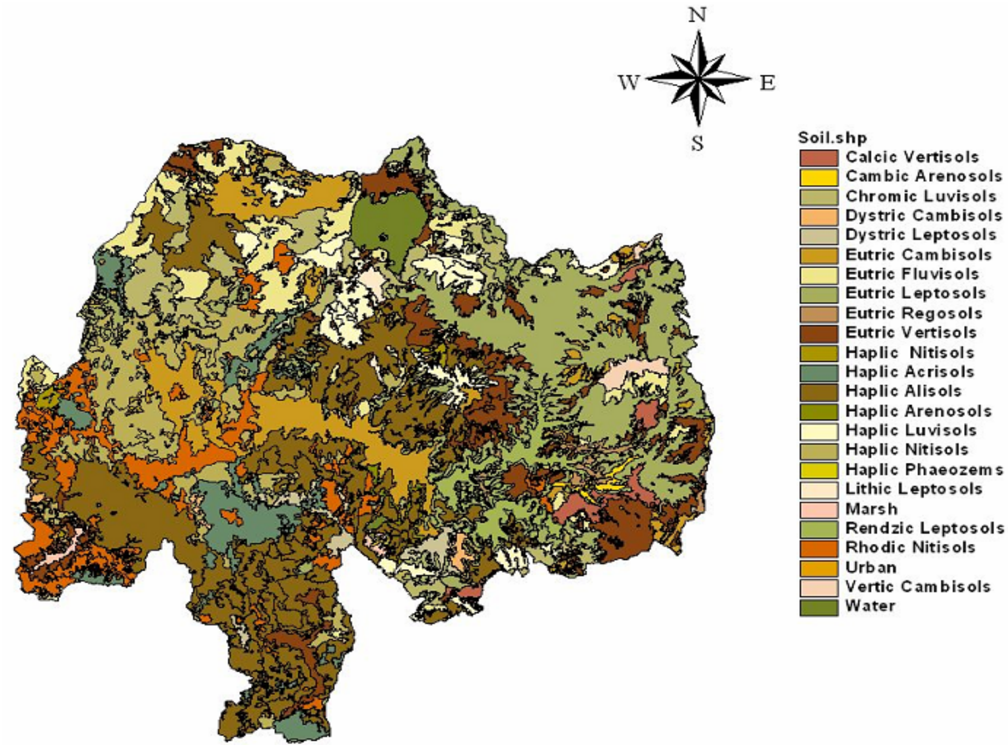


Figure 4.4 Soil map of Blue Nile

Table 4.3 Soil type classification according to FAO-UNESCO and area coverage

S.No.	Soil Type	symbol code of SWAT	Area (Km2)	% of watershed area
1	Calcic Vertisols	CVe	2290.71	1.15
2	Cambic Arenosols	ARb	604.73	0.30
3	Chromic Luvisols	LVx	9808.25	4.91
4	Dystric Cambisols	CMd	745.06	0.37
5	Dystric Leptosols	LPd	2427.27	1.21
6	Eutric Cambisols	CMe	17095.09	8.56
7	Eutric Fluvisols	FLe	11431.65	5.72
8	Eutric Leptosols	LPe	34463.72	17.25
9	Eutric Regosols	VRe	1410.31	0.71
10	Eutric Vertisols	VRe	17228.99	8.62
11	Haplic Nitisols	NTh	737.82	0.37
12	Haplic Acrisols	ACh	8919.11	4.46
13	Haplic Alisols	ALh	41380.74	20.71
14	Haplic Arenosols	ARh	721.83	0.36
15	Haplic Luvisols	LVh	8265.54	4.14
16	Haplic Nitisols	NSh	17828.86	8.92
17	Haplic Phaeozems	PHh	90.10	0.05
18	Lithic Leptosols	LPq	606.10	0.30

Cont'd…

19	Marsh	M	782.81	0.39
20	Rendzic Leptosols	LPk	5387.74	2.70
21	Rhodic Nitisols	NTr	13233.79	6.62
22	Urban	U	54.73	0.03
23	Vertic Cambisols	CMv	1063.35	0.53
24	Water	W	3233.56	1.62
	Total		199,811.88	

As shown above twenty four (24) major soil classification groups are recognized in the study area. The appropriate values of parameters in Table 4.3 shown above were determined from different literature. (Master plan of Abbay, 1998, soil volume part)

4.3.6 WATER SHED DELINEATION

The subdivision of a watershed into discrete sub-watershed areas enables the modeling process to represent the heterogeneity of the watershed. SWAT works on a sub-basin basis and the interface delineates the watershed in to such sub-basins or sub-watersheds based on topographic information. The Blue Nile basin delineation was performed based on topographic information of basins obtained from different sources in the form of digital elevation model (DEM) with X-Y resolution of 90m using a procedure of SWAT 2003. The total Blue Nile basin area is 199810.98 Km^2 (from land use map, Table 4.2), but the delineated area becomes 190347 Km^2. The difference between the actual and the delineated one is may be due to cells of zero values especially at the downstream of lowland areas of Sudan border that almost flat topography. This is not delineated by SWAT 2003 model, because it is jumped or neglected. The other reason, the measured land use map and the one on different literature may not be justified.

The size of sub-basin in the watershed will affect the assumption of homogeneity. Hence, definition of watershed, sub-basin boundaries and streams is decided by selecting a threshold area or the minimum draining area to define streams. Configuration of a lot of sub-basin requires a long time simulation period and even difficult to run it. On the other hand, too small number of sub-watershed could affect the simulation results by ignoring spatial variability and lumps watershed condition together. Therefore, a threshold level, and the number of resulted sub-basin for the study area has been selected carefully as suggested by many literature (Jha et al., 2004) and decided to change from the suggested one by SWAT itself 346, 000 ha that produced 37 sub-basin to threshold level of 100,000 ha, which gave 98 sub-basins.

4.3.7 DIGITIZED STREAM NETWORKS

The digitized stream networks used in this study were found from the Ministry of Water Resources (MoWR) of Ethiopia. The streams were prepared in a shape file format and together with the DEM given as an input to the model to be “burnt” during the delineation process. The model superimposed the digitized stream networks into the DEM to define the location of the stream networks and safe the time of delineation.

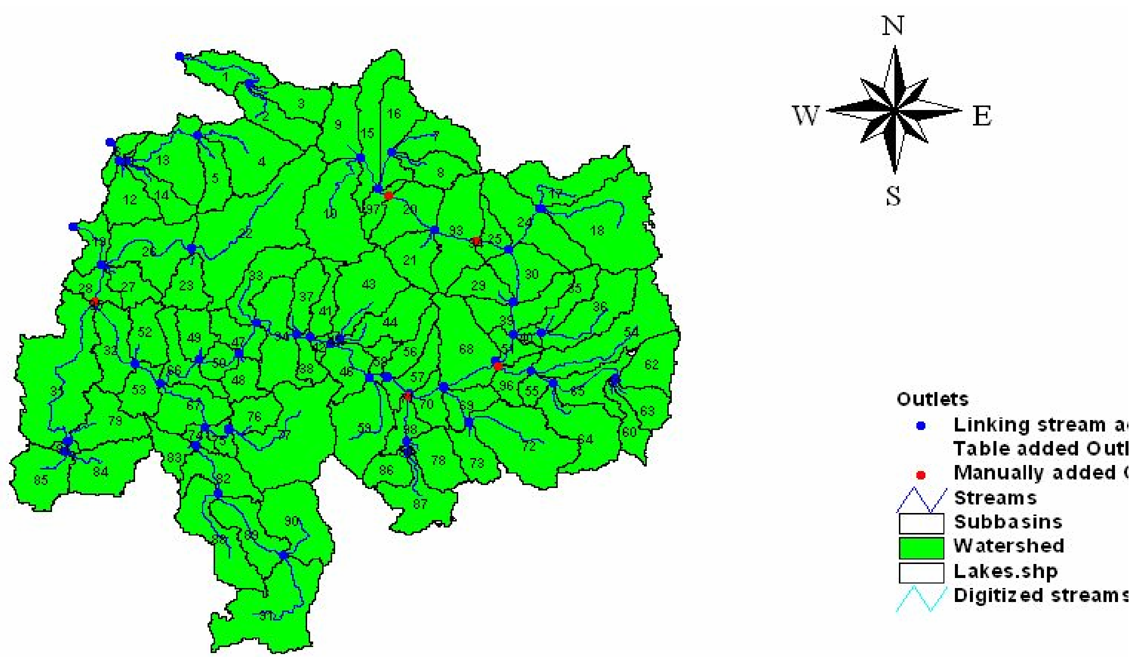


Figure 4.5Watershed delineated sub-basins and outlets

4.3.8 WEATHER DATA

The weather data are among the main intensive input data for SWAT simulation. This data are in daily based long year data's of many stations as much as possible. They are precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. On top of these data statistical analysis of monthly daily average, standard deviations, and probability of wet and dry days, skew ness coefficients and dew temperature were determined by FORTRAN program known as *WXGenParm* (J.R. Williams, 1991) and program *dew02.exe* (S. Liersch, 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.

Finally, all the climate data were prepared in DBF format (basically in access format) as per the character required by SWAT. Unfortunately, SWAT is not run with longy name, dot in the name and decimal number out of predefined characteristic number, it respond "SWAT run is not successful".

SWAT takes data of each climatic variable for every sub basin from the nearest weather station measured from the centroid of the sub basin.

4.3.8.1 Evaporation Data

Data of evaporation and evapo-transpiration is main parameter provided for SWAT model simulation. It has two options, either loading measured evaporation data or choosing the methods for SWAT simulation.

There are three methods of Evaporation determination by SWAT model itself: Prestily-Taylor method, Penman-Monteith method and Hargreve methods. Penman-Monteith methods requires all climate data, Prestily method only depends on radiation data and Hargreve method uses maximum and minimum temperature data to determine potential evaporation (PET) and actual evapotranspiration (ET). For this study, since there is humidity, wind speed and solar radiation data limitation for some basins compared to temperature data, Hargreve method was chosen for simulation of evaporation and evapo-transpiration by SWAT model.

4.3.9 SENSITIVITY ANALYSIS

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results. This may be happened due to different reasons, inaccuracy of input data, different watershed condition than the Model is verified and methodology applied by users. So, to minimize this discrepancy, it is necessary to determine the parameter which are affecting the results and in the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. The sensitivity analysis was undertaken by using a built-in tool in SWAT2003 that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) design method of Morris (1991).

Hence, sensitivity analysis is a method of minimizing the number of parameters to be used in the calibration step by identifying the most sensitive parameters largely controlling the behavior of the simulated process. This appreciably eases the overall calibration and validation process as well as reduces the time required for it. Besides, as Lenhart *et al.* (2002) indicated, it increases the accuracy of calibration by reducing uncertainty.

The category of sensitivity was also defined based on the Lenhart *et al.* (2002) classification. He divided sensitivity into four classes: Between 0 -0.05, small (negligible); 0.05-0.2, medium, 0.2-1.0 high and ≥1, very high.
As, each sub-basin have different characteristics depending on their land use, soil type, elevation, weather condition, slope and other parameters, their response for different parameter were different. Therefore, it is necessary to check sensitivity analysis at different sub-basins. For stream flow of Blue Nile basin, it was checked at three points, (at outlet of Tana basin, near Kessie and at the Sudan Border.) In the entire study sub basin the sensitivity showed that 28 parameters were sensitive. The following are few of them which have significant effect on the results.

Table 4.4the sensitivity results at Bahir Dar outlet

Parameter	**Rank**	**Relative mean sensitivity**	**Sensitivity Class**
CN2	1	3.04	Very high
SOL_AWC	2	1.00	Very high
ESCO	3	0.60	high
sol_z	4	0.582	high
sol_k	5	0.23	high
GE_DEALY	6	0.21	high
ALPHA_BF	7	0.059	medium
SMTMP	8	0.046	Small
canmx	9	0.0432	Small
TIMP	10	0.0417	Small
SMFMX	11	0.0172	Small

4.3.10 EVALUATION OF MODEL SIMULATION

4.3.10.1 Graphical comparison observed and simulated hydrographs and sediment concentrations

Graphical display of simulated and observed flows is very important because the traditional method of evaluating model performance by statistical measures has limitations. Statistical indices are not effective in communicating qualitative information such as trends, types of errors and distribution patterns. In fact one should not depend on only single statistical measures of model performance. Theses are sometimes misleading because of the high possibility of compensation of errors from season to season or over years in long-term calibration. In both calibration and validation processes both observed and simulated hydrographs were compared graphically.

4.3.10.2 Model Efficiency

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods in addition to graphical comparison for this study.
Model simulations efficiency were evaluated during calibration by using mean, standard deviation, regression coefficient (R^2), and the Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe 1970). The regression coefficient (R^2) is the square of the Pearson product–moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to1, the higher is the agreement between the simulated and the measured flows. It is calculated using the following equation:

$$r^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - \overline{q}_s)(q_{oi} - \overline{q}_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - \overline{q}_s)^2 \sum_{i=1}^{n}(q_{oi} - \overline{q}_o)^2} \tag{4.1}$$

Where: s_{ir} is the simulated values of the quantity in each model time step (in this case, daily, monthly and yearly)

q_{oi} is the measured values of the quantity in each model time step (in this case, daily, monthly and yearly)

$\overline{q}_s$ is the average simulated value of the quantity in each model time step (in this case, daily, monthly and yearly)

$\overline{q}_o$ -is the average measured value of the quantity in each model time step (in this case, daily, monthly and yearly.)

The range of values for r^2 is 1.0 (best) to 0.0 (poor). The r2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results. A value of 0.0 for r^2 means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

Nash-Sutcliffe simulation efficiency, E_{NS}, indicates the degree of fitness of the observed and simulated plots with the 1:1 line (Santhi *et al.* 2002). It is calculated as follows with the same variables defined above:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})^2}{\sum_{i=1}^{n}(q_{oi} - \overline{q}_o)^2} \tag{4.2}$$

q_{si} is the simulated values of the quantity in each model time step (in this case, daily, monthly and yearly)

q_{oi} is the measured values of the quantity in each model time step (in this case, daily, monthly and yearly)

E_{NS} can have values ranging from -∞ to 1. If the simulation is accurate, ENS is equal to one. If the accuracy of the simulation results is smaller than the average value of the measured variables, then ENS will have a negative value. The disadvantage of this evaluation tool appears in cases of extreme events; as such events have strong weights (Sintondji 2005).

E_{NS} is a more stringent test of performance than r^2 and is never larger than r^2. E_{NS} measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. A value of 0.0 for E_{NS} means that the model predictions are just as accurate as using the measured data average to predict the measured data. E_{NS} values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. This measure is highly affected by a few extreme errors and can be biased if a wide range of flow events is experienced. (Source: SWAT team)

After each calibration, the regression coefficient (R^2), and the Nash-Suttcliffe (1970) simulation efficiency (ENS) were also checked in accordance to Santhi *et al.* (2001) recommendation (R^2 >0.6 and ENS > 0.5).

4.3.11 MODEL CALIBRATION AND VALIDATION

4.3.11.1 Model Calibration

Once the main SWAT input data are ready to successfully run the model, bulky different simulation results are generated. The annual averaged simulation result is shown in Appendix 11. Depending on the results generated and sensitivity report, model calibration and validation was performed.

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2002) at different spatial and temporal scales.

Parameter estimation for calibration is various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. The process of adjustment can be done “manually” or using computer-based “automatic” methods. Refsgaard and Storm (1996) argued that the manual method is the most common, and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite.

As the number of sub-basins is too many and the watershed of Blue Nile is too vast, difficult to run automatically, hence, even though this method is cumbersome, the manual method was applied for this study.

As it is mentioned above the objective of a calibration procedure is the estimation of values for those parameters, which cannot be assessed directly from field data.

In sediment transporting modeling a two step calibration procedures has been suggested by Neitsch et al. (2002), first check water balance contribution, then calibrate stream flow and followed by sediment calibration.

For this study water balance was checked at selected places, (surface flow, ground water flow, lateral flow and total water yield at a given outlet). Then, calibration of stream flow has been taken place at outlet of sub basin 15, (outlet of Tana sub basin, Bahirdar station), at outlet of sub basin 96, (near Kessie) and at the outlet of sub basin 19, (at Sudan border). These sites were selected due to the availability of measured flow data.

Calibration of sediment was at locations of Tana basin (Gilgel Abbay, outlet number 10 and Addis Zemen at Ribb, outlet number 7) and at Kessie (outlet number 51).

The stream flow and sediment calibration was on annual and monthly average time steps at mentioned locations.

The calibration of flow have been carried out first at Bahirdar station, then at Kessie and finally at the Border. The parameter calibrated at upstream was remaining as it was for calibration downstream.

Regarding temporal scale, average annual stream flow was calibrated first and after getting satisfactory performance of model for yearly time step, monthly stream flow was calibrated for each location again. The period from 1991-1992 is the model "warm-up" period, and the period from 1992-1996 for calibration while validation was performed during the period 1997-2000.

"*Warming-up*" is the very essential part of the simulation process that ensures the establishment of the basic flow conditions for the simulations to follow by bringing the hydrologic processes to an equilibrium condition.

Key hydrological parameters such as SCS runoff curve number for moisture condition II (CN_2), available water capacity of the soil layer (SOL-AWC), soil evaporation compensation factor (ESCO), soil layer depth (SOL-Z), soil hydraulic conductivity (SOL-K), ground water delay time (GW-DELAY), and base flow recession factor (ALPHA_BF) are the sensitive parameters and their class of sensitivity range is from very high to medium. The rest are small and can be neglected (Table 4.4).

SWAT developers in Santhi et. al., (2001) assumed an acceptable calibration for hydrology at $R^2 > 0.6$ and $E_{NS} > 0.5$ (Equation 4.1, 4.2) and these values were also considered in this study as adequate statistical values for acceptable calibration.

After compiling all data, several simulations were carried out. The model generated the surface flow and the base flow volume of the Blue Nile Basin, the flow rate, the peak runoff rate, potential and actual evapotranspiration, aquifers recharge, and the water yield, sediment load and concentration, and other water quality nutrients.

4.3.11.2 Model Validation

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation-period stream flows confirm that the model performs satisfactorily. In the validation process, data for a period of four years was used at all the three calibration sites to evaluate the model accuracy.

The Model validation was performed at three stations similar to that of the calibration-using stream flow data. Calibration and validation of the model is a key factor in reducing uncertainty and increasing user confidence in its predictive abilities, which makes the application of the model effective. Information on calibration and validation of multi-sites, multivariable SWAT models has been provided to assist watershed modelers in developing their models to achieve watershed management goals.

The statistical criteria (R^2 and E_{NS}) used during the calibration procedure were also checked here to make sure that the simulated volume is still within the accuracy limits.

5. RESULTS AND DISCUSSION

5.1 SWAT Hydrological Model Results

After the SWAT model has run, the watershed has showed some modification compared with input data. The Blue Nile basin has an area of 199,812 Km^2 (source master of Abbay basin). But after delineation has done the total area became 190,346.64 Km^2. This is due to some of the site that has zero grid cell will not be accounted by ArcView GIS and SWAT will ignore the flat area.

In addition, the input land cover type was 12, but after simulation it became only 9, and the soil type was 24, now it merged to 21 only. This was because of Hydrological Response Unit (HRU) formation. The HRU formation was ordered by 20% land use and 10% soil type as suggestion of SWAT user guide and the threshold area limit has taken 28% of default suggested value. The land uses less than 20% and soil types less than 10% merged to other types of nearer land cover and soil type to make unique HRU. So, the land covers like Urban, Unused land and State farm; and soil types of Lithic Leptosols, Haplic Phaeozems, and Urban that have small area coverage in the basin (0.01%, 0.01% and 0.59% for land use and 0.3%, 0.05% and 0.03% soil type respectively) were merged to other land use and soil type.

The basin has been divide in to 98 sub basins with threshold area of 100, 000 ha as specified in section 4.3.2.4 and 392 HRU based on the above mentioned threshold area and percentage of land use and soil type combination.

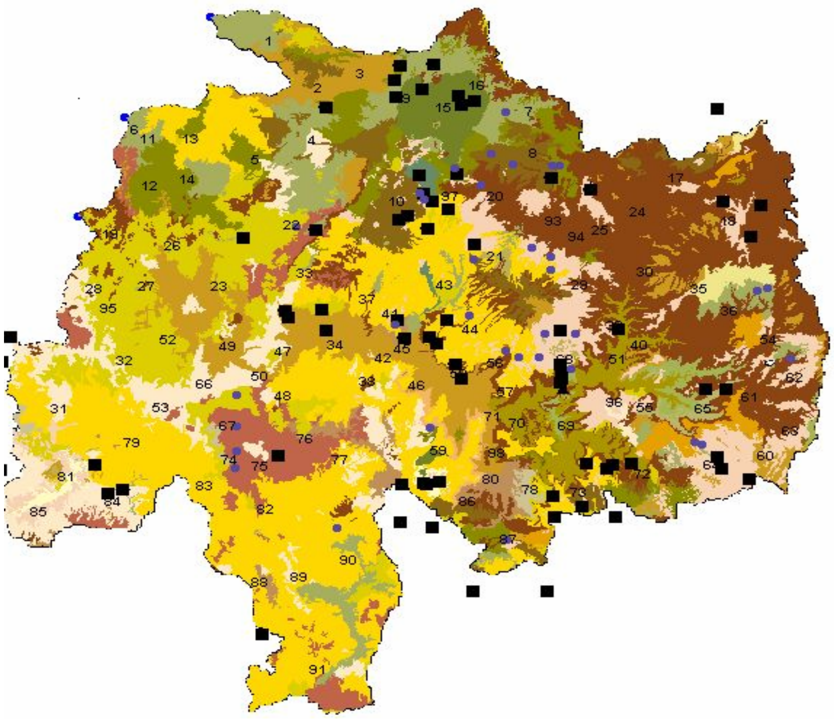


Figure 5.1 Delineated sub-basin, land use and soil map, overlay

5.1.1 SENSITIVITY ANALYSIS

For the Blue Nile sub-basin sensitivity analysis was carried out at three sites for flow as mentioned in section 4.3.3. These are at Bahirdar site, near Kessie site and at Sudan border site. The simulation of model was from Jan, 1991-Dec to Dec 1996. The simulation result from Jan 1991 to Dec 1991 is used as model warm up period and from 1992-1996 as calibration period. Finally the period from Jan 1997 - Dec 2000 was used as model validation time.

As dealt in section 4.3 , 280 iteration have been done by SWAT sensitivity analysis at each site of calibration with the out put of 28 parameters were reported as sensitive in different degree of sensitivity. Among these 28 parameters, only 10 of them have effect on the simulated result when changed. So, on category specified above the parameters changed for calibration were those of very high to medium of sensitivity class, (table 4.4.)

As shown in table 4.4, the first five parameters showed a relatively high sensitivity, being the curve number (CN_2) the most sensitive of all. The three most sensitive parameters controlling the surface runoff in the sub watershed are the soil moisture curve number,

(CN_2), the soil available water capacity (SOL_AWC), and the soil evaporation compensation factor (ESCO). The remaining are controlling base flow, the saturated hydraulic conductivity (SOL_K), depth from soil surface to bottom of layer (SOL_Z) and Groundwater delay time (GW_DELAY) and base flow recession (ALPHA_BF). These are the parameters highly influence the runoff of the watershed.

5.1.2 FLOW CALIBRATION

After sensitivity analysis has been carried out, the calibration of SWAT 2003 model simulated stream flow at the mentioned sites were done manually. The analysis of simulated result and observed flow data comparison was considered monthly and annually. Until the best fit curve of simulated versus measured flow was satisfied, the sensitive parameters were tuned in the allowable range recommended by SWAT developers. In computing the efficiency, the first year of simulated model result was excluded, because it considered as model priming, so that the influence of the initial conditions such as soil water content will be minimized (Grizzetti, et al., 2003.)

The values or ranges selected sensitive calibration parameters before and after calibration are given in Table 5.1 below.

Table 5.1Parameters set before and after calibration of SWAT for stream flow calibration at Bahirdar station

SWAT Parameter Name	Recommended range by sensitivity analysis	Initial value	Calibrated value
CN_2	±50%	Default *	-40.6%
SOL-AWC	±50%	**	-25%
ESCO	0.0 -1.0	0.95	0.1
SOL-Z	±50%	**	-44%
SOL-K	±50%	**	+50%
GW_DELAY	0-100	31	40
ALPHA_BF	0-1	0.048	0.5

** Default value assigned by SWAT itself*

*** Value initially assigned by users, but it may not depends on accurate data*

Table 5.2 Parameters set before and after calibration of SWAT for stream flow calibration at Kessie station

SWAT Parameter Name	Recommended range by sensitivity analysis	Initial value	Calibrated value
CN_2	±50%	Default *	-49.6%
SOL-AWC	±50%	**	-35%
ESCO	0.0 -1.0	0.95	0.7
SOL-Z	±50%	**	-44%
SOL-K	±50%	**	+50%
GW_DELAY	0-100	31	31
ALPHA_BF	0-1	0.048	0.5

Table 5.3parameters set before and after calibration of SWAT for stream flow calibration at Border station:

SWAT Parameter Name	Recommended range by sensitivity analysis	Initial value	Calibrated value
CN_2	±50%	Default *	-49.6%
SOL-AWC	±50%	**	-25%
ESCO	0.0 -1.0	0.95	1.0
SOL-Z	±50%	**	-25%
SOL-K	±50%	**	-25%
GW_DELAY	0-100	31	20****
ALPHA_BF	0-1	0.048	0.5

These parameters are believed to be the governing parameters to partitioning a given precipitation as surface flow and ground water flow (Tetra Tech Inc., 2004) and hence are sensitive components.

The monthly calibration graphical results of the three sites are given in figure 5.2, 5.3 and 5.4.

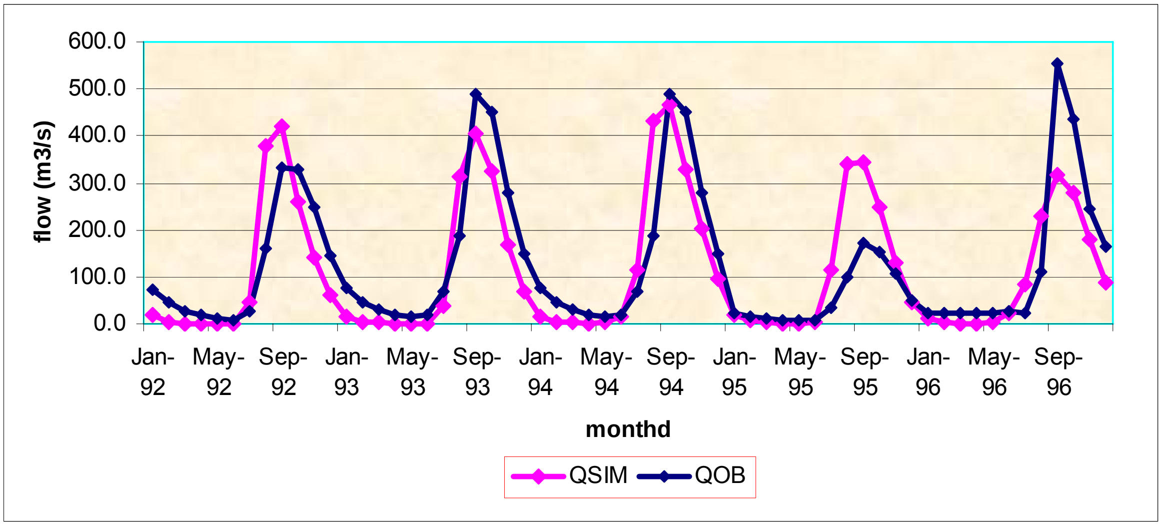


Figure 5.2Comparison of simulated Vs. measured stream flow at Bahirdar outlet for model calibration

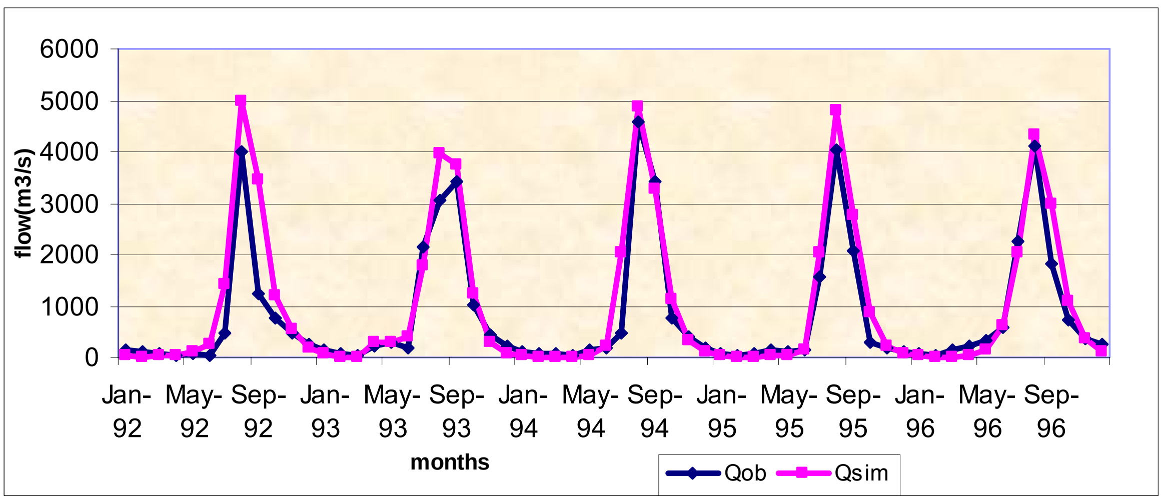


Figure 5.3comparison of simulated Vs. measured stream flow at Kessie outlet for model calibration

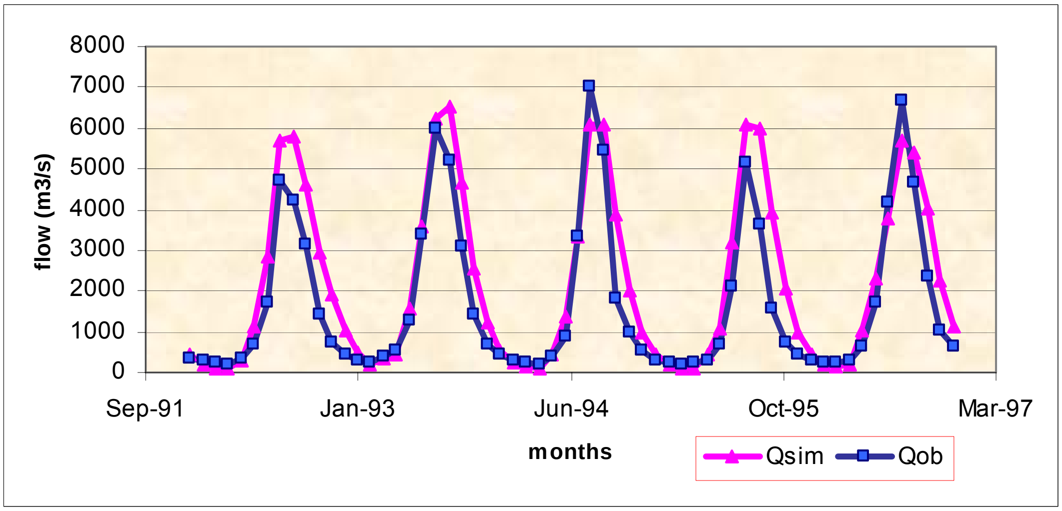


Figure 5.4comparison of simulated Vs. measured stream flow at Border outlet for model calibration

Figure 5.2, 5.3 and figure 5.4 shows the time series comparison of simulated and measured flow at Bahirdar, Kessie and Border sites respectively for year 1992-1996 of calibration period. As the graphs of fig 5.2, 5.3 and 5.4 and Table 5.4 show, the annually and monthly simulated flow is correlated well with measured flow, and it implies that the model performed well annually and monthly for Blue Nile basin. The simulated and the observed flow data match in good way both in magnitude and in temporal variation at the three sites.

Table 5.4Summary of calibrated and observed flow (m3/s) at the three sites:

site	year	1992	1993	1994	1995	1996	Average (m3/s)	Yearly efficiency		Monthly efficiency	
								R^2	E_{NS}	R^2	E_{NS}
Bahirdar	calibrated (m3/s)	139.3	140.7	175.9	131.7	127.4	156.2	0.86	0.8	0.71	0.65
	Measured (m3/s)	138.31	153.58	188.2	57.13	135.39	145.16				
Kessie	calibrated (m3/s)	921.44	923.41	923.89	922.84	880.12	889.34	0.93	0.87	0.91	0.84
	Measured (m3/s)	638.69	931.46	989.93	658.93	912.59	818.01				
Border	calibrated (m3/s)	1811.47	2003.5	1750.7	1702.4	1849.63	1823.53	0.9	0.82	0.89	0.78
	Measured (m3/s)	1502.12	1920.3	1797.68	1299.72	1908.43	1774.42				

The good fitness of model performance is indicated by statistical efficiency indicator of Nash-Sutcliffe of value above satisfactory result (R^2>0.60 and E_{NS}>0.50) for all of the sites as shown in table 5.1.

The regression analysis between the simulated flow and measured flow also shows good result as shown in figure 5.5, 5.6 and figure 5.7

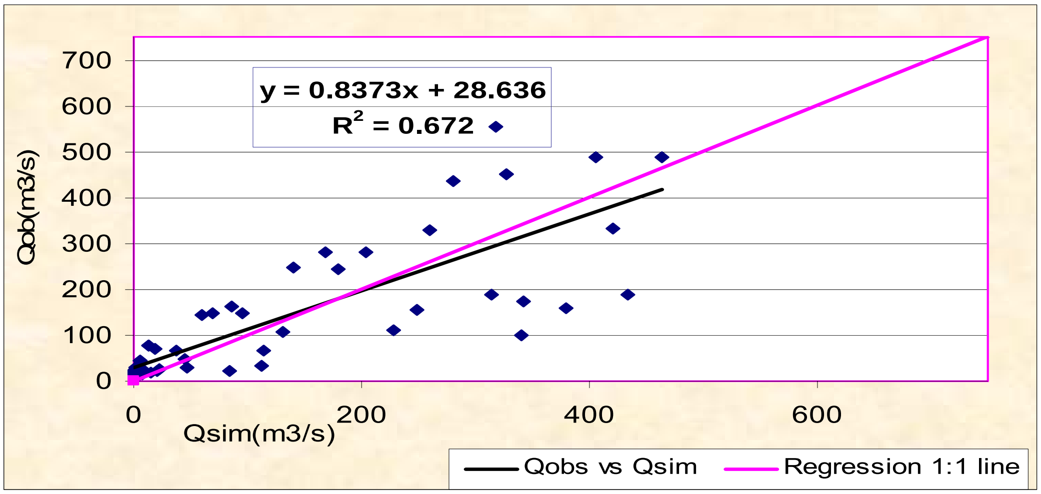


Figure 5.5Regression analysis line and 1: 1 fit line of measured versus simulated flow at Bahirdar

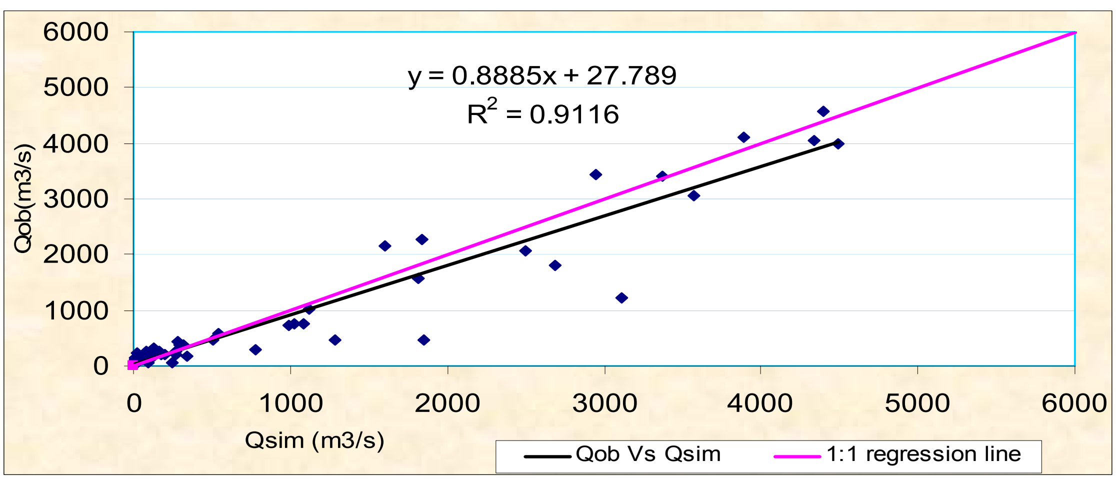


Figure 5.6Regression analysis line and 1: 1 fit line of measured versus simulated flow at Kessie

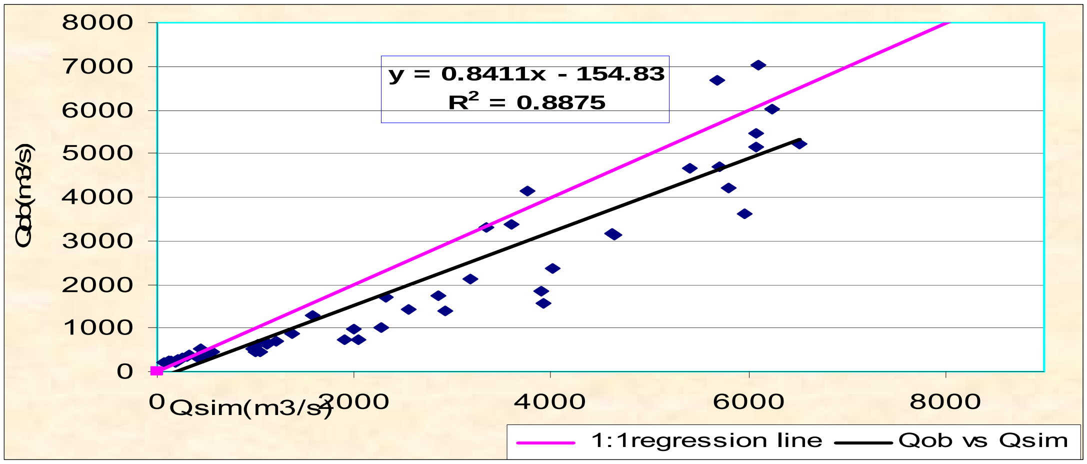


Figure 5.7Regression analysis line and 1: 1 fit line of measured versus simulated flow at Border

The regression coefficient of 0.67, 0.91 and 0.89 respectively for Bahirdar, Kessie and Border outlets are very good correlation and they imply that the SWAT model simulated runoff is a good prediction of measured flow.

5.1.3 FLOW VALIDATION

As it is mentioned above in section 4.3.5, the purpose of model validation is to check whether the model can predict flow for another range of time period or conditions than those for which the model calibrated for. Model validation involves re-running the model using input data independent of data used in calibration (e.g. differing time period), but keeping the calibrated parameters unchanged. In this study the validation period is from year Jan, 1998 to Dec, 2000. One year from Jan 1997 to Dec 1997 is considered as warm-up period for model. The site of validation is the same as calibration sites, at Bahirdar, Kessie and Border stations.

Like as calibration, the three above-mentioned goodness-of-fit measures were calculated and model-to-data plots were inspected.

AS shown below on figure 5.8, 5.9, and 5.10, the simulation predicts well the measured flow at validation time at sites of Bahirdar, Kessie and Border. The good fitness of model performance is indicated by statistical efficiency indicator of Nash-Sutcliffe of value above satisfactory result (R^2>0.60 and E_{NS}>0.50) for all of the sites as shown table 5.5 below.

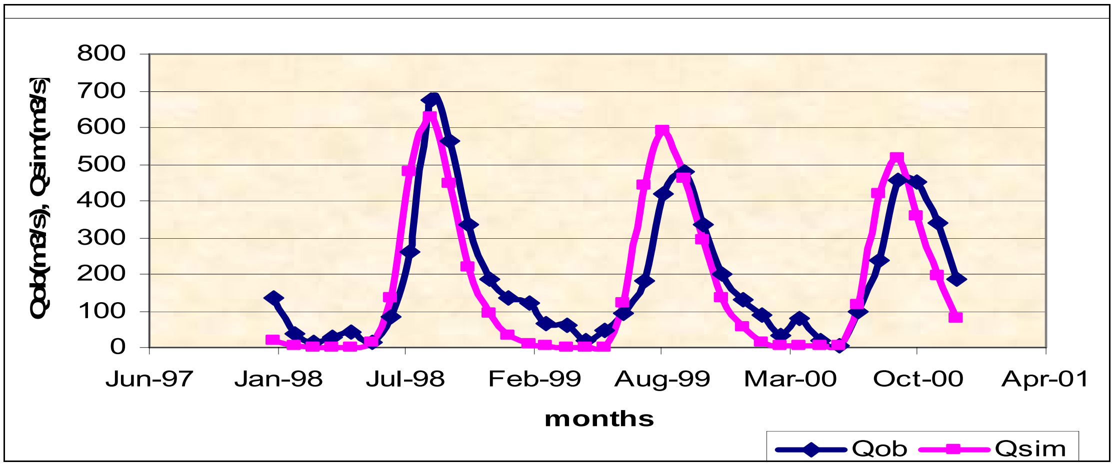


Figure 5.8Graphical comparison of measured Vs. validation Simulated flow at Bahirdar outlet

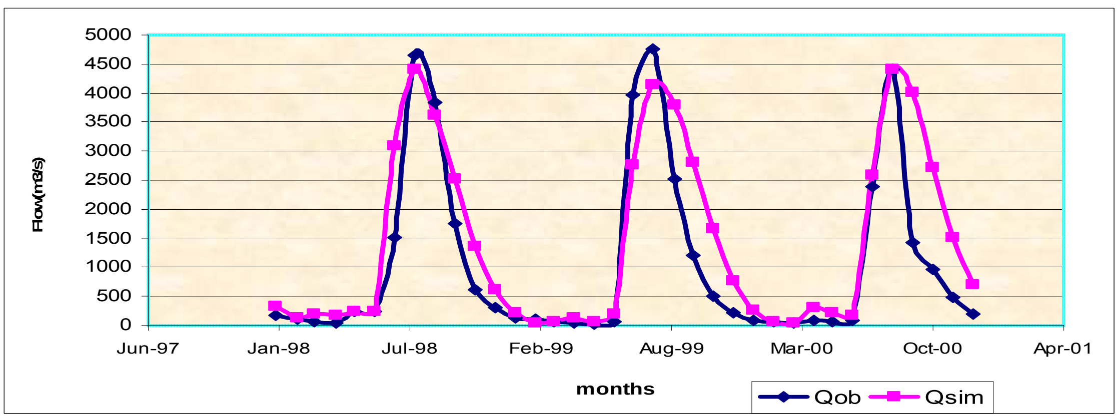


Figure 5.9Graphical comparison of measured Vs. validation Simulated flow at Kessie outlet

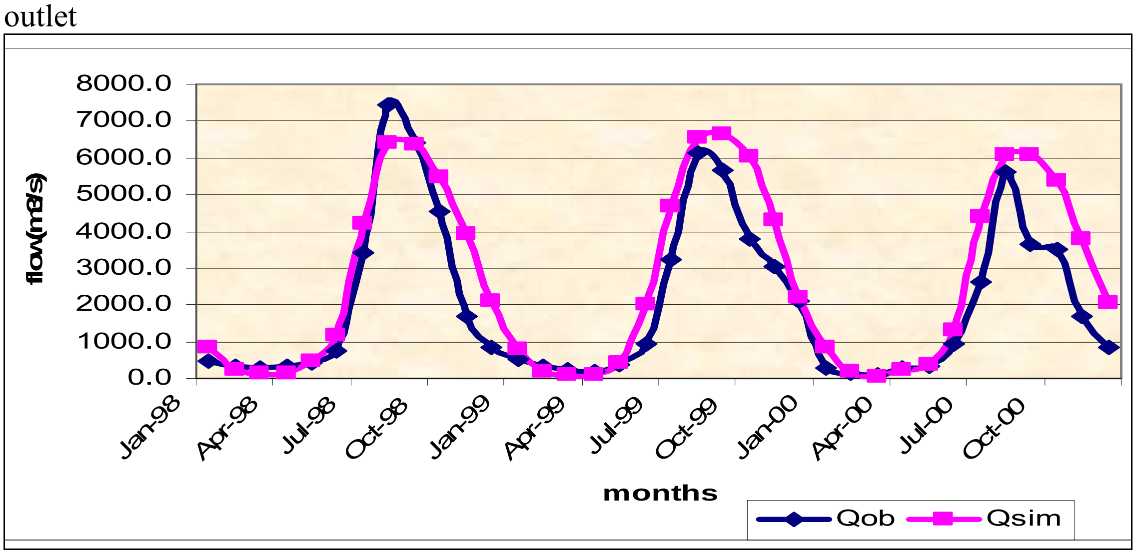


Figure 5.10Graphical comparison of measured Vs. validation Simulated flow at Border outlet

Table 5.5 Summary of validated and observed flow (m3/s) at the three sites:

site / year		1998	1999	2000	Average(m^3/s)	Yearly efficiency		Monthly efficiency	
						R^2	E_{NS}	R^2	E_{NS}
Bahirdar	validated (m3/s)	182.1	186.2	157.9	175.4	0.89	0.75	0.78	0.69
	Measured (m3/s)	197.6	178.9	176.6	184.36				
Kessie	validated (m3/s)	1283.8	1261.8	1289.7	1278.4	0.9	0.81	0.79	0.76
	Measured (m3/s)	1129	1136.9	862.5	1087.24				
Border	validated (m3/s)	2186.6	2360.5	2140.4	2229.16	0.9	0.78	0.88	0.75
	Measured (m3/s)	2247.7	2206.2	1657.8	2037.23				

5.1.4 Sediment Calibration and Validation

In this paper the physically based SWAT 2003 model was applied to Blue Nile gauged watershed for prediction of soil erosion and sediment yield/concentration for the whole basin. There are limited sediment data in Blue Nile basin. It is also on very small tributary river catchments, to perform on large river calibration and validation of watershed models for sediment yield, it is difficult. But it was tried to apply basin similarity to generated sediment load/concentration versus stream flow daily data for calibration and validation purpose.

The first goal of the present study was to test the efficiency of SWAT2003 model in predicting sediment yield by acquiring the most sensitive sediment parameters in gauged watershed.

The second goal was to develop calibrated sediment parameters so that the model can be used in un-gauged watersheds with similar topography and agro climatic characteristics for prediction of sediment yield/concentration.

The SWAT calibration for the sediment yield was conducted after the model was validated for the stream flow.

SWAT model was first calibrated to flows (see section 5.1.2), then to sediment. SWAT model was calibrated for sediment by comparing monthly model simulated sediment yield against monthly measured sediment yield at sites Gilgel Abbay (outlet 10), Addis Zemen at Ribb (out let 7) and near Kessie (outlet 51).

The data for calibration of sediment is not as such reliable, because from few scattered daily data of another site (for Kessie Suha), the sediment discharge curve is derived and by using this curve monthly data for the site of calibration has been generated. To minimize the discrepancy the discharge sediment curve was derived as wet season and dry season curve separately, (Appendix 3.1)

After sensitive analysis have been carried out around 34 parameters have been identified, but the relatively sensitive parameters are 20, from very high to small relative of sensitivity. These parameters with default value and adjusted one are given in table 5.6 below.

As discussed previously in the methodology section, the sediment yield was calibrated manually using the derived sediment yield at the outlet of the sub watershed.

Table 5.6 Sensitive parameter, default value and their adjustment for sediment calibration

Rank of sensitivity	Parameter	Description	Relative mean	Range bound	Initial value	final adjusted value	Class of sensitivity
1	sol_k	Soil depth [mm]	3.29E+00	±50%	*	-50%	Very high
2	SPCON	Linear factor for channel sediment Routing	2.29E+00	0.0001-0.01	0.0001	0.001	Very high
3	SOL-AWC	Soil available water capacity [mm WATER/mm soil]	2.18E+00	±50%	*	-25%	Very high
4	SURLAG	Surface runoff lag time [days]	1.94E+00	0-10	4	8	Very high
5	sol_z	Saturated hydraulic conductivity [mm/hr]	1.81E+00	±50%	*	+18.5%	Very high
6	BIOMIX	Biological mixing efficiency	1.74E+00	0-1	0.20	0.10	Very high
7	CN2	Initial SCS CN II value	1.58E+00	±50%	*	-25%	Very high
8	SLOPE	Average slope steepness [m/m]	1.43E+00	±50%	*	-50%	Very high
9	ALPHA_BF	Base flow alpha factor [days];	1.27E+00	0-1	0.048	0.05	Very high
10	GWQMN	Threshold water depth in the shallow aquifer for flow [mm]	7.13E-01	0-5000	0	150	High
11	USLE_P		6.22E-01	0-1.0	1	0.50	High

		USLE support practice factor					
12	canmx	Maximum canopy storage [mm]	6.02E-01	0-10	0	3	High
13	SLSUBBSN	Average slope length [m];	4.77E-01	±50%	*	+50%	High
14	ch_k2	Channel effective hydraulic conductivity [mm/hr]	4.75E-01	0-150	0	10	High
15	USLE_C	Minimum USLE cover factor	3.97E-01	±50%	0	0	High
16	ESCO	Soil evaporation compensation factor	3.78E-01	0-1.0	0.95	0.70	High
17	rchrg_dp	Deep aquifer percolation fraction	3.70E-01	0-1.0	0.05	0.8	High
18	ch_n	Manning's n value for main channel	2.22E-01	±20	0.014	-20%	High
19	GW_REVAP	Groundwater "revap" coefficient	1.69E-01	0.02-0.2	0.02	0.2	Medium
20	SPEXP	Exponential factor for channel sediment routing	1.02E-01	1-2	1	1.5	Medium

As seen from calibration model efficiency criteria, in all the three sites of sediment calibration, it simulated well with derived sediment, with Coefficient of determination (r^2) value and Nash-Sutcliffe model efficiency (E_{NS}) are above the recommended range. As the calibration of sediment with this unreliable data is not convincing (because of up scaling), I wouldn't stick only on this efficiency criteria since the graphical comparison agree with logic of discharge versus sediment have direct relation, as discharge become peak sediment also be with a little time of lag between the two peaks. Normally rainfall becomes peak first and then runoff of the catchment attains the summit in rainfall-runoff hydrograph. Similarly the peak of sediment comes before runoff may be some times the difference unobserved.

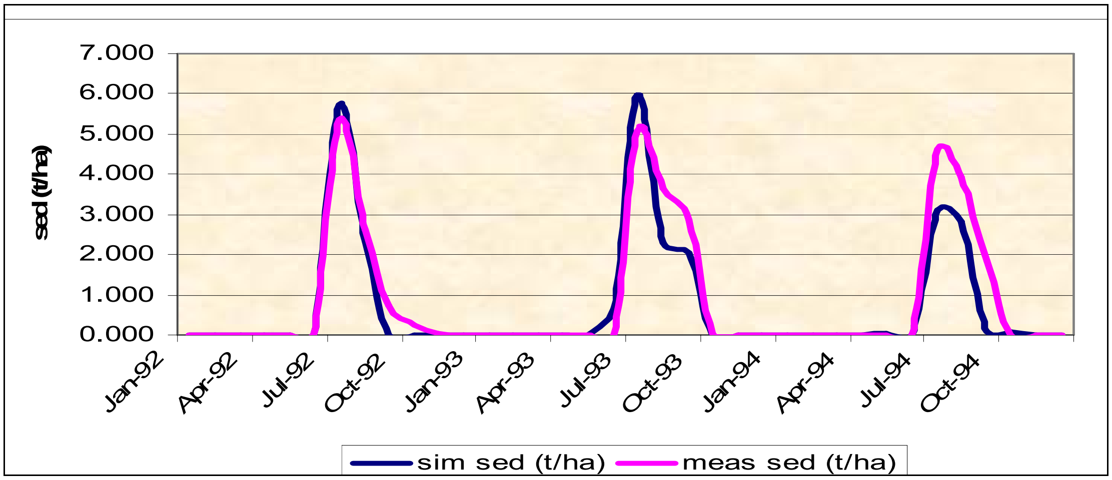


Figure 5.11 Comparison of observed monthly sediment with simulated monthly sediment at Addis Zemen

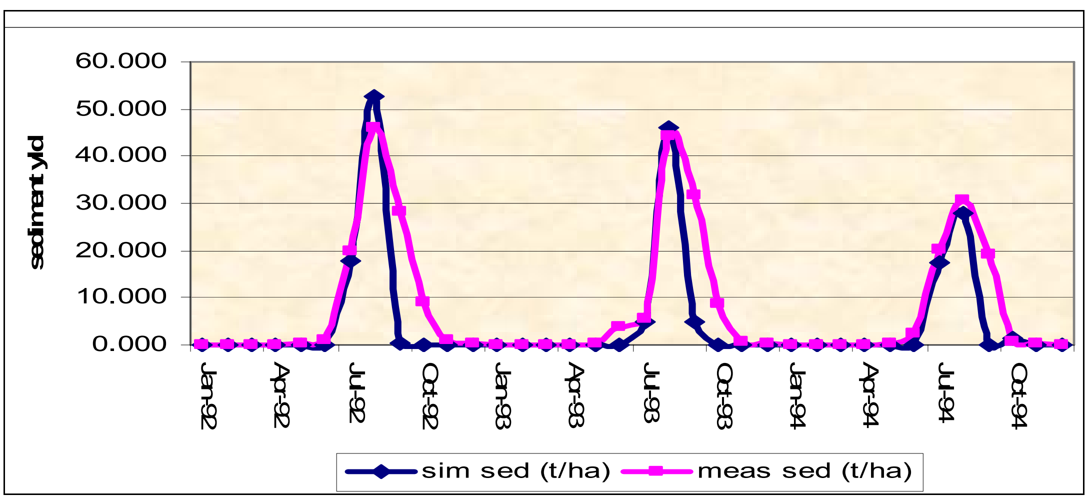


Figure 5.12 Comparison of observed monthly sediment with simulated monthly sediment at Gilgel Abbay

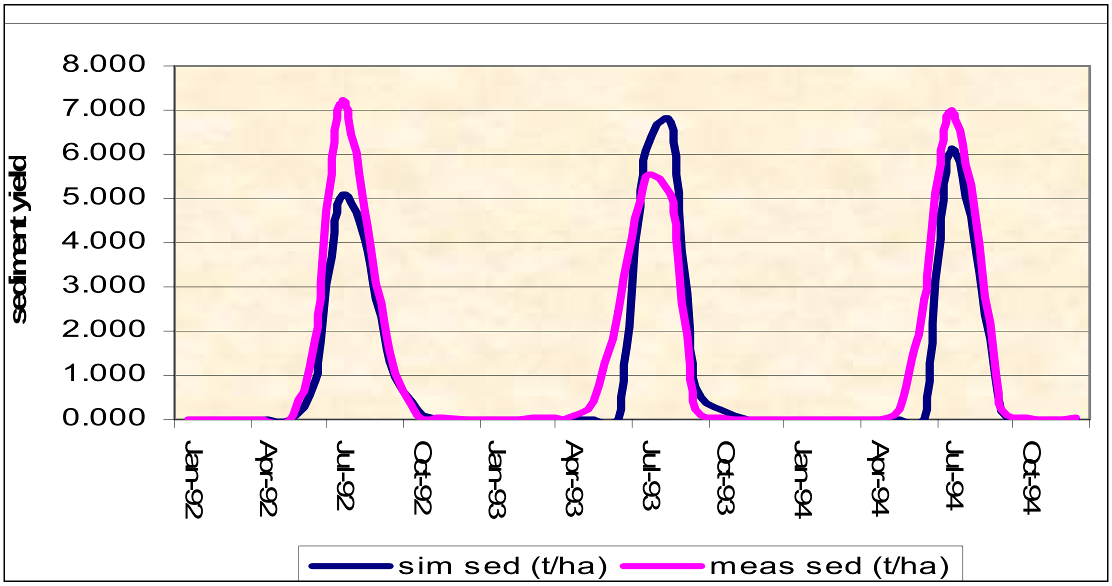


Figure 5.13 Comparison of observed monthly sediment with simulated monthly sediment near Kessie

After calibration, the SWAT model was checked and verified for monthly simulated sediment yield at the calibrated sites without changing parameter of calibration for the period 1996 to 2000. But one year from January 1, 1995 to December 1995 used as model "warm up" period.

Monthly sediment yield versus monthly sediment measured compared graphically and with model efficiency statistical analysis. Still it gave good simulation result.

Table 5.7 SWAT model calibration and validation statistics for monthly sediment yield comparison at selected sites:

Watersheds		Simulation Period	Monthly Average efficiency	
			R^2	E_{NS}
Addis Zemen	Calibration	1992-1994	0.89	0.88
	Validation	1997-2000	0.81	0.75
Gilgel Abbay	Calibration	1992-1994	0.71	0.66
	Validation	1997-2000	0.71	0.65
Kessie	Calibration	1992-1994	0.86	0.85
	Validation	1997-2000	0.82	0.77

In the following Figure 5.14, 5.15 and 5.16 it was shown that the sediment yield from different basin per hectare of the catchment. Different catchments have different sediment yield tendency, looked at the appendices 11 and 12, but here looked for validation purpose at the calibrated sites.

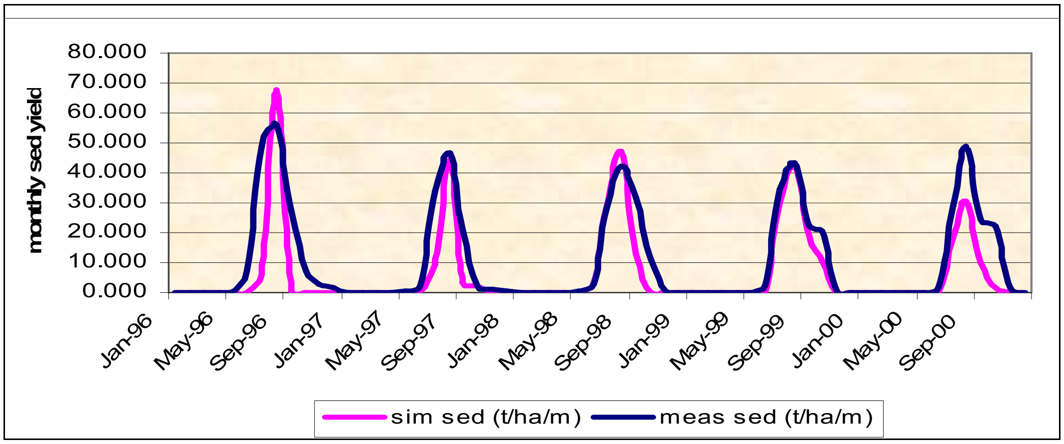


Figure 5.14Comparison of observed monthly sediment yield with simulated monthly sediment yield during validation at Gilgel Abbay

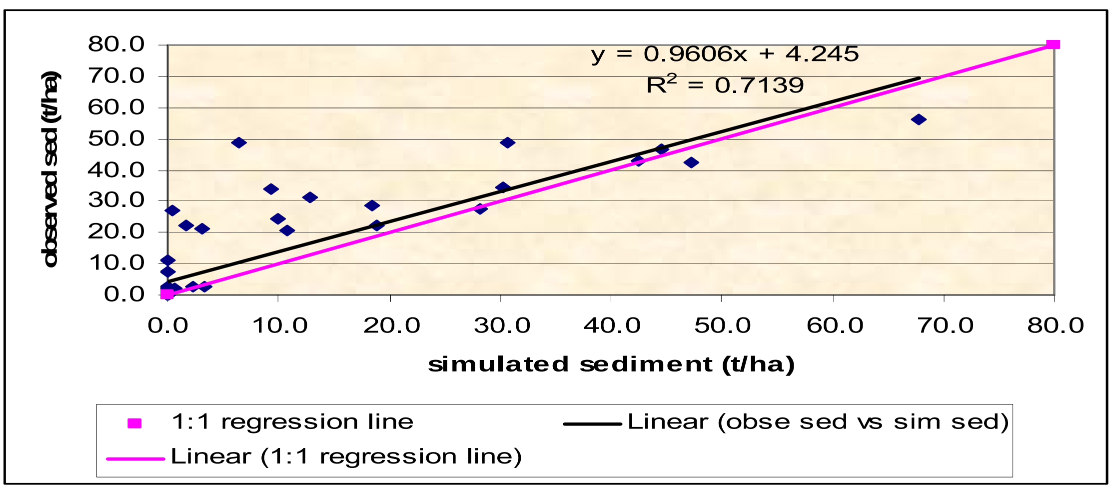


Figure 5.15Regression analysis and 1:1 fit line of measured versus simulated sediment yield at Gilgel Abbay

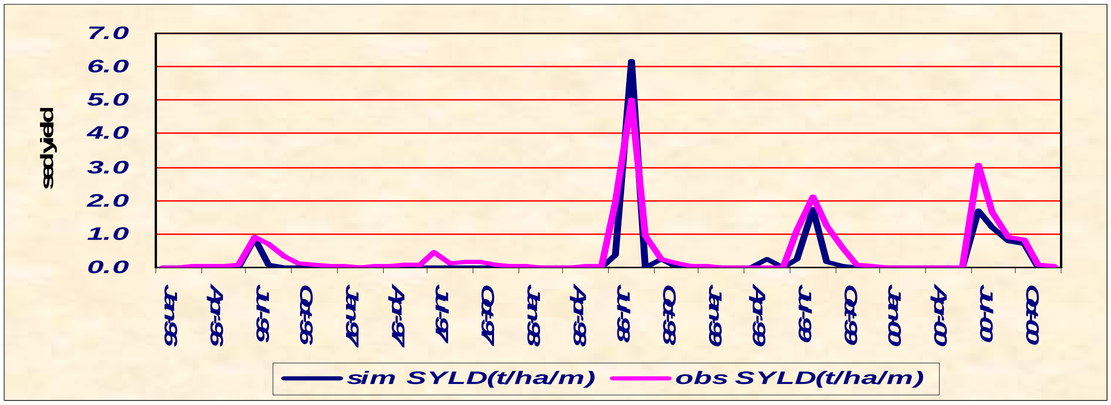


Figure 5.16Comparison of observed monthly sediment yield with simulated monthly sediment yield during validation at Kessie

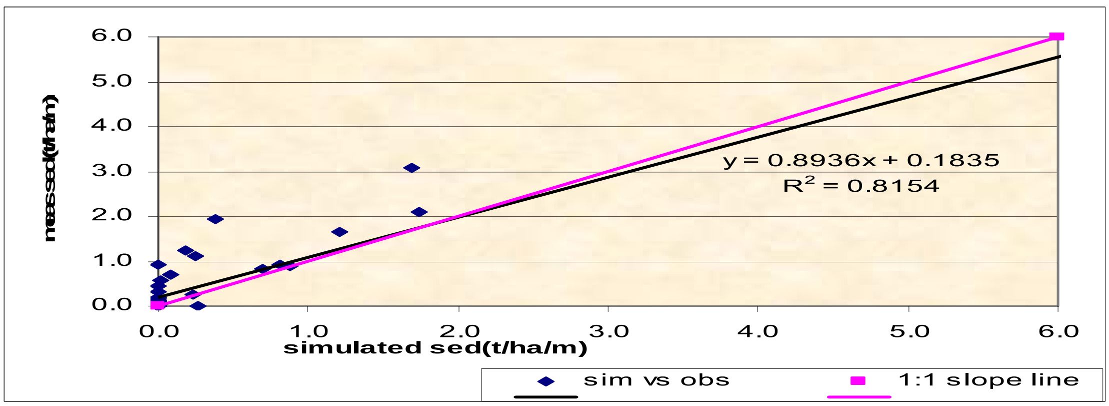


Figure 5.17Regression analysis and 1: 1 fit line of measured versus simulated sediment yield at Kessie

The following figure 5.18, 5.19, 5.20 and Figure 5.21 shows the sediment carried with discharge flow in the stream. This are the comparison of measured sediment carried out monthly with SWAT model simulated monthly sediment transported with stream flow. It shows good agreement as well and the statistical model efficiency criteria are also well fulfilled for this case too. The R^2 and E_{NS} at Kessie is 0.82 and 0.77 respectively.

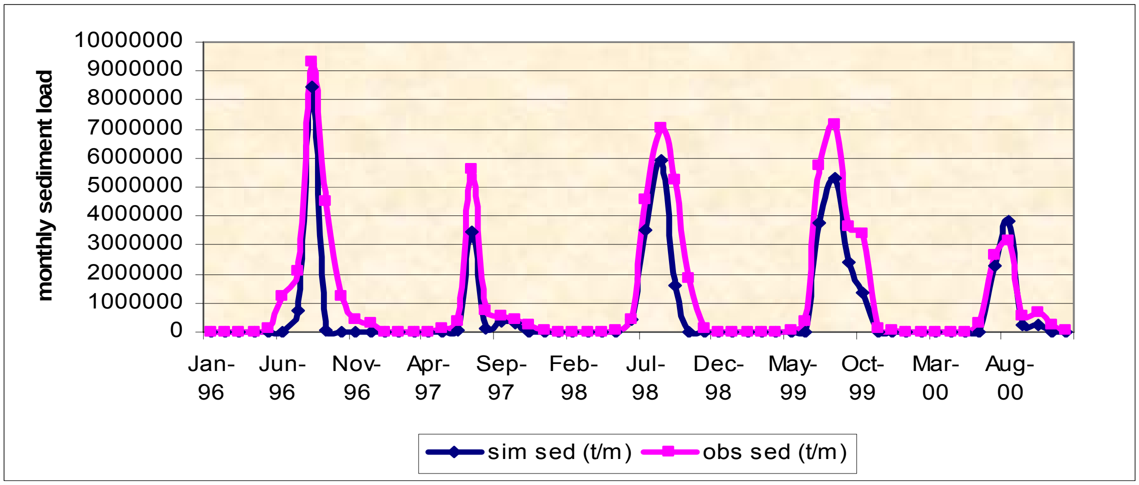


Figure 5.18Comparison of observed monthly sediment carried Vs simulated monthly sediment carried during validation at Gilgel Abbay

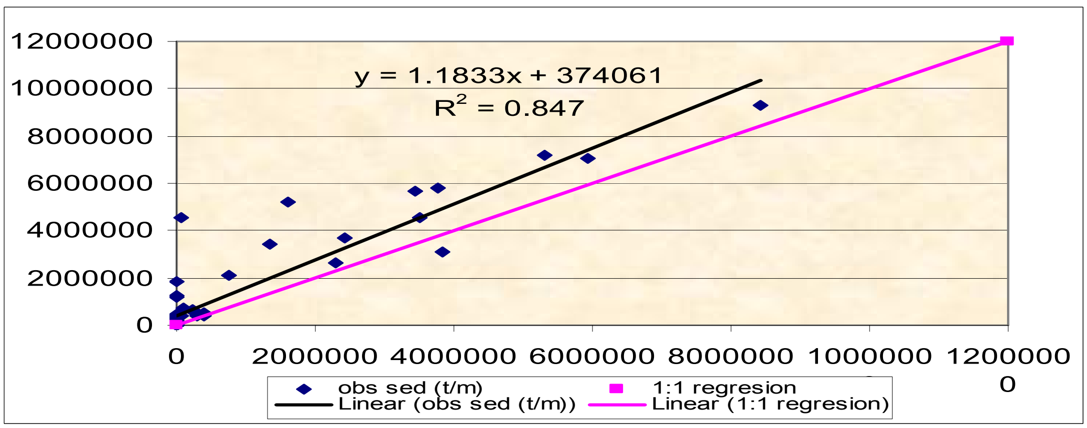


Figure 5.19Regression analysis line and 1:1 fit line of monthly measured sediment load versus simulated sediment load transported Gilgel Abbay

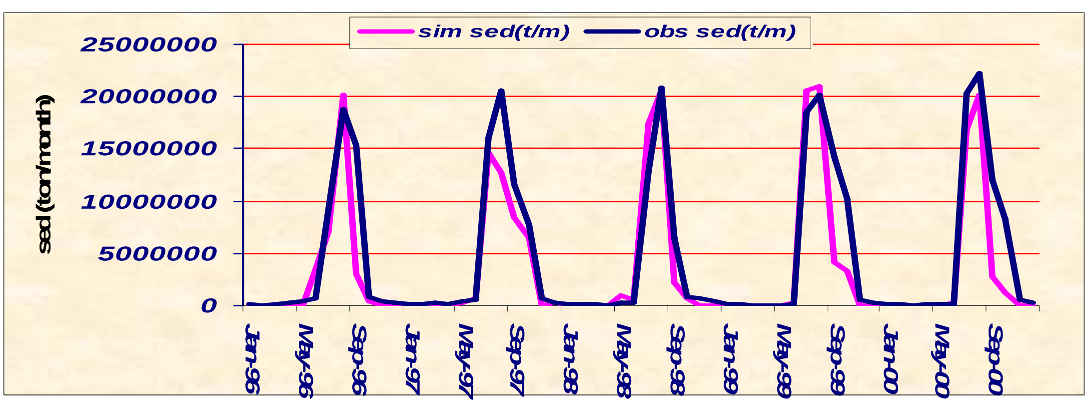


Figure 5.20Comparison of observed monthly sediment carried Vs simulated monthly sediment carried during validation at Kessie

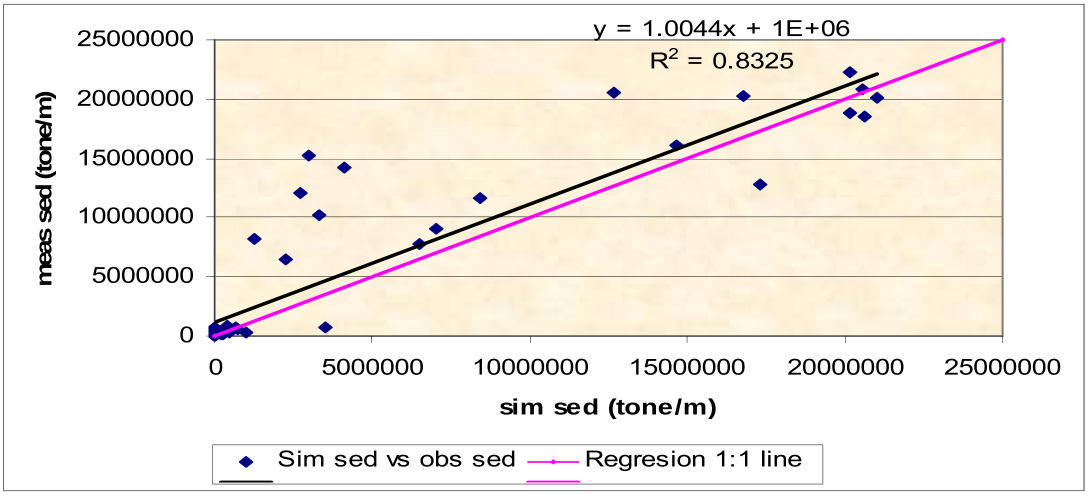


Figure 5.21Regression analysis and 1:1 fit line of monthly measured sediment load versus simulated sediment load transported at Kessie

5.2 Discussion of Model output

Simulation was performed for the whole Blue Nile in Ethiopia from the year 1991 -1996 as calibration period and from 1997-2000 as validation time for runoff result and from 1991-1994 as calibration period and from 1995-2000 as validation period for sediment results.

As discussed above it has given good result both for runoff and sediment of calibration and validation with model efficiency criteria at selected calibration sites.

From these calibration and validation results and sites, it is possible to generalize the model work for other sub basins in the watershed of simulation since the SWAT model is distributed model and predict the same result in the calibration region for the similar HRU.

SWAT predicts unique runoff and sediment yield for a given HRU, as HRU stands for a unique land cover and soil type.

For different sub basin the annual sediment yield is shown in the following chart:

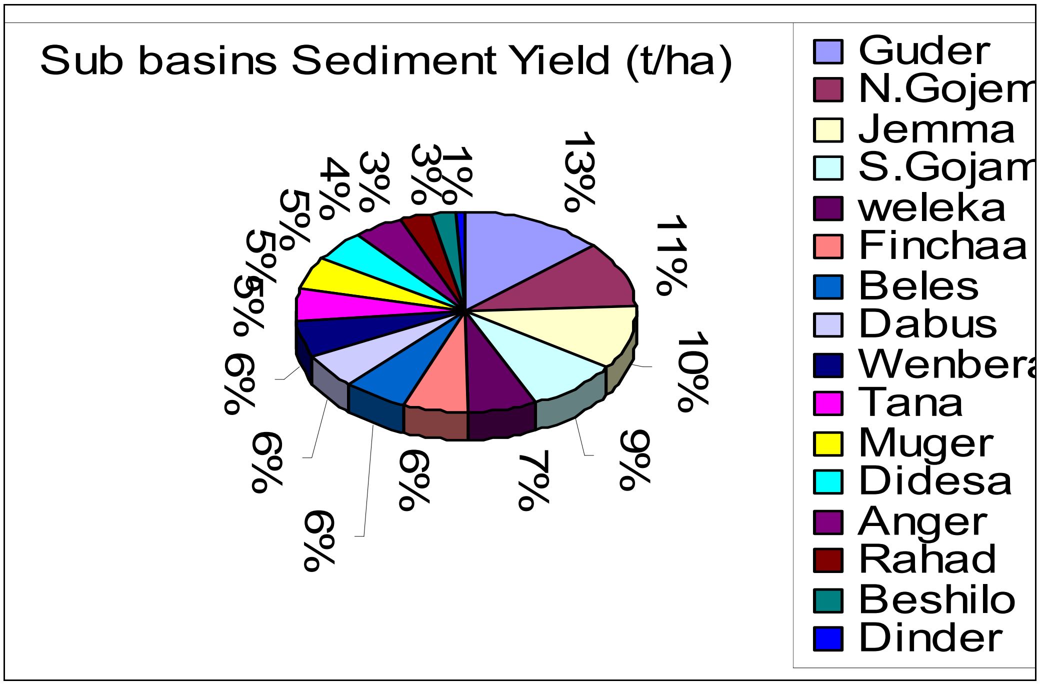


Figure 5.22The diagrammatic comparison of sediment yield from different sub basin

From this diagram, the Guder, N.Gojam and Jemma are the highest sediment yielding sub basin in the mentioned order, cover 13%, 11% and 10% respectively of the whole Blue Nile basin in Ethiopia. 34% of sediment of the Blue Nile basin is eroded from these three sub basins. This is due to different combination effect of land use, slope of the sub basin, slope length and rainfall on the catchments.

Similarly as figured out in the appendix 9, more than 50% (46.128 Million tones out of 91.24 Million tones) of eroded soil of the Blue Nile basin is from an area that covers 14% of the basin. These SWAT created sub basins are distributed mostly through the basins of Jemma, N.Gojam, S.Gojam, and few in Wenbera and Dabus. That may be mountainous area, bare area etc.

Hurni (1983) has conducted a research to estimate the rates of soil formation for Ethiopia and results are presented in Table 5.5 The range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to18 t/ha/y (Hurni, 1985). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y at some sub basins, (appendix 12).

Table 5.8 Zonal Variability of soil formation rates (Sources Hurni, 1983a)

Zone	Soil Formation Rates (tons/ha/year)
Gonder, Rift Valley	6-10
Gojam, Arsi Regions	10-14
Welega, Kefa, Shewa	18-22
Gemo Gofa	10-14
Kenya border	6-10

But the average annual sediment yield of the whole Blue Nile is around 4.26 t/ha/yr and 4.58 t/ha/yr excluding Rahad and Dinder sub basins. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Millions tones without Rahad and Dinder, (appendix 11).

The amount of soil erosion or sediment yield that occurs in given watershed related to five factors: the rainfall and runoff, the soil erodibility, the slope length and steepness, the cropping and management of the soil, and any support practices that are implemented to prevent erosion (Dilnesaw A., Bonn 2006).

The land use/cover of the three highest sediment yielding sub basins are dominated by Agriculture; (Guder: (Agriculture=95.66%, and pastoral land=4.34%), N.Gojam (Agriculture=95.41% and pastoral land=4.59) and Jemma (Agriculture=93.89%, pastoral land= 3.42% and Corn=2.69%)).

The slope of these three highly eroded sub basins (Guder, N.Gojam and Jemma) are stands 3^{rd}, 4^{th} and 6^{th} compared to other sub basins of Blue Nile basins. This is also one of the main factors affecting soil erosion in the watershed.

The three least sediment yielding sub basins are Dinder, Beshilo and Rahad respectively from the lower to up respectively yielding 0.8%, 2.6%, 3% of soil eroded of the whole Blue Nile basin. This comprises 6.4% of sediment yield from the basin.

The land cover/use of these three least sediment producing sub basins are non agriculture except Beshilo sub basin. The Beshilo sub basin is 100% agricultural land, and its slope is the steepest of all sub basins (0.133 m/m). Even though the slope is highest, the land cover is agricultural, the Beshilo sub basin produce the least sediment per hectare of area, may be due to small rainfall on the sub basin (1056.1 mm), the second least next to Weleka sub basin and soil type.

The other two least sediment producing sub basins, Dinder land cover, Range land 96% and corn land 4%, and Rahad land cover, Range land 43.4%, Pastoral land 23.3%, corn 14% and forest land 19.3%.

Looking their slope, Dinder sub basin is the smallest 0.033 m/m, and Rahad 10th steepest among other sub basin (0.078 m/m).

Similarly, the slope of those three high sediment yielding sub basins are relatively high compared to the least sediment yielding sub basin, even though, they are not the highest compared to other medium sediment yielding sub basin.

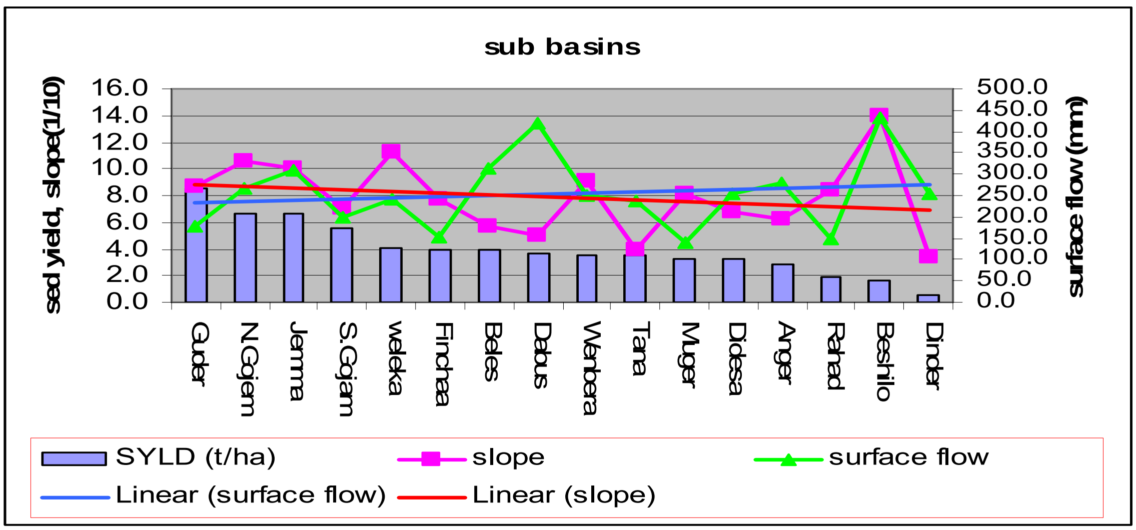


Figure 5.23 The graphical comparison of the effect of surface runoff and slope steepness on sediment yielding

Looking on the figure 5.23, the surface runoff, and slope are not the lonely factors to affect the sediment yield. For example, Guder sub basin, event though, both surface runoff and slope of the basin are below the average and at the average respectively, the sediment yield at this basin is the largest as mentioned above and observed on the figure 5.23. But, for Wonbera sub basin both surface runoff and slope of the basin is greater than that of Guder sub basin, however, the sediment yield from Wonbera sub basin stands 9th in the basin. The land use/cover of Wonbera is (Corn 35.61%, forest 30.2%, Agriculture 30.9% and Range land 3.3%).

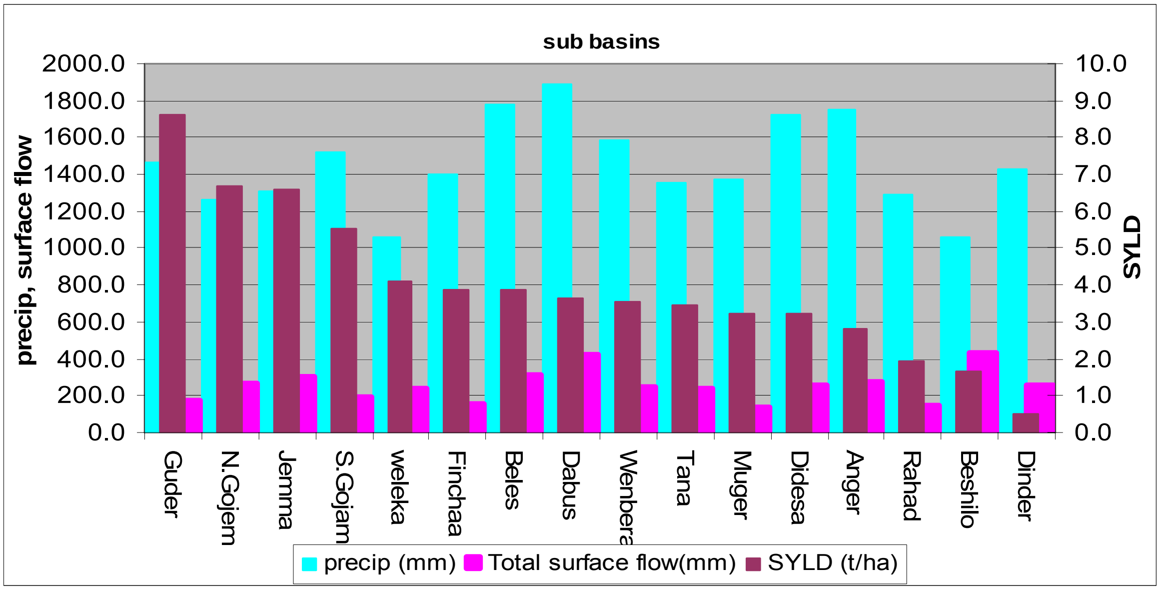


Figure 5.24 Graphical relation of sediment yield, precipitation and surface run off

As shown above on figure 5.24, the precipitation and surface runoff alone have no direct impact on sediment yield. For example, for Dabus sub basin, the precipitation and surface runoff are the highest among the other sub basins of Blue Nile, but the response of land per hectare to sediment yielding is on the 8^{th} range from top. Again the land use is expected to be highly influential for this sub basin as 47.64% is range land, 10.65% agricultural land, and Pastoral, Corn and forest land cover 5.07%, 3.63% and 2.12% respectively. More over, the slope of Dabus sub basin is the 3rd least slope in the basin.

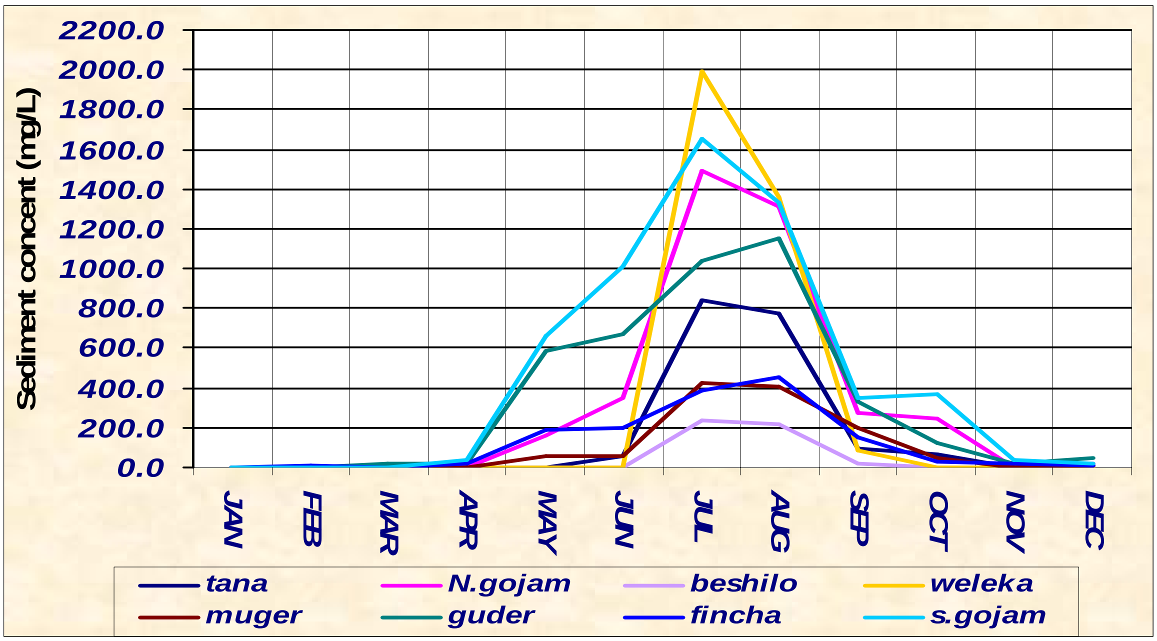
From this, we can observe that, the land use/cover is the most influential parameter for soil erosion and sediment yield from a given watershed in Blue Nile basin.

5.2.1 Looking Relation Between Rainfall-Runoff And Sediment Yield/Load

The relation between rainfall and runoff is a very long history as they have direct relation with some effects of watershed characteristics. But the relation of sediment with runoff and rainfall is not as such common to predict manually or empirically, but with help of recent models like SWAT, it gives the relation between the three phenomena as it considers all parameters that influence sediment yield, sediment concentration and sediment transport. Depending on the output of SWAT model result, the relation between rainfall, runoff and sediment yield/concentration is shown for all 16 sub basins of Blue Nile basin on Appendix 13. This shows logical agreement between them, rainfall peak is come first, with sediment concentration peak the next and the peak of runoff is at the end.

The sediment concentration in the Tana sub basin is represented by out let number 15, the main Abbay outflow from Lake Tana at Bahir Dar. This outlet is not good representing the exact sediment yield of the sub basin as some of the suspended sediment will be deposited in the Lake Tana and only suspended one carried with water out of lake.

Sediment concentrations versus flow at outlet of each sub basins are shown in Appendix 10. The following figures are the summary of monthly sediment concentration in each sub basin of Blue Nile.



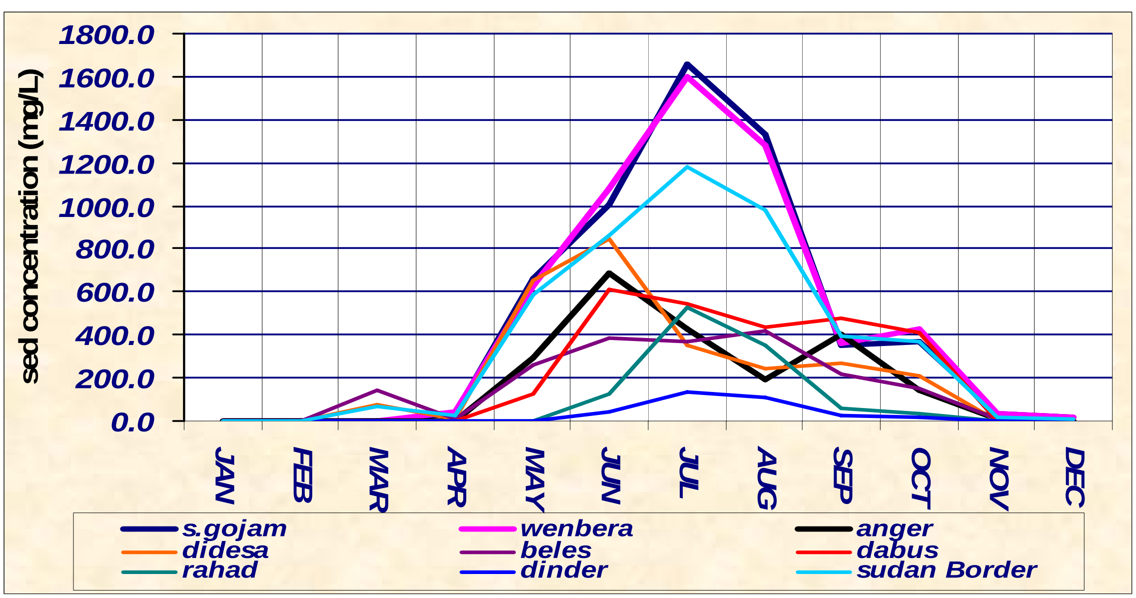


Figure 5.25a & b Comparisons of sediment concentration at the outlet of each sub basins

As looked from the two graphs above, most of the peak of sediment load are occurred in July, but few are in June (Anger, Didesa and Dabus) sub basin on South Western of the basin, and the other are in August (Finchaa, Guder and Muger), sub basins in the south Eastern of the basin. For south eastern sub basins having sediment concentration peak in August have runoff peak in September, but for the south western sub basins which have peak of sediment concentration in June have runoff peak in September. As shown from runoff trend, these sub basins have much discharge flow in April, May and June.

The Runoff and sediment concentration graphical relation are appended on appendix 13.

As observed from above figure 5.24, sediment yield do not have the absolute relation with Rainfall and Runoff lonely, rather the combination of Rainfall-Runoff with other factors have great impacts on soil eroded and sediment yield.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The main objective of this thesis is to determine sediment yield in the different sub basin of Blue Nile in Ethiopia, sediment load and sediment concentration in the main rivers of the tributaries and in the Abbay River. In addition to this, the aim is to look spatial and temporal variation of sediment yield/ concentration in the basin.

As it is looked from the model performance efficiency indicator, regression coefficient (R^2) and the Nash-Sutcliffe (E_{NS}) are in the range of 0.71 to 0.91 in calibration and 0.78 to 0.88 in validation for flow analysis. Similarly, sediment model efficiency by regression coefficient evaluation is in the range of 0.71 to o.89 for calibration and 0.71 to 0.86 in validation. This shows that, the SWAT model simulates well both for stream flow and sediment yield/load in Blue Nile basin.

The SWAT model is a good approach to deal with sediment yield and sediment concentration as the model considers the factors affecting soil erosion and sediment transport. At initial stage before calibration, the model efficiency is poor, finally by fine adjustment of parameters affecting stream flow and sediment yield respectively, a good result was found. The calibration of these parameters was done manually, because for very complicated and many sub basins, 98 sub basins and 392 HRUs for this study, it is hard to calibrate automatically due to different reason, requiring high processor speed computer, time of simulation is too much and may be damage the computer.

The parameters mostly sensitive to change for calibration of stream flow are the curve number (CN_2), soil evaporation compensation factor (ESCO), and soil available water capacity (SOL_AWC). The remaining parameters, SOL_Z, SOL_K, GW_DELAY and ALPHA_BF are the controlling parameters of base flow and adjusted for stream flow calibration.

Similarly, in the sediment yield calibration, some of the stream flow parameters are also appeared, but in the lower sensitivity rank and some are soil erosion parameters; hence, this are adjusted manually till the simulation is good fit to the measured sediment yield/load. A little bit difficult to calibrate sediment yield as the available sediment data are scarce data of few days and only on small streams. To have long year's daily sediment data for sensitivity and monthly data for calibration purpose on the appropriate sites, the discharges versus sediment load relation has been derived, and from discharge-sediment load (tone/day) curve equation, the long year daily sediment yield data derived. It has some discrepancy on the simulated result to adopt the calibration in this way. But the big confidence is once the stream flow calibrated well; sediment yield result is not as such far from the accepted results, as soil erosion has direct relation with stream flow.

As looked in result and discussion part, the 34% of soil is eroded from three sub basins, Guder, N.Gojam and Jemma (in between 6-9 t/ha per average per year) that cover an area of 18.6% of total Blue Nile. In similar manner, more than 50% of soil is eroded from an area of around 16% of the whole basin (ranging from 15-30 t/ha sediment yield). As shown from the SWAT simulated result of rainfall, runoff and slope of these basins are not the highest of all, even it is middle range compared to other basin, but the sub basins are Agriculture dominated area.

Hurni (1983) has conducted a research to estimate the rates of soil formation for Ethiopia and results are presented in Table 5.5. The range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to18 t/ha/y (Hurni, 1985). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y at some sub basins, (appendix 12). But the average annual sediment yield of the whole Blue Nile basin is around 4.26 t/ha/yr and 4.58 t/ha/yr with and excluding Rahad and Dinder sub basins respectively. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Millions tones with and without Rahad and Dinder respectively, (appendix 11).

This value is comparable to the finding of Getnet D. B. (2008), M.Sc thesis paper of 5t/ha/yr and 86.356 Million tones from upper Blue Nile basin. It is has some acceptance of 7.5 t/ha/yr sediment deposited in Rosiers dam in Sudan, as per literature of (BCECOM, 1999) and (NBCBN-RE, 2005).

When we look from the result of sediment concentration (mg/L) in the main streams of Blue Nile, Weleka, S.Gojam and Wenbera have the greater amount of concentration (in the range of 1600 to 2000mg/L) peak monthly sediment concentration compared to other sub basins. But the sub basins that have least peak monthly concentration of sediment are Dinder, Beshilo and Muger from lowest to up and the monthly peak concentrations in these sub basins are in the range of 400 to 800 mg/L.

The sediment concentration in these sub basins become peak in the month of July, next to peak of runoff mostly in August except Finchaa, Anger, Dabus and Didesa which have peak in the month of September.

Coming to annual concentration, S.Gojam, Wenbera and Sudan border are taking the lead ranging from 350 to 900 mg/L annually, and Dinder, Beshilo and Rahad are those which have least concentration ranging from 25 to 90mg/L annually.

6.2 Recommendation

There are many researches on Blue Nile so far in different development sectors, like Irrigation project, Hydropower projects, and water supply projects. Now a day the focus direction seems watershed management and conservation of the environment along with those previous studied projects. I have referred many papers on soil erosion and sediment carried from the Blue Nile, all of them are varying and no one have similarity. The study so far seems from small scale result up scaling to predict for the whole basins. It is known that, there is no similarity of hydrological, topographic, land coverage, soil type, land management, deforestation level, and population density all over the Blue Nile Basins. So, the up scaling technique may bring discrepancy between different studies. But, recently, with distributed model of like SWAT model, it is possible to cover the whole basin study and predict the reasonable soil erosion and sediment load/concentration results with appropriate inputs.

This study has been carried out with few months comparative to the vastness of study area. In, addition to that the problem that has occurred with capacity of the computer to process was a big challenge to successfully work with SWAT model for such vast work. So, the results of this model out put of areal rainfall, runoff and sediment yield/ concentration/load should be considered as an attempt to predict with SWAT model and used carefully for further study and potential project works study. I suggest that the SWAT model is a very powerful tool to fill the gap we have in area of sediment data and even un-quality and scarce stream flow data. Moreover, I have tried my best to put my effort to predict sediment yield and sediment vulnerable area, but I would like to call for further investigation in similar way for different basin and the same basin by incorporating further data and more quality data, which I didn't attempt due to time constraint and lack of access to information to dealt with in detail.

I hope this result give initial information for any researchers, projects on the basin and policy makers, but it may not be remain the same result in the future as land use, management practice, weather changes are some factor which alter the present situation rapidly.

As many researchers around the world and in our country itself come across and suggests, SWAT is a very effective Hydrologic model to predict the suspended sediment yield from a given watershed and sediment concentration in a stream flow. It is better for the Ethiopian situation use SWAT model for sediment data prediction prior to potential project study and plan commencement. Sedimentation of reservoir of Hydropower Dam, erosion of agricultural soil, degradation of cultivable and potential areas, etc is a big challenge in Ethiopia for many years and will be unless mitigation measures are taken.

It was shown that land cover is one of major factors among all other factors influencing soil erosion and sediment yield in a Blue Nile watershed. Hence, as mitigation measure for prevention of severs erosion and conservation mechanism, it is recommended to cover the mountainous and hilly area with plantation and control further degradation by erosion. Further study is required in different scenarios to decide a type of overages and extent of application on different sub basins.

REFEREENCES

Anderson, M. P., and Woessner, W. W., (1992), Applied groundwater modeling: Academic Press, Inc., San Diego.

Arnold, J.G. and P.M. Allen, (1999) Automated methods for estimating base flow and ground water recharge from stream flow records. Journal of the American Water Resources Association 35(2): 411-424

Arnold, J.G., P.M. Allen, and G. Bernhardt, (1993), A comprehensive surface groundwater flow model. J. Hydrol. 142:47-69

BCEOM, BRGM, ISL (1998a), "The Federal democratic Republic of Ethiopia, Ministry of water Resources, Abbay River Basin Integrated Development Master Plan Project", Water Resources, Volume III, Part I & II

BCEOM, BRGM, ISL (1998b), "The Federal democratic Republic of Ethiopia, Ministry of water Resources, Abbay River Basin Integrated Development Master Plan Project", Volume 8, Part 1.

Beck, M. B. 1987. Water quality modeling: A review of the analysis of uncertainty. *Water Resources Res.* 23(8): 1393-1442.

BCEOM, BRGM, ISL (1998c), Abbay River Basin Development Master Plan Project, Land Resources Development, Volume 10, Part 3 & 4.

Chow, V. T., Maidment, D. R., and Mays, L. W. (1988) Applied hydrology, McGraw-Hill, New York

Conway. D. (2000), "The Climate and Hydrology of the Upper Blue Nile River." The Geographical Journal 166(1): 49-62.

Conway D. (1997), "A water balance model of the Upper Blue Nile in Ethiopia" Hydrological sciences Journal 42(2)

DeCoursey, D. G. (1985) Mathematical models for non-point water pollution control. Journal of Soil and Water Conservation 40:408–413

DILNESAW Alamirew, (2006), Modelling of Hydrology and Soil Erosion of Upper Awash River Basin. PhD Thesis, University of Bonn: 233pp.

Dooge, J.C.I., (1968) The hydrologic cycle as a closed system. Bull. Int. Ass. Scient. Hydrol., 13. (1).

Eppink, L.A.A.J. (1993). Processes and models in erosion and soil and water conservation. Water erosion models: an overview. Lecture notes, Wageningen.

Garde R J, Ranja Raju K G, (1985), Mechanics of Sediment Transportation and Alluvial Stream Problems, second edition, Roorkee, India

Haan, C.T., H.P. Johnson and D.L. Brakensiek (1982). *Hydrologic Modeling of Small Watersheds*, American Society of Agricultural Engineers Monograph No. 5, ASAE, St. Joseph, MI, 379 pp.

Hargreaves, G.H. and Z.A. Samani (1985), Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture 1:96-99.

Hurni, H. (1985), Soil conservation manual for Ethiopía. Ministry of Agriculture. Addis Abeba, Ethiopía

Hurni H (1988) Degradation and conservation of the resources in the Ethiopian highlands JSTOR, pp. 123-130.

HYDROCOMP, Inc.: Hydrologic Simulation Models: An Overview, http://www.hydrocomp.com/simoverview.html

Knisel, W.G. (1980). CREAMS, a field scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Rept. No. 26.

Lenhart, T., Eckhardt, K., Fohrer, N., and Frede, H. G.: (2002). Comparison of two different approaches of sensitivity analysis, Phys. Chem. Earth, 27,645–654.

Leonard, R.A., W.G. Knisel., and D.A. Still. (1987). GLEAMS: Groundwater loading effects of agricultural management systems. Trans. ASAE. 30:1403-1418.

Leo C. van Rijn (1993) principles of sediment Transport in Rivers, Estuaries and Coastal seas, University of Utrecht, The Netherlands.

McFarland, A. M. S., and L. M. Hauck. 2001. Determining nutrient export coefficients and source loading uncertainty using in-stream monitoring data. *J. American Water Resources Assoc.* 37(1): 223-236.

Neitsch (a), S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams, K.W. King , 2002. Soil and Water Assessment Tool (SWAT) Theoretical Documentation, Version 2000, Grassland Soil and Water Research Laboratory, Blackland Research Center, Texas Agricultural Experiment Station, Texas Water Resources Institute, Texas Water Resources Institute, College Station, Texas, 506pp.

Neitsch (b), S.L., J.G. Arnold, J.R. Kiniry, R. Srinivasan, J. R. Williams, 2002. Soil and Water Assessment Tool (SWAT) User's Manual, Version 2000, Grassland Soil and Water Research Laboratory, Blackland Research Center, Texas Agricultural Experiment Station, Texas Water Resources Institute, Texas Water Resources Institute, College Station, Texas, 472pp.

Nicks, A.D. (1974), Stochastic generation of the occurrence, pattern and location of maximum amount of daily rainfall. p. 154-171. In Proc. Symp. Statistical Hydrology, Tucson, AZ. Aug.-Sept. 1971. USDA Misc. Publ.1275. U.S. Gov. Print. Office, Washington, DC

Nyle C. Brady (1996), The nature and properties of soil, 10th edition.

Refsgaard, J.C. and Storm, B. (1996), Construction, calibration and validation of hydrological models, Distributed Hydrological Modelling (eds. M.B. Abbott and J.C. Refsgaard), Kluwer Academic Publishers, 41-54.

Sharpley, A. N, P. J. A. Kleinman, R. W. McDowell, M. Gitau, and R. B. Bryant. 2002. Modeling phosphorus transport in agricultural watersheds: Processes and possibilities. *J. Soil and Water Cons.* 57(6): 425-439.

Seo D.J. (1998), Journal of Hydrology, 208

SMEC, (July 2007), Hydrological study of the Tana-Beles Sub-basins draft inception report

Teshale, (2006), Evaluation of Sediment Yield and Reservoir sedimentation on Angereb Watershed, North western Ethiopia, M.Sc Thesis, AMU

Tsintikidis D. (1999), A feasibility study on mean areal rainfall estimation and hydrologic response in Blue Nile region using METEOSAT images

USDA Soil Conservation Service, 1972, National Engineering Handbook: Hydrology Section 4, Chapters 4-10. Washington, DC

USEPA. 2000. National water quality inventory 1998 report to Congress. USEPA 841-R-00-001. Washington, D.C.: USEPA, Office of Water.

Weather parameter calculator WXPARM (Williams, 1991) and dew point temperature calculator DEW02 programs

WAPCOS, (1990), Preliminary Water Resources Development Master Plan for Ethiopia, Final Report Volume IV, Addis Ababa

Williams, J.R., A.D. Nicks, and J.G. Arnold. (1985). Simulator for water resources in rural basins. Journal of Hydraulic Engineering 111(6): 970-986.

APPENDICS

Appendix 1: Rainfall Stations used as in put in the Blue Nile

ID	Station NAME	LATITUDE	LONG	UTM Projection		ELEVATION
				XPR	YPR	
1	ADISZEMEN	12.070	37.520	338914	1334729	1850.000
2	ASGORI	8.580	38.000	389957	948562	2500.000
3	ASSOSA	10.010	34.310	-10500	1108016	1600.000
4	BAHIRDAR	11.360	37.250	309031	1256360	1770.000
5	BAKO	9.070	37.050	285669	1003166	1650.000
6	BAMBIS	9.430	34.430	4000	1043807	1460.000
7	CHAGNI	10.570	36.300	204520	1169713	1620.000
8	DANGLA	11.150	36.500	226949	1233718	2000.000
9	DEBREBIRHAN	9.380	39.300	532939	1036878	2750.000
10	D.MARKOS	10.200	37.400	324734	1127959	2515.000
11	DEBRETABOR	11.530	38.020	393132	1274766	2690.000
12	DEBREWORK	10.440	38.080	399307	1154208	2740.000
13	DEJEN1	10.100	38.090	400295	1116608	2420.000
14	DEK ESTIFANOS	11.540	37.160	299334	1276333	1795.000
15	DELGI	12.100	37.010	283411	1338400	1780.000
16	DENEBA	9.460	39.120	513173	1045711	2900.000
17	DARBA	9.260	38.380	431901	1023657	2350.000
18	ENFRANZ	12.110	37.410	326964	1339221	1950.000
19	ENJIBARA	10.580	36.540	230809	1170602	2670.000
20	FITCHE	9.480	38.420	436335	1047973	2750.000
21	FINCHAA	9.340	37.220	401369	1108864	2280.000
22	GEBREGURACHA	9.490	38.250	304509	1032935	2560.000
23	GEDO	9.030	37.260	417676	1049115	2500.000
24	GONDER	12.330	37.250	308737	998625	1967.000
25	GORGORA	12.150	37.180	309704	1363666	1830.000
26	HARO	9.540	36.270	301956	1343803	2200.000
27	HAROKELIFA	10.380	34.560	11000	1148978	900.000
28	INCHIN	9.190	38.220	414310	1015951	2690.000
29	JARSO	9.270	35.190	80000	1026094	1750.000
30	JIRU	10.020	39.150	516438	1107628	2640.000
31	KOMBOLCHA4	9.360	37.300	516438	1107628	2100.000
32	LEMI	9.490	38.540	313309	1035104	2500.000
33	MAKESGINT	12.220	37.000	449509	1049059	1950.000
34	MENDISCHOOL	9.470	35.060	70000	1048235	1650.000
35	MANGE	10.200	34.440	4275	1129050	1200.000
36	MERAWI	11.250	37.090	291486	1244300	2110.000
37	MOTTA	11.050	37.520	291486	1244300	2440.000
38	NEDJO	9.300	35.270	90390	1029415	1800.000
39	NEFASMEWUCHA	11.440	38.270	420379	1268049	3000.000
40	SHAMBU1	9.340	37.060	420371	1264732	2430.000
41	SHEKUTE	9.260	38.030	286931	1033028	2560.000

42	WEGELTENA	11.360	39.130	393456	1023742	3000.000
43	WERETA	11.550	37.410	514184	1255788	1980.000
44	YETMEN	10.200	38.080	326612	1277276	2060.000
45	YIFAG	12.040	37.430	399230	1127669	1800.000
46	ZEGE	11.410	37.190	329097	1331465	1800.000
47	Abaysheleko	10.070	38.080	302516	1261931	1790.000
48	ADDET	11.160	37.220	399190	1113293	2080.000
49	ALEMKETEMA	10.020	39.020	305622	1234255	2280.000
50	AMBO	8.580	37.520	502192	1107624	2130.000
51	AYKEL	12.320	37.030	337127	948733	2150.000
52	BEDELE	8.270	36.170	285765	1362725	2030.000
53	DEMBECHA	10.340	37.280	188223	915255	2100.000
54	ENEWARI	9.540	39.090	311668	1143512	2650.000
55	FERESBET	10.510	37.350	509877	1054555	2870.000
56	JELDU	9.110	38.040	319433	1162275	2880.000
57	KACHISE	9.350	37.200	394510	1007153	2520.000
58	MEKANESELAM	10.450	38.450	302318	1034052	1720.000
59	PAWEE	11.090	36.030	439786	1143609	1053.000
60	YEJUBIE	10.090	37.440	175509	1227550	2300.000
61	YETENORE	10.120	38.090	329612	1226377	2540.000
62	LAYBIR	10.380	37.070	400301	1118819	2000.000
63	SHINDI	10.430	36.570	233965	1153977	2140.000
64	LALIBELA	12.020	39.090	509797	1328767	2500.000
65	UPPERBIR	10.390	37.230	306223	1149073	2000.000
66	ADDISALEM	10.520	36.320	206663	1164160	2010.000
67	KELALA	11.130	40.010	610293	1230541	1500.000
68	KULEMMEDA	11.110	39.310	533853	1228160	2000.000
69	WETETABAY	11.220	37.030	284911	1241025	1900.000
70	SHASHURA	12.020	36.550	233240	1329953	2000.000
71	TIS ABAY	11.300	37.350	319909	1249659	1620.000
72	SIRINKA	11.330	39.370	540375	1252494	2000.000
73	SULULTA	9.110	38.440	438466	1007061	2610.000
74	TILILI	10.510	37.030	284402	1162477	2570.000

Appendix 2: Temperature Stations used

ID	Station NAME	XPR	YPR	ELEVATION
1	A_SHELt	302516	1261931	1790.000
2	ADETt	399190	1113293	2080.000
3	AMBOt	502192	1107624	2130.000
4	AYKELt	337127	948733	2150.000
5	B_DARt	309031	1256360	1770.000
6	CHAGNIt	204520	1169713	1620.000
7	D_MARKt	324734	1127959	2515.000
8	D_TABOt	393132	1274766	2690.000
9	DANGLAt	226949	1233718	2000.000
10	D_WORKt	399307	1154208	2740.000
11	DEMBCHt	188223	915255	2100.000

12	FINCHAt	401369	1108864	2280.000
13	GONDERt	308737	998625	1967.000
14	LAYBIRt	400301	1118819	2000.000
15	MOTTAt	291486	1244300	2440.000
16	NEDJOt	90390	1029415	1800.000
17	NMEWICHt	420379	1268049	3000.000
18	YETMENt	326612	1277276	2060.000
19	ZEGEt	329097	1331465	1800.000

Appendix 3: Weather generator (WGEN) parameters used by the SWAT model

Legend of the parameters used in the weather generation	
Symbol	***Description***
TMPMX	Average or mean daily maximum air temperature for month (ºC).
TMPMN	Average or mean daily minimum air temperature for month (ºC).
TMPSTDMX	Standard deviation for daily maximum air temperature in month (ºC).
TMPSTDMN	Standard deviation for daily minimum air temperature in month (ºC).
PCPMM	Average or mean total monthly precipitation (mm H2O).
PCPSTD	Standard deviation for daily precipitation in month (mm H2O/day).
PCPSKW	Skew coefficient for daily precipitation in month.
PR_W1	Probability of a wet day following a dry day in the month.
PR_W2	Probability of a wet day following a wet day in the month.
PCPD	Average number of days of precipitation in month.
SOLARAV	Average daily solar radiation for month (MJ/m2/day).
DEWPT	Average daily dew point temperature in month (ºC).
WNDAV	Average daily wind speed in month (m/s).

Appendix 3.1: Sediment calibration station and observed data

Addis Zemen			Gilgel Abbay		Kessie	
Y=366.21x-3992.2 wet season equation			Y=1926.1X-124186 wet season equation		y=278.08x-455.74 wet season equation	
y=12.494x+1.3992 dry season equation			Y=221.52x-465.55 dry season equation		y=37.401x-0.0624 dry season equation	
Date	Flow(m3/s)	Generated sediment (t/day)	flow(m3/s)	Generated sediment (t/day)	Flow(m3/s)	Generated sediment (t/day)
Jan-91	1.83	24.28	3.69	351.42	90.33	3378.37
Feb-91	0.70	10.13	2.50	88.25	62.38	2333.01
Mar-91	0.51	7.75	2.05	69.00	119.60	4473.10
Apr-91	1.30	17.65	4.40	508.25	98.63	3688.80
May-91	1.30	17.65	8.86	1497.12	88.53	3311.05
Jun-91	1.30	17.65	55.34	11793.37	121.10	33219.75
Jul-91	50.00	14318.30	190.64	242999.93	434.00	120230.98
Aug-91	60.00	17980.40	217.30	294349.75	2355.25	654492.18
Sep-91	70.42	21795.21	162.76	189307.96	1396.75	387952.50
Oct-91	6.23	79.20	42.12	8864.87	632.66	23662.05
Nov-91	2.03	26.79	11.05	1981.58	356.15	13320.30
Dec-91	1.15	15.75	6.32	934.90	223.57	8361.68
Jan-92	0.43	6.71	4.19	463.28	137.76	5152.30
Feb-92	0.14	3.12	2.94	185.50	102.00	3814.84
Mar-92	0.08	2.41	2.28	39.52	76.32	2854.38
Apr-92	2.03	26.79	3.78	371.35	53.53	2002.01
May-92	1.00	13.89	6.62	1001.58	59.09	2209.96
Jun-92	1.10	15.17	30.55	6302.33	45.35	12155.19
Jul-92	49.12	13997.13	121.41	109669.51	464.49	128709.64
Aug-92	123.22	41133.29	195.58	252524.49	2177.48	605057.90
Sep-92	42.28	11489.33	145.13	155339.26	1221.77	339294.06
Oct-92	21.07	3724.21	89.78	48746.96	768.42	28739.61
Nov-92	10.36	130.85	29.42	6052.23	463.32	17328.57
Dec-92	0.99	13.78	10.91	1952.12	272.21	10180.86
Jan-93	1.09	15.03	5.51	755.03	135.37	5062.91
Feb-93	0.54	8.16	3.77	369.36	78.71	2943.77
Mar-93	0.39	6.26	3.17	237.33	52.65	1969.10
Apr-93	1.61	21.55	5.02	646.26	207.96	7777.85
May-93	4.19	53.74	8.98	1523.92	273.94	10245.57
Jun-93	4.81	61.46	74.92	20113.56	177.75	48972.98
Jul-93	41.08	11051.71	187.94	237809.09	2141.87	595155.47
Aug-93	54.38	15923.03	179.34	221236.92	3047.76	847065.36
Sep-93	44.82	12420.97	154.84	174045.55	3400.74	945222.04

Oct-93	10.46	132.04	89.74	48658.36	1015.70	37988.13
Nov-93	2.34	30.65	22.92	4611.69	428.60	16030.01
Dec-93	0.62	9.15	8.19	1347.81	216.47	8096.13
Jan-94	0.35	5.76	4.80	598.63	120.07	4490.68
Feb-94	0.09	2.49	3.38	282.30	72.93	2727.59
Mar-94	0.05	2.06	2.44	74.96	55.93	2091.78
Apr-94	0.07	2.32	2.11	2.08	36.20	1353.85
May-94	0.76	10.94	7.18	1123.86	135.76	5077.50
Jun-94	7.22	91.62	61.54	13166.79	190.43	52499.03
Jul-94	66.89	20504.32	147.62	160148.73	459.71	127380.42
Aug-94	95.26	30892.96	177.61	217902.84	6048.29	1681452.74
Sep-94	50.06	14339.91	118.65	104339.99	3426.86	952485.49
Oct-94	1.99	26.29	23.38	4712.92	770.09	28802.07
Nov-94	0.71	10.26	10.46	1852.44	387.05	14475.99
Dec-94	0.45	6.96	6.37	944.42	175.81	6575.41
Jan-95	0.31	5.26	3.57	324.39	61.71	2307.95
Feb-95	0.24	4.44	2.52	92.24	43.88	1641.09
Mar-95	0.23	4.29	1.88	30.00	73.42	2745.92
Apr-95	0.66	9.65	1.95	50.00	143.63	5371.84
May-95	0.57	8.46	11.07	1985.57	120.62	4511.25
Jun-95	1.42	19.14	45.21	9550.26	162.85	6090.69
Jul-95	36.45	9354.87	92.64	54245.98	1570.64	436307.83
Aug-95	71.47	22181.93	198.98	259067.45	3055.55	849231.60
Sep-95	29.14	6678.79	131.77	129620.05	2069.64	575069.75
Oct-95	1.84	24.36	25.43	5167.70	299.34	11195.55
Nov-95	1.03	14.29	10.22	1799.27	191.38	7157.74
Dec-95	0.83	11.74	5.64	783.82	114.51	4282.73
Jan-96	0.55	8.25	3.58	326.83	69.18	2587.34
Feb-96	0.42	6.63	2.27	37.52	50.01	1870.36
Mar-96	0.60	8.92	4.08	438.69	147.64	5521.82
Apr-96	1.47	19.73	3.91	400.59	234.20	8759.25
May-96	7.90	100.15	19.74	3907.92	318.17	11899.81
Jun-96	29.17	365.81	85.19	39892.68	587.08	162799.47
Jul-96	65.58	20023.85	202.98	266764.15	2259.55	627879.92
Aug-96	83.99	26766.51	223.52	306337.80	7689.50	2137840.42
Sep-96	22.32	4181.97	141.70	148732.74	1811.70	503341.80
Oct-96	7.23	91.67	85.51	40514.81	717.91	26850.49
Nov-96	2.95	38.27	68.07	14613.09	381.51	14268.79
Dec-96	1.37	18.49	47.88	10141.05	260.86	9756.36
Jan-97	0.74	10.67	2.94	186.38	139.87	5231.22
Feb-97	0.40	6.40	1.93	46.00	118.07	4415.87
Mar-97	0.66	9.63	1.75	14.00	249.69	9338.59
Apr-97	0.46	7.11	1.67	14.20	167.20	6253.38
May-97	4.64	59.35	18.39	3607.32	359.74	13454.57
Jun-97	7.62	96.57	60.79	13000.65	463.12	128328.67
Jul-97	44.29	12226.51	160.86	185646.45	1898.11	527370.69
Aug-97	52.27	15148.13	196.73	254735.65	2433.77	676327.02

Sep-97	13.02	775.85	125.08	116734.44	549.32	152299.17
Oct-97	8.56	108.37	63.56	13613.82	919.55	34392.03
Nov-97	7.81	98.95	35.67	7436.07	561.45	20998.73
Dec-97	1.63	21.78	10.54	1869.71	278.24	10406.39
Jan-98	0.71	10.23	4.48	526.64	180.22	6740.35
Feb-98	0.32	5.37	2.53	95.12	101.77	3806.24
Mar-98	0.26	4.62	1.85	33.00	70.48	2635.96
Apr-98	0.18	3.59	1.29	30.00	50.50	1888.69
May-98	1.29	17.49	10.14	1779.56	235.51	8808.25
Jun-98	3.86	49.58	64.30	13778.19	235.15	64934.77
Jul-98	48.36	13717.72	142.70	150660.77	5038.86	1400750.45
Aug-98	66.48	20353.07	184.56	231302.72	6246.33	1736523.71
Sep-98	43.01	11759.22	153.73	171915.28	3841.68	1067838.63
Oct-98	12.40	549.17	96.14	60987.33	1749.68	65439.72
Nov-98	3.98	51.16	18.32	3592.03	611.85	22883.74
Dec-98	0.95	13.21	6.54	983.41	303.98	11369.09
Jan-99	0.81	11.46	3.72	358.06	142.32	5322.85
Feb-99	0.49	7.53	2.14	8.06	103.62	3875.43
Mar-99	0.36	5.93	1.43	46.00	54.83	2050.63
Apr-99	0.30	5.12	1.71	50.00	43.71	1634.74
May-99	0.39	6.22	8.91	1508.19	29.80	1114.49
Jun-99	3.42	44.08	57.74	12325.68	76.14	20717.27
Jul-99	45.27	12586.86	163.04	189847.27	3972.07	1104097.49
Aug-99	70.81	21939.86	186.86	235717.34	5154.48	1432902.06
Sep-99	39.86	10605.66	127.08	120584.71	2527.80	702474.88
Oct-99	41.03	11032.30	122.52	111805.55	1215.16	45448.14
Nov-99	12.96	752.05	19.66	3889.98	502.63	18798.80
Dec-99	13.08	799.29	7.60	1217.78	222.03	8304.08
Jan-00	5.05	64.44	3.42	292.93	96.68	3615.87
Feb-00	0.47	7.23	2.03	80.00	66.75	2496.45
Mar-00	0.30	5.18	1.49	60.00	47.72	1784.71
Apr-00	0.99	13.73	3.10	220.50	98.00	3665.24
May-00	0.68	9.92	6.08	881.07	62.33	2331.14
Jun-00	2.01	26.50	49.05	10398.90	91.13	24885.69
Jul-00	40.95	11005.20	146.03	157086.24	2397.56	666257.74
Aug-00	38.01	9929.09	203.22	267237.97	7116.17	1978408.81
Sep-00	35.08	8852.98	134.17	134229.21	1421.51	394837.76
Oct-00	16.20	1939.67	126.98	120386.33	974.07	270413.65
Nov-00	5.19	66.28	36.71	7666.23	493.20	18446.11
Dec-00	1.50	20.13	8.95	1517.72	193.03	7219.45

Appendix 4: Weather generator stations and data

STATION	LATITUDE	LONGITUDE	ELEV	RAIN YRS	TMP MX1	TMP MX2	TMP MX3	TMP MX4	TMP MX5	TMP MX6	TMP MX7	TMP MX8	TMP MX9	TMP MX10	TMP MX11	TMP MX12
ADET	11.16	37.22	2080.0	10.00	26.70	28.70	29.70	29.50	28.30	26.50	23.20	23.20	24.90	25.00	25.60	26.30
aykel	12.32	37.03	2150.0	10.00	25.10	25.80	27.30	27.90	26.10	22.50	20.30	20.00	22.20	22.90	24.00	24.50
Bahirdar	11.36	37.25	1770.0	10.00	26.60	28.20	30.00	29.90	29.10	27.20	24.20	24.20	25.60	25.90	26.50	26.50
chagni	10.57	36.30	1620.0	10.00	29.90	32.30	33.20	31.10	28.60	25.80	24.40	24.40	25.50	26.30	28.00	27.90
dangila	11.15	36.50	2000.0	10.00	25.70	26.80	27.40	27.10	25.00	22.90	21.00	21.80	23.00	23.70	24.40	25.20
Gonder	12.33	37.25	1967.0	10.00	27.70	28.70	29.90	30.00	28.40	25.30	22.70	22.50	24.70	26.10	26.90	27.40
Nmewicha	11.44	0.00	3000.0	10.00	17.90	30.00	20.20	19.20	19.00	18.60	15.00	14.80	16.00	16.60	17.10	17.30
Shashura	12.02	36.55	2000.0	10.00	25.10	26.60	27.60	27.50	26.80	22.90	21.40	20.80	22.40	23.20	24.20	24.00
Laybir	10.38	37.07	2000.0	10.00	30.00	31.90	32.90	32.00	30.10	26.60	23.70	23.70	25.30	26.60	28.40	29.60
Nedjo	9.30	35.27	1800.0	10.00	28.00	29.60	29.70	29.50	26.80	23.60	22.40	22.60	24.00	24.50	25.50	26.90
D_Tabor	11.53	0.00	2690.0	10.00	20.80	23.40	23.60	24.10	22.90	21.50	18.10	18.60	20.10	20.70	19.30	22.10
d_markos	10.20	0.00	2515.0	10.00	23.90	25.10	26.00	25.20	23.50	21.00	18.70	18.90	20.50	21.80	22.70	23.20

STATION	TMP MN1	TMP MN2	TMP MN3	TMP MN4	TMP MN5	TMP MN6	TMP MN7	TMP MN8	TMP MN9	TMP MN10	TMP MN11	TMP MN12
ADET	7.50	8.40	10.80	12.50	13.30	12.70	13.00	13.00	12.00	12.10	9.50	7.80
aykel	12.90	13.60	14.60	15.90	15.40	13.30	12.20	12.10	12.40	12.70	13.00	12.80
Bahirdar	9.40	10.40	13.40	15.30	15.60	14.60	14.40	14.40	13.70	14.00	11.80	9.90
chagni	9.00	10.30	12.60	15.40	15.60	16.40	17.10	15.30	14.10	14.00	10.60	8.80
dangila	3.60	5.00	7.40	10.00	10.80	10.70	10.80	10.50	9.70	8.50	6.40	4.50
Gonder	12.00	13.30	15.10	16.00	15.80	14.20	13.50	13.40	13.30	13.30	12.60	11.90
Nmewicha	7.10	8.10	8.50	9.10	9.40	9.40	8.10	8.00	7.90	7.40	6.60	6.70
Shashura	13.40	14.00	14.90	15.90	16.30	13.40	13.00	12.90	13.20	13.70	13.40	13.30
Laybir	9.80	10.80	13.70	15.40	15.50	14.50	14.60	14.30	13.20	12.70	10.50	9.10
Nedjo	8.90	10.30	12.90	13.40	14.10	14.00	13.80	13.50	13.40	11.60	10.20	8.70
D_Tabor	5.60	8.00	7.80	10.90	10.90	10.40	10.20	10.10	9.40	9.00	5.60	7.80
dmarkos	9.40	10.10	11.50	12.30	12.00	10.90	11.10	11.10	10.30	10.00	9.00	8.80

STATION	TMP STD MX 1	TMPST DMX2	TMPST DMX3	TMPST DMX4	TMPST DMX5	TMPST DMX6	TMPST DMX7	TMPST DMX8	TMPST DMX9	TMPSTD MX10	TMPSTD MX11	TMPSTD MX12
ADET	1.40	1.30	1.50	2.50	1.90	1.90	2.10	2.10	1.70	1.90	1.60	1.10
aykel	1.70	2.00	2.10	1.80	2.30	1.70	1.80	1.70	1.30	1.40	1.30	1.10
Bahirdar	1.70	2.00	1.60	2.10	1.60	1.50	1.50	1.60	1.40	1.30	1.00	1.20
chagni	1.40	0.80	1.10	2.30	2.10	1.20	1.10	1.40	1.00	1.00	0.80	1.70
dangila	1.50	1.60	1.70	1.90	2.20	1.70	2.00	1.40	1.30	1.30	1.10	0.90
Gonder	1.50	1.60	1.70	2.20	2.50	1.90	1.50	1.60	1.50	1.50	1.30	1.10
Nmewicha	1.40	7.00	1.70	2.40	2.20	2.00	1.50	1.00	0.90	0.80	1.10	1.00
Shashura	1.20	1.20	1.20	2.10	2.30	1.80	1.80	1.70	0.90	1.20	0.90	1.50
Laybir	1.30	1.50	1.60	2.50	2.40	1.80	1.60	1.60	1.30	1.70	1.30	0.90
Nedjo	1.20	1.00	1.70	2.10	2.60	1.60	1.60	1.30	1.20	1.30	1.10	0.90
DTabor	14.3	8.80	12.00	2.20	2.20	1.90	1.60	1.40	1.30	1.50	16.6	1.00
d_markos	1.40	1.40	1.60	2.30	2.20	1.80	1.50	1.40	1.40	1.30	1.40	1.00

Station	PCP MM1	PCP MM2	PCP MM3	PCP MM4	PCP MM5	PCP MM6	PCP MM7	PCP MM8	PCP MM9	PCP MM10	PCP MM11	PCP MM12
ADET	1.40	6.00	21.30	52.00	132.9	144.7	327.0	361.0	179.1	147.2	23.8	18.4
aykel	0.00	0.40	14.60	59.30	88.4	159.9	261.6	280.7	160.2	80.1	2.8	0.6
Bahirdar	2.40	0.00	9.30	36.50	102.1	154.7	347.2	400.0	210.7	158.9	20.2	4.4
chagni	0.40	0.00	3.40	71.30	221.1	328.4	305.0	309.7	275.7	350.9	62.8	6.7
dangila	0.40	2.20	54.00	57.50	166.0	245.1	312.7	396.4	237.0	97.3	40.1	6.5
Gonder	0.00	0.70	10.90	28.90	91.5	194.7	327.7	345.2	126.4	91.8	15.8	5.0
Nmewicha	15.90	9.20	55.10	99.10	72.6	54.0	378.6	313.7	122.7	62.9	20.0	6.7
Shashura	1.60	0.70	0.00	3.90	54.5	271.7	308.7	325.0	185.3	179.8	12.2	1.6
Laybir	7.20	2.60	27.10	64.20	115.8	159.2	247.4	159.8	145.2	75.0	32.2	9.3
Nedjo	1.50	1.20	35.90	85.10	215.4	277.2	321.3	262.8	298.1	113.6	29.6	7.7
D_Tabor	8.30	1.70	34.00	53.80	133.2	198.1	432.0	410.6	207.4	133.4	26.0	27.7
d_markos	13.10	10.20	32.50	93.50	153.9	172.5	266.1	320.3	218.0	111.0	37.8	26.0

STATION	PCP STD1	PCP STD2	PCP STD3	PCP STD4	PCP STD5	PCP STD6	PCP STD7	PCP STD8	PCP STD9	PCP STD10	PCP STD11	PCPST D12
ADET	3.10	14.31	7.24	10.07	11.44	8.75	11.04	15.55	10.62	9.23	8.41	14.89
aykel	0.10	0.10	5.94	12.76	7.40	9.78	9.60	9.15	12.06	7.30	2.25	0.10
Bahirdar	3.45	0.10	3.59	9.43	13.72	9.93	12.11	16.12	11.47	9.93	8.09	4.53
chagni	0.64	0.10	0.50	6.47	10.85	12.06	10.14	11.13	8.70	13.50	5.55	3.06
dangila	0.71	1.32	10.97	7.29	8.44	9.47	7.99	23.40	8.94	8.37	9.31	3.90
Gonder	0.10	0.49	2.74	6.19	8.02	10.32	10.66	13.31	8.18	8.38	4.91	2.21
Nmewicha	3.81	2.80	7.58	7.37	6.15	4.54	10.74	9.27	8.01	8.62	4.59	3.77
Shashura	0.80	0.10	0.10	2.41	7.90	15.91	9.56	11.94	9.08	9.51	3.81	0.81
Laybir	3.02	2.22	6.05	7.96	9.25	6.75	10.01	6.70	8.36	7.56	5.68	4.06
Nedjo	1.07	1.47	8.84	13.04	12.87	11.84	11.75	12.48	21.13	10.75	8.15	15.54
D_Tabor	6.37	2.19	8.90	5.97	12.09	11.02	12.18	11.54	9.19	14.65	5.58	15.79
d_markos	3.27	5.01	4.69	7.55	8.18	7.85	13.99	10.05	9.16	9.78	8.33	10.57

STATION	PCPSKW1	PCP SKW2	PCPSKW3	PCP SKW4	PCP SKW5	PCP SKW6	PCP SKW7	PCP SKW8	PCP SKW9	PCP SKW10	PCP SKW11	PCP SKW12
ADET	1.54	0.00	1.51	3.02	2.26	1.96	1.63	2.78	2.15	1.07	1.86	3.14
aykel	0.00	0.00	1.17	3.39	1.54	1.92	1.84	1.16	3.28	2.23	1.81	0.00
BAHIRDAR	0.00	0.00	3.39	1.96	2.27	3.04	1.92	2.28	1.85	1.27	1.16	0.00
chagni	0.00	0.00	-0.82	0.86	2.76	2.57	1.63	1.89	1.25	1.44	1.40	0.20
dangila	0.00	2.04	2.26	1.77	1.52	1.73	1.22	8.80	1.50	2.50	2.72	1.07
Gonder	0.00	0.00	2.09	1.18	1.84	1.18	1.51	1.86	1.32	1.24	2.47	0.85
NMEWICHA	0.74	1.41	1.41	1.41	1.74	2.47	1.20	1.00	2.42	2.40	1.15	0.89
Shashura	0.95	0.00	0.00	-0.61	2.08	2.92	1.28	2.54	1.05	1.45	2.41	-0.56
Laybir	1.16	1.17	2.20	1.81	3.27	1.51	2.30	2.18	2.26	2.59	1.64	2.94
Nedjo	0.00	0.00	1.75	2.28	2.89	1.57	1.53	2.24	6.57	2.63	0.54	0.00
D_Tabor	3.46	0.92	2.81	1.21	2.13	4.16	1.55	1.42	1.59	3.94	0.23	2.38
d_markos	2.00	2.73	1.50	1.48	1.41	2.29	8.88	2.80	2.27	2.10	2.08	1.59

STATION	PR_W1_1	PR_W1_2	PR_W1_3	PR_W1_4	PR_W1_5	PR_W1_6	PR_W1_7	PR_W1_8	PR_W1_9	PR_ W1_10	PR_ W1_11	PR_ W1_12
ADET	0.01	0.01	0.07	0.14	0.31	0.46	0.90	0.93	0.60	0.28	0.09	0.04
aykel	0.00	0.01	0.01	0.13	0.18	0.53	0.87	0.95	0.30	0.23	0.03	0.01
Bahirdar	0.02	0.00	0.08	0.13	0.22	0.57	0.86	0.95	0.59	0.35	0.06	0.01
chagni	0.02	0.00	0.04	0.11	0.51	0.85	0.95	0.83	0.95	0.69	0.23	0.04
dangila	0.01	0.22	0.13	0.16	0.33	0.80	0.75	0.95	0.64	0.27	0.12	0.03
Gonder	0.00	0.01	0.09	0.10	0.30	0.60	0.95	0.90	0.30	0.33	0.12	0.04
Nmewicha	0.06	0.05	0.14	0.26	0.19	0.31	0.95	0.92	0.45	0.19	0.07	0.03
Shashura	0.03	0.02	0.00	0.02	0.14	0.63	0.83	0.95	0.69	0.30	0.09	0.04
Laybir	0.06	0.03	0.11	0.20	0.44	0.58	0.84	0.84	0.60	0.25	0.14	0.07
Nedjo	0.02	0.02	0.15	0.19	0.56	0.78	0.82	0.76	0.50	0.31	0.08	0.02
D_Tabor	0.06	0.02	0.09	0.18	0.34	0.56	0.71	0.91	0.39	0.19	0.08	0.05
d_markos	0.10	0.06	0.13	0.29	0.31	0.42	0.77	0.93	0.58	0.12	0.13	0.05

STATIO N	PR_W2_ 1	PR_W2_ 2	PR_W2_ 3	PR_W2_ 4	PR_W2_ 5	PR_W2_ 6	PR_W2_ 7	PR_W2_ 8	PR_W2_ 9	PR_ W2_10	PR_ W2_11	PR_ W2_12
ADET	0.25	0.33	0.46	0.59	0.63	0.72	0.91	0.90	0.76	0.71	0.38	0.40
aykel	0.00	0.00	0.33	0.53	0.67	0.71	0.91	0.87	0.71	0.54	0.00	0.00
Bahirdar	0.00	0.00	0.44	0.37	0.52	0.69	0.93	0.93	0.78	0.70	0.33	0.00
chagni	0.00	0.00	0.44	0.78	0.80	0.90	0.94	0.95	0.91	0.92	0.64	0.29
dangila	0.00	0.57	0.56	0.50	0.81	0.91	0.95	0.95	0.89	0.70	0.50	0.50
Gonder	0.00	0.00	0.25	0.46	0.54	0.63	0.92	0.88	0.66	0.48	0.24	0.33
Nmewicha	0.40	0.42	0.60	0.59	0.64	0.61	0.92	0.92	0.66	0.65	0.57	0.38
Shashura	0.33	0.00	0.00	0.50	0.68	0.82	0.95	0.86	0.72	0.86	0.40	0.00
Laybir	0.21	0.29	0.53	0.53	0.62	0.84	0.90	0.83	0.76	0.59	0.46	0.25
Nedjo	0.00	0.00	0.20	0.55	0.73	0.83	0.90	0.80	0.82	0.60	0.31	0.00
D_Tabor	0.35	0.20	0.54	0.57	0.54	0.79	0.95	0.95	0.83	0.73	0.29	0.44
d_markos	0.44	0.48	0.60	0.66	0.75	0.91	0.95	0.94	0.87	0.81	0.51	0.55

STATION	PCPD1	PCPD2	PCPD3	PCPD4	PCPD5	PCPD6	PCPD7	PCPD8	PCPD9	PCPD10	PCPD11	PCPD12
ADET	0.40	0.30	3.50	7.50	14.00	18.80	28.10	28.10	21.30	15.40	3.70	2.00
aykel	0.00	0.20	3.00	6.40	11.00	19.40	28.00	27.40	15.40	10.40	0.80	0.20
BAHIRDAR	0.50	0.00	3.80	5.00	9.70	19.50	28.70	28.80	21.80	16.70	2.50	0.30
chagni	0.50	0.00	2.20	10.00	22.20	26.80	29.50	29.50	27.80	27.80	11.80	1.80
dangila	0.40	1.40	7.20	7.20	19.60	27.00	29.40	30.20	25.60	14.80	5.60	1.60
Gonder	0.00	0.40	3.20	4.80	12.20	18.60	29.00	27.20	14.20	12.00	4.20	1.80
Nmewicha	3.00	2.40	8.00	11.80	10.60	13.20	28.60	28.60	17.20	10.80	4.20	1.60
Shashura	1.50	0.50	0.00	1.00	9.50	23.20	29.50	27.50	21.20	21.00	3.80	1.20
Laybir	2.30	1.20	5.70	8.80	16.50	23.30	27.80	25.70	21.30	11.80	6.20	2.70
Nedjo	0.60	0.60	5.00	8.80	21.00	24.60	27.60	24.40	22.00	13.60	3.20	0.60
D_Tabor	2.40	0.70	5.00	8.90	13.10	21.90	30.00	29.40	20.70	12.70	3.00	2.60
d_markos	4.60	3.00	7.40	13.70	17.00	24.60	29.10	29.00	24.60	12.00	6.10	3.10

STATION	SOLAR AV1	SOLAR AV2	SOLAR AV3	SOLAR AV4	SOLAR AV5	SOLAR AV6	SOLAR AV7	SOLAR AV8	SOLAR AV9	SOLAR AV10	SOLAR AV11	SOLAR AV12
ADET	23.00	24.00	24.00	22.00	20.00	18.00	15.00	16.00	19.00	22.00	23.00	22.00
aykel	23.00	23.00	21.00	21.00	17.00	16.00	14.00	15.00	17.00	19.00	22.00	21.00
bahirdar	24.00	25.00	24.00	23.00	21.00	19.00	15.00	16.00	19.00	21.00	24.00	24.00
chagni	24.00	24.00	23.00	22.00	21.00	15.00	14.00	14.00	17.00	19.00	23.00	23.00
dangila	20.00	22.00	21.00	22.00	22.00	17.00	15.00	16.00	18.00	18.00	19.00	19.00
Gonder	20.00	21.00	21.00	22.00	20.00	16.00	16.00	16.00	20.00	20.00	21.00	19.00
nmewicha	22.00	24.00	23.00	21.00	20.00	19.00	14.00	15.00	19.00	21.00	22.00	22.00
Shashura	23.00	24.00	24.00	22.00	21.00	18.00	16.00	16.00	19.00	20.00	22.00	22.00
Laybir	24.00	24.00	23.00	21.00	19.00	17.00	13.00	15.00	18.00	22.00	23.00	24.00
Nedjo	17.00	19.00	20.00	21.00	23.00	21.00	16.00	18.00	18.00	19.00	18.00	18.00
D_Tabor	19.00	20.00	21.00	19.00	20.00	17.00	16.00	17.00	19.00	19.00	19.00	18.00
d_markos	23.00	24.00	22.00	20.00	19.00	17.00	13.00	14.00	18.00	22.00	23.00	23.00

STATION	DEWPT1	DEWPT2	DEWPT3	DEWPT4	DEWPT5	DEWPT6	DEWPT7	DEWPT8	DEWPT9	DEWPT10	DEWPT11	DEWPT12
ADET	16.07	16.94	17.86	17.90	19.04	18.81	17.02	17.26	17.65	17.81	16.77	16.17
aykel	5.28	7.23	6.84	3.61	3.95	12.36	13.78	13.13	12.59	10.52	5.59	5.44
Bahirdar	15.22	15.01	14.83	15.83	17.98	20.17	18.60	19.30	6.75	20.13	18.29	16.35
chagni	10.34	10.94	11.06	11.31	10.89	10.56	10.40	10.41	10.52	10.60	10.62	10.64
dangila	13.69	4.32	16.67	16.17	17.21	17.64	16.49	16.67	16.45	15.11	14.65	14.29
Gonder	-50.00	7.60	9.00	10.36	12.45	14.39	15.18	15.36	14.56	11.73	10.18	8.59
Nmewicha	6.72	7.28	8.28	8.43	8.38	8.19	7.48	7.27	7.40	6.53	5.75	4.58
Shashur	10.45	10.21	10.82	9.80	10.02	10.95	10.38	10.38	10.78	10.65	10.14	9.73
Laybir	11.62	9.64	11.07	12.43	11.74	14.34	15.82	15.76	15.37	14.69	12.79	11.14
Nedjo	9.71	9.31	11.71	12.54	18.08	15.98	16.23	15.81	16.11	13.36	11.39	9.75
D_Tabor	9.31	9.95	10.55	12.44	14.61	16.01	14.06	14.24	12.76	14.73	13.37	12.27
dmarkos	5.25	2.40	5.39	8.57	10.20	11.57	11.83	12.49	11.32	9.42	6.86	5.75

Station	WND A V1	WND AV2	WND AV3	WND AV4	WND AV5	WND AV6	WND AV7	WND AV8	WND AV9	WND AV10	WND AV11	WND AV12
ADET	0.68	0.79	0.88	0.98	0.94	0.92	0.80	0.74	0.70	0.68	0.63	0.61
aykel	2.23	2.48	2.62	2.55	2.31	2.35	1.97	2.05	1.90	2.11	1.89	2.02
Bahirdar	0.51	0.57	0.71	0.78	0.77	0.77	0.66	0.63	0.60	0.66	0.57	0.47
chagni	0.22	0.24	0.25	0.57	0.27	0.22	0.18	0.17	0.16	0.24	0.16	0.20
dangila	0.95	1.04	1.10	1.25	1.29	1.16	1.16	1.09	0.99	0.81	0.72	0.80
Gonder	1.60	1.69	1.78	1.72	1.91	1.90	1.37	1.17	1.39	1.29	1.37	1.38
Nmewicha	1.33	1.45	1.57	1.71	1.75	1.90	1.62	1.53	1.23	1.23	1.16	1.21
Shashura	2.19	2.34	2.54	2.28	2.42	2.30	2.00	2.11	1.86	1.91	1.95	1.97
Laybir	2.13	2.48	2.80	2.96	2.86	2.67	1.97	1.46	1.55	1.73	1.76	1.54
Nedjo	2.15	1.86	2.54	2.34	2.46	2.25	2.40	2.36	2.42	1.80	1.75	2.05
D_Tabor	1.15	1.30	1.29	1.40	1.29	1.28	1.17	1.27	1.20	0.91	0.97	1.09
d_markos	1.15	1.22	1.30	1.24	1.25	1.11	1.03	0.96	1.05	1.33	1.12	1.22

Appendix 5: Soil Physiochemical properties as required by SWAT

Name	Description
NLAYERS	Number of layers in the soil (min 1 max 10)
HYDGRP	Soil hydrologic group (A, B, C, D)
SOL_ZMX	Maximum rooting depth of soil profile
ANION_EXCL	Fraction of porosity from which anions are excluded
SOL_CRK	Crack volume potential of soil [optional]
TEXTURE	Texture of soil layer [optional]
SOL_Z	Depth from soil surface to bottom of layer
SOL_BD	Moist bulk density
SOL_AWC	Available water capacity of the soil layer
SOL_K	Saturated hydraulic conductivity
SOL_CBN	Organic Carbon content
CLAY	Clay content
SILT	Silt content
SAND	Sand content
ROCK	Rock fragment content
SOL_ALB	Moist soil albedo
USLE_K	Soil erodibility (K) factor

Appendix 6: SWAT input format user soil data base

Value	1	2	3	4	5	6	7	8	9	10	11
SNAM	VRc	ARb	LVx	CMd	LPd	CMe	FLe	LPe	RGe	VRe	NSh
CMPPCT	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NLAYERS	3	1	3	3	1	3	3	2	2	3	3
HYDGRP	C	B	D	D	B	D	A	B	B	C	D
SOL_ZMX	1800.00	300.00	1600.00	950.00	350.00	1400.00	1300.00	900.00	900.00	1800.00	1800.00
ANION_EXCL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOL_CRK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TEXTURE	C-C-C	C	C-C-C	SIC-C-C	SIC	C-C-C	C-C-C	CL-C	C-C	C-C-C	C-C-C
SOL_Z1	300.01	300.01	300.01	350.01	350.01	400.01	200.00	200.00	300.01	300.01	300.01
SOL_BD1	1.10	1.10	1.10	1.20	1.20	1.10	1.10	1.41	1.10	1.10	1.10

SOL_AWC1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
SOL_K1	0.50	0.50	0.50	0.50	0.50	2.00	0.50	0.50	0.50	0.50	0.50
SOL_CBN1	2.05	2.05	2.00	2.00	2.00	2.00	0.05	2.00	2.00	2.00	2.00
CLAY1	73.00	73.00	58.00	51.00	51.00	47.00	62.00	39.00	42.00	68.00	57.00
SILT1	22.00	22.00	33.00	40.00	40.00	28.00	32.00	35.00	30.00	25.00	30.00
SAND1	5.00	5.00	9.00	9.00	9.00	25.00	6.00	26.00	28.00	7.00	13.00
ROCK1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
SOL_ALB1	0.13	0.13	0.15	0.13	0.13	0.13	0.09	0.15	0.13	0.13	0.14
USLE_K1	0.20	0.20	0.25	0.20	0.20	0.20	0.15	0.25	0.20	0.20	0.23
SOL_EC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOL_Z2	800.01	0.00	700.01	750.02	0.00	800.01	800.01	900.02	900.02	800.01	800.01
SOL_BD2	1.36	0.00	1.36	1.36	0.00	1.36	1.36	1.36	1.36	1.36	1.36
SOL_AWC2	0.08	0.00	0.08	0.08	0.00	0.08	0.08	0.08	0.08	0.08	0.08
SOL_K2	0.30	0.00	0.30	0.30	0.00	0.30	0.30	0.30	0.30	0.30	0.30
SOL_CBN2	0.15	0.00	0.15	0.15	0.00	0.15	0.15	0.15	0.15	0.15	0.15
CLAY2	76.00	0.00	65.00	40.00	0.00	46.00	66.00	56.00	40.00	74.00	68.00
SILT2	17.00	0.00	26.00	34.00	0.00	31.00	25.00	25.00	30.00	19.00	22.00
SAND2	7.00	0.00	9.00	26.00	0.00	23.00	9.00	19.00	30.00	7.00	10.00
ROCK2	5.00	0.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
SOL_ALB2	0.11	0.00	0.12	0.11	0.00	0.11	0.13	0.15	0.12	0.11	0.14
USLE_K2	0.08	0.00	0.12	0.18	0.00	0.18	0.23	0.25	0.12	0.08	0.23
SOL_EC2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOL_Z3	1800.02	0.00	1600.02	950.02	0.00	1400.02	1300.02	0.00	0.00	1800.02	1800.02
SOL_BD3	1.36	0.00	1.36	1.36	0.00	1.36	1.36	1.36	1.36	1.36	1.36
SOL_AWC3	0.08	0.00	0.08	0.08	0.00	0.08	0.08	0.00	0.00	0.08	0.08
SOL_K3	0.30	0.00	0.30	0.30	0.00	0.30	0.30	0.00	0.00	0.30	0.30
SOL_CBN3	0.05	0.00	0.05	0.05	0.00	1.00	0.05	0.00	0.00	1.00	0.05
CLAY3	77.00	0.00	68.00	54.00	0.00	54.00	72.00	0.00	0.00	74.00	74.00
SILT3	18.00	0.00	22.00	29.00	0.00	26.00	22.00	0.00	0.00	17.00	19.00
SAND3	5.00	0.00	10.00	17.00	0.00	20.00	6.00	0.00	0.00	9.00	7.00
ROCK3	7.00	0.00	7.00	7.00	0.00	7.00	7.00	0.00	0.00	7.00	7.00
SOL_ALB3	0.11	0.00	0.12	0.11	0.00	0.11	0.13	0.00	0.00	0.11	0.14
USLE_K3	0.08	0.00	0.12	0.18	0.00	0.18	0.23	0.00	0.00	0.08	0.23
SOL_EC3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Value	12	13	14	15	16	17	18	19	20	21	22	23	24
SNAM	ACh	ALh	ARh	LVh	NTh	PHh	LPq	M	LPk	NTr	CMv	W	U
CMPPCT	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000 0
NLAYERS	3	3	1	3	1	1	3	1	2	3	3	1	1
HYDGRP	D	A	B	D	D	C	B	D	B	D	D	D	A
SOL_ZMX	1650.00	1800.00	700.00	1800.00	200.00	200.00	1300.00	200.00	600.00	1800.00	1200.00	200.00	300.00
ANION_EXCL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOL_CRK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TEXTURE	C-C-C	C-C-C	LS	C-C-C	C	C	L-C-C	L	L-CL	C-C-C	SIC-C-C	SI	C
SOL_Z1	300.01	400.01	700.01	200.00	200.00	200.00	200.00	200.00	200.00	300.01	200.00	200.00	300.01
SOL_BD1	1.10	1.10	1.72	1.10	1.10	1.10	1.60	1.60	1.50	1.10	1.20	1.20	1.10
SOL_AWC1	0.08	0.08	0.05	0.08	0.08	0.08	0.05	0.05	0.05	0.08	0.08	0.11	0.08
SOL_K1	0.50	0.50	100.00	0.50	0.50	0.50	30.00	30.00	30.00	0.50	0.50	0.50	0.50
SOL_CBN1	4.00	3.00	1.00	3.00	3.00	3.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
CLAY1	45.00	45.00	8.00	54.00	54.00	54.00	23.00	23.00	26.00	57.00	47.00	47.00	57.00
SILT1	29.00	31.00	12.00	31.00	31.00	31.00	33.00	33.00	37.00	28.00	40.00	40.00	28.00
SAND1	26.00	24.00	80.00	15.00	15.00	15.00	44.00	44.00	37.00	15.00	13.00	13.00	15.00
ROCK1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
SOL_ALB1	0.12	0.14	0.12	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.13	0.13	0.14
USLE_K1	0.12	0.23	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.23	0.20	0.20	0.23
SOL_EC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOL_Z2	900.02	1000.01	0.00	900.02	0.00	0.00	550.02	0.00	600.01	900.02	700.01	0.00	0.00
SOL_BD2	1.36	1.36	0.00	1.36	0.00	0.00	1.36	0.00	1.60	1.36	1.36	0.00	0.00
SOL_AWC2	0.08	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.08	0.08	0.08	0.00	0.00
SOL_K2	0.30	0.30	0.00	0.30	0.00	0.00	0.30	0.00	1.15	0.30	0.30	0.00	0.00
SOL_CBN2	0.15	0.15	0.00	0.15	0.00	0.00	0.15	0.00	0.30	0.15	0.15	0.00	0.00
CLAY2	79.00	62.00	0.00	68.00	0.00	0.00	54.00	0.00	32.00	74.00	58.00	0.00	0.00
SILT2	15.00	22.00	0.00	23.00	0.00	0.00	25.00	0.00	39.00	18.00	32.00	0.00	0.00
SAND2	6.00	16.00	0.00	9.00	0.00	0.00	21.00	0.00	29.00	8.00	10.00	0.00	0.00
ROCK2	5.00	5.00	0.00	5.00	0.00	0.00	5.00	0.00	5.00	5.00	5.00	0.00	0.00
SOL_ALB2	0.11	0.14	0.00	0.12	0.00	0.00	0.15	0.00	0.15	0.14	0.11	0.00	0.00
USLE_K2	0.18	0.23	0.00	0.12	0.00	0.00	0.25	0.00	0.25	0.23	0.18	0.00	0.00
SOL_EC2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOL_Z3	1650.04	1800.02	0.00	1800.02	0.00	0.00	1300.02	0.00	0.00	1800.02	1200.02	0.00	0.00
SOL_BD3	1.36	1.36	0.00	1.36	0.00	0.00	1.36	0.00	1.60	1.36	1.36	0.00	0.00

SOL_AWC3	0.08	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.08	0.08	0.00	0.00
SOL_K3	0.30	0.30	0.00	0.30	0.00	0.00	0.30	0.00	0.00	0.30	0.30	0.00	0.00
SOL_CBN3	0.05	1.00	0.00	1.00	0.00	0.00	0.05	0.00	0.00	0.05	1.00	0.00	0.00
CLAY3	88.00	70.00	0.00	68.00	0.00	0.00	55.00	0.00	0.00	81.00	62.00	0.00	0.00
SILT3	10.00	17.00	0.00	22.00	0.00	0.00	35.00	0.00	0.00	13.00	28.00	0.00	0.00
SAND3	2.00	13.00	0.00	10.00	0.00	0.00	10.00	0.00	0.00	6.00	10.00	0.00	0.00
ROCK3	7.00	7.00	0.00	7.00	0.00	0.00	7.00	0.00	0.00	7.00	7.00	0.00	0.00
SOL_ALB3	0.14	0.14	0.00	0.12	0.00	0.00	0.15	0.00	0.00	0.14	0.11	0.00	0.00
USLE_K3	0.11	0.14	0.00	0.12	0.00	0.00	0.25	0.00	0.00	0.23	0.18	0.00	0.00
SOL_EC3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 7: SWAT delineated sub basin included in the physical sub basin of Blue Nile

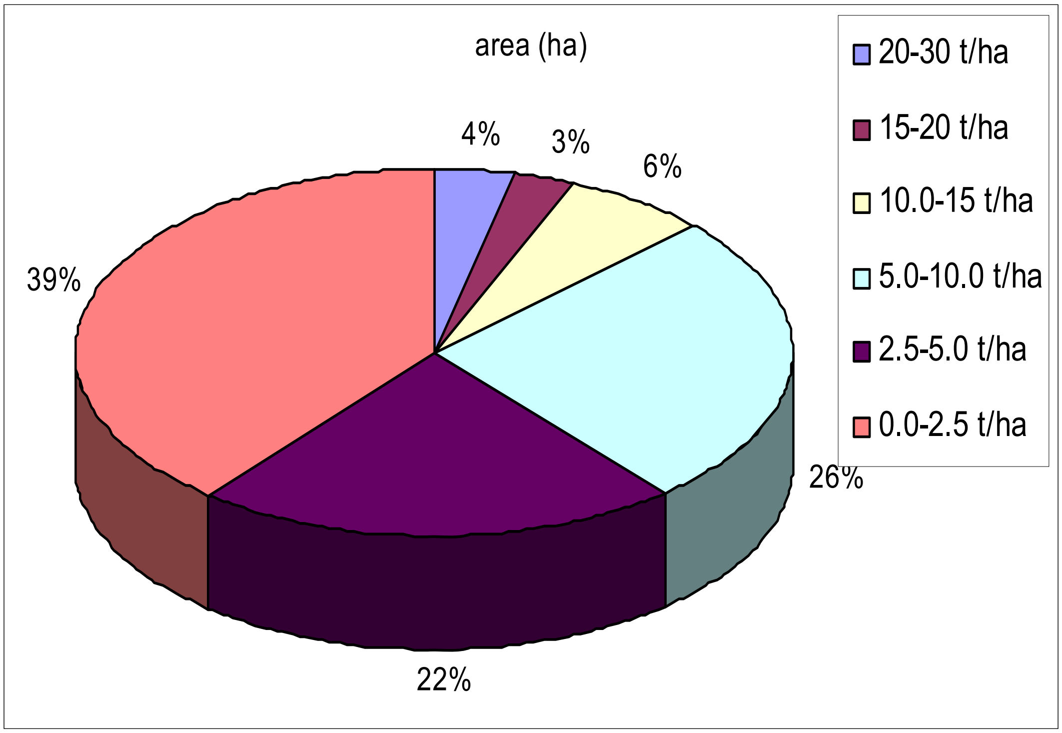
S.NO.	Physical sub basin	SWAT sub basins
1	Tana	7,8,9,10,15,16
2	Beshilo	17,18,24,30
3	N.Gojam	20,21,25,29,39,51,93,94,68*
4	Weleka	35,38,40
5	Jemma	54,55,60,61,62,63,64,65,96
6	Muger	72,73,89,90,70*
7	Guder	78,80,86,87,98
8	Finchaa	59,46*
9	S.Gojem	33,37,41,43,44,45,56,57,58,34*
10	Wenbera	38,47,48,49,50,52,66,34*,42*,46*
11	Anger	75,76,77
12	Didesa	74,82,83,88,89,90,91,67*
13	Dabus	28,31,53,79,81,84,85,19*,32*
14	Beles	22,23,26,27,28*
15	Rahad	1,2,3
16	Dinder	4,5,6,11,12,13

* SWAT delineated sub basin included in two or more Physical sub basin

Appendix 8: Annual averaged Sediment concentration at outlet of each sub basins of Blue Nile Basin

Name of sub basins	FLOW_OUT (m3/s)	sediment concentration (mg/L)	suspended sediment concentration (Kg/s)	Annual suspended sediment concentration (Million tones)
S.Gojam	1044.89	866.70	905.61	28.55925
Wenbera	1438.33	487.31	700.91	22.10380
Sudan Border	1756.28	375.184	658.93	20.77995
Jemma	296.81	361.75	107.37	3.38603
Guder	61.03	332.46	20.29	0.63986
N.Gojam	410.15	321.49	131.86	4.15826
Weleka	30.95	286.70	8.87	0.27980
Didesa	218.11	221.86	48.39	1.52604
Dabus	216.48	216.81	46.93	1.48011
Anger	84.04	180.18	15.14	0.47751
Beles	204.85	163.28	33.45	1.05481
Tana	142.92	151.82	21.70	0.68425
Finchaa	26.44	123.33	3.26	0.10285
Muger	69.98	99.93	6.99	0.22054
Rahad	49.09	90.96	4.47	0.14081
Beshilo	94.61	40.35	3.82	0.12040
Dinder	152.31	27.72	4.22	0.13316
Total				85.847

Appendix 9: Sediment yield percentage distribution in Blue Nile basin



Appendix 10: Flow and sediment concentration at the outlet of sub basins in the Blue Nile sub basins

Sub basins	TANA SUB BASIN		NORTH GOJEM		BESHILO		WELEKA		JEMMA	MUGER		
MONTHS	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_OU T (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)
JAN	21.01	0.00	56.19	0.00	5.68	0.00	3.77	0.00	53.25	0.12	15.13	0.00
FEB	5.93	0.00	13.97	0.00	2.16	0.00	0.60	0.00	15.34	0.00	3.87	0.00
MAR	0.97	0.00	26.01	0.00	16.45	0.00	1.31	0.00	11.28	12.00	1.27	0.00
APR	0.04	0.00	49.17	1.93	36.95	1.94	2.01	0.00	19.18	136.32	1.33	0.00
MAY	0.00	0.00	44.12	159.35	28.29	0.11	1.40	0.00	34.69	221.82	8.75	61.25
JUN	9.77	52.98	81.71	346.72	23.93	0.00	2.24	0.00	102.18	659.12	30.38	52.86
JUL	265.42	838.60	1087.00	1494.56	354.99	240.00	81.29	1991.8	755.76	1547.9	133.27	420.84
AUG	623.29	770.36	1589.60	1314.60	398.57	219.66	112.24	1362.0	1011.84	1316.8	170.22	404.58
SEP	316.59	90.26	840.10	274.86	149.04	22.52	73.51	83.55	658.50	248.88	179.50	197.66
OCT	254.26	69.26	616.13	247.46	69.77	0.00	52.98	3.02	484.84	159.23	145.46	49.56
NOV	146.45	0.38	350.40	0.14	36.71	0.00	28.44	0.00	276.16	36.04	95.51	0.18
DEC	71.25	0.00	167.39	18.21	12.77	0.00	11.60	0.00	138.68	2.64	55.10	12.17
Average	142.92	151.82	410.15	321.49	94.61	40.35	30.95	286.70	296.81	361.75	69.98	99.93
Outflow (BMC)	4.51		11.93		2.98		0.98		7.36		2.21	

Sub basins	GUDER		FINCHAA		S.GOJEM		WENBERA		ANGER		DIDESA	
MONTHS	FLOW_OUT (m3/s)	SED CONC (mg/l)	FLOW_OUT (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_ OUT (m3/s)	SED CONC (mg/l)	FLOW_OUT (m3/s)	SED CONC (mg/l)	FLOW_OUT (m3/s)	SED CONC (mg/l)
JAN	15.54	0.00	8.98	0.00	233.06	0.01	253.69	0.01	32.06	0.00	71.31	0.00
FEB	4.65	0.00	2.05	12.83	65.16	1.42	66.72	1.04	7.93	0.00	21.75	0.00
MAR	1.79	15.96	0.48	4.59	36.20	3.16	33.37	3.17	1.75	0.43	5.14	78.58
APR	2.15	23.16	0.08	21.11	58.85	54.19	56.69	41.31	1.28	2.69	2.31	8.12
MAY	12.78	582.76	1.98	189.23	130.40	1361.54	137.09	624.56	44.21	296.11	74.33	655.13
JUN	41.02	668.88	6.71	200.36	409.05	2127.28	457.04	1077.00	77.25	686.96	298.50	848.58

JUL	109.56	1036.64	42.76	391.80	2320.07	2538.18	2413.50	1595.20	123.93	430.04	317.57	347.90
AUG	153.48	1147.52	64.14	452.32	3261.72	2085.60	3378.60	1284.80	155.05	193.61	397.07	246.66
SEP	143.66	327.84	69.79	153.24	2239.06	932.64	2348.90	363.50	202.48	400.12	447.24	265.70
OCT	123.66	126.27	58.55	25.81	1943.82	1198.46	2063.30	428.74	160.17	143.11	471.18	210.20
NOV	77.87	14.52	39.68	19.35	1191.19	77.79	1275.10	35.53	124.05	9.07	319.83	1.45
DEC	46.18	46.01	22.13	9.35	650.08	20.16	708.60	17.66	78.29	0.00	191.13	0.00
Average	61.03	332.46	26.44	123.33	1044.89	866.70	1099.38	456.04	84.04	180.18	218.11	221.86
Outflow (BMC)	1.92		0.83		32.95		34.67		2.65		6.88	

Sub basins	BELES		DABUS		RAHAD		DINDER		at sudan Border	
MONTHS	FLOW_OUT (m3/s)	SEDCONC (mg/l)	FLOW_OUT (m3/s)	SEDCONC (mg/l)	FLOW_OUT (m3/s)	SEDCONC (mg/l)	FLOW_OUT (m3/s)	SEDCONC (mg/l)	FLOW_OUT (m3/s)	SEDCONC (mg/l)
JAN	59.85	0.00	46.50	0.00	15.91	0.00	44.42	0.00	446.70	0.00
FEB	18.46	0.00	10.24	0.00	3.85	0.00	11.04	0.00	114.57	0.50
MAR	7.83	144.08	1.41	0.00	0.56	0.00	1.86	0.00	37.89	69.81
APR	4.07	4.31	4.87	2.26	0.01	0.02	0.09	0.00	56.14	29.20
MAY	59.74	261.77	34.85	122.92	0.04	2.49	5.94	3.24	372.14	587.96
JUN	207.13	382.34	249.29	609.36	15.09	121.42	88.50	41.59	1334.43	865.52
JUL	344.21	369.56	389.89	545.86	74.70	524.70	271.19	136.78	3430.52	1180.72
AUG	469.23	416.94	478.36	433.80	156.52	351.08	458.74	112.85	4582.26	981.96
SEP	446.02	219.83	529.07	479.30	116.90	61.77	340.44	24.59	3872.09	391.14
OCT	422.75	153.41	449.99	406.92	98.17	30.02	288.31	13.59	3446.17	364.54
NOV	267.82	7.11	258.93	1.23	68.75	0.00	202.32	0.02	2157.91	20.55
DEC	151.08	0.00	144.36	0.00	38.57	0.00	114.94	0.00	1224.52	10.31
Average	204.85	163.28	216.48	216.81	49.09	90.96	152.31	27.72	1756.28	375.18
Outflow (BMC)	6.46		6.83		1.55		4.80		55.39	

Appendix 11: Annual averaged simulation results of all SWAT created sub basins of Blue Nile

sub basin	PRECIP (mm)	PET (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)	SYLD (t/ha)	Sub basin area KM^2	suspended sediment (M tones)
1	1440.968	1756.558	717.810	895.077	549.090	155.286	509.568	666.769	0.137	1998.2781	0.027
2	1365.579	1750.580	803.219	1187.491	377.559	158.973	363.732	528.893	6.393	1900.2843	1.215
3	1365.579	1750.698	734.685	1202.850	445.501	160.655	409.749	579.525	0.181	1542.7988	0.028
4	1365.579	1626.674	541.602	1295.049	595.052	220.545	542.483	767.419	2.744	3486.5802	0.957
5	1365.579	1629.609	481.262	1367.242	620.126	243.044	577.282	823.246	0.160	1464.7473	0.023
6	1371.098	1629.541	491.275	1334.706	633.097	244.079	579.421	823.844	0.022	687.2121	0.001
7	1254.407	1754.391	690.092	960.925	346.959	247.240	363.323	611.969	3.708	2125.8369	0.788
8	1686.642	1409.039	693.801	1504.601	573.932	399.339	502.283	904.602	7.837	1400.2470	1.097
9	986.029	1976.792	1139.713	1047.769	214.907	46.374	237.181	283.901	0.136	2071.4860	0.028
10	1665.917	1829.954	856.982	1389.266	420.311	414.959	363.173	778.436	6.377	4181.2849	2.666
11	1360.676	1640.171	491.728	1238.431	635.421	229.075	568.767	797.930	0.019	71.6121	0.000
12	1505.503	1636.362	601.878	1579.460	659.495	260.925	620.170	881.210	0.063	1799.5446	0.011
13	1392.497	1629.852	496.714	1539.114	601.967	239.804	563.743	803.662	0.058	3105.2969	0.018
14	1505.503	1636.248	601.492	1469.341	701.509	234.838	651.553	886.703	0.071	1253.4508	0.009
15	1307.240	1969.057	1108.887	917.062	350.015	188.142	360.055	548.365	2.097	2752.7040	0.577
16	1114.636	2076.607	1155.112	1125.521	274.325	204.036	263.429	467.638	2.889	2473.9587	0.715
17	943.723	1234.217	582.795	840.878	293.945	136.673	268.258	409.073	6.555	2841.2613	1.862
18	961.358	1152.099	466.676	382.978	26.062	3.744	54.799	524.669	0.013	5637.5757	0.007
19	1830.043	1604.131	570.910	397.052	830.821	377.868	693.623	1079.837	0.241	1163.1681	0.028
20	1476.336	1621.283	726.627	922.406	434.875	294.474	431.498	730.721	17.163	2320.8525	3.983
21	1327.463	1696.504	806.360	1296.817	393.405	117.706	362.156	486.332	4.955	1815.3396	0.899
22	1800.897	1645.746	705.150	922.218	817.288	277.390	727.669	1006.767	5.549	7465.8186	4.143
23	1852.161	1646.571	812.511	816.367	756.837	227.959	726.738	959.214	9.612	1444.6836	1.389
24	1228.336	1191.740	602.637	348.721	89.064	5.307	150.311	722.971	0.115	3418.7021	0.039
25	1200.865	1149.571	560.460	577.500	37.833	4.930	31.946	638.055	0.006	972.4131	0.001
26	1841.505	1604.067	648.947	610.123	833.310	312.732	697.450	1023.438	0.182	3451.1427	0.063
27	1868.975	1647.224	704.696	692.670	872.416	269.096	824.366	1095.969	0.166	1223.9991	0.020
28	1868.975	1647.729	620.606	678.384	905.141	352.579	838.798	1191.886	0.109	1067.2074	0.012
29	1062.469	1595.662	712.317	971.606	274.872	75.151	312.636	392.592	4.582	1288.1268	0.590
30	1100.212	1180.085	570.278	404.370	31.190	4.535	54.028	559.456	0.012	2162.8457	0.003
31	1673.326	1592.203	802.183	1099.747	597.270	216.294	482.833	714.326	0.074	7086.0421	0.052
32	1705.699	1633.383	648.655	675.980	720.073	366.621	677.538	1044.984	0.355	2272.5926	0.081

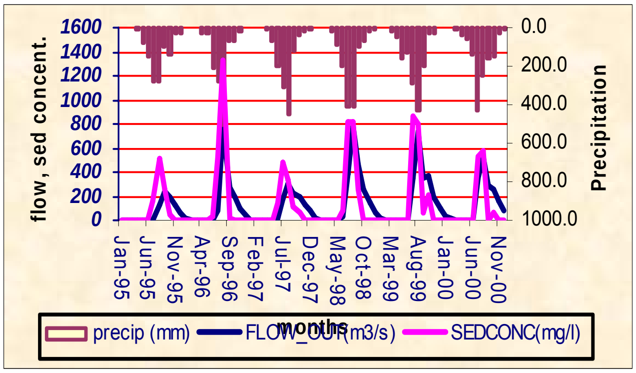
33	1976.943	1644.583	816.814	1378.201	753.367	316.470	694.636	1014.988	14.592	2262.5244	3.302
34	1853.522	1649.422	897.389	1512.241	704.758	221.348	668.035	896.776	9.317	3118.0787	2.905
35	1128.944	1440.146	753.717	705.290	314.215	128.901	322.492	455.359	9.909	1230.2847	1.219
36	1222.925	1429.157	720.390	737.728	320.556	163.791	292.195	458.953	6.154	2887.5366	1.777
37	2007.178	1630.942	933.540	1669.763	696.480	331.650	625.588	959.075	3.730	1418.4154	0.529
38	1156.818	1442.041	771.740	1359.609	333.059	55.600	316.341	375.430	1.567	774.5949	0.121
39	1102.352	1579.775	767.391	938.938	247.222	99.844	243.581	348.702	5.440	2213.8678	1.204
40	1119.335	1585.011	534.170	309.688	24.447	2.241	40.691	603.678	0.000	336.1662	0.000
41	2018.685	1733.979	961.945	1705.073	661.867	312.133	559.015	891.525	2.367	1102.0374	0.261
42	1156.818	1451.055	660.113	471.983	53.845	26.949	106.496	576.633	0.243	285.9057	0.007
43	1876.585	1423.931	760.690	1547.397	648.127	395.574	538.042	946.349	10.205	3163.1148	3.228
44	2027.847	1422.223	854.014	1759.408	729.131	430.626	674.392	1108.566	14.427	2209.2101	3.187
45	1086.739	1424.792	733.011	1172.582	338.963	36.717	329.718	372.289	1.541	105.5187	0.016
46	1453.684	1424.881	677.895	1350.313	586.228	141.275	512.208	677.317	4.877	1586.0367	0.773
47	1771.004	1633.697	840.281	1227.057	637.483	259.992	596.990	864.456	10.719	1317.5540	1.412
48	1696.987	1651.831	931.460	1194.130	662.602	101.165	606.544	711.552	0.044	1095.6547	0.005
49	1799.973	1650.770	563.545	1460.256	845.274	354.477	782.034	1144.026	0.245	1309.3164	0.032
50	1808.327	1651.151	659.207	1488.222	787.040	340.933	722.941	1077.462	6.658	821.9556	0.547
51	1276.507	1760.343	768.020	705.605	475.598	41.870	453.524	529.054	1.475	810.3240	0.119
52	1974.290	1665.676	581.343	426.174	1003.388	355.477	872.313	1229.937	0.245	1627.9461	0.040
53	2591.650	1651.142	712.436	1483.666	832.390	1005.865	784.854	1796.219	1.003	1445.8580	0.145
54	1193.981	1448.953	713.292	811.496	346.113	161.394	383.941	551.040	10.020	4269.3642	4.278
55	1147.245	1575.211	599.999	686.599	397.466	144.227	360.537	513.832	3.517	608.0022	0.214
56	1433.793	1437.756	693.079	1340.872	525.337	163.618	458.940	626.050	4.741	1189.0476	0.564
57	1184.861	1696.032	749.189	1065.621	350.025	88.509	345.500	439.123	2.113	1379.4624	0.292
58	1442.163	1442.899	714.592	1546.164	542.046	153.327	471.706	628.271	3.035	648.7128	0.197
59	1393.582	1549.227	881.691	1590.564	457.402	114.876	435.501	551.955	2.822	3293.9461	0.929
60	2463.251	1562.134	875.438	1529.923	846.127	694.363	764.844	1466.191	19.517	1113.2477	2.173
61	1272.328	1445.530	650.740	428.808	74.684	12.405	145.596	696.640	0.224	1.1178	0.000
62	1211.419	1431.845	614.824	703.208	33.094	11.680	27.317	588.437	0.016	1927.5165	0.003
63	1211.419	1432.927	701.365	881.811	328.459	150.634	270.255	435.924	8.716	1251.4906	1.091
64	1413.085	1547.988	824.487	1493.994	491.228	127.075	451.424	580.014	1.688	3123.0845	0.527
65	1250.386	1444.437	686.791	928.806	361.784	165.412	338.440	508.249	4.823	1819.1142	0.877
66	1778.130	1634.542	631.757	1356.052	735.887	340.860	655.871	1005.237	0.255	1679.1219	0.043
67	1677.464	1604.118	704.807	1361.372	747.723	221.396	694.387	919.783	0.227	2280.2957	0.052
68	1327.447	1597.909	796.367	1066.959	466.079	76.835	440.249	530.001	2.920	3573.7444	1.043

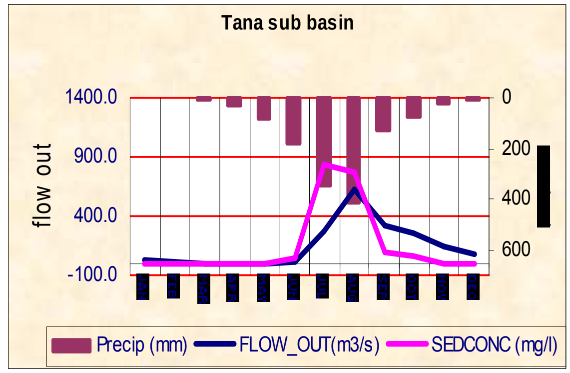
69	1528.605	1618.740	846.951	905.293	538.213	101.530	476.708	601.668	3.478	1237.7367	0.430
70	1186.021	1628.052	699.726	398.631	413.880	41.404	400.127	479.589	3.393	1093.3299	0.371
71	1455.241	1440.019	714.977	1067.475	587.098	111.205	518.445	649.309	3.177	0.9558	0.000
72	1456.172	1545.523	822.125	1030.660	541.532	116.005	509.895	641.848	2.825	4539.1590	1.282
73	1582.183	1628.256	859.429	1104.857	550.570	115.491	486.047	622.788	2.153	1442.0349	0.310
74	1645.150	1603.259	719.346	1403.371	659.297	236.398	617.964	855.892	0.128	452.1096	0.006
75	1669.111	1600.733	746.250	1686.885	672.382	234.529	623.557	858.750	0.102	577.9755	0.006
76	1688.633	1648.839	746.154	1329.290	720.891	211.966	660.825	875.649	0.071	1275.9039	0.009
77	1624.601	1699.992	913.250	1710.005	536.587	143.032	512.112	658.448	5.648	5956.0028	3.364
78	1485.141	1573.018	830.459	839.141	552.732	147.201	499.517	654.543	8.585	1879.4592	1.613
79	2611.881	1645.918	821.872	1811.885	759.437	934.996	658.441	1594.642	30.077	2217.0995	6.668
80	1379.420	1568.956	803.085	751.456	569.040	103.153	567.770	673.860	4.852	75.4434	0.037
81	2618.089	1646.426	690.220	880.303	1336.041	546.675	1109.939	1661.744	0.138	207.1575	0.003
82	1629.829	1609.182	763.255	1620.659	632.506	187.658	708.139	899.231	2.715	1943.5140	0.528
83	1564.531	1620.342	721.036	1545.420	669.144	159.042	603.840	769.369	2.572	1082.4435	0.278
84	1527.371	1625.184	773.472	1634.008	576.757	165.998	544.745	712.092	1.495	2746.6696	0.411
85	1812.833	1655.768	780.389	1568.344	620.963	417.454	579.630	999.427	5.740	2378.3867	1.365
86	1377.782	1570.471	818.414	970.020	484.685	120.298	465.983	589.549	8.321	1109.7891	0.923
87	1544.113	1551.227	869.924	1197.525	499.893	135.819	457.191	595.557	7.020	2415.2417	1.695
88	1971.520	1641.746	956.704	1812.818	686.149	251.863	613.405	869.374	6.605	3194.0567	2.110
89	1973.720	1644.898	994.624	1672.750	720.981	247.869	665.001	917.107	5.803	2358.0639	1.368
90	1254.626	1586.611	807.235	1251.362	391.894	82.485	409.978	494.352	1.844	3352.3146	0.618
91	1975.480	1644.785	994.720	1638.908	668.373	259.422	571.165	834.214	3.473	5211.9045	1.810
92	1838.355	1650.653	608.127	319.632	968.645	301.089	876.885	1178.384	0.042	0.5346	0.000
93	1739.826	1414.917	731.809	1077.219	606.677	380.337	603.128	993.376	25.057	3475.1186	8.708
94	1189.035	1174.122	574.346	354.911	42.242	2.134	104.404	684.959	0.003	0.1944	0.000
95	1841.505	1606.075	589.793	224.596	937.786	299.729	770.517	1082.128	0.150	7.9461	0.000
96	1935.200	1630.896	818.292	1122.267	614.140	484.339	604.934	1103.475	17.098	1027.0557	1.756
97	1450.035	1619.658	719.210	1241.382	410.839	286.103	382.438	669.895	10.180	814.9005	0.830
98	1385.973	1622.669	846.093	1199.010	489.055	85.665	462.532	567.110	2.784	1047.8727	0.292
Average	1543.32	1582.24	739.46	1106.71	538.08	217.87	498.60	771.45	4.26	190346.64	91.24
Excluding Rahad and Dinder	1558.57	1573.14	754.01	1087.84	534.99	218.41	495.82	774.49	4.58	174290.28	88.96

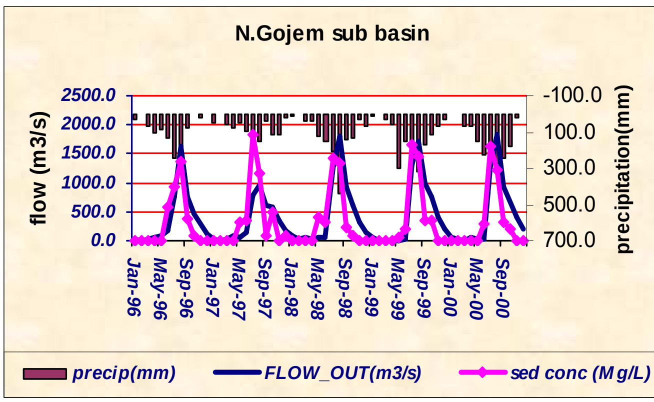
Appendix 12: Average Annual sediment yield from each sub basin of Blue Nile

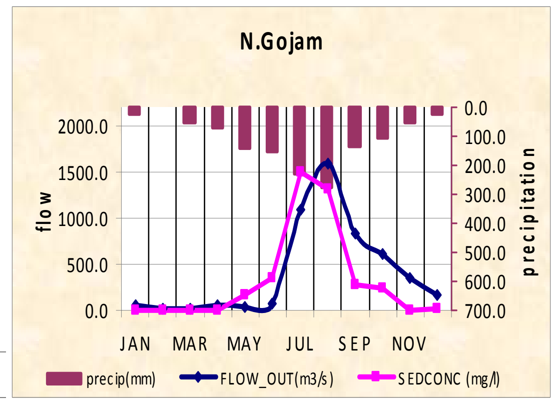
S.No	sub basins	SYLD (t/ha/yr)	precip (mm)	Total surface flow(mm)	sub basin slope	sub basin slope length	Dominant land use/cover
1	Guder	8.609	1464.028	175.942	0.087	29.27	Agriculture
2	N.Gojam	6.690	1261.596	269.032	0.106	26.62	Agriculture
3	Jemma	6.589	1311.228	307.813	0.100	27.96	Agriculture
4	S.Gojam	5.527	1516.476	197.736	0.070	41.62	Agriculture
5	weleka	4.545	1056.658	241.174	0.112	16.79	
6	Finchaa	3.881	1405.243	154.250	0.078	38.87	
7	Beles	3.878	1782.947	312.885	0.056	53.05	
8	Dabus	3.634	1890.644	421.082	0.050	71.14	Range brush land
9	Wenbera	3.529	1581.330	250.401	0.091	31.11	
10	Tana	3.519	1351.011	235.224	0.040	80.79	
11	Muger	3.246	1375.170	138.010	0.081	30.18	
12	Didesa	3.234	1726.436	254.462	0.067	42.30	
13	Anger	2.832	1748.738	277.790	0.062	54.88	
14	Rahad	1.913	1293.476	149.340	0.085	45.73	Range brush land
15	Beshilo	1.676	1056.100	433.863	0.140	5.77	Agriculture
16	Dinder	0.486	1431.454	254.510	0.033	103.66	Range brush land
Average		3.987	1453.283	254.595	0.079	43.73	

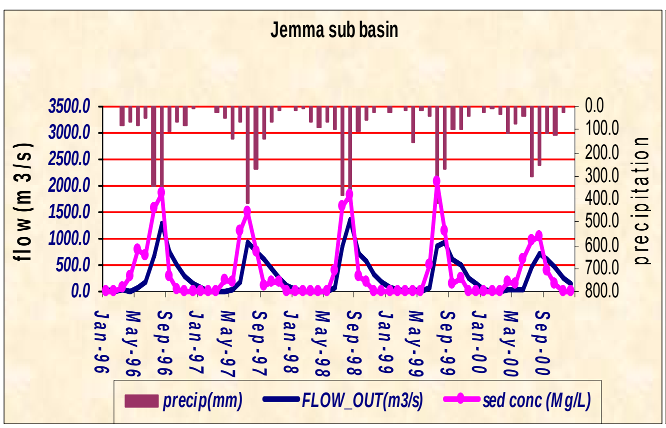
Appendix 13: Graphical presentation of flow versus sediment concentration relation

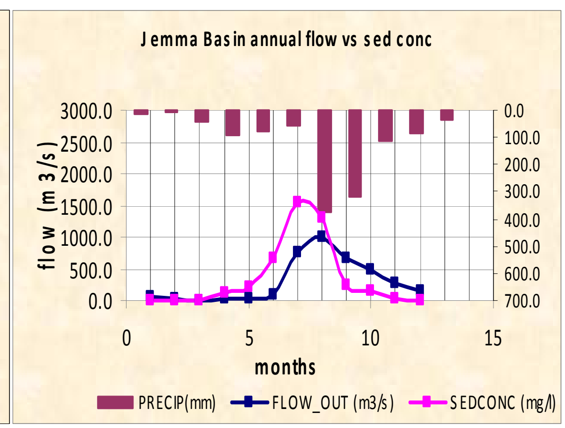


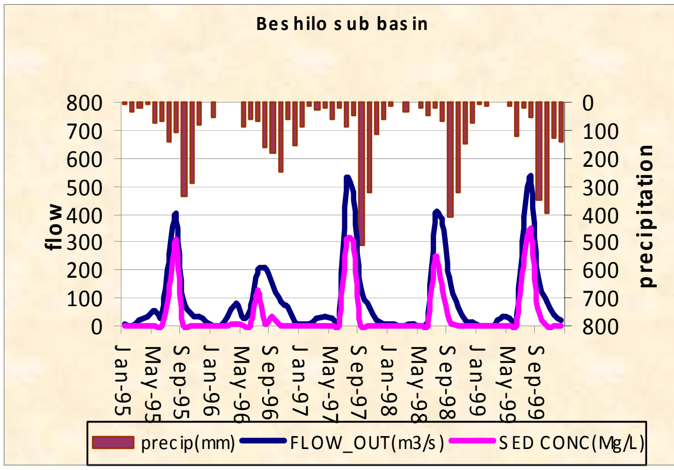


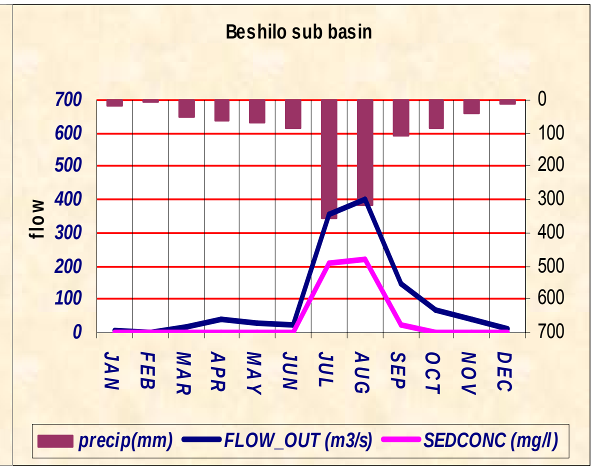


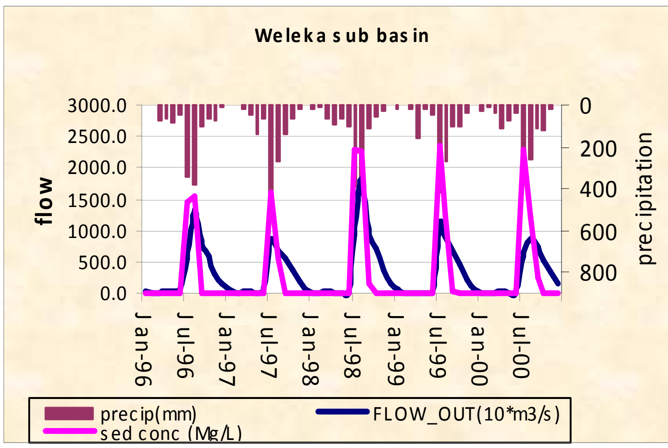


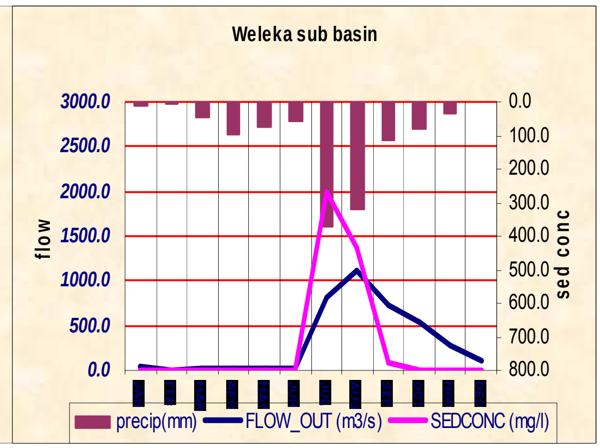


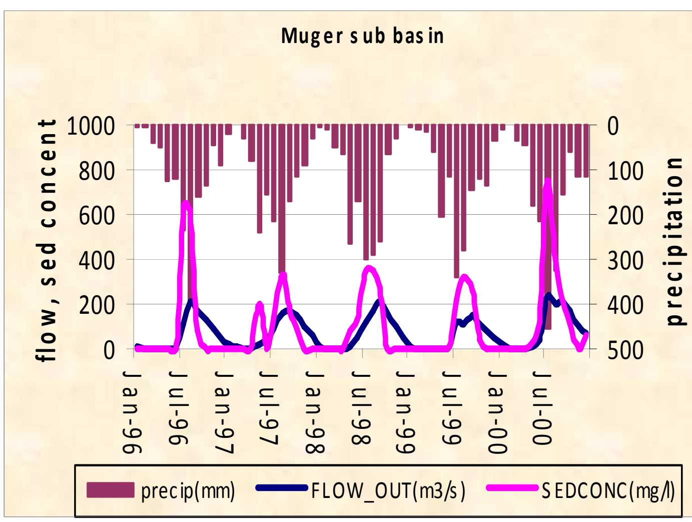


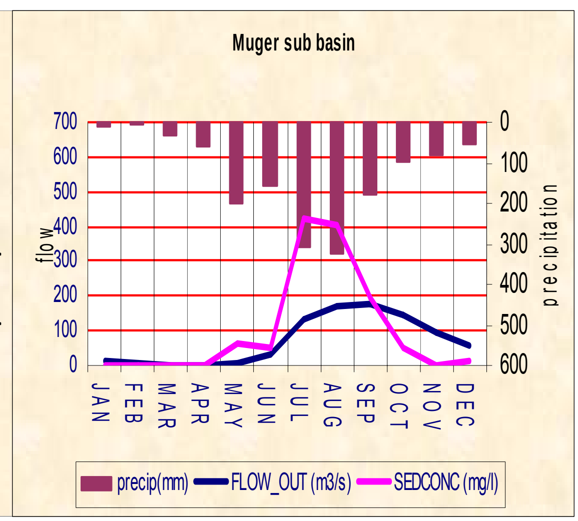

Beshilo sub basin
flow
precipitation
precip(mm)
FLOW_OUT(m3/s)
SED CONC(Mg/L)

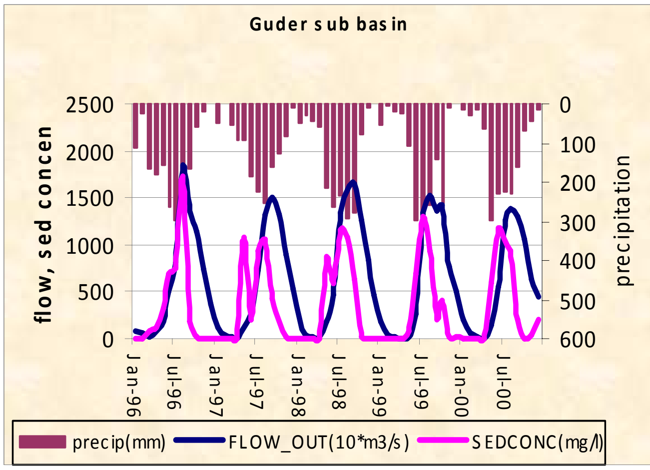

Beshilo sub basin
flow
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

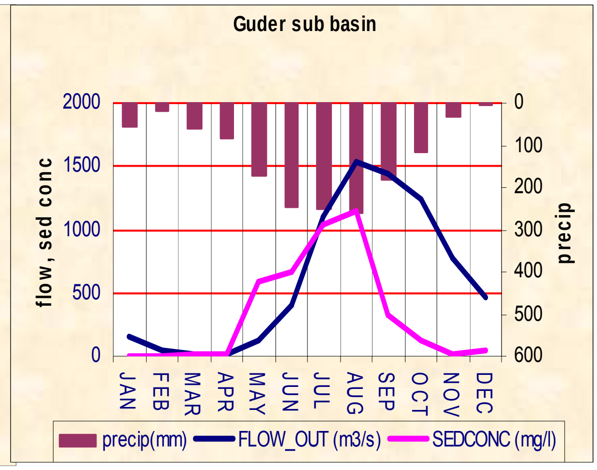

Weleka sub basin
flow
precipitation
precip(mm)
FLOW_OUT(10*m3/s)
sed conc (Mg/L)

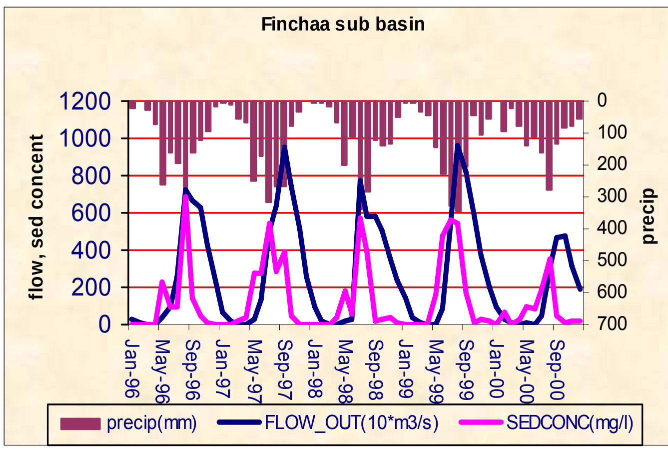

Weleka sub basin
flow
sed conc
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

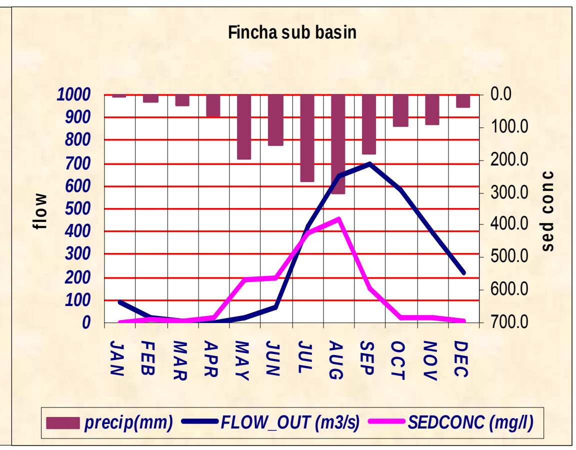

Muger sub basin
flow, sed concent
precipitation
precip(mm)
FLOW_OUT(m3/s)
SEDCONC(mg/l)

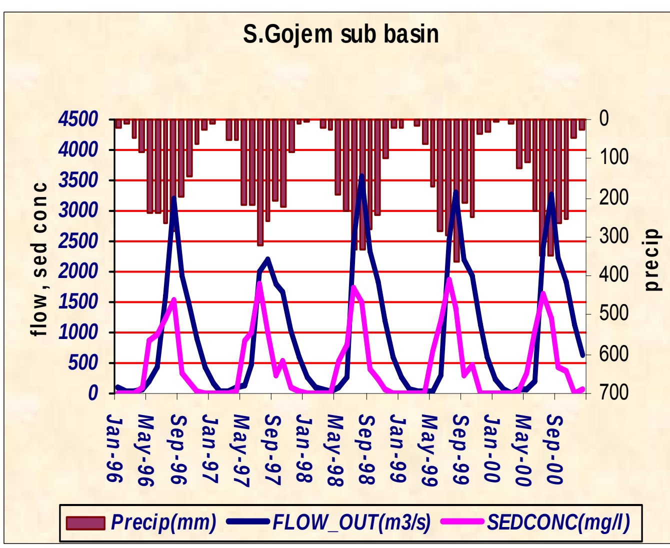

Muger sub basin
flow
precipitation
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

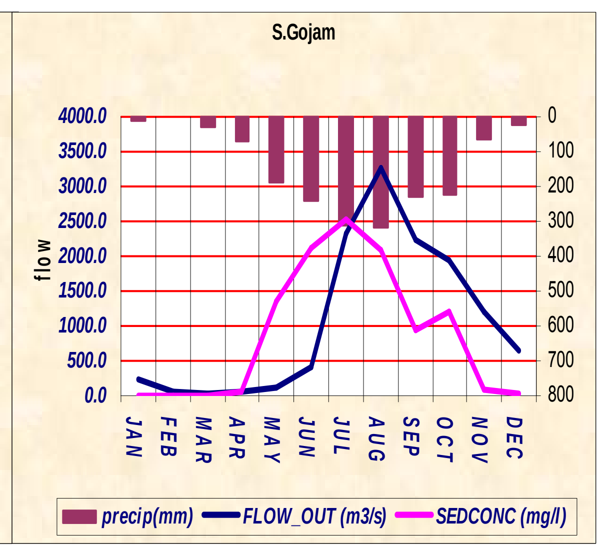

Guder sub basin
flow, sed concen
precipitation
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
precip(mm)
FLOW_OUT(10*m3/s)
SEDCONC(mg/l)

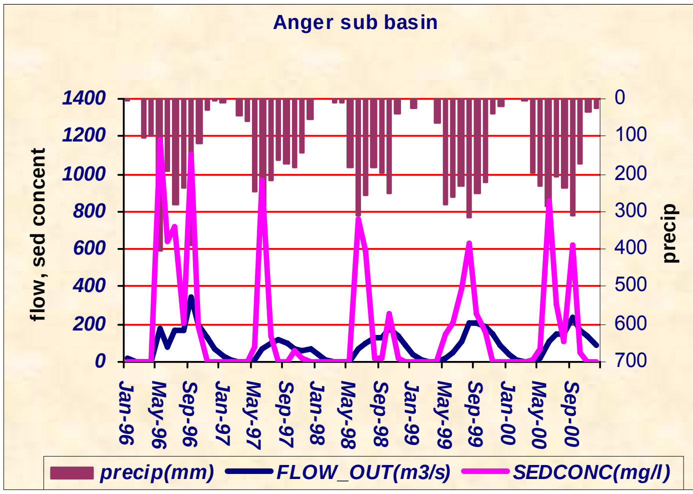

Guder sub basin
flow, sed conc
precip
2000
1500
1000
500
0
0
100
200
300
400
500
600
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

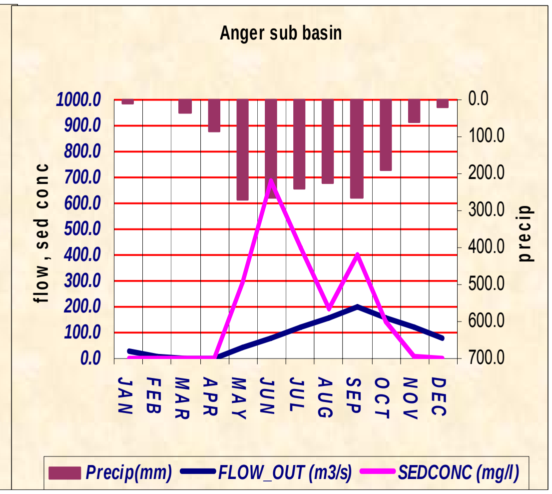

Finchaa sub basin
flow, sed concent
precip
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
precip(mm)
FLOW_OUT(10*m3/s)
SEDCONC(mg/l)

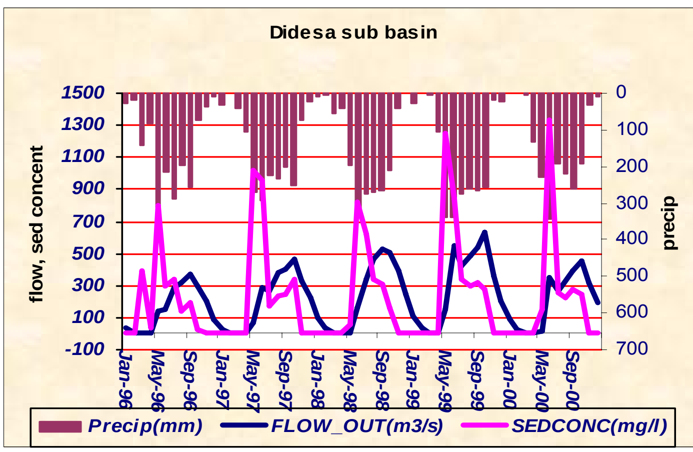

Fincha sub basin
flow
sed conc
1000
900
800
700
600
500
400
300
200
100
0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

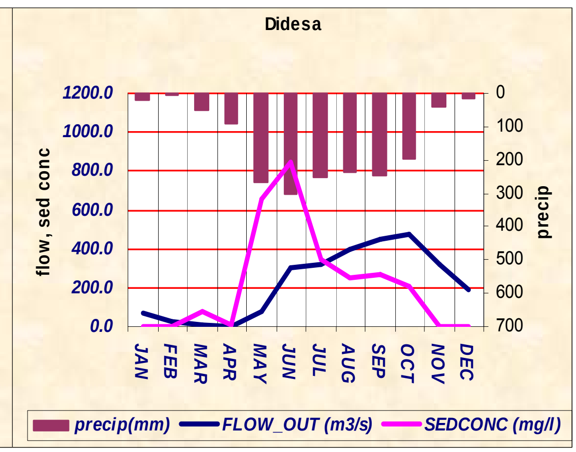

S.Gojem sub basin
flow, sed conc
precip
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Precip(mm)
FLOW_OUT(m3/s)
SEDCONC(mg/l)

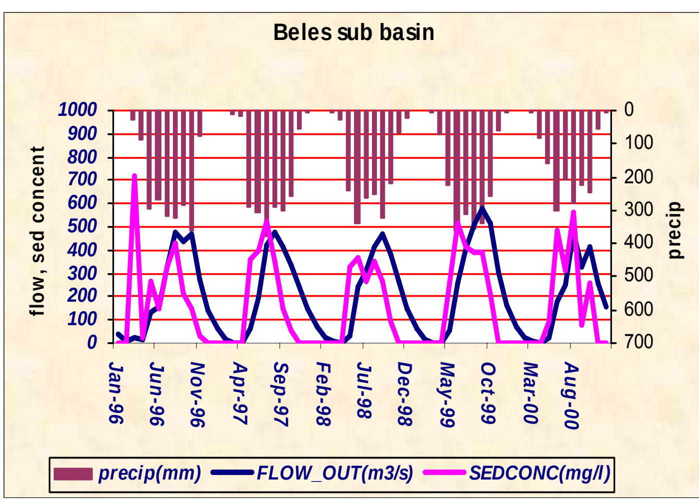

S.Gojam
flow
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
0
100
200
300
400
500
600
700
800
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

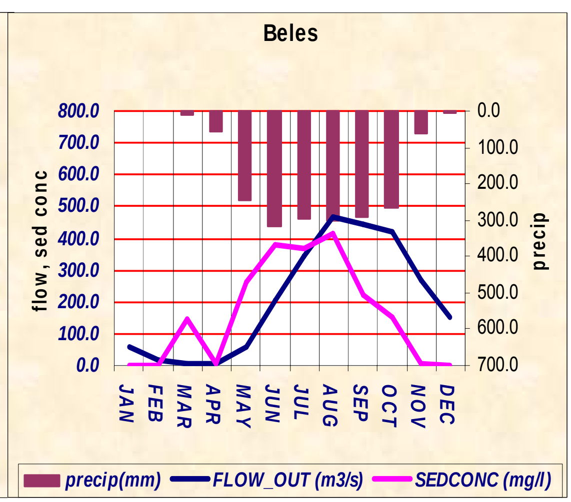

Anger sub basin
flow, sed concent
precip
precip(mm)
FLOW_OUT(m3/s)
SEDCONC(mg/l)

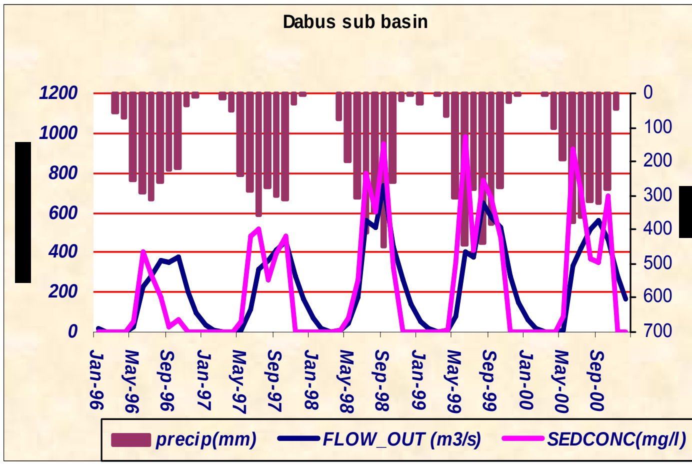

Anger sub basin
flow , sed conc
precip
Precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

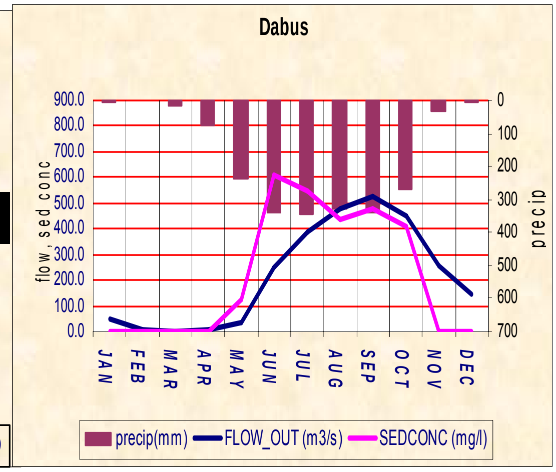

Didesa sub basin
flow, sed concent
precip
Precip(mm)
FLOW_OUT(m3/s)
SEDCONC(mg/l)

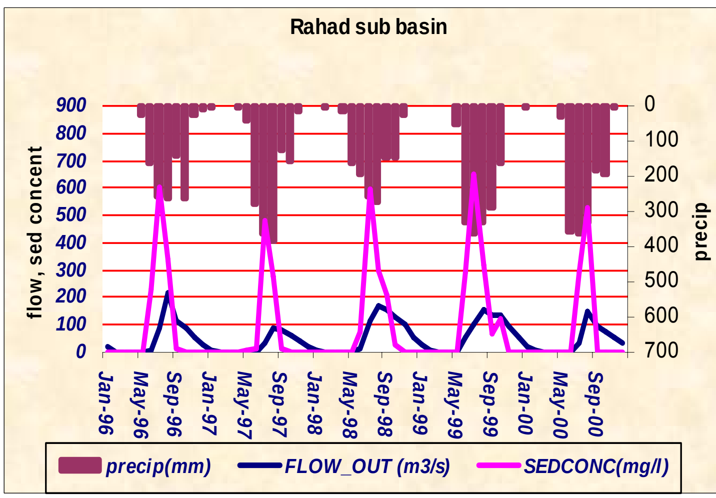

Didesa
flow, sed conc
precip
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

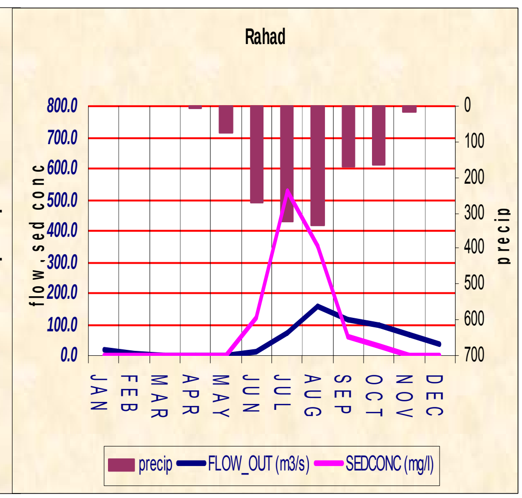

Beles sub basin
flow, sed concent
precip
precip(mm)
FLOW_OUT(m3/s)
SEDCONC(mg/l)

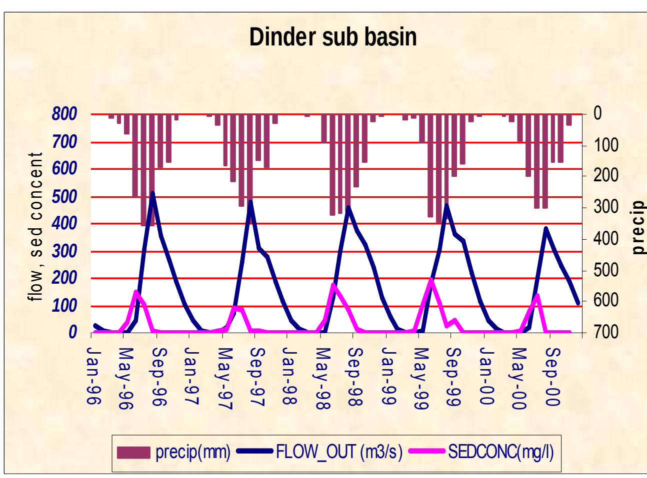

Beles
flow, sed conc
precip
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)

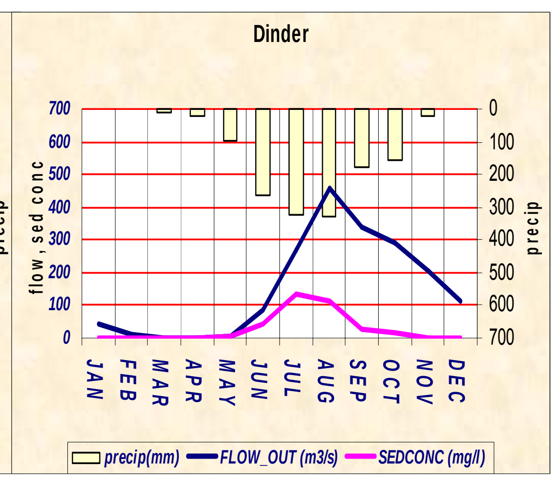

Dabus sub basin
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
Jan-96 May-96 Sep-96 Jan-97 May-97 Sep-97 Jan-98 May-98 Sep-98 Jan-99 May-99 Sep-99 Jan-00 May-00 Sep-00
precip(mm)
FLOW_OUT (m3/s)
SEDCONC(mg/l)


Dabus
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
flow, sed conc
precip
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)


Rahad sub basin
flow, sed concent
precip
Jan-96 May-96 Sep-96 Jan-97 May-97 Sep-97 Jan-98 May-98 Sep-98 Jan-99 May-99 Sep-99 Jan-00 May-00 Sep-00
precip(mm)
FLOW_OUT (m3/s)
SEDCONC(mg/l)


Rahad
flow, sed conc
precip
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
precip
FLOW_OUT (m3/s)
SEDCONC (mg/l)


Dinder sub basin
flow, sed concent
precip
Jan-96 May-96 Sep-96 Jan-97 May-97 Sep-97 Jan-98 May-98 Sep-98 Jan-99 May-99 Sep-99 Jan-00 May-00 Sep-00
precip(mm)
FLOW_OUT (m3/s)
SEDCONC(mg/l)


Dinder
flow, sed conc
precip
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
precip(mm)
FLOW_OUT (m3/s)
SEDCONC (mg/l)