Sedimentation Modeling for Ribb Dam

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School of Graduate Studies
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Sedimentation Modeling
For Ribb Dam

A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering under Hydraulics Engineering

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Date defended--------------------

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CERTIFICATION

The undersigned certify that he has read the thesis entitled**: Sedimentation Modeling for Ribb Dam** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

The soil and water assessment tool (SWAT) is tested for the prediction of sediment yield in Ribb River watershed. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients. In this research a physically based watershed model, AVSWATX is applied to the Upper Ribb River watershed for modelling of the hydrology and sediment yield. The main objective of this study is to predict the sediment yield to Ribb dam reservoir. The model is calibrated and validated taking the Upper Ribb gauging station near Debretabor. 20 years daily metrological, flow and sediment rating curve equation for sediment data BCEOM (1999) are used for model calibration and validation. The model is calibrated and validated for both flow and sediment concentration at upper Ribb (844km^2) and run at Ribb dam reservoir outlet (686km^2) to estimate the sediment yield. Flow calibration gives coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) 0.817 and 0.812 respectively. Flow validation gives 0.817 and 0.8 for R^2 and E_{NS} values respectively. Sediment calibration gives R^2 and E_{NS} 0.78 and 0.59 respectively and validation test gives R^2 and E_{NS} 0.54 and 0.52 respectively. This result indicates that the observed values show good agreement with simulated value for both flow and sediment yield.

In this study the SWAT model yields average annual sediment of 72.79 ton/km^2 (7279 ton/ha) at Ribb dam site. This result is similar with research done by BCEOM (1999) which is 82 ton/km2/y.

The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flows and soil erosion. The result of the study could help different stakeholders to plan and implement appropriate soil and water conservation strategies.

Key words

SWAT,Map,DEM,sedimentation,Ribbdam,Watershed,Digitizing,simulation,calibration validation.

Acknowledgment

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List of Acronyms and Nomenclatures

AAIT	Addis Ababa Institute of Technology
MOWE	Ministry of Water and Energy
SWAT	Soil and Water Assessment Tool
GIS	Geographical Information Systems
WWDSE	Water Work Design and Supervision Enterprise
Masl	Meter above Sea Levels
Mm3	Million Meter Cube
CREAMS	Chemicals Runoff and Erosion from Agricultural Management System
AGNPS	Agricultural Non Point Source
Alpha__Bf	Alpha base factor
BMP	Best Management Practices

CDF	Cumulative Density Function
Ch__N	Main canal Manning's Roughness Coefficient
Cn2	Moisture Condition Curve Number
DEM	Digital Elevation Model
EHRS	Ethiopian Highland Reclamation Study
Esco	Soil Evaporation Compensation Factor
ET	Evapotranspiration
GW_Delay	Groundwater Delay Time
GW_Revap	Groundwater Revap Coefficient
GWQMN	Threshold Water Depth in the Shallow Aquifer for Flow
HRU	Hydrologic Response Unit
MUSLE	Modified Universal Soil Loss Equation
MoWR	Ministry of Water Resource
NSE	Nash-Sutcliffe Efficiency
Sol_Awc	Soil Available Water Content
Sol_K	Soil Saturated Hydraulic Conductivity
NSE-	Nash-Sutcliffe Simulation Efficiency
Yiobs -	Observed Value
Ymean-	Mean of all Observed Values
Yi sim -	Modeled Value
Oi –	Observed Value
P_i-	Predicted Value
P^-	Mean of Predicted Value
O^-	Mean of Observed Value
Pi -	Predicted Values
Pav -	Mean of Predicted value
Oav -	Mean of the Observed Value
HEC-HMS	Hydrologic engineering center Hydrologic modeling system
USLE	Universal Soil Lose Equation
PET	Potential Evapo transpiration
USA	United States of America
ISO	International Standards Organization
US	United States
HYMO	Hydrologic Model

BCEOM	French Engineering Consultant
MCM	Million meter Cube
KW	Kinematic wave
PD	Probability distribute
ANSWERS	Areal Nonpoint Source Watershed Environmental Resources Simulation
CSU	Colorado State University
KINEROS	Kinematic Runoff and Erosion Model
RUSLE	Revised Universal Soil Loss Equation
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USLE	Universal Soil Loss Equation
USPED	Unit Stream Power - based Erosion Deposition
WEPP	Water Erosion Prediction Project
CASC2D-SED	The two-dimensional upland erosion model

1. INTRODUCTION

1.1 Back Ground

Ethiopia experiences persistent land, water and environmental degradation due to localized and global climatic anomalies. These leave the country to recurrent crop failures and severe food shortages. Low soil fertility coupled with temporal imbalance in the distribution of rainfall and the substantial non- availability of the required water at the required period are the principal contributing factors to the low and declining agricultural productivity. Hence, proper utilization of the available soil and water resources and development of irrigation is essential to Ethiopia's agricultural development and to achieve food security.

The poor land use practices, improper management systems and lack of appropriate soil conservation measures have been major causes of soil erosion and land degradation problems in the country. Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high. For more than 34% of the land area of Ethiopia the soil depth is already less than 35 cm (Zemenfes, 1995: SCRP, 1996). Hurni (1989) indicated that Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. These call for immediate measures to save the soil and water resources degradation of the country.

A river does not only convey water, but it also transports erosion products (boulders gravel, sand, silt and clay) from its catchment. If the transport capacity of the river is affected by diversion of water from the river or by storing water in the reservoir, deposition of sediment can occur. Some depositions could be, harmful if they are not properly taken care. Many reservoirs are suffering from excessive sedimentation often due to the fact that either the upstream sediment supply was never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data. Change in sediment yield due to changed land use in the upstream catchments causes detrimental sedimentation.

A systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects. Although empirical formulas are adopted, which simply simulates rainfall runoff relationship which is developed in other similar agro climatic zone; there is a great uncertainty on the estimations because it does not consider complex interaction that takes place in the watershed.

Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes. Hence to analyze the sediment yield of Ribb dam watershed with respect to quantity and quality of runoff is essential for the proper and sustainable utilization of Ribb dam Irrigation Project. A proper investigation of the sediment and runoff yield of the catchment is essential for management of sedimentation and utilization of water resource. If these are not investigated the life of Ribb dam reservoir is shortened by sedimentation.

This thesis is intended to provide a basis for future scenario analysis of water resource management of Ribb dam catchment and also to evaluate the SWAT model capability to predict the sediment yield of Upper Ribb River catchment to the Ribb dam reservoir.

The problem of land degradation is a threat and devastating challenge to the proposed Ribb dam reservoir and downstream areas due to generating high runoff discharges and imposing hug sediment yield, which may result in reducing water storage capacity of the dam reservoir, unless the upper watershed is treated with appropriate watershed management interventions and strategies(MOWR).

Therefore, to address the above situation, watershed management is one of the most important approaches, which helps to reduce land degradation, increase vegetation cover, and increases the productivity of the watershed area.

1.2 Statement of the Problem

- There is a knowledge gap with respect to the interdependence between the sediment yield and watershed on different temporal and spatial scale in Ribb river catchment.
- Even though assessment of soil erosion, transport and deposition of sediments in reservoirs, irrigation and hydropower systems are considered essential for land and water management, theses are not studied in-depth in the Ribb river basin.
- The magnitude of sediment transported by the upper Ribb catchment has become a serious concern for planning, design and implementation of numerous national development projects in the area.
- Furthermore reduction in the soil production capacity, reservoir siltation, change in river bank and flooding due to sediment deposition are problems calling for estimation of annual sediment yield in upper Ribb river catchment.
- Although a number of researchers have conducted erosion studies in Ethiopia, the lack of compelling tool or method has hindered adoption and implementation of their findings (Yanda,1995; Ndomba et al,2005; Ndomba 2007). Both mathematical and parametric methods require a lot of information, which is a major constraint in many developing countries (Yanda,1995). These countries have no appropriate and accurate soil erosion prediction models although universal soil lose equation (USLE) is used in different tropical countries (Mulengera ,1999). Assessment of SWAT model for predicting sediment yield in Upper Ribb river catchment is imperative.

1.3 Objective of the Research

From the background information and problem statement the following general and specific research objectives are formulated for this thesis work.

General Objective:-the general objective is:

- To estimate the sediment inflow to the Ribb dam reservoir by using GIS interface SWAT model.

Specific Objectives are:-

- To identify the most erodible sub catchment
- To forecast the sediment yield of each sub catchment

1.4 Thesis Outline

This thesis contains eight chapters organized as follows. Chapter one gives a general introduction to the study with its back ground of the problem objectives of the research study and layout of the thesis.

Chapter two describes the reviewed literature related to the study on the concept of sedimentation models, hydrological models and overview of the SWAT model. Chapter three gives a brief description of the study area and data availability. Chapter four deals with the methodology adopted for the study. In Chapter five the main part of research study, data analysis and model simulations, model calibration and validation and results are presented in this chapter. Finaly,in Chapter 6 conclusion and recommendations are given. In chapter 7 references which are used for this study are listed. In chapter 8 annexes which are used for more information are shown.

2 Literature Review

2.1 Introduction

According to the objectives, the following topics are reviewed in the literature review: a) soil erosion models b) Soil erosion modeling using SWAT model.

2.2 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster an Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998). The major forces originate from raindrop impact and flowing water. Figure .1 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

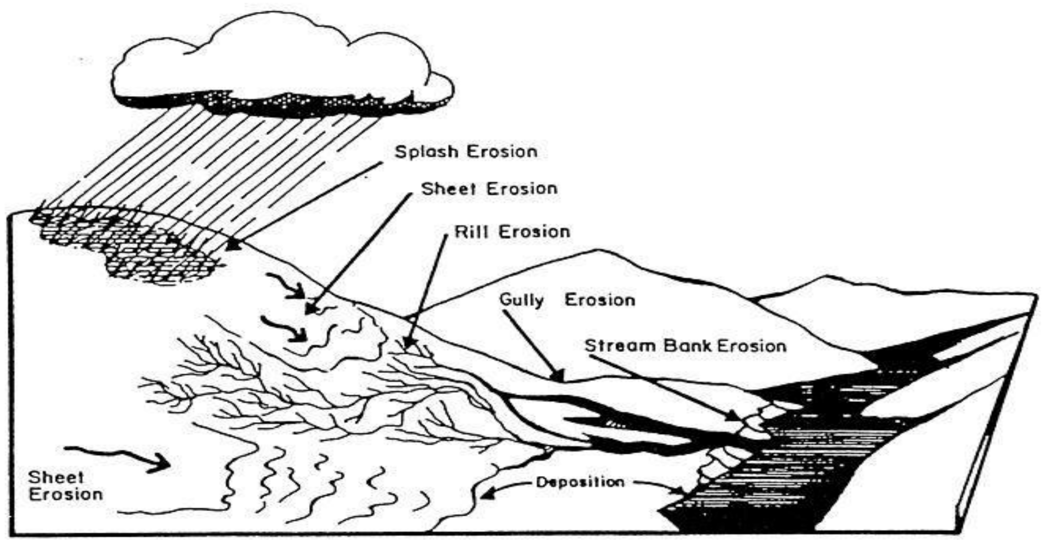

Figure.1: The mechanisms of soil erosion (USACE, 1985)

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by Wischmeier and Smith (1965) in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots. The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley, 1989) and Unit Stream Power - based Erosion Deposition (USPED) (Mitasova et al., 1996) are based on the USLE and represent an improvement of the former. In 1996, when the

U.S. Department of Agriculture (USDA) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new calculation procedure to calculate the cover vegetation factor, and the revision of the length and gradient of slope.

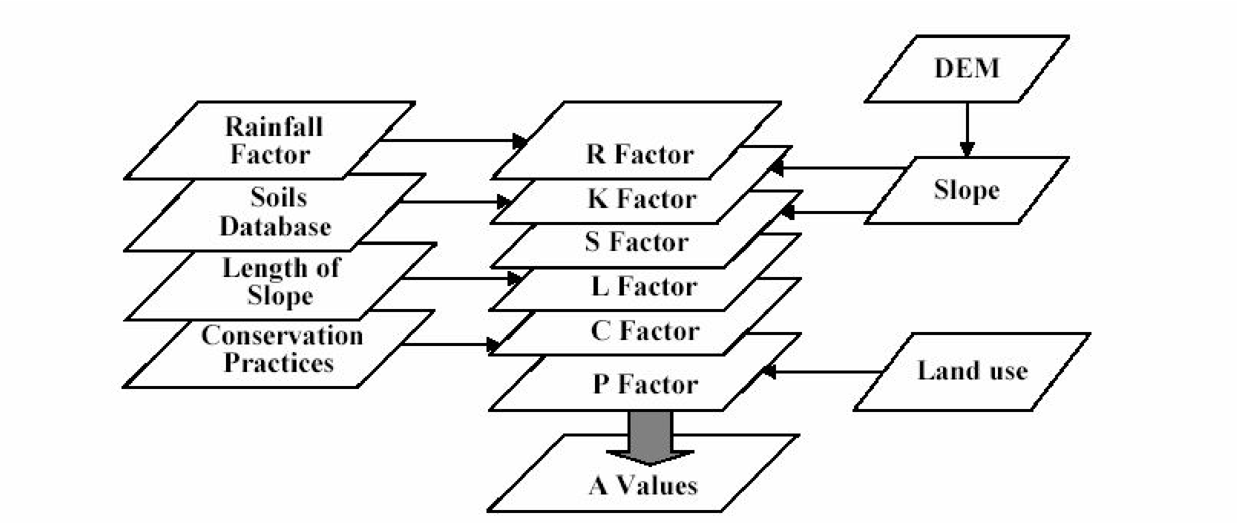

Figure .2: Procedures of RUSLE implementation in GIS

The use of the USLE and its derivatives is limited to the estimation of gross erosion, and lacks the capability to compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS. USDA developed the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995) to replace the USLE family of models and expand the capabilities for erosion prediction in a variety of landscapes and settings. This model is a physically based, distributed parameter, single-event simulation erosion prediction model. Processes within the model include erosion, sediment transport and deposition across the landscape and in channel via a transport equation. The KINEROS model (Woolhiser et al., 1990) is also a physically based, singleevent simulation erosion model, which uses the infiltration model and the kinematic wave approximation to route overland flow and sediment. The two dimensional soil erosion model CASC2D-SED was developed at Colorado State University (CSU) to simulate the dynamics of upland erosion during single rainstorms. This model is based on the raster-based surface runoff calculations from CASC2D. CASC2D-SED (Julien and Saghafian, 1991; Julien et al., 1995; Ogden,1997a, 1997b; Johnson, 1997; Johnson et al., 2000) is a physically based, distributed, raster, hydrologic and soil erosion model that simulates the hydrologic response of a watershed subject to a given rainfall field.

2.3 Hydrological Models

Hydrological models are characterizations of the real world system. Modeling of the rainfall-runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 2000). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungauged catchments and into the future to assess the likely impact of future hydrological changes. A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes for which the modeling is made. Beven (2000) stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models, it is very important to understand how the catchment responds to rainfall under different conditions.

2.3.1 Types of Hydrological Models

a) Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan et al., 1982). Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 2000).

b) Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller subbasins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 2000). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin.

c) Distributed models: Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behaviour. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy**.**

2.3.2 SWAT Development and Interface

SWAT (Arnold et al. 1998) is a semi-distributed, time continuous watershed simulator operating on a daily time step. It is developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds. The major components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The program is provided with an interface in Arc GIS (Arc SWAT 2005, Winchell et al., 2008) for the definition of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data.

2.3.2Theoretical Description of SWAT

The large scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further discredited into a series of hydrologic response units (HRUs), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated at each HRU and then aggregated for the sub basin by a weighted average. Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. For climate, SWAT uses the data from the station nearest to the centric of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method. The water in each HRU in SWAT is stored in four storage volumes: shallow soil profile (0-2m), snow shallow aquifer (typically 2-20m), and deep aquifer. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula (Chow et al., 1988). The watershed concentration time is estimated using Manning's formula, considering both overland and channel flow.

The soil profile is subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone. Down ward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer.

Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal to 0oc, no percolation is allowed from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation.

The model computes evaporation from soils and plants separately. Potential evapotranspiration can be modeled with the Penman-Monteith (Monteith, 1965), Priestly-Taylor (Priestley and Taylor, 1972), or Hargreves methods (Hargreves and Samani, 1985), depending on data availability. Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index, and root depth, and can be limited by soil water content. Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by wischmeier and Smith (1978). The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stoke's law (Chow et al.. 1988) and is calculated as a function of particle diameter squared. The depth of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold's stream power concept (Bagnold, 1977; Williams, 1980).

Hydrological Component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$Swt = Sw_0 + \sum \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad \text{Eq 2.1}$$

Where SWt is the final soil water content (mm), Sw_0 is the initial soil water content for day is (mm), t is the days (days), R_{day} is the day precipitation (mm), Q_{surf} is the surface runoff (mm), E_a is the evapotranspiration (mm), W_{seep} is the seepage from the bottom soil layer (mm) and Q_{gw} is the groundwater flow on day I (mm).

Sediment Component of SWAT

SWAT computes erosion caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). The modified universal soil loss equation (Williams, 1995) is given by equation 2.6:

$$Sed = 11.8.\left(Q_{surf}.Q_{peak.area_{hu}}\right)^{0.56}.K_{USLe.}C_{USLe.}P_{USLE.}LS_{USLE.}CFGR \qquad \text{Eq 2.2}$$

Where sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/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, 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. In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

2.4 Sediment Properties

2.4.1 General

Sediment is 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 rounded to angular. They also vary in specific gravity and mineral composition, the predominant material being quartez. 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 source or resting place is called erosion. In a channel**,** the water flow erodes the available material in the banks and/ or the stream bed until the flow is "loaded" with as much 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,
- Suspended particle motion.

When the value of the bed-shear velocity just exceeds the critical value for initiation of motion, ***bed material*** particles will be rolling and/or sliding in continuous contact with the bed. For increasing values of the bed-shear velocity the particles will be moving along the bed by more or less regular jumps, which are called saltations.

When the value of the bed-shear velocity begins to exceed the fall velocity of the particles, the sediment particles can be lifted to a level at which the upward turbulent forces will be of comparable or higher order than the submerged weight of the particles and as a result the particles may go into suspension.

Usually, the transport of particles by rolling, sliding and saltating is called bed-load transport, while the suspended particles are transport as ***suspended load transport.***

The suspended load may also include the fine silt particles brought into suspension from the catchment area rather than from streambed material (bed material load) and is called the *wash load.* A grain size of $50\mu m$ is frequently used to make the separation between bed material load and wash load. Sometimes a value of $63\mu m$ is used (USA). Another method of discrimination is given by Bagnold (1962). Based on energy considerations it can be shown that all particles with a fall velocity smaller than $1.6\bar{u}I$ ($\bar{u}$ = depth-averaged velocity, I= water surface gradient) can be transported in unlimited quantities, the latter being a typical feature of wash load transport.

Bed load and suspended load may occur simultaneously, but the transition zone between both modes of transport is not well-defined.

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

The whole process can be seen as a continuous cycle of:

Soil erosion ~ sediment transport ~~ sediment deposition

Soil erosion and sediment yield (in tones per km2 per year) strongly depend on the local climatic (rain fall), soil, land (surface slope) and vegetation conditions. Values may vary from 50 to 500 tons per km2 per year. Universal formulae are not available. Based on local data, regional formulate have been developed.

Proper land use and management can substantially reduce the problems related to sediment transport in rivers and estuaries. The design of work (terracing, debris dams, slope fixation) can also help to control surface erosion.

The following classification and definitions in accordance with the ISO-standards (ISO 4363) are given:

Bed material : The material, the particle sizes of which are found in appreciable quantities in that part of the bed that is affected by transport.

Bed material load : The part of the total sediment transport which consists of the bed material and which rate of movement is governed by the transport capacity if the channel.

Suspended load: The part of the total sediment transport which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water.

Bed load: The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

Wash load: That part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the bed material. It is in near-permanent suspension and, therefore, is transported through the stream without deposition. The discharge of the wash load through a reach depends only on the rate with which these particles become available.

2.4.2 Sediment Transport Modes

According to the mechanisms of transport, the total sediment load can be subdivided by source or by mode of transport .for source; the total load is split between the bed material load and wash load. The bed material load is derived from the river bed and is typically sand-sized or gravel-sized. The wash load consists of sediment that has been flushed into the river from upload source and is sufficiently fine-grained that the river is always able to carry it in suspension. For mode of transport, the total sediment transport is divided into suspended load transport and bed load transport. The suspended load transport is dispersed in the flow by turbulence and is carried for considerable distance without touching the bed. The bed load transport is typically coarse sediment moving in almost continuous contract with the bed by rolling, sliding, or saltating under the tractive force exerted by the water flow (Campos, 2001).

2.5 Fluid Properties

All real fluids have certain measurable characteristics or properties such as density, viscosity, compressibility, capillarity, surface tension etc. some properties are combinations of other properties. For example, kinematic viscosity involves dynamic viscosity and density. Herein, the two most basic properties being the density and the viscosity are given.

2.5.1 Density

$$\rho = 1000 + 1.455 \; CL - 0.0065 \left(Te - 4 + 0.4\, CL\right)^2 \qquad \text{Eq2.3}$$

In which:

$CL = chlorinity \; (in \; \%)$
$Te = temperature \; (in \; ^0C)$
$\rho = fluid \; density \; (in \; kg/m^3)$

The Chlorinity follows from:

$$S = 0.03 + 1.805\, CL \qquad \text{Eq 2.8}$$

In which:

S= salinity (total quantity of dissolved salt in grams per kilograms of sea water (in %, weight ratio)

2.5.2 Viscosity

The kinematic viscosity coefficient v is defined as:

$$v = \frac{\eta}{\rho}$$

In which:

v= kinematic viscosity coefficient (m^2/s)

η = dynamic viscosity coefficient (Ns/m^2)

ρ = fluid density (kg/m^3)

2.6 Sediment Properties

2.6.1 Density and Porosity

The density of quartz and clay minerals is approximately equal to $\rho_s = 2650\ kg/m^3$. The density of carbonate material may be somewhat smaller $(\rho_s = 2500\ to\ 2650\ kg/m^3)$. The specific gravity is defined as the ratio of the sediment density and the fluid density, $s = \rho_s / \rho = 2.65$.

The dry sediment density is the dry sediment weight per unit volume (=concentration) and is equal to:

$$\rho_{dry} = (1 - \rho)\rho_s \qquad \text{Eq 2.4}$$

In which:

ρ_{day} = Dry sediment density (kg/m^3);

ρ_s = Sediment density (kg/m^3)

ρ = Porosity factor.

The wet density or volume weight of deposited material (assuming total saturation) is the weight of water and sediment per unit volume (sometimes called the wet bulk density) and is equal to:

$$\rho_{wet} = p\,\rho + (1 + p)\rho_s \qquad \text{Eq2.5}$$

The porosity of sediment material is often related to the deposition history of the sediment bed. Loose packing occurs when sediments settle from suspension in still water. Basically, four packing arrangements are possible for spherical particles. The most unstable arrangement is the cubic arrangement with the sphere centers forming a cube yielding a porosity of 48%. The Rhombohedral arrangement with the spheres in the hollows of each other yields the most stable packing and the smallest porosity of 36%. Random packing of spheres yields porosity ranges from 36% to 40%. Natural sediments with particles of various sizes have relatively small porosity values because the smaller particles can occupy the large void spaces. A poorly stored (many sizes) coarse sand has a porosity of about 40%. A well sorted (almost uniform) fine sand has a porosity of about 45%. The porosity of coral sand (mixture of coral and shell fragments) has been found in the range from 0.5 to 0.65 (van der Meulen, 1988).

2.6.2 Shape

Most of the sand particles on the face of the Earth are more or less rounded because their edges and corners are smoothed by abrasion as running water or wind moves the sand particles from their origin (source) to their final resting place. Roundness is a function of abrasion induced by transport and it increases slowly with distance. Thousands of kilometers if transports in a river are required to achieve even moderate rounding. Beaches where sand moves in and out with each wave are ideal places for rounding of sand particles if they stay there for any length of time.

The shape of particles generally is represented by the Corey shape factor, defined as:

$$SF = \frac{c}{(a\,b)^{0.5}} \qquad \text{Eq2.6}$$

In which:

a = length along longest axis perpendicular to other two axes

b = length along intermediate axis perpendicular to other two axes

c = length along short axis perpendicular to other two axes. The SF- factor for natural sand is approximately 0.7.

The shape factor is essentially a flatness ratio and does not take into account the distribution of the surface area and the volume of the particle. For example, a cube of a given length and a shape of a diameter equal to the length of the cube have the same shape factor (SF = 1). To overcome this, another shape factor is also applied, defined as:

$$SF_* = SF\,\frac{d_s}{d_n} \qquad \text{Eq2.7}$$

In which:

SF_* = Shape factor according to Eq(2.12)

d_s = Diameter of a shaper having the same surface area as that of the particle

d_n = Diameter of a sphere having the same volume as that of the particle

SF_* approaching unity implies increasing sphericity of the particles (sphericity is ratio of surface area of a sphere and surface area of the particle at equal volume). A behavioral measure of shape is expressed by the roll ability parameter (Winkelmolen, 1971). The roll ability is a functional shape property measured by the time it takes for grains of equal size and density to travel the length of a cylinder revolving with its axis inclined at an angle of 2.5^0 to the horizontal.

2.6.3 Size

Usually, sediments are referred to as gravel, sand, silt or clay. These terms refer to the size of the sediment particle.

Various methods are available to determine the particle size. Cobbles can be measured directly with a ruler. Gravel, sand and silt are analyzed by wet or dry sieving methods yielding sieve diameters. Clay materials are analyzed hydraulically by using setting methods (Van Grensvenet al,,2005) yielding the particle fall velocity from which the standard fall diameter is computed. Clay materials can also be analyzed with various electronic techniques such as the Coulter counter and the Laser Diffraction technique (Van Grensven et al,, 2005). Thus, the size of a sediment particle is closely related to the analysis method.

Typical "diameters" are:

- **Sieve Diameter** which is the diameter of a sphere equal to the length of the side a square sieve opening though which the given particles will just pass.
- **Nominal Diameter** which is the diameter of a sphere that has the same volume as the particle.
- **Standard Fall Diameter** which is the diameter of a sphere that has a specific gravity of 2.65 and has the same fall velocity as the particle in still, distilled water of 24^0C.

2.6.4 Particle Fall Velocity

a) Sphere Falling in a Still Fluid

Basically, the fall velocity is a behavioral property. The terminal fall velocity (w_s) of a sphere is the fall velocity when the fluid drag force= $1/2(D_D\ \rho\ w_s^2)\,1/4(\pi\, d^2)$ on the particle is in equilibrium with the

Gravity force $=1/6(\rho_s - \rho)gd^3$, giving:

$$w_s = \left[\frac{4(s-1)gd}{3C_D}\right]^{0.5} \qquad \text{Eq2.8}$$

In which:

w_s = Terminal fall velocity of a sphere in a still fluid

d = Sphere diameter

s = Specific gravity (=2.65)

C_D = drag coefficient

g = Acceleration of gravity

The drag coefficient C_D is a function of the Reynolds number $R_e = w_s\, d / v$ and shape factor in the stocks region (RE < 1) the drag coefficient is given by: $C_D = 24/\mathrm{Re}$, yielding:

$$w_s = \frac{(s-1)gd^2}{18v} \qquad \text{Eq 2.9}$$

Outside the Stokes region there is no simple expression for the drag coefficient. The C_D-value decreases rapidly outside the Stokes region (Re < 1) and becomes nearly constant for $10^3 < \mathrm{Re} < 10^3$, yielding w_s proportional to $d^{0.5}$.

The effect of temperature on the fall velocity is taken into account by the kinematic viscosity coefficient v. the largest effect occurs for the smallest sphere diameters.

a) Non Spherical Particles

The expressions valid for a sphere cannot be applied for a natural sediment particle because of the differences in shape. The shape effect is largest for relatively large particles (> 300 μm) which deviate more from a sphere than a small particle. Experiments show differences in fall velocity of the order to 30% for SF in the range from 0.5 to 1. The terminal fall velocity of non-spherical sediment particles can be determined from the following formulae:

$$w_s = \frac{(s-1)gd^2}{18v} \qquad 1 < d \le 100\ \mu m \qquad \text{Eq2.10}$$

$$w_s = \frac{10v}{d}\left[\left(1 + \frac{0.01(s-1)gd^3}{v^2}\right)^{0.5} - 1\right] \qquad \text{Eq2.11}$$

For $100 < d < 1000\ \mu m$

$$w_s = 1.1\left[(s-1)gd\right]^{0.5} \qquad \text{Eq2.12}$$

For $d \geq 1000\ \mu m$ In which:

d = sieve diameter

s = specific gravity (=2.65)

v = kinematic viscosity coefficient

The fall velocity of *coral sand* (particles larger than 300 μm) may be considerably smaller than that of quartz sand (Van der Meulen, 1988). The differences are mainly caused by differences in shape. Coral sand particles are more angular and have, therefore, a smaller fall velocity. The density of coral sand may also be somewhat smaller

(= 2500 to 2650 kg/m^3).

2.6.5 Angle of Response

The angle of (natural) repose is a behavioral property of sand particles. Grains piled up on each other have an equilibrium slope which is called the angle of natural repose (ϕ_n).

This parameter appears to be a function of size, shape and porosity. The angle increase with decreasing roundness. Values from the literature are in the range of ϕ_n = 30^0 to 40^0 for sand sizes from 0.001 to 0.01m. Observations in nature on the avalanche less slope of desert dunes and river bed dunes also show values in the range of 30^0 to 40^0.

The angle of repose (ϕ) also referred to as the angle of internal friction is a characteristics angle related to the particle stability on a horizontal or sloping bed .The angle of repose (ϕ) may differ from the angle of natural repose (ϕ_n). Usually, the angle of repose is determined from initiation of motion experiments for horizontal and sloping beds .The critical bed-shear stress for a particle on a sloping bed can be expressed, as:

$$\tau_{b,c\tau} = \tau_{b,c\tau,o} \frac{\sin(\phi - \beta)}{\sin \phi} \qquad \text{Eq2.13}$$

$\tau_{b,c\tau}$ = Critical bed-shear stress on a sloping bottom

$\tau_{b,c\tau,o}$ = Critical bed-shear stress on a horizontal bottom

ϕ = Angle of repose

β = Angle of (longitudinal) bottom slope

For a given β - value the $\tau_{b,c\tau}$ and the $\tau_{b,c\tau,o}$-values can be determined from the measured variables. Equation (3.2.28) can then be used to determine the ϕ -value.

2.7 Sediment Transport Equations

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) develop by Wischmeier and Smith (1965, 1975). 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 rations (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.

2.7.1 Modified Universal Soil Loss Equation (MUSLE)

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

$$sed = 11.8.\left(Q_{surf}.q_{peak}.area_{hru}\right)^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}.LS_{USLE}.CFRG \qquad \text{Eq2.14}$$

Where sed is the sediment yield on a given day (metric tons), Q_{Surf} is the surface runoff volume (mm water/ha), q_{peak} is the peak runoff rate $\left(m^3/s\right)$ $area_{hru}$ is the area of the hydrological research unit (HRU) (ha), K_{USLE} is the USLE soil erodibility factor (($0.013\ metric\ ton\ m^2\ hr/\left(m^3 - metric\ ton\ cm\right)$), 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.

2.7.2 Surface Runoff

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 Calculation

SWAT uses two methods for surface runoff calculation: (1) SCS curve number method, and (2) Green-Ampt infiltration method (Green and Ampt, 1911). It is reported in literature that SCS curve number performs better than Green-Ampt method (Ponce and Hawkins 1996, Kannan et al. 2006). In addition, Green-Ampt infiltration method requires hourly precipitation data, and flow routing at hourly time step which makes the model computationally demanding for long-term simulations. Therefore SCS curve Number method is used in this thesis. Curve Number for antecedent moisture condition II (CN2) are adjusted for sub watershed slope in the model, and these values are updated on daily time step based on soil moisture conditions in the root zone.

Runoff Volume

The SCS runoff equation is an empirical model that came into common use in the 1950s. It was the product of more than 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The equation was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Evans,BM and D.A Miller, 1988).
The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad \text{Eq 2.15}$$

Where Q_{surf} is the accumulated runoff or rainfall excess $(mm\ H_2O)$, R_{day} is the rainfall depth of the day $(mm\ H_2O)$, I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff $(mm\ H_2O)$, and S is the retention parameter $(mm\ H_2O)$. 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:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad \text{Eq2.16}$$

Where, CN is the curve number for the day. The initial abstractions, I_a, is commonly approximated as 0.2S and equation 2.15 becomes

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \qquad \text{Eq 2.17}$$

Runoff will only occur when $R_{day} > I_a$.

Detail curve numbers for moisture condition II are located in annexe A (A.17-A.19)

Peak Runoff Rate

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 method is widely used in the design of ditches, channels and storm water control systems.

The rational method is based on the assumption that if a rainfall of intensity i begins at time t=0 and continues indefinitely, the rate of runoff will increase until the time of concentration, $t = t_{conc,}$ when the entire sub basin area is contributing to flow at the outlet. The rational formula is

$$q_{peak} = \frac{CiArea}{3.6} \qquad \text{Eq 2.18}$$

where q_{peak} is the peak runoff rate $(m^3\ s^{-1})$, 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.

2.8 Hydrologic Group of Soils

Soil may be place 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:

A. (Low runoff potential). The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of depth, 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 thought wetted. They chiefly are moderately depth to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have 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 the 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 are of clay soils that have high swelling potential, soils that have a permanent water table, and soils that have a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. They have a slow rate of water transmission. Dual hydrologic group are given certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained condition. Only soils that are rated D in their natural condition are assigned to dual classes. For further information see annex A (Table A1-A3).

2.9 Antecedent Soil Moisture Condition

SCS defines three antecedent moisture conditions: I-dry (wilting Point), II-average moisture, and III-wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry condition. The curve numbers for moisture conditions I all III are calculated with the equations:

$$CN_1 = CN_2 - \frac{20.(100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636.(100 - CN_2)])} \qquad \text{Eq 2.19}$$

$$CN_3 = CN_2.\exp[0.00673.(100 - CN_2)]$$

Where CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve number, and CN_3 is the moisture condition III curve number.

The retention parameter varies with soil profile water content according to the following equation:

$$S = S_{max}.\left(1 - \frac{SW}{(SW + \exp(w_1 - w_2.SW))}\right) \qquad \text{Eq 2.20}$$

Where S is the retention parameter for a given moisture content (mm), S_{max} is the maximum value the retention parameter can achieve on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point $(mm\ H_2O)$, and w_1 and w_2 are shape coefficients. The shape coefficients are determined by solving equation 2.20 assuming that

1) The retention parameter for moisture condition I curve number corresponds to wilting point soil profile water content,

2) The retention parameter for moisture condition III curve number corresponds to field capacity soil profile water content, and

3) The soil has a curve number of 99 (S=2.54) when completely saturated.

$$w_1 = In\left[\frac{FC}{1-S_3 . S_{max}^{-1}} - FC\right] + w_2 . FC$$

$$w_2 = \frac{\left(In\left[\frac{FC}{1-S_3 . S_{max}^{-1}} - FC\right] - In\left[\frac{SAT}{1-2.54 . S_{max}^{-1}} - SAT\right]\right)}{(SAT - FC)} \qquad \text{Eq2.21}$$

where w_1 is the first shape coefficient, w_2 is the second shape coefficient, FC is the amount of water in the soil profile at field capacity $(mm\ H_2O)$, S_3 is the retention parameter for the moisture condition III curve number, S_{max} is the retention parameter for the moisture condition I curve number, SAT is the amount of water in the soil profile when completely saturated $(mm\ H_2O)$, and 2.54 is the retention parameter value for a curve number of 99.

2.10 Equations of Water Routing

SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. Both the variable storage and Muskingum routing methods are variations of the kinematic wave model.

2.10.1 Variable Storage Routing

The variable storage routing method was developed by Williams (1969) and used in the HYMO (Williams and Hann, 1973) and RTOT (Arnold et al., 1995) models.

For a given river segment, storage routing is based on the continuity equation:

$$V_{in} - V_{out} = \Delta V_{stored} \qquad \text{Eq 2.22}$$

where V_{in} is the volume of inflow during the time step $(m^3\ H_2O)$ and V_{out} is the volume of outflow during the time step $(m^3\ H_2O)$, and ΔV_{stored} is the change in volume of storage during the time step $(m^3\ H_2O)$. The equation can be written as

$$\Delta t \cdot \left(\frac{q_{in,1} + q_{in,2}}{2}\right) - \Delta t \cdot \left(\frac{q_{out,1} + q_{out,2}}{2}\right) = V_{atored,2} - V_{stored,1} \qquad \text{Eq2.23}$$

where Δt is the length of the time step (s), $q_{in,1}$ is the inflow rate at the beginning of the time step (m^3/s), $q_{in,2}$ is the inflow rate are the end of the time step (m^3/s), $q_{out,1}$ is the outflow rate at the beginning of the time step (m^3/s), $q_{out,2}$ is the outflow rate at the end of the time step (m^3/s), $V_{stored,1}$ is the storage volume at the beginning of the time step $(m^3\ H_2O)$, and $V_{stored,2}$ is the storage volume at the end of the time step $(m^3\ H_2O)$. Rearranging equation 2.23 so that all known variables are on the left side of the equation,

$$q_{in,ave} + \frac{V_{stored,1}}{\Delta t} - \frac{q_{out,1}}{2} = \frac{V_{stored,2}}{\Delta t} + \frac{q_{out,2}}{2} \qquad \text{Eq2.24}$$

Where $q_{in,ave}$ is the average inflow rate during the time step: $q_{in,ave} = \frac{q_{in,1} + q_{in,2}}{2}$.

Travel time is computed by dividing the volume of water in the channel by the flow rate.

$$TT = \frac{V_{stored}}{q_{out}} = \frac{V_{stored,1}}{q_{out,1}} = \frac{V_{stored,2}}{q_{out,2}} \qquad \text{Eq 2.25}$$

Where

TT is the travel time (s), V_{stored} is the storage volume $(m^3\ H_2O)$, and q_{out} is the discharge rate (m^3/s).

To obtain a relationship between travel time and the storage coefficient Eq 2.25 is substituted into Eq 2.24 and

This simplifies to

$$q_{out,2} = \left(\frac{2\cdot\Delta t}{2\cdot TT+\Delta t}\right)\cdot q_{in,ave} + \left(1-\frac{2\cdot\Delta t}{2\cdot TT+\Delta t}\right)\cdot q_{out,1} \qquad \text{Eq 2.26}$$

This equation is similar to the coefficient method equation

$$q_{out,2} = SC\cdot q_{in,ave} + (1-SC)\,q_{out,1} \qquad \text{Eq2.27}$$

where SC is the storage coefficient.

Eq 2.26 is the basis for the SCS convex routing method (SCS, 1964) and the Muskingum method (Brakensiek, 1967: Overton, 1966). From Eq (2.26), the storage coefficient in Eq (2.27) is defined as

$$SC = \frac{2\cdot\Delta t}{2\cdot TT+\Delta t} \qquad \text{Eq 2.28}$$

It can be shown that

$$(1-SC)\,q_{out} = SC\cdot\frac{V_{stored}}{\Delta t} \qquad \text{Eq2.29}$$

Substituting this into Eq 2.31 gives

$$q_{out,2} = SC\cdot\left(q_{in,ave}+\frac{V_{stored,1}}{\Delta t}\right) . \qquad \text{Eq2.30}$$

To express all values in units of volume, both sides of the equation are multiplied by the time step

$$V_{out,2} = SC\cdot(V_{in}+V_{stored,1}) \qquad \text{Eq2.31}$$

2.10.2 Muskingum Routing Method

The Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages in a reach segment (After Chow et al., 1988). When a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave recedes, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length.

As defined by Manning's equation the cross-sectional area of flow is assumed to be directly proportional to be discharge for a given reach segment. Using this assumption, the volume of prism storage can be expressed as a function of the discharge, $K \cdot q_{out,}$ where K is the ratio of storage to discharge and has the dimension of time. In a similar manner, the volume of wedge storage can be expressed as $K \cdot X \cdot (q_{in} - q_{out})$, where X is a weighting factor that controls the relative importance of inflow and outflow in determining the storage in a reach .Summing these terms gives a value for total storage

$$V_{stored} \ K \cdot q_{out} + K \cdot X \cdot (q_{in} - q_{out}) \qquad \text{Eq2.32}$$

where V_{stored} is the storage volume $(m^3\ H_2O)$, q_{in} is the inflow rate (m^3/s), q_{out} is the discharge rate (m^3/s),K is the storage time constant for the reach (s), and X is the weighting factor. This equation can be rearranged to the form

$$V_{stored} = K \cdot (X \, . q_{in} + (1 - X) \cdot q_{out}) \qquad \text{Eq2.33}$$

The weighting factor, X, has a lower limit of 0.0 and an upper limit of 0.5. this factor is a function of the wedge storage. For reservoir-type storage, there is no wedge and X=0.0. For a full-wedge, X=0.5. For rivers, x will fall between 0.0 and 0.3 with a mean value near 0.2.

The definition for storage volume in equation 2.38 can be incorporated into the continuity equation and simplified to

$$q_{out,2} = C_1 \cdot q_{in,2} + C_2 \cdot q_{in,1} + C_3 \cdot q_{out,1} \qquad \text{Eq 2.34}$$

where $q_{in,1}$ is the inflow rate at the beginning of the time step (m^3/s), $q_{in,2}$ is the inflow rate at the end of the time step (m^3/s), $q_{out,1}$ is the outflow rate at the beginning of the time step (m^3/s), $q_{out,2}$ is the outflow rate at the end of the time step (m^3/s), and

$$C_1 = \frac{\Delta t - 2 \cdot K \cdot X}{2 \cdot K \cdot (1 - X) + \Delta t}$$ Eq2.35

$$C_2 = \frac{\Delta t + 2 \cdot K \cdot X}{2 \cdot K \cdot (1 - X) + \Delta t}$$ Eq2.36

$$C_3 = \frac{2 \cdot K \cdot (1 - X) - \Delta t}{2 \cdot K \cdot (1 - X) + \Delta t}$$ Eq2.37

Where, $C_1 + C_2 + C_3 = 1$. To express all values in units of volume, both sides of equation 2.34 are multiplied by the time step

$$V_{out,2} = C_1 \cdot V_{in,2} + C_2 \cdot V_{in,1} + C_3 \cdot V_{out,1}$$ Eq 2.38

To maintain numerical stability and avoid the computation of negative outflows, the following condition must be met:

$$2 \cdot K \cdot X < \Delta t < 2 \cdot K \cdot (1 - X)$$ Eq 2.39

The value for the weighting factor, X, is input by the user. The value for the storage time constant is estimated as:

$$K = coef_1 \cdot K_{bankfull} + coef_2 \cdot K_{0.1bankfull}$$ Eq2.40

Where K is the storage time constant for the reach segment (s), $coef_1$ and $coef_2$ are weighting coefficients input by the user, $K_{bankfull}$ is the storage time constant calculated for the reach segment with bank full flows (s), and $K_{0.1bankfull}$ is the storage time constant calculated for the reach segment with one-tenth of the bank full flows (s). To calculate $K_{bankfull}$ and $K_{0.1bankfull}$, an equation developed by cunge (1969) is used:

$$K = \frac{1000 \cdot L_{ch}}{c_k}$$ Eq2.41

Where K is the storage time constant (s), L_{ch} is the channel length (km), and c_k is the celerity corresponding to the flow for a specified depth (m/s). Celerity is the velocity with which a variation in flow rate travels along the channel. It is defined as

$$c_k = \frac{d}{dA_{ch}}\left(q_{ch}\right) \qquad \text{Eq2.42}$$

Where the flow rate, q_{ch} is defined by Manning's equation. Differentiating manning's equation with respect to the cross-sectional area giv es

$$c_k = \frac{5}{3}\cdot\left(\frac{R_{ch}^{2/3}\cdot slp_{ch}^{1/2}}{n}\right) = \frac{5}{3}\cdot v_c \qquad \text{Eq 2.43}$$

Where c_k is the celerity (m/s), R_{ch} is the hydraulic radius for a given depth of flow (m), slp_{ch} is the slope along the channel length (m/m), n is Manning's "n" coefficient for the channel, and v_c is the flow velocity (m/s).

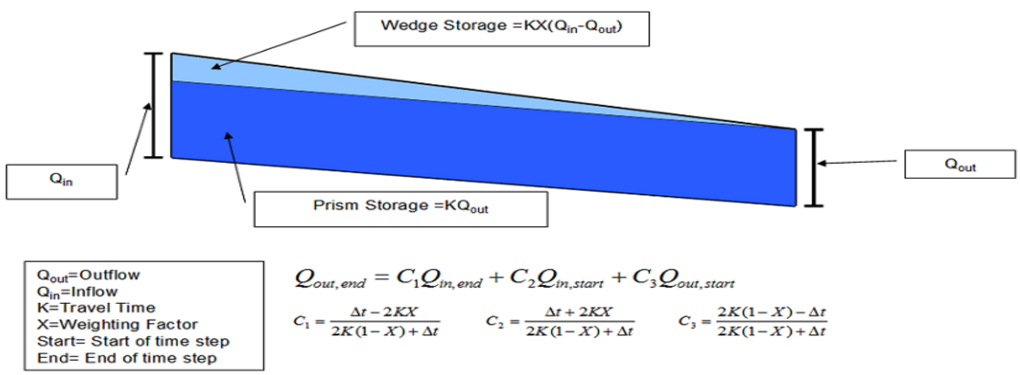

Figure .3: Muskingum routing

Flow Rate and Velocity

Manning's equation for uniform flow in a channel is used to calculate the rate and velocity of flow in reach segment for a given time step:

$$Q_{ch} = \frac{A_{ch} * R_{CH}^{2/3} SLP_{CH}^{1/2}}{n} \qquad \text{Eq2-44}$$

$$v_c = \frac{R_{ch}^{2/3} * slp_{ch}^{1/2}}{n} \qquad \text{Eq2-45}$$

where q_{ch} is rate of flow in the channel(m3/s),A_{ch} is cross-sectional area of flow in the channel(m^2),R_{ch} is the hydraulic radius for a given depth of flow(m),slp_{ch} is the slope along the channel length(m/m),n is the mannings 'n' coefficient for the channel,and v_c is the flow velocity(m/s).

2.11 Benefits of SWAT Model Approach

- Watersheds with no monitoring data (e.g., stream gage or water quality data) can be modeled.
- The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, or land use) on water quality or another variable of interest can be quantified.
- The model uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to run the model are commonly available from government agencies.
- SWAT is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment.

The model enables users to study long-term impacts. Many of the problems currently addressed by users involve the gradual build up 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. Ideally, however, inputs from many years (5+) are desirable to calibrate the model. The SWAT model can be applied to support various watershed and water quality modeling studies. Applications include national and regional scale water resource assessment.

- SWAT explicitly incorporates elevation or orographic effects on precipitation and temperature.
- SWAT was developed for and has been widely applied to simulation of watersheds in arid regions.
- SWAT explicitly incorporates routines for agricultural diversions and irrigation.

- SWAT includes routines designed to address the impacts on flow and pollutant loading of multiple small (or large) farm ponds within a basin.

- SWAT is designed to use either observed meteorological data or statistically generated meteorology, facilitating the development of long-term analyses.

Because the model is physically based and uses commonly available geographic data, it is claimed "Watersheds with no monitoring data…can be modeled", allowing the efficient evaluation of "relative impact of alternative input data (e.g., changes in management practices, climate, vegetation, etc.) on water quality…" (USEPA CREM, 2004).

2.12 Limitation of SWAT

The following are some of the limitations using SWAT for hydrological modelling:

1. Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to represent the spatial variation in the hydrometeorological characteristics in the area. The lack of adequate number of observation stations affects the model output.

2. In order to calibrate the model for the historic land use scenarios, the corresponding land use maps are needed. In order to get the real time picture of the land use pattern, this information can be extracted from the remote sensing satellite imageries by using digital image processing technique. However, acquisition of satellite imageries is expensive and also the expertise required for the image interpretation is another major limitation.

3. Though SWAT is a free software tool, in order to represent the spatial variation in the catchments characteristics, GIS software is the prerequisite to run the model.

4. While SWAT is a process-based model, it intentionally incorporates simplified representations of most processes so that many parameters can be obtained from readily available geospatial coverages. For upland generation of flow and sediment, SWAT relies on the well-tested, semi-empirical approaches of the SCS Curve Number and MUSLE. The basic time step of the model is one day (although hydrology can be simulated at a finer scale using Green-Ampt infiltration); so actual flow hydrographs are not represented. The MUSLE approach is most applicable to the estimation of cumulative loads, rather than loads from individual events. It should also be noted that the default SWAT algorithm may yield unrealistic results from HRUs that contain a mix of urban pervious and impervious land cover because MUSLE is calculated with the peak flow from the entire HRU, using a weighted curve number, and not from the flow from the pervious section. This is equivalent to assuming that all impervious area runoff proceeds as sheet flow across the pervious sections, rather than being piped or channelized, and can result in a significant over-estimation of sediment load from developed areas.

2.13 Model Evaluation

The performance of SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) are the goodness of fit measures used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). The R^2 and E_{NS} values are explained in equations below.

$$\mathbf{R^2} = \frac{\left(\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})\right)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2\sum_{i=1}^{n}(P_i-\bar{O})^2} \dots \qquad \text{Eq2.46}$$

$$\mathbf{E_{NS}} = \frac{\sum_{i=1}^{n}(O_i-\bar{O})^2-\sum_{i=1}^{n}(P_i-O_i)^2}{\sum_{i=}^{n}(O_i-\bar{O})^2}$$

Where: n is the number of observations during the simulation period

O_i and P_i are the observed and predicted values at each comparison point i

O^- and P^- are the arithmetic means of the observed and predicted values.

3 Study Area Descriptions

3.1 Geography and Natural Features

Location and Description of Research Area

Ribb Watershed is situated mainly in Farta Wereda (with small part engulfing into Ebinat wereda) of South Gonder Zone in Amhara Region. It is located at a distance of 625km north-of Addis Ababa (60km from Bahir Dar town, capital city of the Amhara Region).

Geographical coordinate of the area is 12^{0} 35' North and 41^{0} 25' East and 13^{0} 54'N and 35^{0} E. The elevation in the watershed ranges from 1900masl around dam to almost in the upper ridge (4135masl). The mean annual precipitation is about 1295mm and means annual temperature is about $20.4^{0}C$[1]. The minimum monthly rainfall is 1mm in January and maximum 411 mm in July while mean minimum temperature is 19.0c in December and monthly maximum temperature is 23.0c in April. Average daily sunshine hours are 8.1 while average atmospheric idity. is 79%.

The total upstream watershed area of the Rib Dam is about 686 Km^2 (68576 ha) out of which 59.56% is cultivated for crop production, 16.41% is grazing land 19.27% bush/shrub lands, 1.91% tree vegetation, 2.76% bare land, 0.08% wood and afro-alpine land and 0.01% urban area. The land escape the area is highly rugged with high (Guna) mountain range on the south and closely dispersed and their escarpments in the central and northern parts of the watershed, which are dissected deep and narrow bedded gorges and valleys as well as plains on the top of the hills. There also exist gentle slopes on the most hills upper reaches and middle bodies, which are thoroughly cultivated for annual (cereal) food crops.

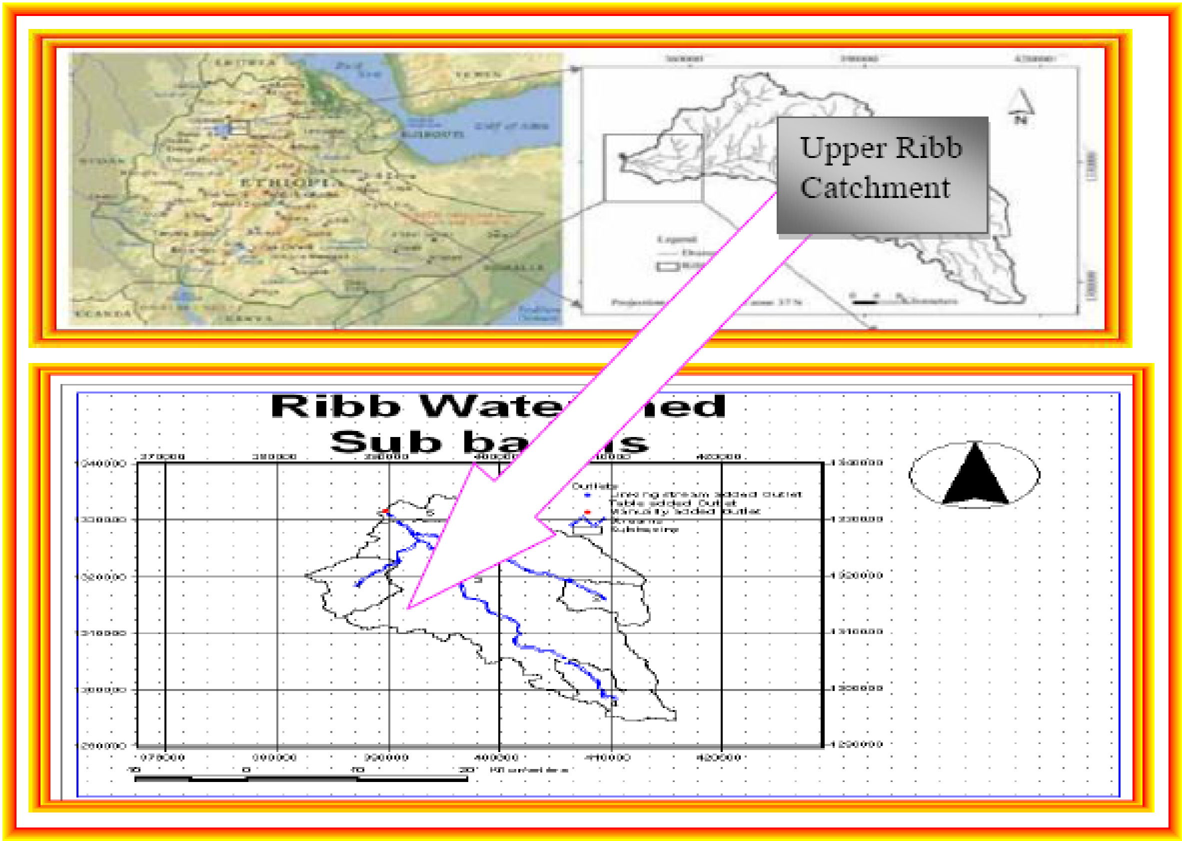

Figure.4: study area

3.2 Morphology

3.2.1 Shape of the Watershed

River Ribb is direct tributary of the Lake Tana. This study, however, focuses on upstream of the Ribb dam site that the shape of the watershed area refers to the upstream of the reservoir.

The shape of the watersheds is somewhat long from south to north with relatively large width in the northern three quarter part and narrow in the southern one-quarter area. South to north length of the watershed is estimated to reach 42km while the width at the northern half 18km and in the sourthern part less than 10km. The sitting of the watershed is oriented from slightly southeast to northwest. The relief of the watershed is mainly rolling plains and steep hilly slopes, which are the dominant landforms. As observed during the field survey and on top-map sheet of scale 1:50,000, there are many permanent and intermittent streams, which are not map able in small-scale maps. Most of the Ribb tributaries of the Ribb River are short; joining to the main river channel in few km travels. This indicates that all parts of the watershed contribute run-off to the main channel of the river simultaneously, but not necessarily to the out let point. This certainly varies with the duration of rainfall.

As the watershed lies in humid high to medium altitude receiving relatively high rainfall and 48% of the total area lies on steep slopes (15 to 50%), the common type of erosion is water erosion exhibited with all forms of erosion such as sheet, rills gully, river embankments and land sliding on very steep slope areas. The watershed subbasins, dam site and irrigation sites to be irrigated by Ribb dam are shown in figure below.

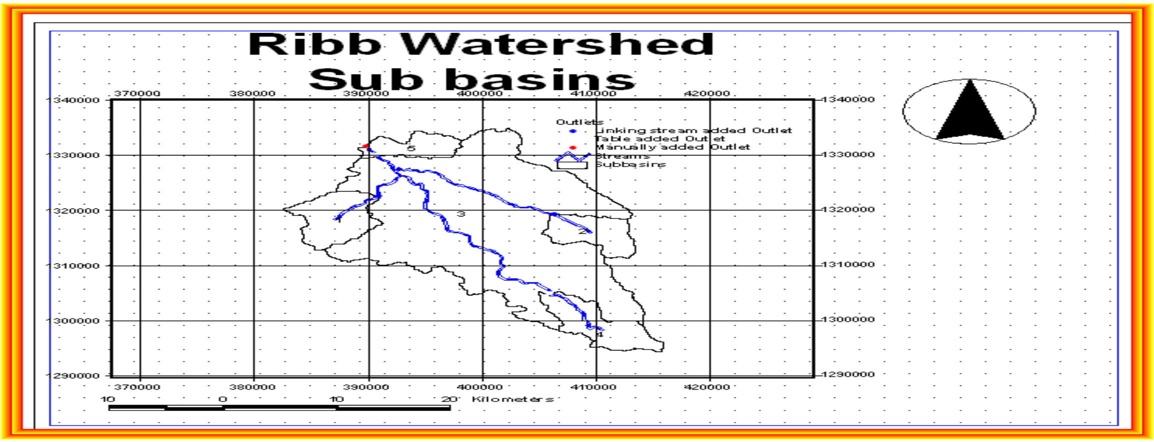

Figure .5: Study area, watershed subbasins

Figure .6: dam site (source site visit)

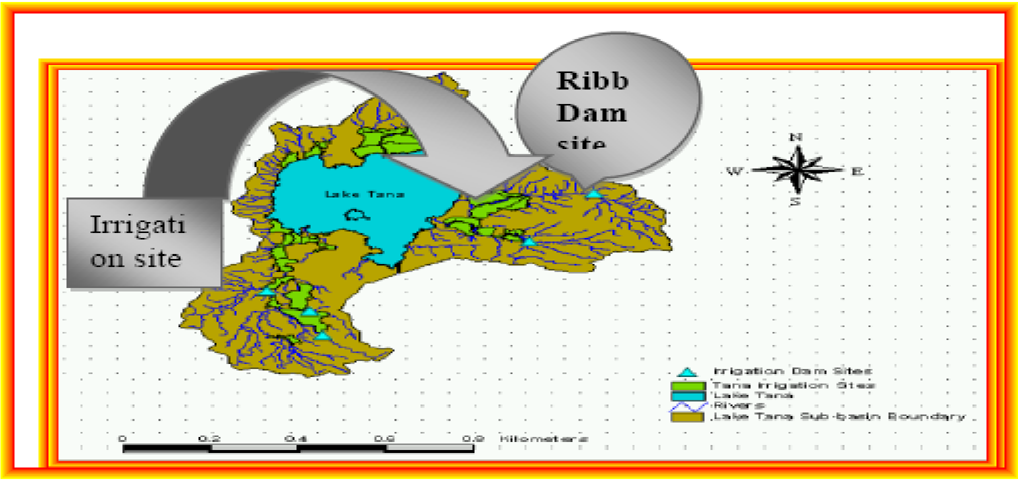

Figure .7: Locations of Dam and Irrigation Sites

3.2.2 Landform and Landscape of the Watershed Area

The major landform in the watershed include flat, gentling slopping to undulating and rolling hills and mountains as depicted in table 1 below

Table .1: Landform and Landscape of the Watershed Area

Slope range (%)	Land form	Size (ha)	Coverage (%)
0-3	Flat or almost flat	8330.6	12.15
3-8	Gentle slopping, undulating plain	10413	15.18
8-15	Rolling plain	16932	24.69
15-30	Hilly plains	21792	31.78
30-50	Steep hilly, very steep slopes, ridges and mountains	11108	16.2
Total		68576	100

The average slope of the watershed is determined from the topographic map of scale 1:50,000 and is estimated to be about 25% with dominantly hilly plains, rolling plains and steep sloped mountains' ranges. As indicated in the above table 0 to 30 slope classes cover 84% of the total watershed area while 30 to 50% slope classes, which is characterized with very steep slopes on mountains and hills, cover 16%. (MOWE).See annexes B Figure 49.

3.3 Geology and Soils

3.3.1 Geology

Ribb Dam site investigation report of geologists' describes that the Ribb basin which is a sub basin of Lake Tana basin is dominated by a huge volcano system named as Guna mountain shield volcano. It corresponds to the eruptive events that occurred during the early Miocene to Pliocene period and classified in the shield group basalt. The common rock type for this material is basalt with large amount of interbeded scoriaceous lava, volcanic ash and other acidic rocks such as rhyolite and trachyte with rare ignimbrites. Agglomerates and paleo-soils are also common.

The other smaller volcanoes located in northern part of the basin are also considered having been active during the same geological period as Guna volcano. The lava flow from the northern source is toward south where as lava from Guna in this basin is toward north. Here the river follows the area of confluence. This is clearly indicated by the sudden change of the river direction from South to North. Probably this change is the result of blocking of the river by the hard basaltic flows from north side.

At the end of the Ribb River (near Lake Tana), the area is completely overlain by recent flood materials, which are mainly covered by silt to clayey deposits (MOWE).An example of eroded materials are shown in figures 8 and 9 below. Additional information is shown on annex B(Figure B42-B47).

Figure 8: Ribb River Channel Recent Silty Sand and Gravel Deposit
(Source: field visit)

Figure 9**:** Addis Zemen Bridge at Ribb River (source: MOWE)

For further information see Annex B (FigureB.92-B.97)

3.3.2 Soils

Geology, climate and vegetation have been the major soil forming entitles active in the watershed area. Luvisols soil fromed in the south to north through south-west (large belt crossing from north-east west and west-north) of the watershed from the basaltic rock cap are deep, well structured, inherently well drained and relatively productive agricultural soil. The second large group of soil in the watershed is Leptosols on the eastern reach with some at the middle and very small on the southern part. This soil is on hill slopes partly on continued hard rocks and partly gravels. The soil is limited in depth having calcareous material or cemented layer within 30 to 40cm depth. There are small pockets of vertisols particularly on hills and mountains tops and fluvisols in valleys along rivers and streams particularly around the proposed dam/reservoir site.

The major soils of the watershed are therefore Chromic Luvisols (57.3%), Eutric Leptosols(42%), and Eutric fluvisols (0.6%) in their respective area coverage with small pockets of vertisols on the hill tops and river and streams' valleys and Chromic Luvisols as small pockets in different parts. The soils seem to have derived from basalts and tuffs. They are brownish to reddish in color, clay to clay loam and sandy to sandy loam in texture, well drained but very shallow on steep slopes. (MOWE)The Luvisols, fluvisols and vertisols have good inherent fertility and agricultural productivity, although those Leptosols on the mountain ranges and hillsides are severely eroded and further prone to soil erosion. The soil erosion on the hillside slopes and sedimentation at the valleys have already taken place because of intensive annual crop cultivation without soil erosion protection measures. (MOWE).Figure 10 shows the soil classes of Ribb dam watershed.

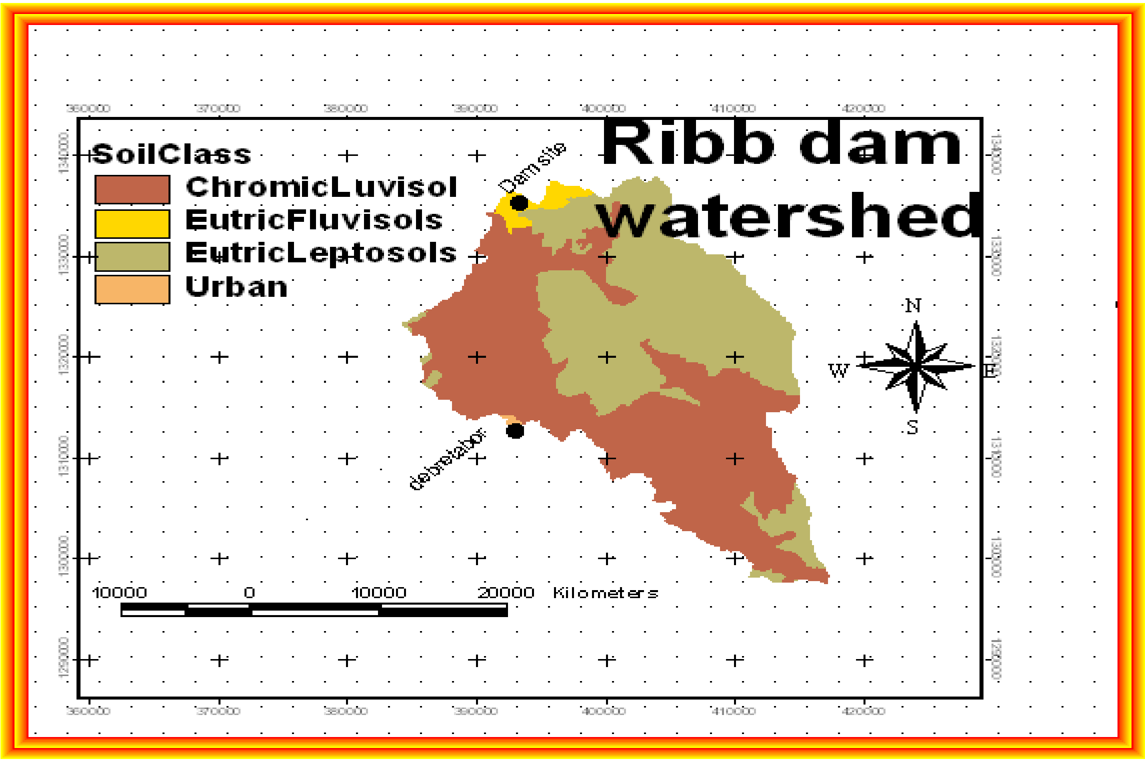

Figure 10: Soil Classes of Ribb Dam Catchment (source: MOWE shape file)

3.4 Climate and Hydrology

3.4.1 Climate

Basing on the agro climatic classification of Ethiopia (Hurni, 1986), Ribb watershed is characterized with High wurch (on southern edges), wet dega and Wet Woyna Dega (northern area) agro-climatic zones, with altitude ranges from 1900masl around dam (northern edge) to 4135 masl in the upper ridge (southern edge). The watershed area represents humid, with moderately cool to high frost, agro-climate. Generally, the rainfall pattern in the watershed is unimodal. The mean annual precipitation is about 1295mm with the minimum monthly rainfall of 1mm in January and maximum 411mm in July. Dependable rainfall varies from less than 13mm during the dry season to 80 to 275mm/month during the period of June to July/August, equivalent to 40-80% of the average values. The mean annual temperature is about 20.4^{0}C while

mean minimum temperature is 19^0C in December and monthly maximum temperature is 23^0C in May. Humidity values vary between 70% in December and 88% in August. Average daily sunshine hours are 8.1. Wind speed is reportedly low minimizing potential evapo-transpiration values between 95mm in December and 140mm in April. In general, a year in the area is divided into two seasons: a rainy season (Kiremt), which occurs from May to September and a dry season (Bega) from October to April. Seasonal variations are four namely, winter (rainy season), summer (dry season), autumn (Small rain), and spring (a spell between rainy and dry season) where dry conditions with high rate off evapo-transpiration occur. The Evaporation from the Ribb reservoir is compared to other evaporation estimates near the project area. BCEOM(1999) estimate of PET at Bahirdar was 1,428mm. While mean annual rainfall was 1450/1500mm.
The agro ecological zone of the catchment area varies from Woina Dega to Dega. However, at the dam site, the elevation of the river is approximately 1867 masl, which is Woinadega.Consecuative figures show rainfall,temperature,Relative humidit and sunshine hours Graph of Ribb dam reservoir.

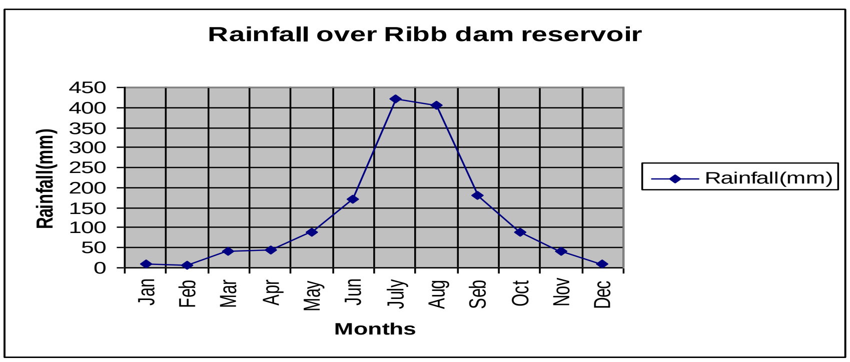

Figure 11: Rainfall over Ribb Dam Reservoir

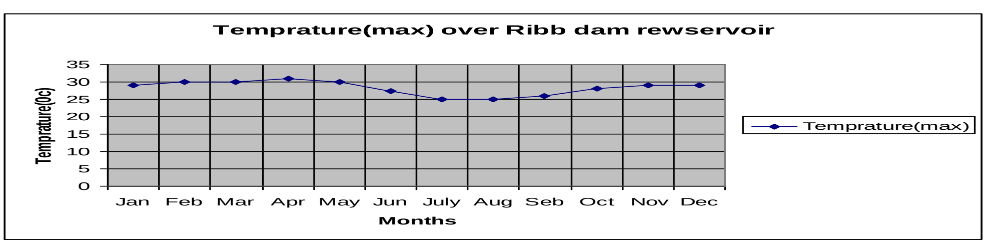

Figure 12: Temperature (max) over Ribb Dam Catchment

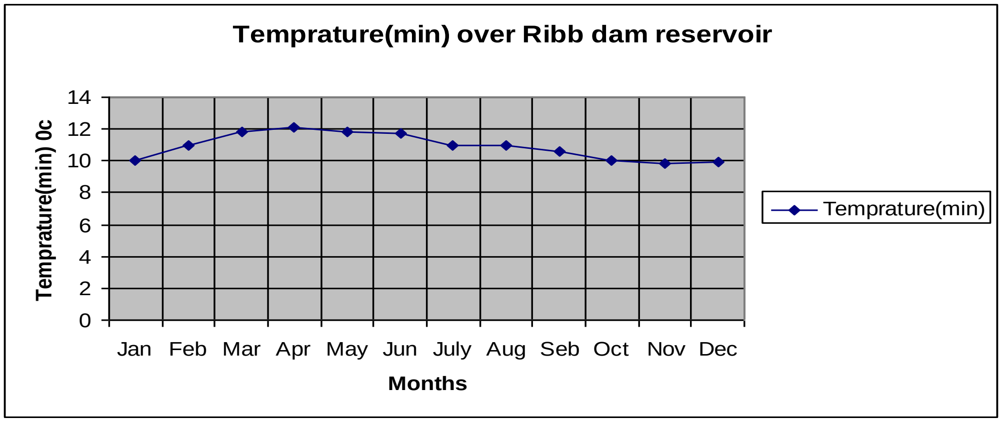

Figure13**:** Temperature (min) over Ribb Dam Catchment

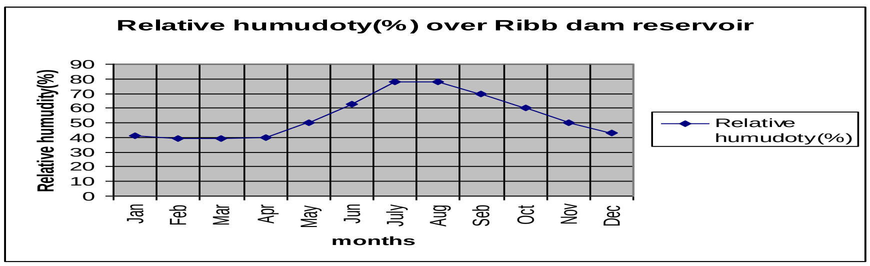

Figure 14: Relative Humidity over Ribb Dam Catchment

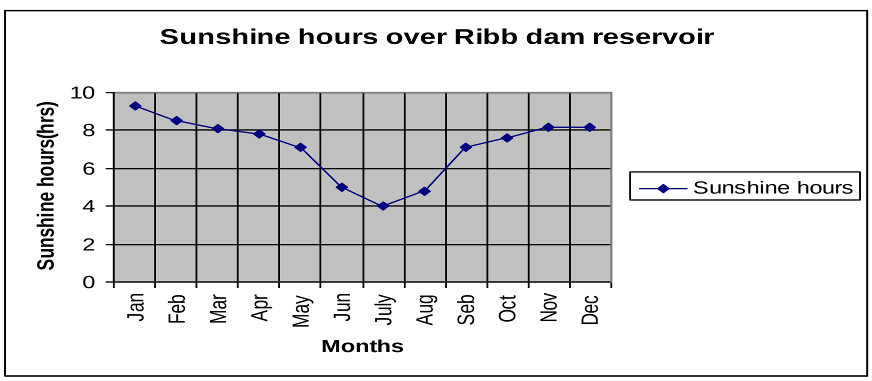

Figure.15: Sun shine hours over Ribb Dam Catchment

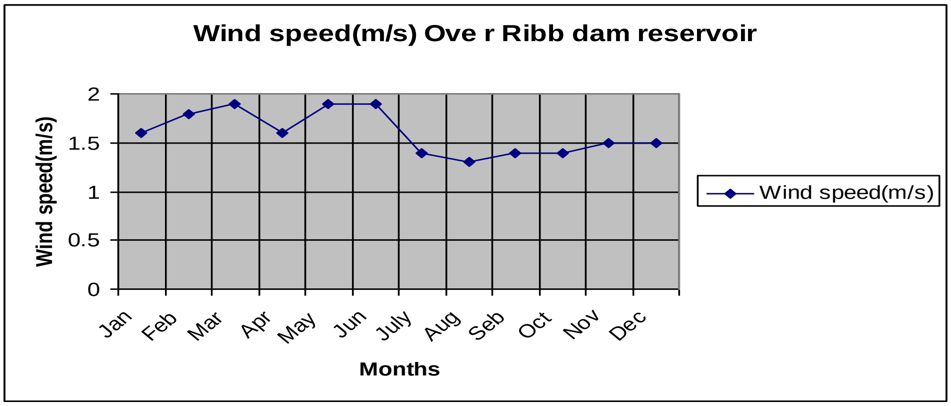

Figure16: Wind Speed over Ribb Dam Catchment

3.4.2 Hydrology

The Ribb River, which is a major tributary to Lake Tana, originates at mainly Guna Mountain at the elevation of 4135masl. It collects water from number of streams, within the watershed area of (only in the upstream of the dam site), on the way flowing to the reservoir site and enters to the Ribb Dam reservoir on the elevation of about 1900masl. Some of the major tributary stream includes Hamusit, which collects surface runoff from the eastern parts and Kolay, which collects from western parts. Collecting water from the streams, the river discharges mean annual average of 11.6m^3/s at the dam site, which corresponds to specific discharge of 17.1 l/s/km^2.

The Ribb River is located on the east side of Lake Tana in Amhara National Regional State and has a total drainage area of about 1790 km^2. The length of the main river is about 129.7 km. The river flows generally in a westerly direction and empties into Lake Tana. Daily flows of Ribb River recorded for 20 years (1985-2004).The relevant hydrometric station to estimate river flows at the Ribb dam site (685Km^2) is the Upper Ribb near Debre Tabor station (No. 1009), with catchment area of 844 km^2. It has recorded during the rainy season (July6-September) for the wet year of 1988 (with annual flow of 531 Mm^3) and the dry year of 1987 (83Mm^3), nearly 15% of the wet year flows. July and August rainfall in 1987 (606mm) were about 60% of the 1988 annual rainfall (1, 016mm). The upper section of the valley runs to the north, following the Guna flows direction, while downstream of the dam site it runs westwards to join Lake Tana, probably because it was blocked by the hard basaltic flows coming from the North

(MOWE).Staff gauges which are being used for flow measurement are shown in Figure 18 and 19. Figure 17 and Table2 give additional information.See annex A (Table A4-A8)

Table.2: Monthly Inflow Series at Ribb Dam Site (MCM)

	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov.	Dec.	Annual
Mean	1.8	1.3	1.3	2	2.1	7.7	54	92	35.2	10.4	5.4	2.6	215.7
Max	6.7	5.3	7	9.5	11.3	41.7	162.5	168.5	83.9	26	29	7.4	431.5
Min	0.2	0.1	0.1	0.1	0	0.5	2.1	5.2	5.6	1.5	0.6	0.4	62.5

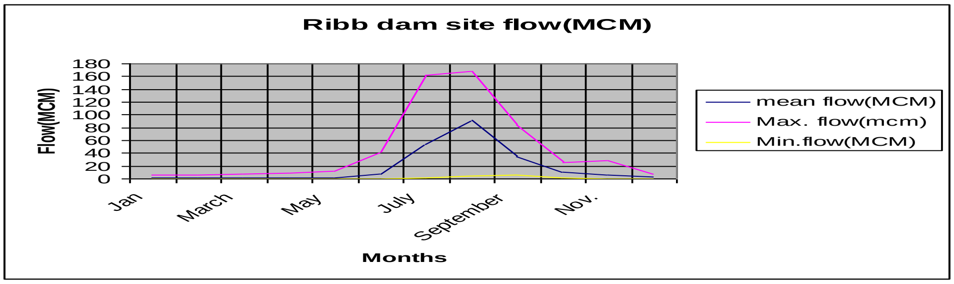

Figure 17: Ribb dam site flow

Figure 18: Staff Gauges Fixed at unstable River Bank


Figure 19: Staff Gauges Fixed at Ribb River Bank

For detail Hydrological data see annex A (table A.20- table A.24).

3.5 Land Use and Land Cover

3.5.1 Land Use

The farming system in the watershed is mixed with dominantly oxen plough cereal crop production and livestock rearing, which is centuries old system. Accordingly, the major land use types in the watershed include cultivated, grazing, very spares and patches of shrub/bushes, plantations, settlement and miscellaneous lands. According to Farta and Ebinat Wereda Agriculture and Rural Development Departments report, about 59% and 5.8% of the watershed area is used for annual and perennial crops cultivation respectively. Grazing land occupies 11240.9 ha that is about 16.4% of the total watershed area. In addition, 14655 ha shrub lands, afro alpine and man made plantations, which account for about 21.4.2% of the watershed area, is used for grazing. Excluding 158 ha of state owned natural forestland, the land under natural and man made forest is insignificant (MOWE). Land use map is shown in figure 20 ,Table3 and Table 4.

Table 3: Land Use Data of the Ribb Watershed

Land use/Land cover type	Size (ha)	Coverage (%)
Cultivated land	40798.7	59.56
Grazing land	11241.3	16.41
Plantation	1307.53	1.91
Shrub Land	13200	19.27
Wood Land	68	0.01
Afro-Alpine	56.97	0.08
Bare land	1819.5	2.66
Urban	8	0.01
Total	68500	100

Table4: land use/land cover types in the Study Area and Redefinition according to SWAT Code

Original land use/land cover	Redefined land use according to SWAT database	SWAT code
Afro alpine	Forest deciduous	FRSD
Dominantly cultivated	Teff	TEFF
Moderately cultivated	Agricultural land –row crops	AGRR
Plantation	Agricultural land -generic	AGRL
Urban	Urban	URBN
Shrub land	Range-brush	RNGB

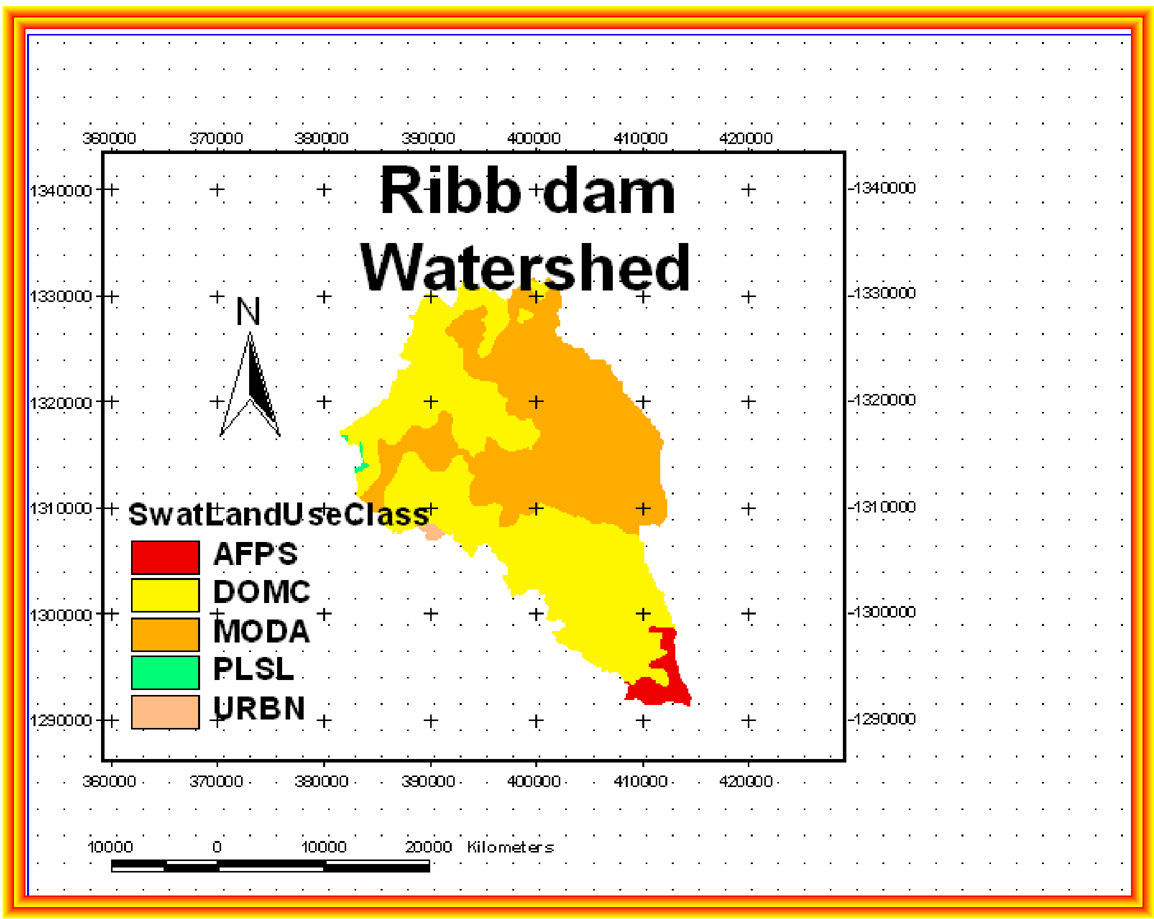

Figure20: Land use Classes of Ribb Dam Watershed

3.5.2 Vegetation Cover

It is well understood that Vegetation in a watershed plays multiple effects that include intercepting raindrops, reducing surface runoff, and there by control erosion, maintain soil fertility and maintain the microclimates. It also helps to enrich ground water sources. Nevertheless, in this watershed, the vegetation cover is very scant. There is no natural dense vegetation cover. Only patches of spare and open trees, bush/shrubs exist in hillsides, along rivers' courses and pocket areas. Economically and ecologically important indigenous trees are almost disappeared because of the use of tree resources for different socio-economic and socio-cultural needs at the rate of beyond its regenerative capacity. The main needs and uses of tree resources include firewood, construction, charcoal making and rapid population growth and accompanied expansion of cultivation in to marginal lands. Over livestock population and overgrazing systems also contributed for aggravating the loss of vegetations.

The sparse patches of bushes exist particularly in the northern reach hills and natural big trees around churches and on the southern mountain (mount Guna) range while man made plantations along main roads, towns and rural homesteads. The central part, all across east to west edges, is absolutely denuded of vegetation cover except only very sparse on farm trees here and there observed. There are, however, two state forest areas, one on the southern mountain (Guna) range of which some parts in the watershed and another on the northeast of the watershed. These will be a good seed source to be used during the watershed management plan implementation (MOWE).

4.Approach and Methodology

4.1 Data Collection

This part of the work includes both desk and field investigation for the gathering of important data in order to achieve paper objective. It comprises the methods employed to achieve the theme. The deskwork will carry out the essential literature review on modeling books, and previous work. It also include collection of topographic map, soil data, land use/land cover data, Digital model (DEM), Meteorological data, hydrological data and make ready computer code that help for modeling like SWAT, Arc GIS (View), Global Mapper 8, and so on.

The field investigation made the measuring width of river and water level, observation of hydro geological features, the confirmation of the secondary data collected at the deskwork and visit detail investigation for specific sites for confidential conceptual model. The data source was Ministry of water resource, Ethiopian Mapping agency, National Meteorological agency, and water works construction Enterprise.

4.1.1 Metrological Data

The metrological data required were: daily precipitation, daily maximum and daily minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. If any of these data was not available, which is very likely, SWAT can generate data using weather generator. For this monthly statistical values are needed from daily data values were needed to be generated from daily ones.

- Precipitation and temperature: the daily precipitation and temperature of all gauging stations (Bahirdar, Dangila, Addis zemen, and Debrebretabor) were prepared in text format.

- Solar radiation, relative humidity, and wind speed data were available only for principal stations (Bahirdar and Dangila).these datas for the rest of the stations were generated by SWAT.more over these datas were required when penman Montheith equation is used to evaluate potential evapotranspiration.

- Weather simulation data: these data consists of monthly average values of all the values required by the SWAT model in order to generate daily values.

All the above data were collected from Ethiopian National metrological agency for the period from (1985-2004 G.C).

4.1.2 Hydrological Data

The Ribb River flow data which was used to calibrate the SWAT model were collected from ministry of water and energy, hydrological department from 1985-2004 G.C.the time resolution of flow data was daily. Upper Ribb flow gauging station was used for this thesis.

4.2 Digital Elevation Model (DEM)

The digital elevation model (DEM) is any digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input of SWAT hydrological model. The Ribb River watershed was delineated and River networks were generated from DEM. The DEM obtained for this study was obtained from ministry of water and energy and it has a horizontal resolution of 90m.

Elevation of the study area ranges from 1900 amsl around the dam site to 4100 amsl at the ridges.See Annex B (Figure B48,B49).

4.3 Soil Map

The soil data were required for SWAT model to provide both the distribution of the soil type in the catchments and the various parameters describing the soils hydrological and textural properties .The soil parameters were obtained from Abbay River master plan project prepared by BCEOM .The shape file which describes the distribution of soil in the study area were obtained from the base line maps available at MOWE at a scale of 1: 250,000.It was observed that Chromicluvisols,Eutric Fluvosols, and Eutric leptosols are the most dominant soils in the catchment.See Table 5 and 6.

Table 5: Soil Distribution in Upper Ribb River Catchment.

Ser.No	Soil type	Area,(ha)	Percentage of watershed(%)
1	Chromicluvisols	38630.8	57.79
2	Eutric Fluvosols	62.86	0.09
3	Eutric leptosols	28043	41.95

4.4 Land use /land Cover Map

Spatial distribution and specific land use parameters were required for modeling. 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 interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Agricultural land use is the dominant land use in the Upper Ribb River catchment.

Table 6: Land use in Upper Ribb Catchment

Ser.No	Land use/land cover type	Area,ha	Percent of watershed area(%)
1	Dominantly cultivated	34867.3	52.16
2	Moderately cultivated	29664.3	44.38
3	Plantation	123.23	0.18
4	Afro-Alpine	1944.58	2.91
5	Urban	244.9	0.37

4.5 Data Screening

Engineering studies of water resources development and management depend heavily on hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, we need a simple but efficient screening procedure. A time series of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the choice of time origin. (By ‘unaffected’, we mean that estimates of these properties agree within the range of expected statistical variability.) The basic data-screening procedure presented here is based upon split-record tests for stability of the variance and mean of such a time series.

A time series of hydrological data may exhibit jumps and trends owing to what Yevjevich and Jeng **(**1969) call inconsistency and non-homogeneity. Inconsistency is a change in the amount of systematic error associated with the recording of data.

It can arise from the use of different instruments and methods of observation. Homogeneity is a change in the statistical properties of the time series. Its causes can be either natural or man-made. These include alterations to land use, relocation of the observation station and implementation of flow diversions. I used RAINBOW software for this thesis work.See AnnexB(figure B1-B23).

4.5.1 RAINBOW Homogeneity Test

Rainbow software has been used to check the homogeneity of data. Frequency analysis of rainfall data and flow data and their potential use in agrometeorolgical decision-making processes requires that the data be of long series; they should be homogeneous and independent. The restrictions of homogeneity assure that the observations are from the same population. In RAINBOW the test for homogeneity is based on the cumulative deviation from the mean. the following figures shows the homogeneity test of datas.

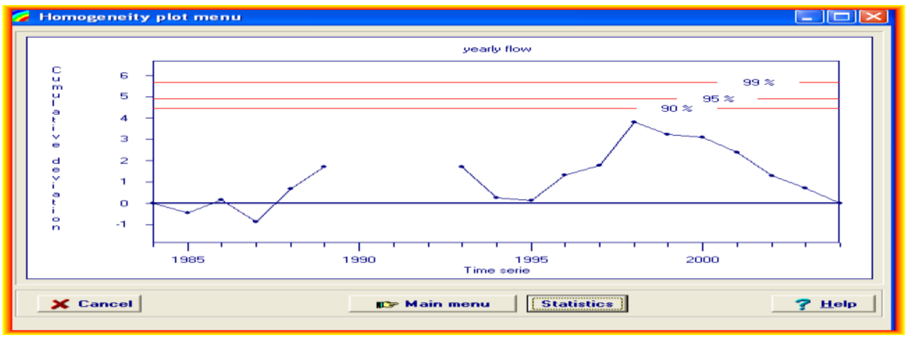

Figure 21: Commutative Deviation of Annual Flow at Upper Ribb Gauging Station

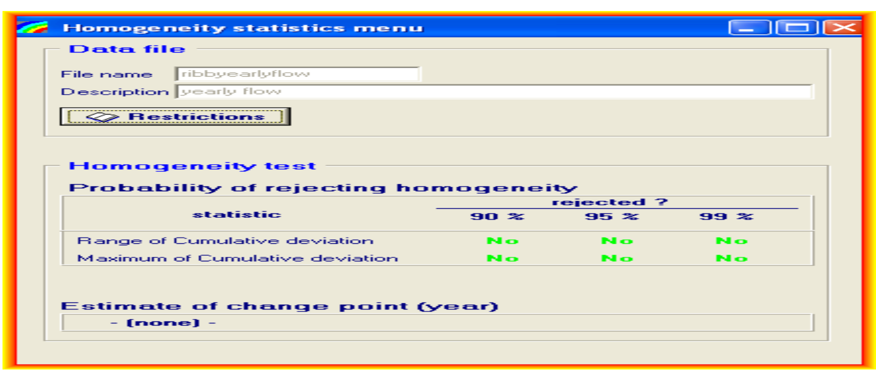

Figure 22: Probability of Rejecting Homogeneity of annual Flow at Upper Ribb Gauging Station

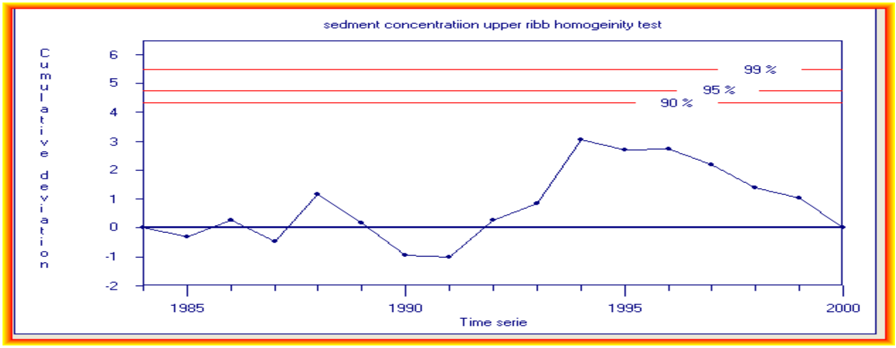

Figure 23: Commutative Deviation of Sediment Concentration at Upper Ribb Gauging Station

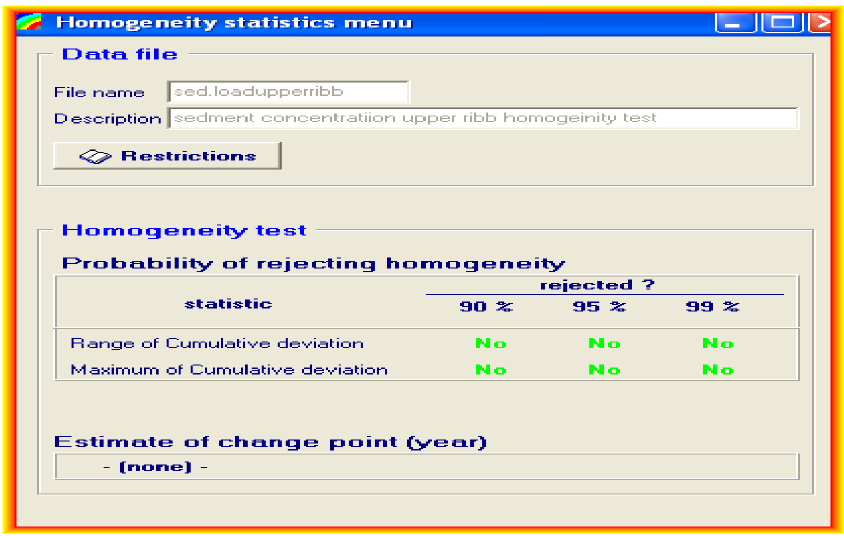

Figure 24: Probability of Rejecting Sediment Load at Upper Ribb Gauging Station

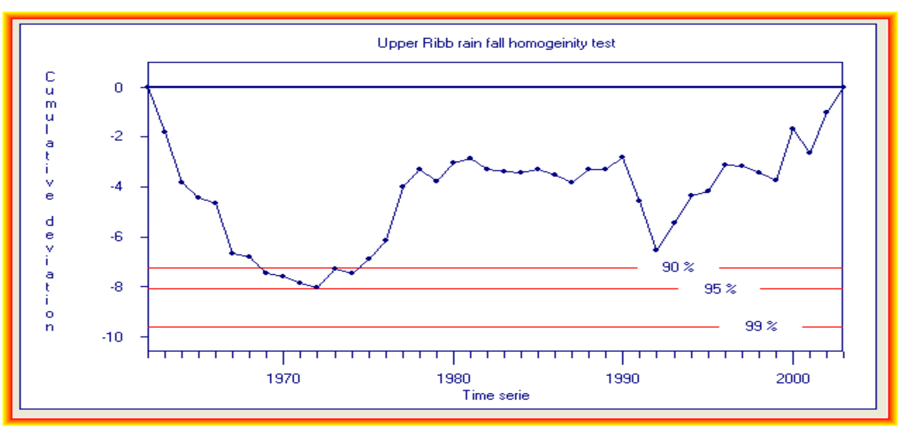

Figure 25: Commutative Deviation of Rainfall at Upper Ribb Gauging Station

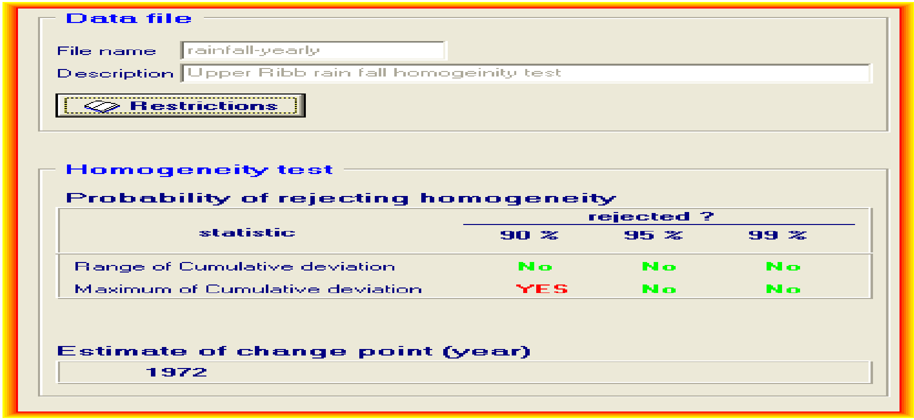

Figure26: Probability of Rejecting Rainfall at Upper Ribb Gauging Station

4.6 Modeling the Upper Ribb River Watershed

The aim of this thesis is to collect the needed data for a SWAT model of the Upper Ribb River Watershed and estimate the sediment yield to Ribb dam site. Once, the data is collected, the model was calibrated and validated for stream flow using measured flow values. The model was then calibrated and validated for sediments using available measured suspended sediment concentration values.

The calibrated and validated SWAT model for the Upper Ribb River Watershed can then be used to assess the impact of land use changes, management practices, and climate change impacts on the flows and sediment dynamics in the watershed. The simulated value is shown at annex A (TableA.9).

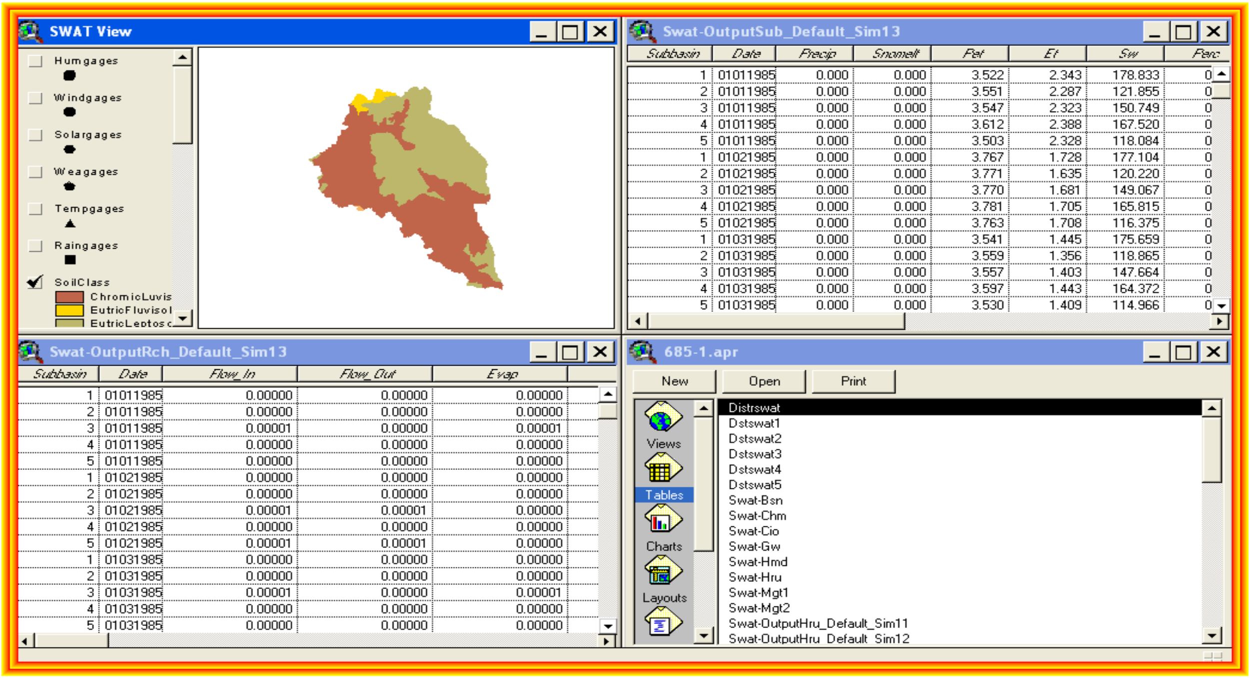

Figure 27: Ribb dam watershed modeling

4.6.1 SWAT Model Set up

4.6.1.1 Using AVSWATX

The Upper Ribb River watershed modeling is done by the SWAT model that is compiled using the AVSWATX interface (Di Luzio et al., 2002b). This allowed model parameters to be derived from readily available geographic data within the popular ArcGIS Geographic Information System (GIS) software.

4.6.1.2 Model Parameterization

a) Watershed and Channel Delineation

The DEM is used to derive the watershed boundary, channel network, and sub basin size and distribution. The Upper Ribb River watershed was delineated with an outlet point at the Ribb dam site. The overall watershed was further broken down into sub-basins based on the algorithms provided by the SWAT model. As a consequence these sub-basins influence the level of spatial complexity that is represented in the SWAT model. A sub-basin in SWAT is defined as the hydrologic area contributing to only one stream channel. Stream channels were defined as DEM cells having at least a 500 hectare contributing area. The contributing area resulted in 5 sub-basins being delineated.

b) Hydrologic Response Unit Analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land use and the soil data in a projected shape file format were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 10 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to consideration, 15%, and

20%% threshold levels for the land use, and soil were applied, respectively so as to encompass most of spatial details.See Annex A. table A.9.

4.6.2 SWAT Model Input

The spatially distributed data (GIS input) needed for the AVSWATX interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on weather and river discharge were also used for prediction of stream flow and calibration purposes.

Digital Elevation Model

Topography is defined by a DEM that describe the elevation of any point in a given area at a specific spatial resolution. A 90 m by 90 m resolution DEM was taken from the Ministry of Water and Energy (MoWE). The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.See Annex B.Figure B.52 (stream network).

Soil Data

SWAT model requires different soil textural and physico-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic car-bon content for different layers of each soil type. These data were obtained mainly from the following sources: MOWE(master plan Nile BASIN), Major Soils of the world CD-ROM FAO, (2002), Abbay River basin Integrated Development Master Plan Project - Semi detailed Soil Survey and the Soils of Anjeni Area, Ethiopia (SCRP 2000). Major soil types in the watershed are Chromic Luvisols, ,Eutric Fluvisols, Eutric Leptosols,and Eutric Vertisols.

Land Use

Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from ministry of water and energy. I have reclassified the land use map of the area based on the available topographic map (1:50,000), aerial photographs and satellite images. The reclassification of the land use map was done to represent the land use ac-cording to the specific land cover types such as type of crop, pasture and forest.

Weather Data

SWAT requires daily meteorological data that could either be read from a measured data set or be generated by a weather generator model. In this research, the weather variables used for driving the hydrological balance are daily precipitation, minimum and maximum air temperature for the period 1985 – 2004. These data were obtained from Ethiopian National Meteorological Agency (NMA) for stations located within and around the watershed to fill the gaps due to missing data.

River Discharge and Sediment yield

Daily river discharge values and sediment concentration for Ribb River were obtained from the Hydrology Department of the MoWE, Ethiopia. These daily river discharges and sediment concentrations at Upper Ribb River were used for model calibration and validation. The nearest site to the Ribb dam outlet is Upper Ribb gauging site.I used this site for calibration purpose.See annex A (Table A.11-A.14).

4.7 Sediment Yield

In this study the SWAT model which was calibrated and validated at Upper Ribb gauging station was used to estimate the sediment yield at Ribb dam outlet with their respective distribution among the sub basins. Based on this simulation, the annual sediment yield at the Ribb dam outlet is in the range of 35.80 to 106.97 tons per km^2 during the year 1985 to 2004 with annual average yield of 72.79 tons/km^2. See annex A (A.12-A.14).

4.7.1 Sediment Distribution

The spatial variability of sedimentation rate were identified and based on which the potential area of intervention can identified. The average annual yield of sedimentation for each sub-basin was used to generate sediment source map The output of model showed that Sub-basin 3 of Ribb dam catchment at the existing condition generates a maximum annual average sediment yield of 54.11 ton/km^2.. And the minimum yield of 0.706tons/km^2 was obtained for sub basin 2.

Hurni (1989) had conducted a research to estimate the rate of soil formation for Ethiopia and found that the range of tolerable soil loss level for various agro-ecological zone of Ethiopia from 2 to 18 tons/ha (200 to 1800 tons/km^2).The simulated sediment yield in this study area was found to be in the tolerable rate.

4.8 Sensitivity Analysis

Once the SWAT model for Upper Ribb river watershed was compiled using SWAT interface, a stream flow sensitivity analysis was performed on model parameters. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization (van Griensven et al.,2005), The sensitivity analysis was performed using SWAT interface for a period of 1985-2004.See annex A (Table A.10) for further information.

Table 7: SWAT Parameters Selected for Calibration based on Sensitivity Analysis

SWAT parameter	Description	Rank
GW_DELAY	Groundwater delay time	6
GW_REVAP	Groundwater ‘’revap’’	5
CH_K2	Effective hydraulic conductivity in main channel	1
surlag	Surface runoff lag coefficient	2
ch_n	Manning’s ‘’n’’ value for the main channel	4
rchrg_dp		3

Table 8: Sensitivity Ranking for Flow Calibration

	OF1	OUT1
SMFMX	28	28
SMFMN	28	28
ALPHA_BF	28	15
GWQMN	28	**8**
GW_REVAP	28	**5**
REVAPMN	28	16
ESCO	28	12
SLOPE	28	**9**
SLSUBBSN	28	18

TLAPS	28	28
CH_K2	28	**1**
CN2	28	17
SOL_AWC	28	28
surlag	28	**2**
SFTMP	28	28
SMTMP	28	28
TIMP	28	28
GW_DELAY	28	**6**
rchrg_dp	28	**3**
canmx	28	13
sol_k	28	**10**
sol_z	28	**7**
sol_alb	28	11
epco	28	19
ch_n	28	**4**
blai	28	28
BIOMIX	28	14

4.9 Model Calibration

The target of this thesis was to calibrate the model and predict the sediment flow to the outlet of the Ribb dam reservoir. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two. Manual calibration is the most widely used approach. However it is tedious, time consuming, and success of it depends on the experience of the modeler and knowledge of the watershed being modeled (Eckhardt & Arnold, 2001). Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is desirable as it is less subjective and due to extensive search of parameter possibilities can give results better than if done manually. SWAT has two built-in calibration tools. The manual calibration approach helps to compare the measured and simulated values, and then to use the expert judgment to determine which variable to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained. The autocalibration technique is used to obtain an optimal fit of process parameters which is based on a multi-objective calibration and incorporates the Shuffled Complex Evolution Method algorithms (Green and van Griensven, 2005). In this study manual calibration was employed to get the best model parameters.

Flow Calibration period (1985-1994)

Sediment calibration period (1985-1989

For further information see annex B (B.24-B.29).

4.10 Model Validation

Validation is a process of proving the performance of model. Validation is carried out for time periods different from calibration period, but without any further adjustment of calibrated parameters. Consequently, flow validation is performed from 1st, 1995 to December 31, 2004.
Based on the available model input data parameters the time periods of modeling are:

Flow Calibration period (1985-1994)

Flow Validation period (1995-2004)

Sediment calibration period (1985-1989)

Sediment validation period (1996-2003)

The first year of each period used (1985, 1995) and (1985, 1996) is used as a model warm up period and is not fused for model evaluation

5 Results and Analysis

5.1 Stream Flow Calibration

Upper Ribb watershed gauging station has been used for calibration purpose. Figure B.35 and B.36 shows the watershed and land use map of Upper Ribb catchment respectively.After sensitive model parameters were selected manual calibration was then performed by trial and error (changing the value of one parameter while keeping constant the others) during the periods of 1985-1994. (1985 was used as a “warm-up” year; values from that year were not evaluated).
The final set of parameters obtained from the calibration process were then entered into the Upper Ribb River catchment SWAT model and run for the period 1995-2004 and the results were evaluated (1995 was used as a “warm-up” year, values from that year were not evaluated). The results were evaluated by comparing the modeled results with the measured stream flow at the Upper Ribb River gauging station. Some stream flow events are still not completely represented by the calibrated modeled. This may be due to inaccurate representation of the spatial distribution of precipitation within the watershed by the available rain gages used as model input. Overall peak flows of calibrated modeled and observed values correspond more closely than the un-calibrated modeled stream flow values see annex B. Observed stream flow

values are represented on the x-axis and corresponding modeled values are represented on the y-axis. A best fit trend line was applied to each scatter plot, and the resulting line equation was used to quantify model performance.See annexB.

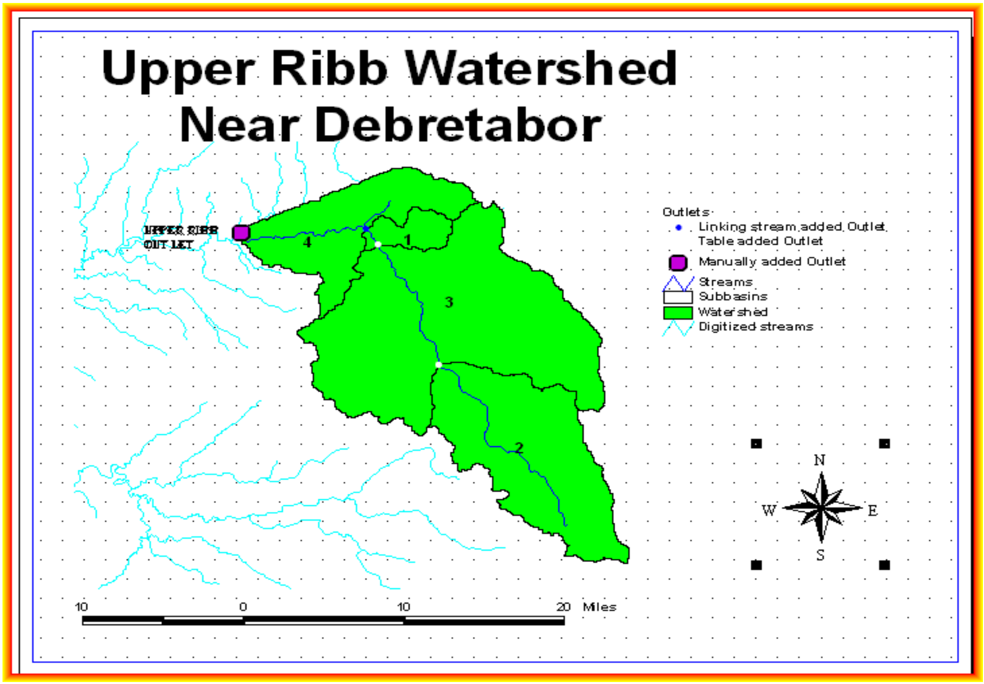

Figure 28: Upper Ribb Watershed where Calibration takes Place

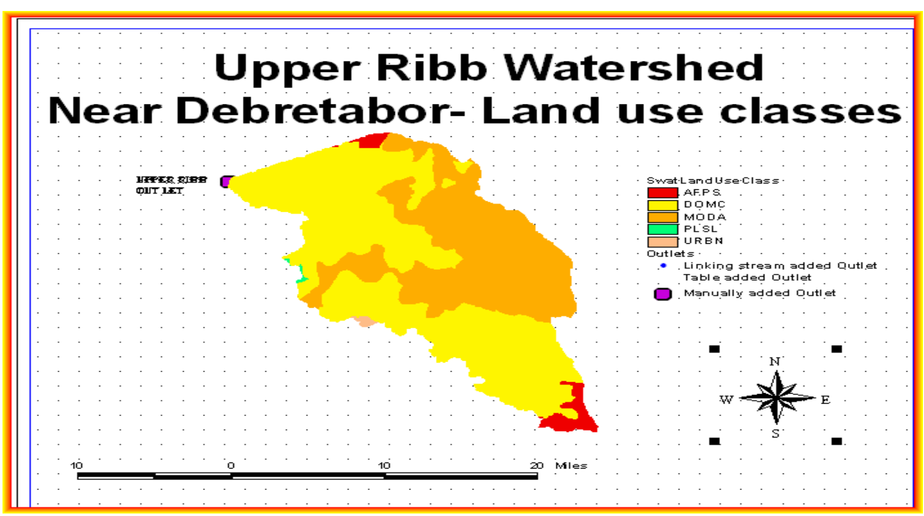

Figure 29: Upper Ribb Land use Classes

Further information see annex B (Figure B50-B53)

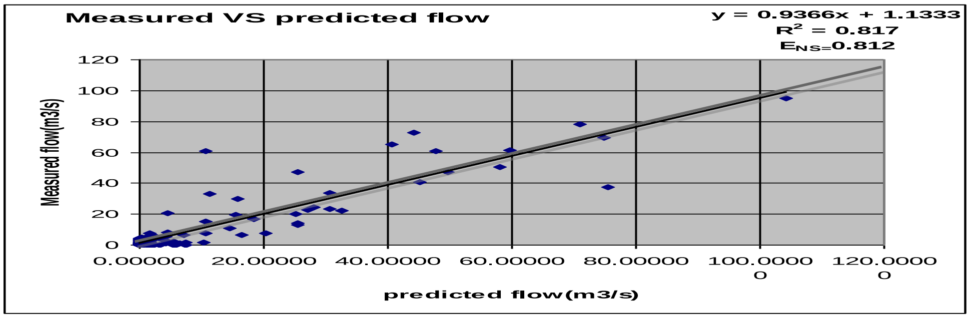

Figure 30: Monthly Measured VS Predicted Flow

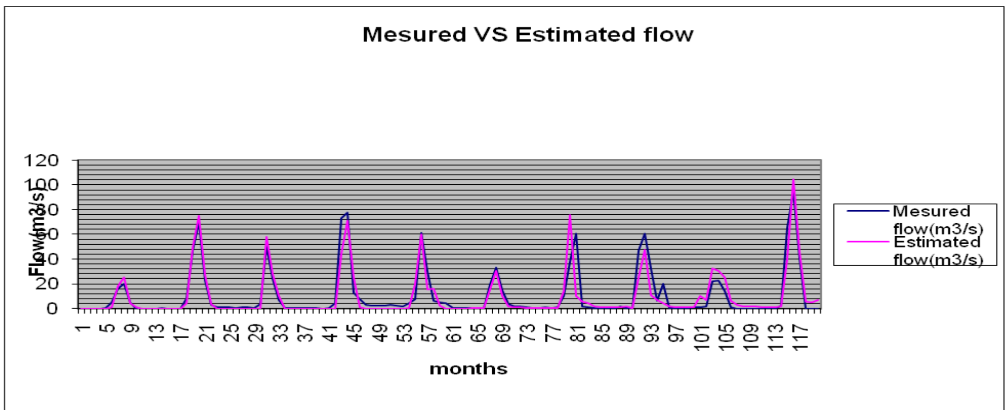

Figure 31: Monthly Measured VS Predicted Flow

5.2 Stream Flow Validation

Calibrated parameters were validated for the period of 1995-2004(1995 being the "warm-up" period). This period is selected based on the availability of sediment measurements within the Upper Ribb River watershed. It necessary to ensure that flow is adequately represented by the model before calibrating the model for suspended sediment concentration (Santhi et al., 2001).

The model is run for the period of 1995-2004 and modeled results are then compared with observed stream flow values measured at the Upper Ribb gauging station.

Flow data of Upper Ribb gauging station with a catchment area of 844km^2 has been selected (1985-2004)

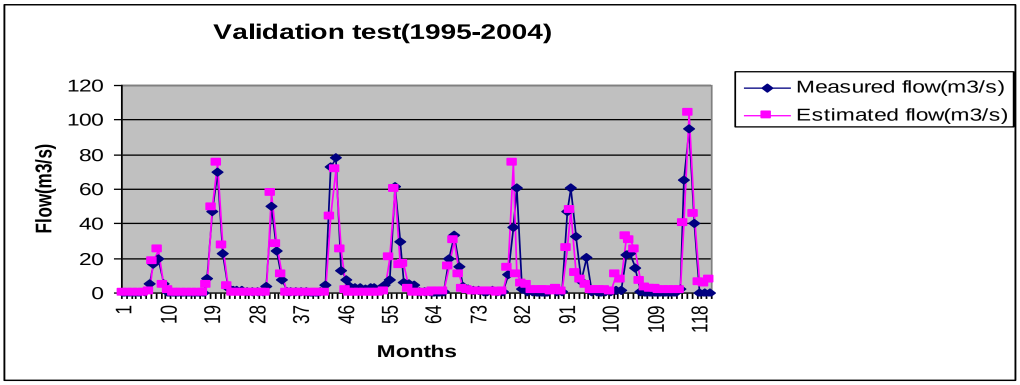

Figure 32: Monthly Validation Test of Flow

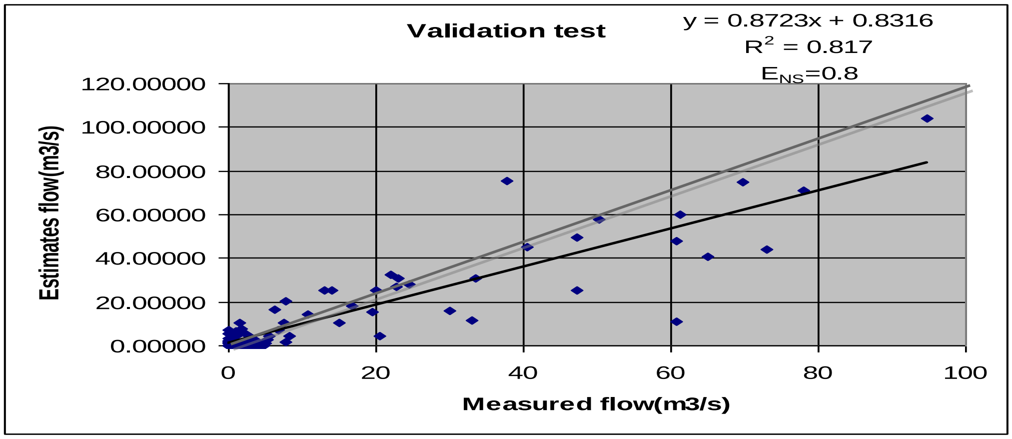

Figure 33: Monthly Validation Test of Flow

5.3 Sediment Flow Sensitivity Analysis

Once it is shown that the flow was accurately represented by the model the focus is shifted to the calibration of the model for sediments. This involves changing parameter values that control sediment generation within the model.

The sediment parameters used for calibration are selected based on previous SWAT modeling studies including Santhi et al.(2001), and Van Liew et al., (2007). The time period of calibration for sediments is based on the available measured sediment data at Upper Ribb gauging station.

5.3.1 Sediment Flow Calibration and validation

Once the sediment parameter values are established through use of the manual calibration within AVSWATX, the model is run again with the calibrated parameters. Only the daily statistics are examined due to the inadequate number of months or years within the period of measured data.

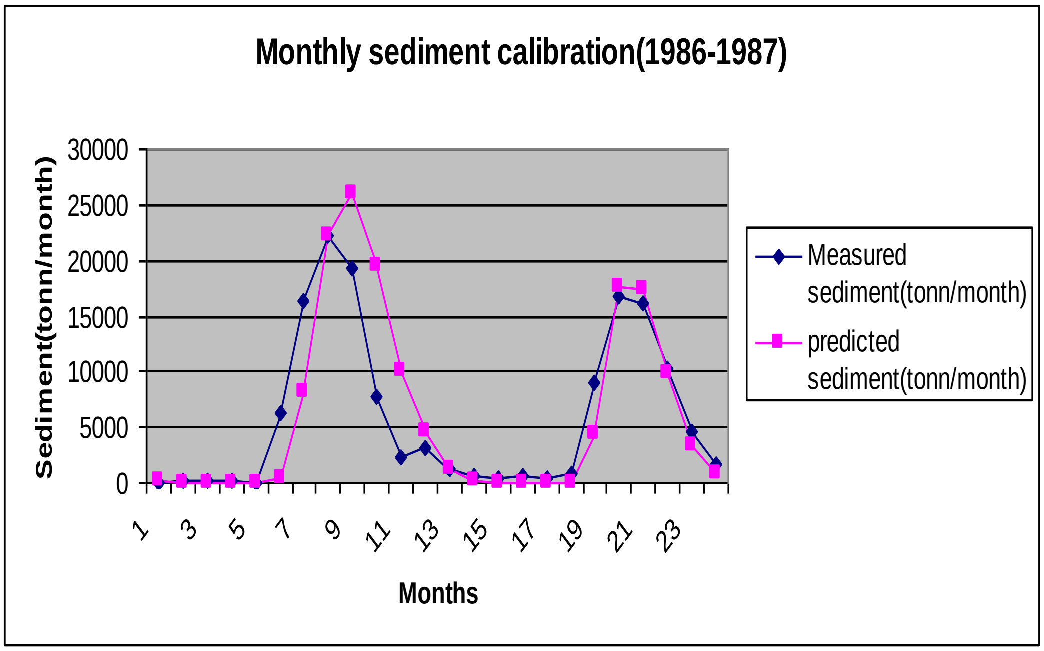

Figure 34: Monthly Sediment Calibration

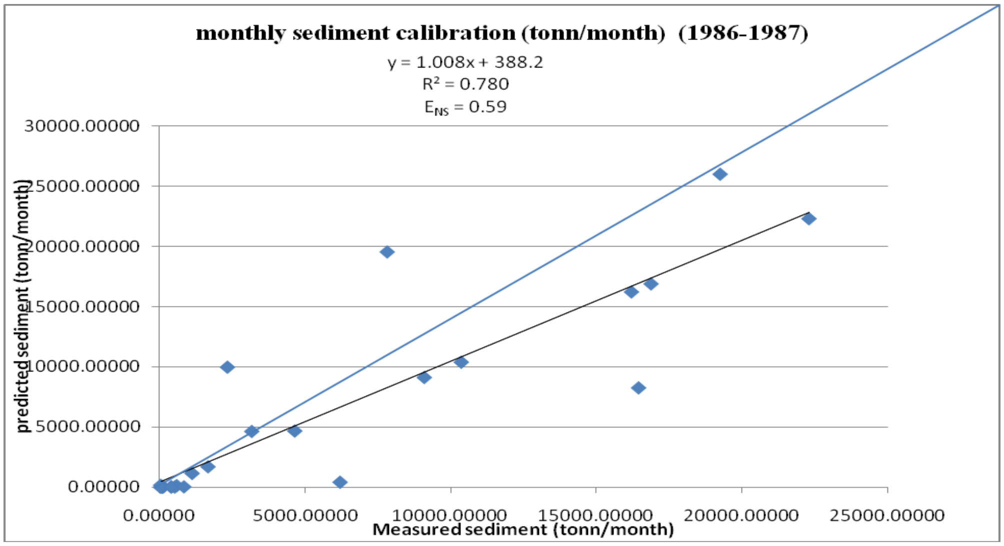

Figure 35: Monthly Sediment Calibration test

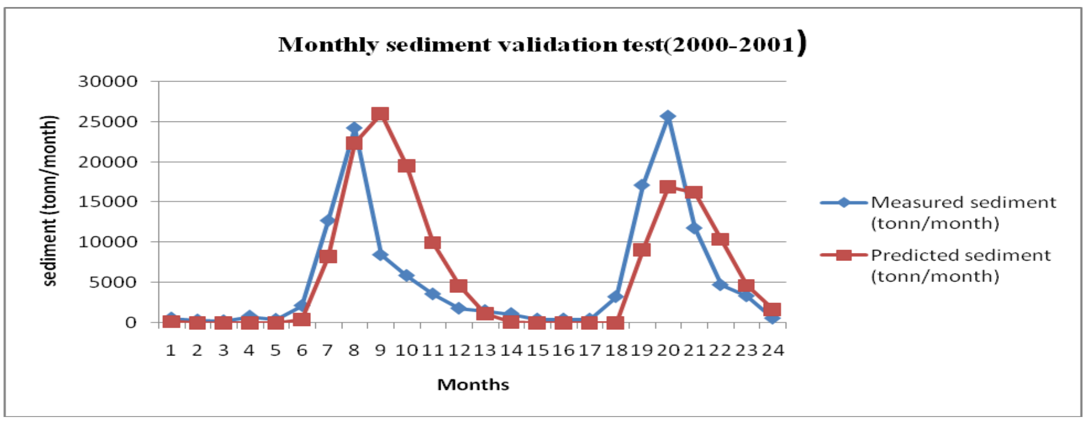

Figure 36: Monthly sediment Validation Test

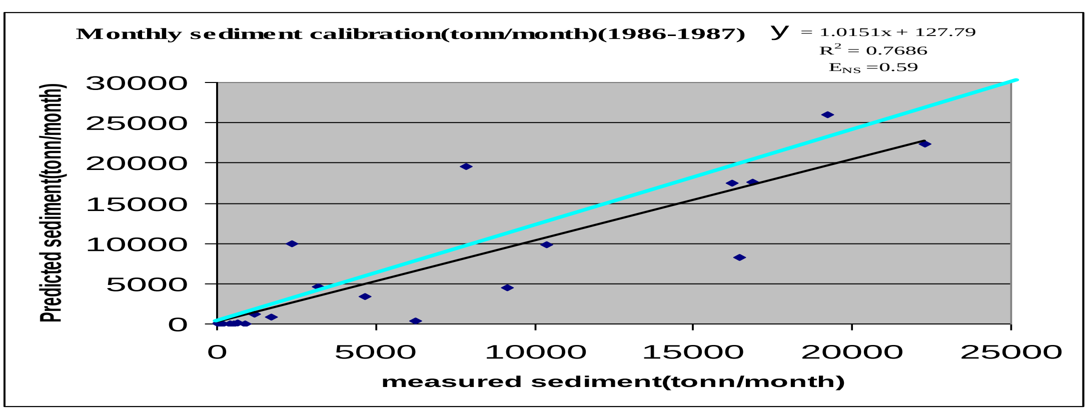

Figure 37: Monthly sediment Validation Test

Table 9: Calibrated sediment parameters

SWAT Parameter	Description	Original Value	Calibrated Value
Ch_Cov	Channel Erodibility Factor	0	0.2931
Ch_Erod	Channel Erodibility Factor	0	0.1
USLE_P	USLE equation support practice (P) factor	1	0.51

Table above shows the parameters altered for calibration of sediment parameters.

Parameters represent both channel erosion processes (Ch_Chov, Ch_Erod) and overland erosion processes (USLE_P). Modeled and observed time series for suspended sediment concentration are represented in Figure below (graph). The un-calibrated model severely under estimates suspended sediment concentration compared with the observed values. The calibrated model time series is much closer to the observed suspended sediment concentrations. The timing of sediment peaks is accurately represented by the model.The model results of flow and sediment concentration at the Ribb dam outlet and for each sub basins are show are in table A-10,A-11,A.12.A.13 andA.14 (1985-2004).Annual yield of sub basins is shown in table A.15.Figure B.46-B.50 shows the SWAT model output of sediment concentration for each basin.

Table 10: Sediment and flow yields at Ribb dam outlet (sub basin-5)

year	Predicted flow(m3/s)	Predicted sediment concentration(mg/l)
1985	10.03	45.13
1986	22.55	53.46
1987	14.65	56.03
1988	19.94	50.63
1989	20.13	62.31
1990	12.85	61.06
1991	17.3	57.45
1992	17.74	64.48

1993	21.26	68.37
1994	25.93	60.6
1995	18.12	57.26
1996	20.26	64.07
1997	26.02	63.51
1998	24.16	72.35
1999	23.76	55.92
2000	25.64	68.21
2001	18.7	59.09
2002	24.74	67.45
2003	13.6	58.38
2004	15.26	61.36
Aver	**19.63**	**60.36**

Table 11: Results for Sub Basin-1

Year	predicted flow (m3/s)	Predicted sediment concentration (mg/l)
1985	0.7642	0.09944
1986	1.767	0.1798
1987	1.135	56.6
1988	1.581	0.9888
1989	1.602	8.793
1990	0.9852	0.00032
1991	1.31	21.2
1992	1.398	0.00011
1993	1.694	0.00011
1994	2.059	14.22
1995	1.433	21.15
1996	1.61	6.43
1997	2.05	18.24
1998	1.911	0.00006
1999	1.863	0.00489
2000	2.011	0.00011
2001	1.449	29.24
2002	1.894	44.95
2003	1.005	0.00003
2004	1.169	0.00011
Aver	**1.534**	**11.11**

Table 12: Results for Sub Basin-2

Year	predicted flow (m3/s)	predicted sediment concentration (mg/l)
1985	0.5741	0.133
1986	1.326	0.00109
1987	0.867	1.676
1988	1.182	0.01821
1989	1.175	0.1661
1990	0.7549	0.00031
1991	1.056	0.3072
1992	1.07	0.00021
1993	1.248	0.00013
1994	1.545	0.2141
1995	1.067	0.00051
1996	1.215	0.1304
1997	1.587	0.3428
1998	1.462	0.0001
1999	1.462	0.00294
2000	1.584	0.00011
2001	1.191	0.866
2002	1.61	1.134
2003	0.9429	0.00041
2004	0.9884	0.00033
Aver	1.195	0.2497

Table13: Results for Sub Basin-3

Year	predicted flow (m3/s)	Predicted sediment concentration (mg/l)
1985	9.56	24.88
1986	21.56	29.47
1987	13.99	33.21
1988	19.07	31.47
1989	19.26	37.38
1990	12.24	35.32
1991	16.51	34.34
1992	16.97	35.81
1993	20.33	37.84
1994	24.82	34.41
1995	17.33	32.15
1996	19.39	36.02

1997	24.91	36.62
1998	23.12	39.91
1999	22.75	30.72
2000	24.55	37.56
2001	17.92	33.77
2002	23.71	41.82
2003	13.06	33.76
2004	14.62	35.04
Aver	18.78	34.57

Table 14: Results for Sub- Basin-4

Year	predicted flow (m3/s)	predicted sediment concentration (mg/l)
1985	0.7782	0.1573
1986	1.715	0.02027
1987	1.099	68.64
1988	1.494	0.00083
1989	1.536	10.66
1990	1.011	0.00035
1991	1.332	22.49
1992	1.341	0.00023
1993	1.635	0.00015
1994	1.981	15.24
1995	1.396	3.174
1996	1.566	5.808
1997	1.988	20.89
1998	1.846	0.0001
1999	1.8	0.00232
2000	1.94	0.00015
2001	1.413	38.84
2002	1.831	57.62
2003	0.9939	0.00007
2004	1.131	0.0005
Aver	1.491	12.18

Table 15: Annual Sediment Yield of Sub Basins

	Sediment load (Ton/year) of sub -basins				
Year	Sub bsain-1	Sub basin-2	Sub basin-3	Sub basin-4	Sub basin-5
1985	0.00045	0.00052	13240	0.00076	25000
1986	34.22	0.0007	30320	3.554	56950
1987	7515	120	22750	8225	38850
1988	72.44	1.218	27000	0.00092	50220
1989	1346	15.93	29140	1488	52140
1990	0.00071	0.00071	16890	0.00106	31780
1991	2200	23.05	26690	2350	46410
1992	0.0006	0.0007	23570	0.00102	44390
1993	0.0007	0.0007	28390	0.00104	53500
1994	2250	24.84	37740	2314	67830
1995	155.4	0.0007	24330	31.47	45640
1996	275.4	4.498	27790	261.4	51600
1997	2523	31.61	39240	2725	69290
1998	0.00067	0.0007	32370	0.00104	60990
1999	0.3355	0.1763	31810	0.1277	59860
2000	0.0007	0.0007	34340	0.00105	64670
2001	7440	101.2	29190	8446	50460
2002	19190	264.3	47260	22140	74670
2003	0.00031	0.00071	17920	0.00059	33800
2004	0.00046	0.0007	20190	0.00103	38160
Aver	2150	29.34	28010	2399	50810

For further information see annexA (Table A12), Annex B (Figure B30-B41).

5.4 Comparison with Previous Studies and Estimates from Other *Reservoir*

The mean annual sediment load estimates by USBR (1964) and BCEOM (1999) for the Ribb dam site were 260,000 ton (363 ton/km^2/year) and 490,000 ton (675 ton/km^2/year) respectively. Design report of MOWE estimate 897 ton/km^2/year based on the 1964 -2005 data it is higher than the above mentioned estimates for the dam site.

Bathymetric survey conducted on Legedadi and Gefersa reservoirs in 1979 and 1989 showed mean annual sediment deposition of 760 ton/km^2/year and 1,200 ton/km^2/year, respectively. The

Hydrology Department of the MoWR conducted bathymetric survey on Angerb reservoir (a tributary of Megech River with watershed area 48 km^2) and found that a mean annual sediment deposition of 0.14 Mm^3 estimated over ten years (1995-2004), taking the density of sediment as 1.2 gm/cc the sediment yield is 3500 ton/km^2/year, which is very high. Studio Pietrangeli (2005) gave a comparison of total sediment load estimate for five hydropower reservoirs (Table A.16). Mott MacDonald (2004) estimated 57 665 ton/year (350 tons/km^2/year) sediment deposition in Koga reservoir.

BCEOM (1999) gave suspended sediment rating equation for upper Ribb River near Debre Tabor gauging site (844 km^2):

$Q_s = 19.50\ Q^{1.044}$ with $R^2 = 0.971$

Where: Q_s = Suspended sediment mass transport rate (ton/day)

Q = discharge (m^3/s)

Based on the above rating equation the monthly suspended sediment loads were estimated at the Upper Ribb gauging site for the period of 1960-2002. The mean annual suspended sediment transport (1960-2004) was estimated as 68,992 ton which corresponds to mean sediment specific rate :

G = 82 ton/km^2/year.

In this study SWAT model estimate of Ribb Dam reservoir sediment load of 72.79 ton/km^2/year is very much less than the previous studies at dam site but very close to study of BCEOM (1999) for Upper Ribb River near Debre Tabor which is down stream of dam site. For further information see annex A (table A11-Table A 14).

Table A.16 Sediment Yield Estimate for some Reservoirs in Ethiopia

Hydropowerreservoirs	Tons/km^2/year
Gefersa	1200
Koga	350
Gibe 1	1,300
Gojeb	218
Halele Weabesa	1,200
Chemoga Yeda	1,600
Tekeze	1,283

6 Conclusion *and Recommendations*

6.1 Conclusion

SWAT model for upper Ribb watershed was compiled and calibrated and then validated for stream flow and suspended sediment concentrations .Readily available spatial data is collected and combined using GIS. Model parameters were derived, spatial data including elevation (DEM) obtained from MOWR. The watershed parameters were derived from DEM resulting in 5-subbasins. Sub basins were further broken down in to hydrological response units based on the land use and soil data. This resulted in 13 HRU's .

Sensitivity analysis is performed to select important model parameters; manual calibration is performed for stream flow using measured data at Upper Ribb gauging station for a period of 1985-1994. It is shown that the model could adequately represent stream flow for monthly time steps.It is shown that the model performed well with E_{NS} and R^2 0.812, 0.817 respectively. The model is validated for the stream flow for the period of 1995-2004. The model performed well monthly time steps with E_{NS} and R^2.0.8 and 0.817 respectively.

The model is then calibrated with sediment flow data that is taken from rating curve equation measured during (1986-1987). Model parameters were selected that control sediment generation processes for calibration. It is shown that suspended sediment concentration at Upper Ribb river watershed could be represented by SWAT model with E_{NS} and R^2 0.59 and 0.78 respectively. The model is validated for a period of (2000-2001).The model could adequately represent suspended sediment concentrations at Upper Ribb river watershed E_{NS} and R^2 0.52 and 0.57 respectively.

The calibrated and validated SWAT model for Upper Ribb watershed can then be used to assess the impact of land use changes, management practices, and climate change impacts on flow and sediment dynamics in the watershed.

Model calibration reduces the parameter uncertainty, which in turn reduces the uncertainty in the simulated results.

SWAT Model performed well in predicting the sediment yield to the Ribb dam reservoir. Apart from intensive effort in preparing the data for the model, the model is very friendly to work with and hence it should be incorporated in the prediction of sedimentation for other cases.

6.2 Recommendations

The reliability of data is of primary importance for carrying out any modeling studies. Therefore, the statistical reliability and dependency of this data needs to be checked prior to its application. The performance of this model should also be evaluated at other upstream measurement stations in future studies to predict/assess surface water resources and sediment yield. With regards to integrated project studies, it is recommended that an uncertainty analysis of model results should be carried out for further use in scenario analysis and generating an assessment of the overall water resources of the Ribb River basin ($844km^2$). The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flows and soil erosion. The result of the study could help different stakeholders to plan and implement appropriate soil and water conservation strategies. The model developed could be used in prediction mode to take appropriate measures in advance.

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8 ANNEXES

Annex A: Tables

Table A.1: Runoff Curve Numbers for Cultivated Agricultural Lands

Cover					
Treatment or practice	Hydrologic condition	Hydrologic Soil Group			
		A	B	C	D
Bare soil	------	77	86	91	94
Crop residue cover*	Poor	76	85	90	93
	Good	74	82	88	90
Straight row	Poor	72	81	88	91
	Good	67	78	85	89
Straight row w/residue	Poor	71	80	87	90
	Good	64	75	82	85
Contoured	Poor	70	79	84	88
	Good	65	75	82	86
Contoured w/residue	Poor	69	78	83	87
	Good	64	74	81	85
Contoured & terraced	Poor	66	74	80	82
	Good	62	71	78	81
Contoured & terraced w/residue	Poor	65	73	79	81
	Good	61	70	77	80
Straight row	Poor	65	76	84	88
	Good	63	75	83	87
Straight row w/residue	Poor	64	75	83	86

TableA.2: Count: Runoff Curve Numbers for Cultivated Agricultural Lands

Cover					
Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
	Good	60	72	80	84
Contoured	Poor	63	74	82	85
	Good	61	73	81	84
Contoured w/residue	Poor	622	73	81	84
	Good	60	72	80	83
Contoured & terraced	Poor	61	72	79	82

	Good	59	70	78	81
Contoured & terraced w/residue	Poor	60	71	78	81
	Good	58	69	77	80
Straight row	Poor	66	77	85	89
	Good	58	72	81	85
Contoured	Poor	64	75	83	85
	Good	55	69	78	83
Contoured & terraced	Poor	63	73	80	83
	Good	51	67	76	80

TableA.3: Runoff Curve Numbers for other Agricultural Lands

(From SCS Engineering Division, 1986)

Cover					
Cover Type	Hydrologic condition	Hydrologic Soil Group			
		A	B	C	D
Pasture, grassland, or range-conditions forage for grazing'[1]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	--------	30	58	71	78
Brush-brush-weed-grass mixture with brush the major element2[2]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods-grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82

Table A.4 **:**Ribb Flow Data Near Addis Zemen Mm^3

year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1960	1.93	0.97	0.86	0.86	1.8	0.54	53	185.5	101	14.1	4.94	2.1	**367.65**
1961	1.18	2.98	1.51	2.18	0.37	1.62	139	341.9	131	14	8.45	5.7	**649.81**
1962	2.33	1.42	1.01	0.58	1.52	2.82	125	375	153	41.1	7.93	4.2	**716.27**
1963	2.46	0.65	0.75	1.04	3.32	1.53	100	219.4	65	14	6.64	4.1	**418.57**
1964	2.72	1.47	0.59	0.73	1.09	5.25	160	323.3	136	40.2	15.6	7.5	**694.86**
1965	3.51	1.88	1.1	2.14	0.34	1.18	27	11.62	30	30.8	9.14	5.9	**124.4**

1966	2.26	1.76	2.15	1.23	0.05	4.36	158	199.9	87	13.3	6.62	3.2	**478.95**
1967	1.8	1.22	2.19	1.44	3.67	5.41	203	278.6	111	42.3	15.9	8.2	**674.73**
1968	3.64	2.26	1.72	1.54	2.15	9.79	170	219.1	58	23.2	9.67	4.7	**506.38**
1969	1.67	1.31	2.72	1.5	1.54	1.15	87	241.6	57	8.5	3.73	1.7	**409.32**
1970	1.25	0.67	0.56	0.18	0.3	7.98	50	199.3	105	25.5	4.56	2.4	**397.92**
1971	1.68	1.33	0.69	0.32	1.92	9.15	50	146.9	83	15.4	6.6	3.2	**319.83**
1972	2.03	1.07	0.47	0.66	0.68	4.74	67	125.6	48	10	7.55	5.2	**272.25**
1973	1.97	0.89	0.71	0.46	1.67	5.54	85	280.3	142	42.3	5.11	2.4	**568.88**
1974	1.18	0.68	0.38	0.29	1.45	12.71	156	236.7	92	9.28	2.55	1.3	**514.79**
1975	1.15	0.91	0.54	0.65	0.13	50.41	72	256.6	210	22.3	5.81	4.2	**624.11**
1976	2.22	2.24	0.68	0.47	1.91	8.23	103	206.1	91	13.4	14.5	4.5	**448.35**
1977	2.57	1.2	1.7	1.51	4.06	24.75	163	228	74	34.6	42	7.3	**583.87**
1978	5.67	3.9	3.58	3.41	4.11	7.44	119	226.7	75	19.4	8.76	5.1	**482.99**
1979	2.3	0.71	0.37	0.13	2.52	2.15	44	155	79	12.9	4.7	2.5	**306.15**
1980	1.28	0.82	0.54	1.96	0.43	3.27	101	171	59	15.4	3.4	2	**359.57**
1981	2.21	1.51	1.12	0.96	1.62	5.88	94	198	83	16	7.18	4.7	**415.62**
1982	0.92	0.55	1.37	2.19	2.14	1.16	26	123.3	39	18.8	5.1	2.4	**223.19**
1983	0.85	0.42	0.13	0.03	0.55	4.56	52	151.9	40	9.46	6.75	3.7	**270.16**
1984	0.75	0.9	2.94	0.1	1.27	18.7	59	86.44	47	5	1.4	0.9	**224.24**
1985	0.23	0.18	0.02	0.77	5.13	5.4	76	84.3	74	7.39	2.39	1.6	**257.28**
1986	0.62	0.27	0.07	0.11	0.01	22.58	146	221.4	131	20.7	4.06	2.5	**549.89**
1987	1.16	0.59	0.67	0.43	6.21	8.59	19	93.62	33	4.76	1.95	0.9	**170.31**
1988	0.42	0.31	0.11	1.5	0.53	7.4	138	213	123	41.6	7.72	3	**536.78**
1989	2.64	1.38	1.33	1.31	1.71	12.39	66	182.3	57	18.5	6.92	4.8	**357.15**
1990	3.08	1.86	1.36	1.22	1.05	2.7	92	151.2	119	21	7.82	6.7	**408.94**
1991	4.9	1.77	1.36	3.37	0.78	6.17	133	293.7	184	16.7	5.26	3.1	**654.53**
1992	1.16	0.34	0.21	5.26	3.72	4.03	132	330.2	110	27.8	54.7	2.7	**671.16**
1993	3.22	1.32	1.05	4.19	11.2	12.47	110	145.6	117	28	6.07	1.7	**442.28**
1994	0.93	0.21	0.16	0.37	2.05	18.72	186	255.3	130	5.33	1.84	1.2	**602.62**
1995	0.83	0.59	0.63	1.71	1.52	1.52	104	191.9	76	4.94	2.69	2.2	**389.14**
1996	1.48	1.06	1.62	3.82	21.2	73.32	178	226.6	83	30.3	13.7	7.8	**641.54**
1997	5.03	2.96	4.23	3.34	19.5	30.42	170	200.9	50	35.1	31.5	8.9	**561.64**
1998	4.82	2.56	2.49	1.92	6.74	16.16	185	253.4	159	49.6	17.5	5.9	**705.43**
1999	2.16	1.19	0.97	0.77	1.04	8.85	121	189.7	103	110	33.6	35	**607.73**
2000	13.5	1.17	0.81	2.56	1.83	5.21	110	207.3	91	43.4	13.5	4	**493.88**
2001	2.15	1.16	1.32	1.11	1.42	39.69	154	196.1	69	13.5	4.78	2.4	**486.98**
2002	1.45	0.69	0.77	1.17	0.35	19.68	61	124.9	62	8.34	3.22	3.3	**287.4**
2003	1.89	1.23	1.51	0.34	0.17	10.3	119	176.7	115	22.5	10.6	8.3	**466.95**
2004	6.02	4.56	3.68	6.3	4.28	12.52	104	149.1	58	20.4	9.33	6.2	**383.86**

Mean	**2.4**	**1.3**	**1.2**	**1.5**	**2.9**	**11.5**	**108**	**201.7**	**92**	**23.1**	**10.1**	**4.7**	**460.6**
Max	**13.5**	**4.6**	**4.2**	**6.3**	**21.2**	**73.3**	**203**	**375**	**210**	**110**	**54.7**	**35**	**716.3**
Min	**0.2**	**0.2**	**0**	**0**	**0**	**0.5**	**19**	**11.6**	**30**	**4.8**	**1.4**	**0.8**	**124.4**

Table A.5: Upper Ribb Flow Data Mm^3

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
1960	1.87	1.09	1.15	1.47	1.98	0.555	32	102.8	45	8.22	3.23	1.6	201.49
1961	1.15	3.37	2.03	3.73	0.41	1.652	84	189.4	59	8.17	5.53	4.4	363.08
1962	2.26	1.61	1.36	0.99	1.68	2.876	76	207.7	69	24	5.19	3.2	395.81
1963	2.39	0.74	1.01	1.78	3.67	1.56	61	121.5	29	8.18	4.34	3.1	238.17
1964	2.64	1.66	0.79	1.25	1.21	5.355	98	179.1	61	23.4	10.2	5.8	390.05
1965	3.41	2.13	1.48	3.67	0.38	1.204	16	6.435	13	18	5.98	4.5	76.98
1966	2.2	1.99	2.89	2.11	0.06	4.442	96	110.7	39	7.73	4.33	2.5	273.74
1967	1.75	1.38	2.94	2.47	4.06	5.518	124	154.3	50	24.7	10.4	6.3	387.25
1968	3.54	2.56	2.31	2.64	2.38	9.986	104	121.3	26	13.5	6.32	3.6	298.14
1969	1.62	1.48	3.65	2.57	1.7	1.173	53	133.8	25	4.96	2.44	1.3	233.26
1970	1.21	0.76	0.75	0.31	0.33	8.143	30	110.4	47	14.8	2.98	1.9	219.17
1971	1.63	1.5	0.93	0.55	2.12	9.333	30	81.38	37	8.97	4.32	2.4	180.66
1972	1.97	1.21	0.63	1.13	0.75	4.835	41	69.55	21	5.83	4.94	4	156.8
1973	1.91	1	0.95	0.79	1.84	5.648	52	155.2	64	24.7	3.34	1.8	312.96
1974	1.14	0.76	0.51	0.49	1.6	12.96	95	131.1	41	5.41	1.67	1	293.08
1975	1.12	1.03	0.72	1.11	0.15	51.42	44	142.1	94	13	3.8	3.3	355.39
1976	2.16	2.53	0.91	0.8	2.11	8.396	63	114.2	41	7.81	9.48	3.5	255.48
1977	2.5	1.36	2.28	2.58	4.49	25.25	99	126.3	33	20.2	27.4	5.6	350.06
1978	5.51	4.41	4.8	5.84	4.54	7.589	73	125.6	34	11.3	5.73	3.9	285.83
1979	2.23	0.8	0.5	0.22	2.79	2.192	27	85.84	35	7.54	3.07	2	169.31
1980	1.24	0.93	0.73	3.36	0.48	3.335	61	94.68	26	8.98	2.22	1.6	205.24
1981	2.15	1.71	1.5	1.64	1.79	6.002	57	109.6	37	9.36	4.7	3.6	236.31
1982	0.89	0.62	1.84	3.75	2.37	1.183	16	68.3	18	10.9	3.34	1.8	12 8.48
1983	0.66	0.36	0.18	0.11	0.4	2.5	16	89.99	20	10.8	4.85	2.8	148.3
1984	0.32	0.99	1.06	11.7	13.9	17.46	2.6	66.87	6.9	1.89	1.32	1.6	126.71
1985	0.54	0.39	0.36	0.97	3.3	13.79	50	54.73	34	7.86	3	1.2	169.46
1986	0.6	1.14	0.79	0.93	0.7	22.22	79	142.3	63	19.2	6.68	5.9	341.58
1987	4.72	2.54	3.03	3.2	2.88	10.8	14	11.83	12	12.4	3.69	3	83.44
1988	1.91	1.96	1.1	0.51	3.14	12.35	200	198.6	59	32	11.9	9.1	531.79
1989	8.26	6.52	8.58	7.57	6.35	12.37	25	164.9	103	28	4.53	3.7	379.62
1990	2.99	2.1	1.83	2.09	1.16	2.758	56	83.73	53	12.2	5.11	5.1	228.53
1991	4.76	2	1.83	5.77	0.86	6.292	81	162.6	83	9.73	3.44	2.4	363.44
1992	1.13	0.38	0.28	9.01	4.12	4.111	80	182.8	49	16.2	35.8	2	385.19

1993	1.75	1.01	1.28	3.2	12.4	5.509	64	63.15	57	16.3	2.09	1.3	229.34
1994	0.51	0.27	0.22	0.29	0.65	19.09	114	141.4	58	3.11	0.77	0.4	338.64
1995	0.21	0.11	1.26	3.13	1.68	2.592	68	106.3	81	5.42	1.76	1.7	272.97
1996	0.92	0.52	1.64	4.13	8.84	37.01	150	197.2	55	8.83	5.29	3.7	472.91
1997	2.28	1.35	1.91	2.87	5.41	15.03	126	127.6	21	8.63	24.9	5.5	343.42
1998	4.69	0.27	0.21	0.12	1.52	5.084	137	140.3	65	10.3	1.05	0.4	365.78
1999	1.75	0.74	0.52	0.37	0.53	4.018	46	59.65	17	17.7	7.91	4.3	161.16
2000	2.78	1.75	1.35	3.71	2.12	8.703	49	92.06	34	23.9	14.9	7.8	241.97
2001	6.65	5.03	2.24	2.22	2.23	13.46	94	108.6	46	19.4	13.9	2.7	316.54
2002	2.28	1.5	2.15	1.71	1.22	14.22	37	69.19	28	2.13	1.18	1.1	161.87
2003	0.54	0.35	0.59	0.12	0.12	2.659	37	53.02	38	9.23	4.01	2.5	147.97
2004	1.67	1.41	1.15	2.39	1.37	12.77	35	43.43	24	11.8	4.58	3.2	142.3
Mean	**2.2**	**1.5**	**1.6**	**2.5**	**2.6**	**9.5**	**67**	**113.4**	**43**	**12.8**	**6.6**	**3.2**	**265.8**
Max	**8.3**	**6.5**	**8.6**	**11.7**	**13.9**	**51.4**	**200**	**207.7**	**103**	**32**	**35.8**	**9.1**	**531.8**
Min	**0.2**	**0.1**	**0.2**	**0.1**	**0.1**	**0.6**	**2.6**	**6.4**	**6.9**	**1.9**	**0.8**	**0.4**	**77**

Table A.6**: Monthly** Inflow Series at Ribb Dam Site having Watershed Area of 715Km^2 (Mm^3)

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
1960	1.59	0.93	0.97	1.24	1.68	0.47	27	87.05	38	6.97	2.74	1.4	170.7
1961	0.97	2.85	1.72	3.16	0.35	1.4	72	160.4	50	6.92	4.68	3.7	307.58
1962	1.92	1.36	1.15	0.84	1.42	2.437	65	175.9	58	20.3	4.39	2.7	335.31
1963	2.02	0.63	0.85	1.51	3.11	1.321	51	102.9	25	6.93	3.68	2.7	201.77
1964	2.24	1.41	0.67	1.06	1.02	4.537	83	151.7	52	19.9	8.63	4.9	330.44
1965	2.89	1.8	1.25	3.11	0.32	1.02	14	5.452	11	15.2	5.06	3.8	65.21
1966	1.86	1.69	2.44	1.79	0.05	3.763	81	93.77	33	6.55	3.67	2.1	231.9
1967	1.48	1.17	2.49	2.09	3.44	4.675	105	130.7	42	20.9	8.8	5.3	328.06
1968	3	2.17	1.96	2.24	2.01	8.46	88	102.8	22	11.5	5.36	3	252.57
1969	1.37	1.26	3.09	2.18	1.44	0.994	45	113.3	22	4.2	2.07	1.1	197.61
1970	1.03	0.64	0.64	0.26	0.28	6.898	26	93.49	40	12.6	2.53	1.6	185.67
1971	1.38	1.27	0.78	0.46	1.8	7.907	26	68.94	31	7.6	3.66	2.1	153.04
1972	1.67	1.03	0.53	0.96	0.64	4.096	34	58.92	18	4.94	4.18	3.4	132.83
1973	1.62	0.85	0.81	0.67	1.56	4.785	44	131.5	54	20.9	2.83	1.6	265.13
1974	0.97	0.65	0.43	0.42	1.36	10.98	81	111	35	4.59	1.41	0.8	248.28
1975	0.95	0.87	0.61	0.94	0.12	43.56	37	120.4	80	11	3.22	2.8	301.07
1976	1.83	2.14	0.77	0.68	1.79	7.112	53	96.71	34	6.62	8.03	2.9	216.43
1977	2.11	1.15	1.93	2.18	3.8	21.39	84	107	28	17.1	23.2	4.7	296.56
1978	4.67	3.74	4.07	4.95	3.85	6.429	62	106.4	29	9.61	4.85	3.3	242.14
1979	1.89	0.68	0.42	0.18	2.36	1.857	23	72.72	30	6.39	2.6	1.7	143.43
1980	1.05	0.79	0.61	2.84	0.41	2.826	52	80.21	22	7.61	1.88	1.3	173.87

1981	1.82	1.45	1.27	1.39	1.52	5.084	48	92.88	31	7.93	3.98	3.1	200.19
1982	0.76	0.52	1.56	3.18	2	1.002	13	57.86	15	9.27	2.83	1.5	108.84
1983	0.56	0.3	0.15	0.09	0.34	2.118	13	76.24	17	9.12	4.11	2.3	125.63
1984	0.27	0.84	0.9	9.95	11.8	14.79	2.2	56.65	5.8	1.6	1.12	1.4	107.34
1985	0.46	0.33	0.3	0.82	2.8	11.68	42	46.37	29	6.66	2.54	1	143.56
1986	0.51	0.97	0.67	0.79	0.6	18.82	67	120.6	53	16.3	5.66	5	289.37
1987	4	2.15	2.57	2.71	2.44	9.149	12	10.02	10	10.5	3.13	2.5	70.69
1988	1.62	1.66	0.93	0.43	2.66	10.46	170	168.2	50	27.1	10.1	7.7	450.51
1989	7	5.52	7.27	6.41	5.38	10.48	22	139.7	88	23.7	3.83	3.1	321.6
1990	2.53	1.78	1.55	1.77	0.98	2.337	47	70.93	45	10.4	4.33	4.4	193.6
1991	4.03	1.7	1.55	4.89	0.73	5.331	69	137.8	70	8.24	2.91	2	307.89
1992	0.95	0.33	0.24	7.63	3.49	3.482	68	154.9	42	13.7	30.3	1.7	326.31
1993	1.48	0.86	1.08	2.71	10.5	4.667	55	53.49	48	13.8	1.77	1.1	194.28
1994	0.43	0.23	0.18	0.24	0.55	16.18	96	119.8	49	2.63	0.65	0.4	286.89
1995	0.18	0.1	1.07	2.65	1.42	2.196	58	90.04	68	4.59	1.49	1.4	231.25
1996	0.78	0.44	1.39	3.5	7.49	31.36	127	167.1	47	7.48	4.48	3.1	400.63
1997	1.93	1.14	1.62	2.43	4.58	12.73	107	108.1	18	7.32	21.1	4.7	290.93
1998	3.97	0.23	0.18	0.1	1.29	4.307	116	118.9	55	8.71	0.89	0.4	309.87
1999	1.48	0.63	0.44	0.32	0.45	3.404	39	50.53	15	15	6.7	3.7	136.53
2000	2.36	1.48	1.14	3.15	1.79	7.373	42	77.99	28	20.2	12.6	6.6	204.99
2001	5.64	4.26	1.9	1.88	1.89	11.4	80	92	39	16.4	11.8	2.3	268.15
2002	1.93	1.27	1.82	1.45	1.03	12.05	32	58.62	24	1.81	1	0.9	137.13
2003	0.46	0.3	0.5	0.1	0.1	2.253	31	44.92	32	7.82	3.39	2.1	125.36
2004	1.41	1.2	0.98	2.02	1.16	10.82	29	36.8	20	9.97	3.88	2.7	120.55
Mean	**1.9**	**1.3**	**1.3**	**2.1**	**2.2**	**8**	**56**	**96**	**37**	**10.9**	**5.6**	**2.7**	**225.1**
Max	**7**	**5.5**	**7.3**	**9.9**	**11.8**	**43.6**	**170**	**175.9**	**88**	**27.1**	**30.3**	**7.7**	**450.5**
Min	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.5**	**2.2**	**5.5**	**5.8**	**1.6**	**0.7**	**0.4**	**65.2**

Table A.7: Monthly Inflow Series at Ribb Dam Site having Watershed Area of 685Km^2 **(**Mm^3).

Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
1960	0.86	1.5	0.888	0.93	1.19	1.61	0.45	26.16	83.4	36.8	7	2.62	1.304
1961	0.93	2.7	1.645	3.03	0.33	1.34	68.5	153.7	47.8	6.63	4	3.55	294.6
1962	1.84	1.3	1.1	0.81	1.36	2.33	62	168.5	55.6	19.5	4	2.62	321.2
1963	1.94	0.6	0.817	1.44	2.98	1.27	49.2	98.61	23.7	6.64	4	2.55	193.3
1964	2.14	1.3	0.643	1.01	0.98	4.35	79.3	145.3	49.5	19	8	4.67	316.5
1965	2.77	1.7	1.198	2.98	0.31	0.98	13.4	5.223	10.8	14.6	5	3.68	62.5
1966	1.78	1.6	2.341	1.71	0.05	3.61	77.9	89.83	31.5	6.27	4	2	222.1
1967	1.42	1.1	2.385	2	3.29	4.48	100	125.2	40.4	20	8	5.12	314.3

1968	2.87	2.1	1.873	2.14	1.93	8.1	84.2	98.47	21.2	11	5	2.92	241.9
1969	1.32	1.2	2.962	2.09	1.38	0.95	43.1	108.6	20.6	4.02	2	1.09	189.3
1970	0.99	0.6	0.61	0.25	0.26	6.61	24.6	89.56	38.3	12	2	1.52	177.9
1971	1.32	1.2	0.751	0.44	1.72	7.57	24.7	66.04	30.1	7.28	4	1.97	146.6
1972	1.6	1	0.512	0.92	0.61	3.92	32.9	56.44	17.3	4.73	4	3.23	127.2
1973	1.55	0.8	0.774	0.64	1.5	4.58	42.2	126	51.7	20	3	1.5	254
1974	0.93	0.6	0.415	0.4	1.3	10.5	77.2	106.4	33.6	4.39	1	0.79	237.8
1975	0.91	0.8	0.583	0.9	0.12	41.7	35.5	115.3	76.2	10.6	3	2.64	288.4
1976	1.75	2.1	0.735	0.65	1.72	6.81	51.1	92.65	33	6.34	8	2.82	207.3
1977	2.03	1.1	1.852	2.09	3.64	20.5	80.5	102.5	26.8	16.4	22	4.54	284.1
1978	4.47	3.6	3.899	4.74	3.69	6.16	59.1	101.9	27.4	9.2	5	3.15	232
1979	1.81	0.7	0.405	0.18	2.27	1.78	21.9	69.66	28.6	6.12	2	1.59	137.4
1980	1.01	0.8	0.588	2.72	0.39	2.71	49.8	76.83	21.4	7.29	2	1.27	166.6
1981	1.74	1.4	1.219	1.33	1.45	4.87	46.4	88.97	30	7.59	4	2.93	191.8
1982	0.72	0.5	1.492	3.04	1.92	0.96	12.8	55.42	14.4	8.88	3	1.47	104.3
1983	0.54	0.3	0.142	0.09	0.32	2.03	12.8	73.03	16.2	8.73	4	2.24	120.3
1984	0.26	0.8	0.86	9.53	11.3	14.2	2.13	54.27	5.58	1.53	1	1.32	102.8
1985	0.44	0.3	0.289	0.78	2.68	11.2	40.2	44.41	27.4	6.38	2	0.98	137.5
1986	0.49	0.9	0.64	0.75	0.57	18	63.8	115.5	50.8	15.6	5	4.77	277.2
1987	3.83	2.1	2.459	2.6	2.34	8.76	11.1	9.6	9.56	10	3	2.43	67.7
1988	1.55	1.6	0.893	0.41	2.55	10	163	161.1	47.8	26	10	7.42	431.5
1989	6.7	5.3	6.963	6.14	5.15	10	20.7	133.8	83.9	22.7	4	3.01	308.1
1990	2.43	1.7	1.481	1.7	0.94	2.24	45.5	67.95	43.3	9.93	4	4.17	185.5
1991	3.86	1.6	1.481	4.68	0.7	5.11	65.9	132	67	7.9	3	1.92	294.9
1992	0.91	0.3	0.229	7.31	3.34	3.34	65.1	148.4	39.9	13.1	29	1.65	312.6
1993	1.42	0.8	1.036	2.6	10.1	4.47	52.2	51.24	46.2	13.3	2	1.04	186.1
1994	0.41	0.2	0.175	0.23	0.53	15.5	92.2	114.7	47.3	2.52	1	0.36	274.8
1995	0.17	0.1	1.02	2.54	1.36	2.1	55.4	86.25	65.3	4.39	1	1.39	221.5
1996	0.74	0.4	1.329	3.35	7.18	30	122	160	44.6	7.17	4	3.01	383.8
1997	1.85	1.1	1.552	2.33	4.39	12.2	103	103.6	17.4	7.01	20	4.46	278.7
1998	3.8	0.2	0.171	0.09	1.24	4.13	111	113.9	52.8	8.35	1	0.36	296.8
1999	1.42	0.6	0.424	0.3	0.43	3.26	37.4	48.41	14.2	14.4	6	3.5	130.8
2000	2.26	1.4	1.092	3.01	1.72	7.06	40.1	74.71	27.2	19.4	12	6.33	196.4
2001	5.4	4.1	1.818	1.8	1.81	10.9	76.3	88.13	37.4	15.7	11	2.21	256.9
2002	1.85	1.2	1.744	1.39	0.99	11.5	30.2	56.15	22.7	1.73	1	0.87	131.4
2003	0.44	0.3	0.475	0.09	0.1	2.16	29.6	43.03	31.1	7.49	3	2.01	120.1
2004	1.36	1.1	0.937	1.94	1.11	10.4	28.1	35.25	19.4	9.55	4	2.59	115.5
Mean	1.81	1.3	1.265	2.01	2.13	7.67	54	92	35.2	10.4	5	2.6	215.7
Max	6.7	5.3	6.963	9.53	11.3	41.7	163	168.5	83.9	26	29	7.42	431.5
Min	0.17	0.1	0.142	0.09	0.05	0.45	2.13	5.223	5.58	1.53	1	0.36	62.5

Table A.8: Upper Ribb Average Flow (m3/s)

year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Seb	oct	Nov	Dec
1985	0.202	0.2	0.20216	0.372	1.23	5.322	38.93	13.05	2.934	1.15	1	0.232
1986	0.472	0.3	0.3558	0.258	8.57	29.54	53.13	24.13	7.17	2.58	2.2	1.765
1987	1.049	1.1	1.23457	1.055	4.17	5.088	4.418	4.546	4.617	1.43	1.1	0.713
1988	0.782	0.4	0.19427	1.174	4.77	74.77	78.39	22.74	11.95	4.59	3.4	3.086
1989	2.693	3.2	2.84243	2.371	4.77	9.513	61.64	39.9	10.45	6.33	5.4	1.153
1990	0.771	0.5	0.47133	0.393	1.04	34.32	55.89	45.93	7.833	3.02	2.5	1.831
1991	0.699	0.5	1.3014	0.904	1.29	12.33	38.21	70.42	6.227	2.03	1.1	0.425
1992	0.138	0.1	2.03177	1	1.1	49.12	123.2	42.28	10.36	21.5	1	0.653
1993	0.419	0.5	1.23447	1.813	2.13	23.94	23.58	21.98	0.616	0.81	0.3	0.19
1994	0.112	0.1	0.11027	0.244	2.54	66.89	95.26	50.06	0.765	0.3	0.2	2.436
1995	0.047	0.5	1.20597	1.852	1	25.5	58.46	31.06	2.022	0.82	0.8	0.343
1996	0.213	0.6	1.59233	3.302	14.3	55.95	73.63	21.21	3.297	2.04	1.4	0.849
1997	0.558	0.7	1.10763	2.02	5.8	47.22	47.64	8.267	3.224	9.62	2.1	1.75
1998	0.11	0.1	0.0445	0.569	1.96	51.07	152.2	25.09	3.84	0.4	0.2	0.653
1999	0.307	0.2	0.1436	0.199	1.55	17.22	22.27	6.747	6.625	3.05	1.6	1.039
2000	0.697	0.5	1.433	0.79	3.36	18.44	34.37	12.95	8.91	5.75	2.9	2.483
2001	2.08	0.8	0.85663	0.831	5.19	16.92	26.92	17.78	7.241	5.38	1	0.85
2002	0.62	0.8	0.65917	0.454	5.49	8.228	5.283	2.599	0.796	0.45	0.4	0.202
2003	0.146	0.2	0.044	0.044	1.03	13.64	19.79	14.79	3.447	1.55	0.9	0.623
2004	0.563	0.4	0.92107	0.512	0.89	12.84	16.22	9.23	4.392	1.77	1.2	
Average	**0.634**	**0.6**	**0.89932**	**1.008**	**3.61**	**28.89**	**51.47**	**24.24**	**5.336**	**3.73**	**1.5**	**1.119**

Table A.9:
SWAT model simulation Sun Jul 17 23:31:52 2011 MDL

MULTIPLE HRUs LandUse/Soil OPTION THRESHOLDS : 15 / 20 [%]
Number of HRUs: 13
Number of Subbasins: 5

	Area [ha]	Area [acres]	%Wat.Area
WATERSHED:	69796.5204	172470.6917	
LANDUSE:			
Moderately Cultivated-->MODA	30607.6404	75633.0098	43.85
Dominantely Cultivated-->DOMC	37578.6758	92858.7868	53.84
Afro-alpine-->AFPS	1610.2042	3978.8952	2.31
SOIL:			
EutricFluvisols	1469.6726	3631.6344	2.11
EutricLeptosols	23276.5881	57517.6129	33.35
ChromicLuvisols	45050.2598	111321.4444	64.55

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # **1**	5568.8260	13760.8475	7.98	
LANDUSE:				
Moderately Cultivated-->MODA	1686.8649	4168.3274	2.42	30.29
Dominantely Cultivated-->DOMC	3881.9611	9592.5201	5.56	69.71
SOIL:				
ChromicLuvisols	5568.8260	13760.8475	7.98	100.00
HRUs: Moderately Cultivated-->MODA/ChromicLuvisols	1686.8649	4168.3274	2.42	30.29
Dominantely Cultivated-->DOMC/ChromicLuvisols	3881.9611	9592.5201	5.56	69.71

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # **2**	4150.0712	10255.0334	5.95	
LANDUSE:				
Moderately Cultivated-->MODA	4150.0712	10255.0334	5.95	100.00
SOIL:				
ChromicLuvisols	1210.6144	2991.4888	1.73	29.17
EutricLeptosols	2939.4568	7263.5447	4.21	70.83
HRUs:				
Moderately Cultivated-->MODA/EutricLeptosols	2939.4568	7263.5447	4.21	70.83
Moderately Cultivated-->MODA/ChromicLuvisols	1210.6144	2991.4888	1.73	29.17

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # **3**	51768.9856	127923.7519	74.17	
LANDUSE:				
Moderately Cultivated-->MODA	24112.8380	59584.0283	34.55	46.58
Dominantely Cultivated-->DOMC	27656.1476	68339.7236	39.62	53.42
SOIL:				
ChromicLuvisols	33700.4705	83275.5477	48.28	65.10
EutricLeptosols	18068.5151	44648.2041	25.89	34.90
HRUs:				
Moderately Cultivated-->MODA/EutricLeptosols	18068.5151	44648.2041	25.89	34.90
Moderately Cultivated-->MODA/ChromicLuvisols	6044.3229	14935.8241	8.66	11.68
Dominantely Cultivated-->DOMC/ChromicLuvisols	27656.1476	68339.7236	39.62	53.42

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area

SUBBASIN #	**4**	5313.9600	13131.0609	7.61	
LANDUSE:					
Dominantely Cultivated-->DOMC		3703.7558	9152.1657	5.31	69.70
Afro-alpine-->AFPS		1610.2042	3978.8952	2.31	30.30
SOIL:					
ChromicLuvisols		4570.3488	11293.5604	6.55	86.01
EutricLeptosols		743.6112	1837.5004	1.07	13.99
HRUs:					
Dominantely Cultivated-->DOMC/ChromicLuvisols		3703.7558	9152.1657	5.31	69.70
Afro-alpine-->AFPS/EutricLeptosols		743.6112	1837.5004	1.07	13.99
Afro-alpine-->AFPS/ChromicLuvisols		866.5930	2141.3947	1.24	16.31

		Area [ha]	**Area [acres]**	**%Wat.Area**	**%Sub.Area**
SUBBASIN #	**5**	2994.6776	7399.9981	4.29	
LANDUSE:					
Moderately Cultivated-->MODA		657.8663	1625.6206	0.94	21.97
Dominantely Cultivated-->DOMC		2336.8113	5774.3775	3.35	78.0
SOIL:					
EutricFluvisols		1469.6726	3631.6344	2.11	49.08
EutricLeptosols		1525.0050	3768.3637	2.18	50.92
HRUs:					
Moderately Cultivated-->MODA/EutricLeptosols		657.8663	1625.6206	0.94	21.97
Dominantely Cultivated-->DOMC/EutricLeptosols		867.1387	2142.7431	1.24	28.96
Dominantely Cultivated-->DOMC/EutricFluvisols		1469.6726	3631.6344	2.11	49.08

Detailed LANDUSE/SOIL distribution SWAT model class Sun Jul 17 23:31:27 2011

	Area [ha]	**Area [acres]**
Watershed	69796.5204	172470.6917

	Area [ha]	**Area [acres]**	**%Wat.Area**
LANDUSE			
Not defined in SWAT database --> URBN	244.9547	605.2954	0.35
Moderately Cultivated --> MODA	30295.9718	74862.8611	43.41
Dominantely Cultivated --> DOMC	37178.1350	91869.0304	53.27
Plantations --> PLSL	123.1853	304.3971	0.18
Afro-alpine --> AFPS	1954.2736	4829.1078	2.80

SOIL				
EutricFluvisols	1411.5830	3488.0922	2.02	
EutricLeptosols	29469.5025	72820.6141	42.22	
Urban	107.6102	265.9101	0.15	
ChromicLuvisols	38807.8247	95896.0753	55.60	

		Area [ha]	**Area [acres]**	**%Wat.Area**	**%Sub.Area**
SUBBASIN #	1	5568.8260	13760.8475	7.98	
LANDUSE:					
Moderately Cultivated --> MODA		1649.5505	4076.1219	2.36	29.62
Dominantely Cultivated --> DOMC		3796.0901	9380.3285	5.44	68.17
Plantations --> PLSL		123.1853	304.3971	0.18	2.21
SOIL:					
ChromicLuvisols		5250.2433	12973.6136	7.52	94.28
EutricLeptosols		318.5827	787.2338	0.46	5.72
--					

		Area [ha]	**Area [acres]**	**%Wat.Area**	**%Sub.Area**
SUBBASIN #	2	4150.0712	10255.0334	5.95	
LANDUSE:					
Moderately Cultivated --> MODA		4150.0712	10255.0334	5.95	100.
SOIL:					
ChromicLuvisols		1210.6144	2991.4888	1.73	29.17
EutricLeptosols		2939.4568	7263.5447	4.21	70.83

		Area [ha]	**Area [acres]**	**%Wat.Area**	**%Sub.Area**
SUBBASIN #	3	51768.9856	127923.7519	74.17	
LANDUSE:					
Not defined in SWAT database --> URBN		244.9547	605.2954	0.35	0.47
Moderately Cultivated --> MODA		23838.4837	58906.0852	34.15	46.05
Dominantely Cultivated --> DOMC		27341.4778	67562.1588	39.17	52.81
Afro-alpine --> AFPS		344.0693	850.2126	0.49	0.66
SOIL:					
Urban		107.6102	265.9101	0.15	0.21
ChromicLuvisols		27978.6433	69136.6265	40.09	54.05
EutricFluvisols		62.3006	153.9480	0.09	0.12
EutricLeptosols		23620.4315	58367.2673	33.84	45.63
--					

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # 4	5313.9600	13131.0609	7.61	
LANDUSE:				
Dominantely Cultivated --> DOMC	3703.7558	9152.1657	5.31	69.70
Afro-alpine --> AFPS	1610.2042	3978.8952	2.31	30.30
SOIL:				
ChromicLuvisols	4169.9428	10304.1371	5.97	78.47
EutricLeptosols	1144.0172	2826.9238	1.64	21.53

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # 5	2994.6776	7399.9981	4.29	
LANDUSE:				
Moderately Cultivated --> MODA	657.8663	1625.6206	0.94	21.97
Dominantely Cultivated --> DOMC	2336.8113	5774.3775	3.35	78.0
SOIL:				
ChromicLuvisols	198.3810	490.2093	0.28	6.62
EutricFluvisols	1349.2824	3334.1443	1.93	45.06
EutricLeptosols	1447.0142	3575.6445	2.07	48.32

Table A.10: Calibrated SWAT Parameter Values

Name of the parameter	**Original value**	**Calibrated value**
SOL_BD	1.1	1.3
SOL_K	0.0	2.08
SOL_CBN	0.05	2.2
SOL_ALB	0.0	0.12
USLE_K	0	0.5
CH-N1	0.0	0.014
CH-W2	0.0	14.4
CH-D	0.0	0.65
CH-S2	0.0	0.034
CH-L2	0.0	15
CH-cover	0.001	0.45
CH-erod	0.05	0.6
ALPHA_BNQ	0.0	0.5
GW_delay	0	31
ALPHA_BF	0.0	0.048
GW_Revap	0.02	0.02
RCHRG_DP	0.0	0.05

Table A.11: Table for Measured Sediment Concentration at Upper Ribb

Months	sed(ton)*1000	flow(m3/s)
January	5	0.004419
February	4	0.038786
March	3	0.052968
April	5	0.2649
May	6	0.966258
June	18	5.0337
July	180	16.65594
August	380	19.96594
September	94	5.550667
October	22	0.270484
November	8	0.1206
December	6	0.326161

Table A.12: Sediment Yield of All Basins (Ribb dam catchment)

Sub basin-1		Sub basin-2	Subbasin-3	Subbasin-4	Sub basin-5
Year	**sediment yield(Ton/km2/y)**	**Sediment yield(Ton/km2/y)**	**Sediment yield(Ton/km2/y)**	**Sediment yield(Ton/km2/y)**	**Sediment yield(Ton/km2/y)**
1985	8E-06	1E-05	25.5796	1.43E-05	35.8166
1986	0.61458	2E-05	58.5781	0.066893	81.5903
1987	134.968	2.8916	43.9529	154.809	55.659
1988	1.30101	0.0293	52.1638	1.73E-05	71.9484
1989	24.1739	0.3839	56.2983	28.00678	74.6991
1990	1.3E-05	2E-05	32.6314	2.00E-05	45.5301
1991	39.5115	0.5554	51.5649	44.23113	66.49
1992	1.1E-05	2E-05	45.5371	1.92E-05	63.596
1993	1.3E-05	2E-05	54.8493	1.96E-05	76.6476
1994	40.4095	0.5986	72.9134	43.55355	97.1777
1995	2.79095	2E-05	47.0054	0.592321	65.3868
1996	4.94612	0.1084	53.6901	4.920008	73.9255
1997	45.3125	0.7617	75.8114	51.28929	99.2693
1998	1.2E-05	2E-05	62.5386	1.96E-05	87.3782
1999	0.00603	0.0042	61.4567	0.002404	85.7593
2000	1.3E-05	2E-05	66.3447	1.98E-05	92.6504
2001	133.621	2.4386	56.3949	158.9686	72.2923
2002	344.648	6.3687	91.306	416.7137	106.977
2003	6E-06	2E-05	34.6213	1.11E-05	48.4241
2004	8E-06	2E-05	39.007	1.94E-05	54.6705
Aver	**38.6135**	**0.707**	**54.1151**	**45.1534**	**72.7937**

Table A.13: data used for sediment calibration

Months (1986-1987)	Measured sediment (tonn/month) Qs = 19.50 Q^1.044 (ton/day)	predicted sediment(tonn/month)
1	80.32000	169.90000
2	170.54000	36.91000
3	118.78000	22.13000
4	136.65000	14.18000
5	73.76000	5.79400
6	6224.65000	422.10000
7	16453.87000	8251.00000
8	22290.00000	22290.00000
9	19246.65000	25980.00000
10	7840.32500	19530.00000
11	2365.72500	9967.00000
12	3200.81700	4636.00000
13	1154.00000	1154.00000
14	626.06700	141.30000
15	436.06500	43.56000
16	560.07600	22.38000
17	439.32400	17.76000
18	876.94000	37.87000
19	9112.00000	4506.00000
20	16880.00000	17570.00000
21	16210.00000	17490.00000
22	10380.00000	9839.00000
23	4672.00000	3394.00000
24	1702.00000	903.10000

Table A.14: data used for sediment validation

Months (2000-2001)	Measured sediment (tonn/month) Qs = 19.50 Q^1.044(ton/day)	predicted sediment (tonn/month)
1	566.1242301	169.90000
2	330.2716526	36.91000
3	233.9021957	22.13000
4	801.5527225	14.18000
5	412.3263119	5.79400
6	2120.284383	422.10000
7	12715.50526	8251.00000
8	24243.30391	22290.00000
9	8451.339145	25980.00000
10	5869.768051	19530.00000
11	3569.344128	9967.00000

12	1779.708518	4636.00000
13	1497.00251	1154.00000
14	1120.533804	141.30000
15	441.1027628	43.56000
16	440.9630764	22.38000
17	438.9846278	17.76000
18	3225.044516	37.87000
19	17112.46043	9112.00000
20	25708.45588	16880.00000
21	11778.93063	16210.00000
22	4710.611057	10380.00000
23	3328.386955	4672.00000
24	550.5871776	1702.00000

Annex B: Figures

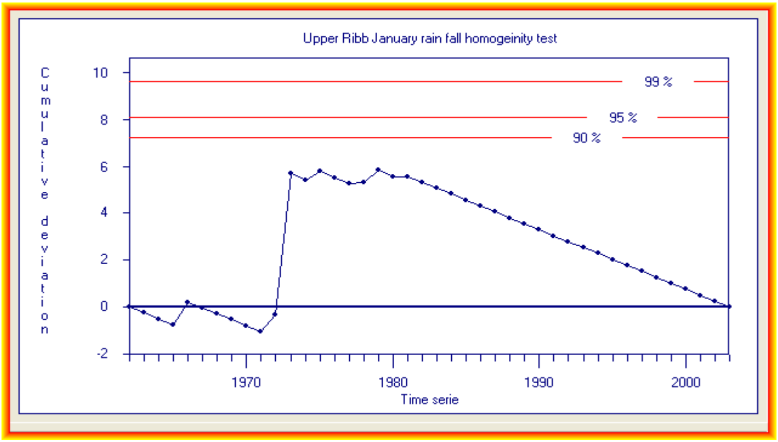

Figure B.1: January Rain fall Test

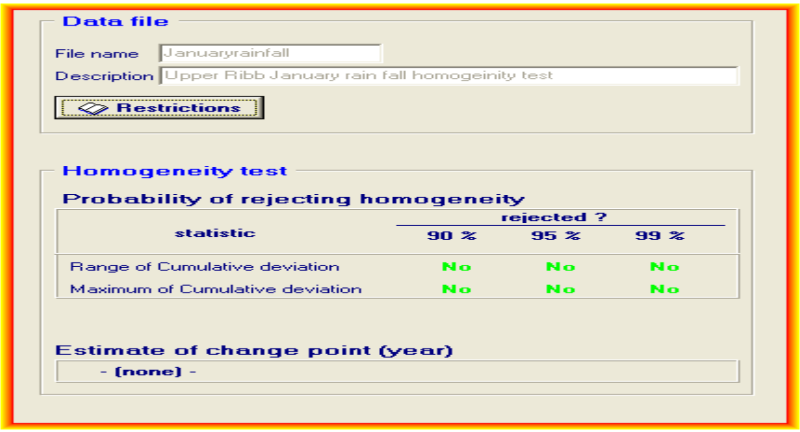

Figure B.2: January Rain fall Test

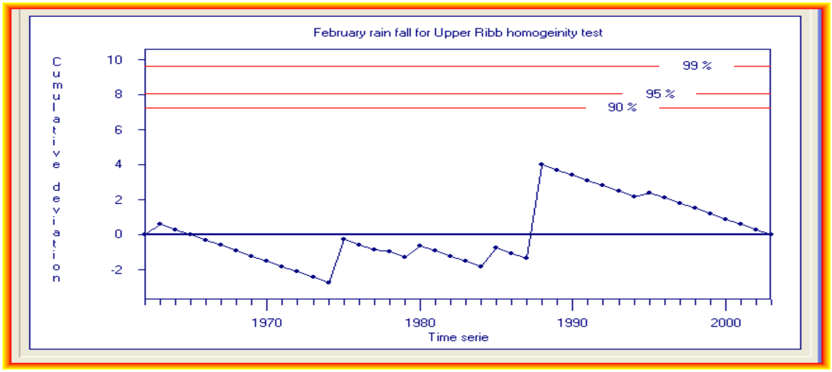

Figure B.3: February Rain fall Test

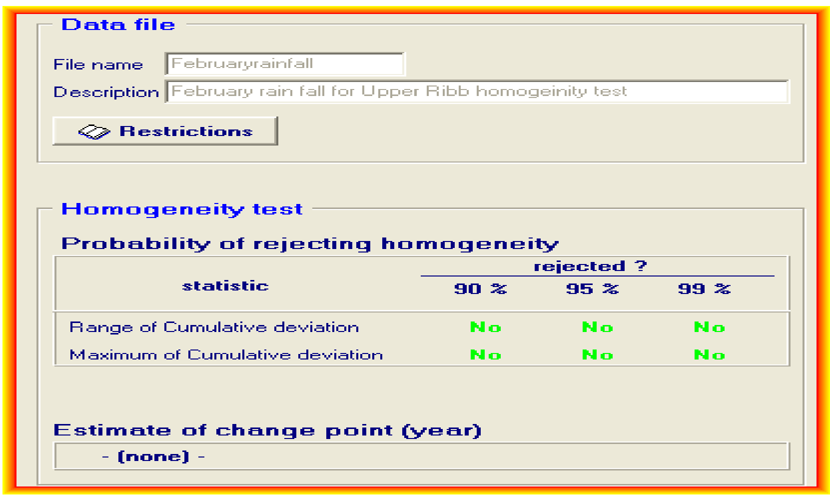

Figure B.4: February Rain fall Test

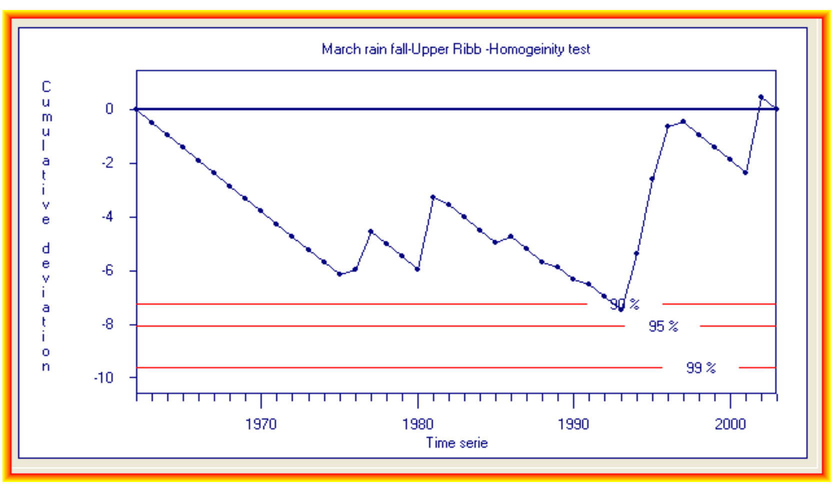

Figure B.5: March Rain fall Test

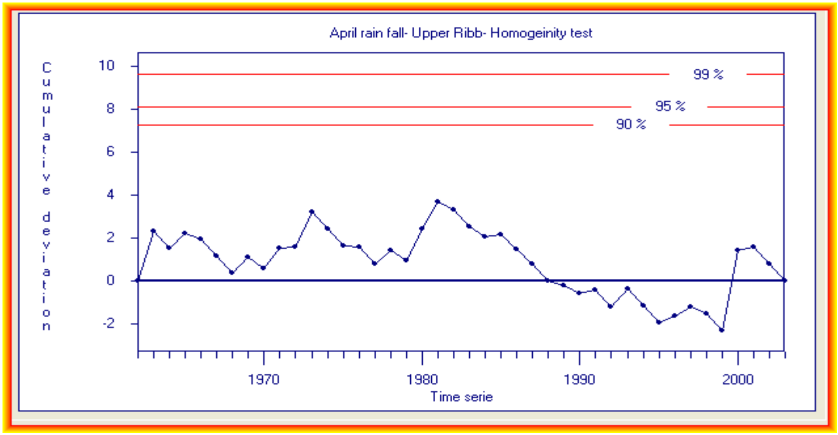

Figure B.6: April Rain fall Test

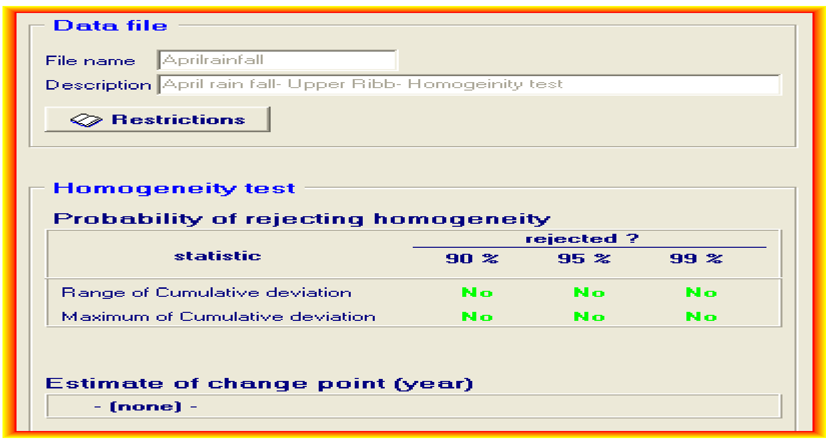

Figure B.7: April Rain fall Test

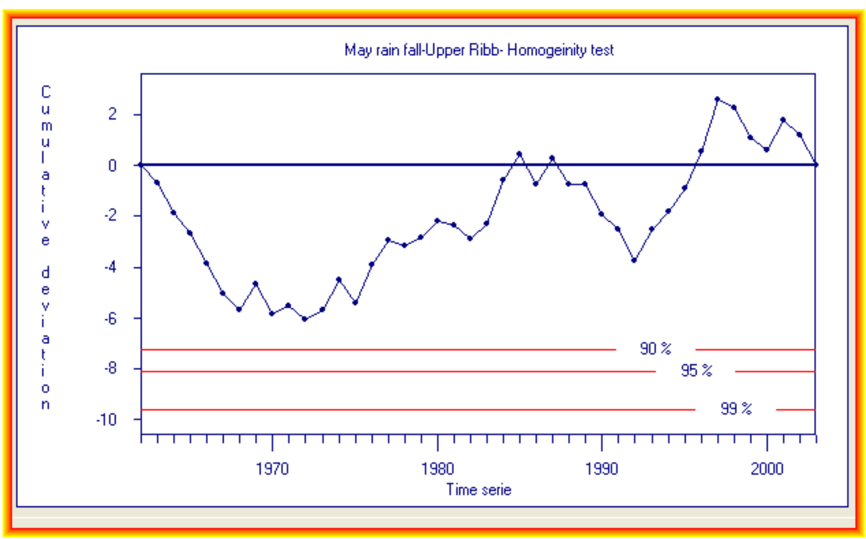

Figure B.8: May Rain fall Test

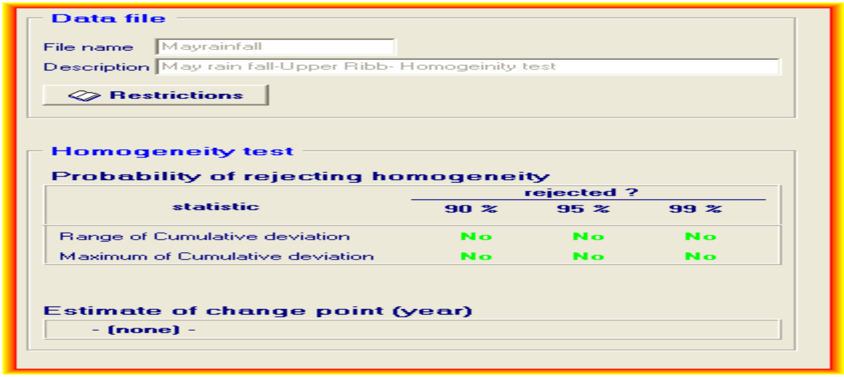

Figure B.9: May Rain fall Test

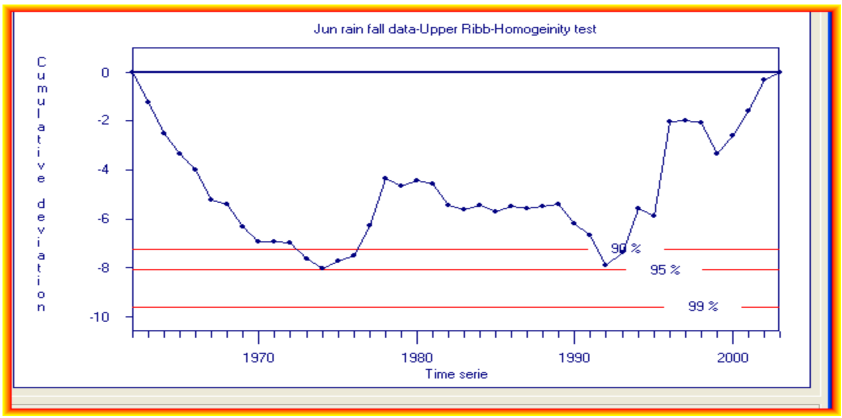

Figure B.10: Jun Rain fall Test

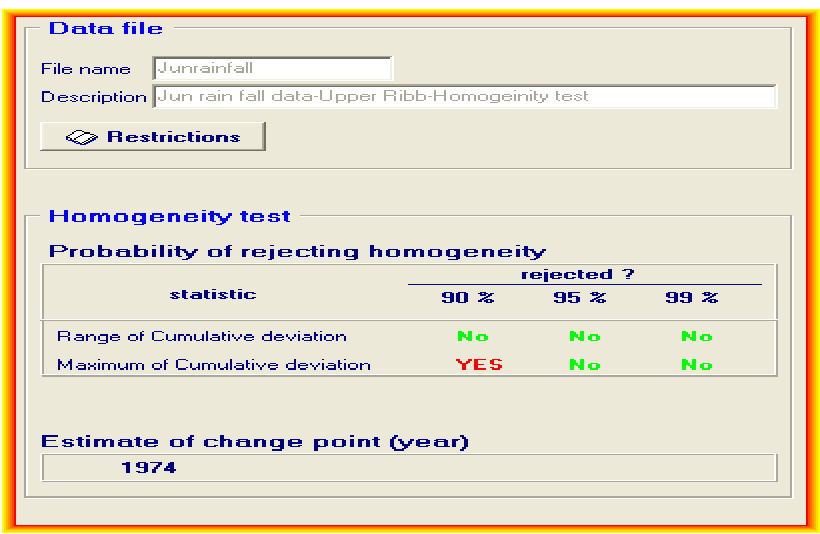

Figure B.11: June Rain fall Test

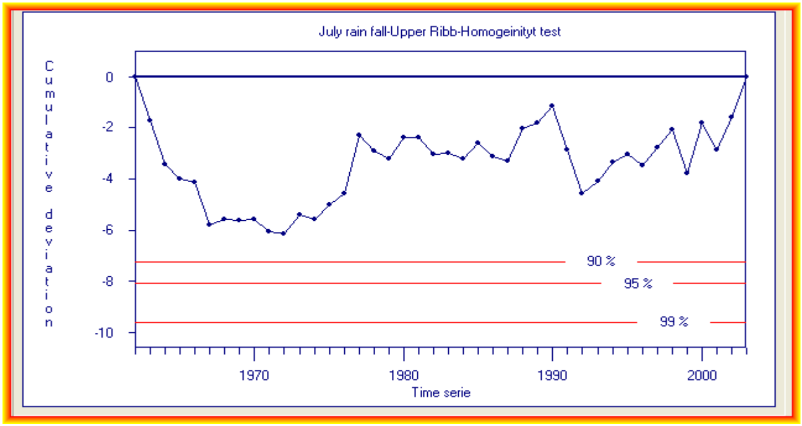

Figure B.12: July Rain fall Test

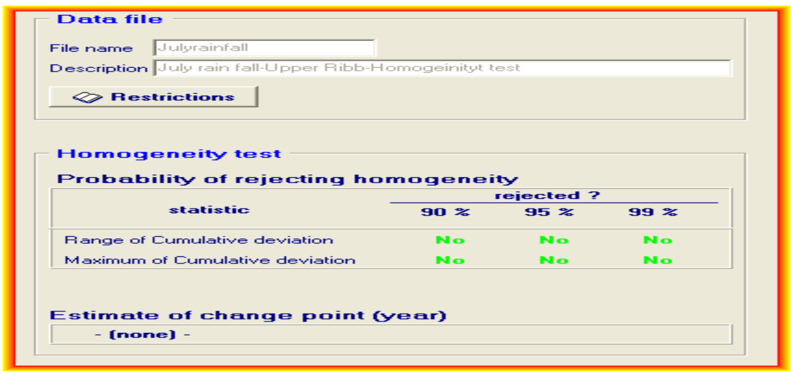

Figure B.13: July Rain fall Test

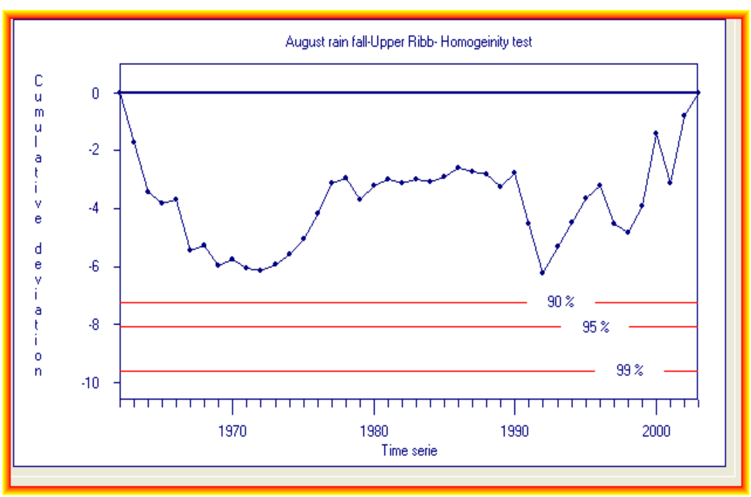

Figure B.14: August Rain fall Test

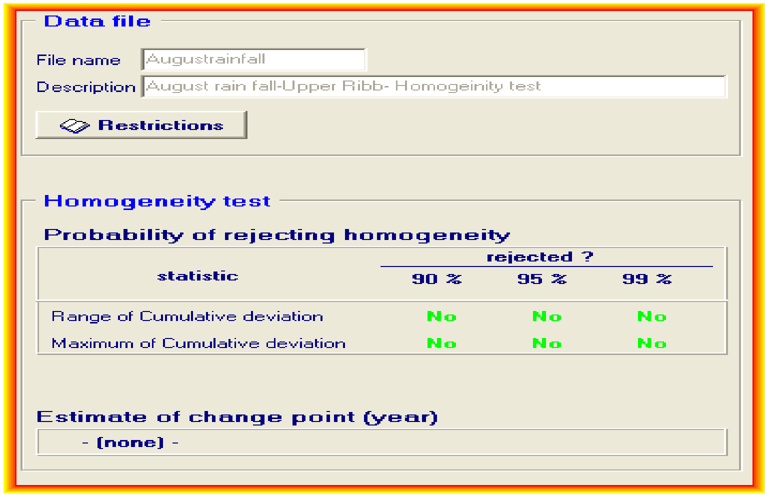

Figure B.15: August Rain fall Test

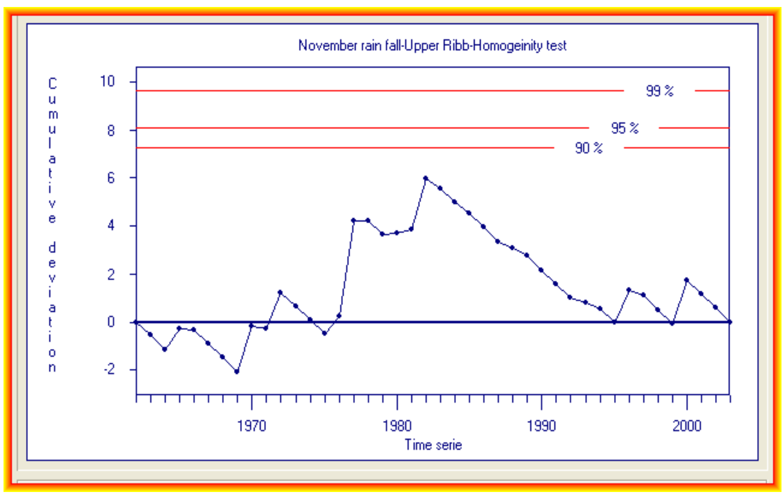

Figure B.16: November Rain fall Test

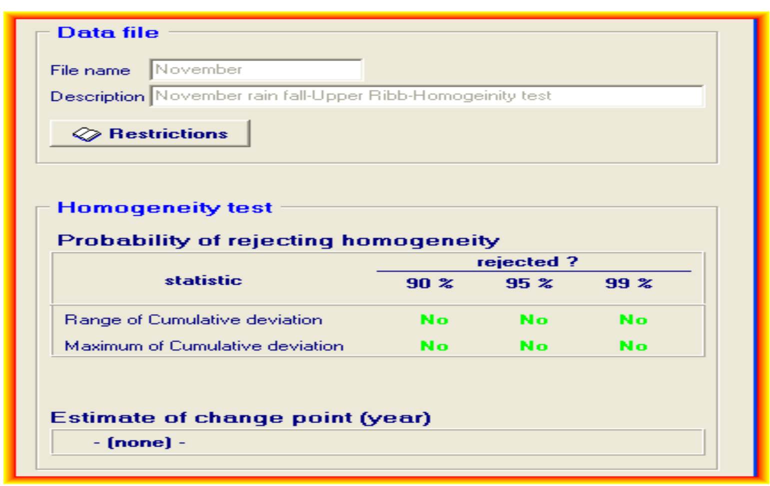

Figure B.17: November Rain fall Test

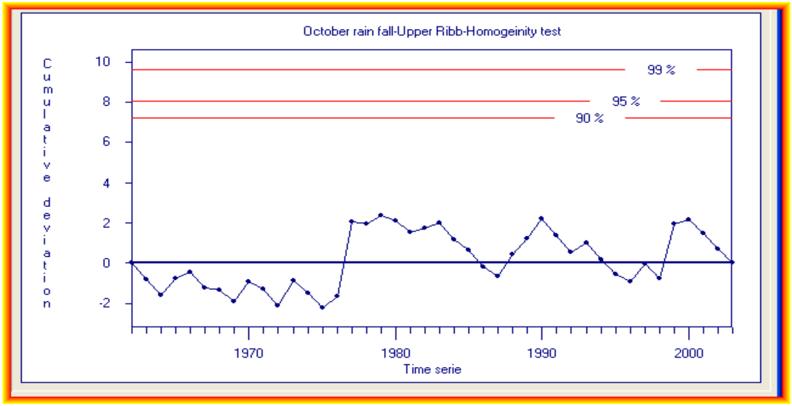

Figure B.18: October Rain fall Test

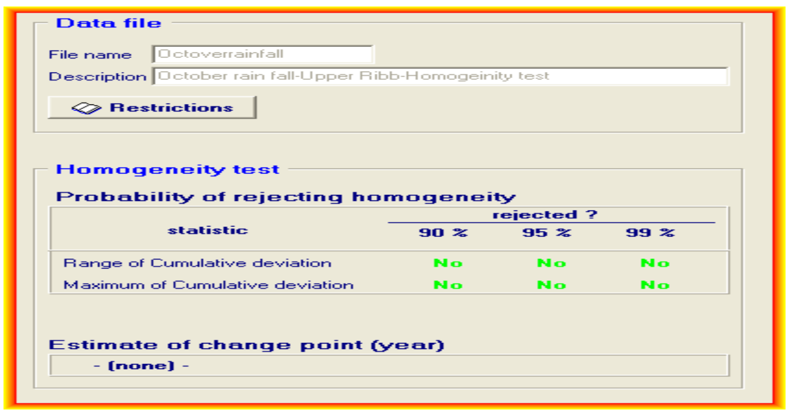

Figure B.19: October Rain fall Test

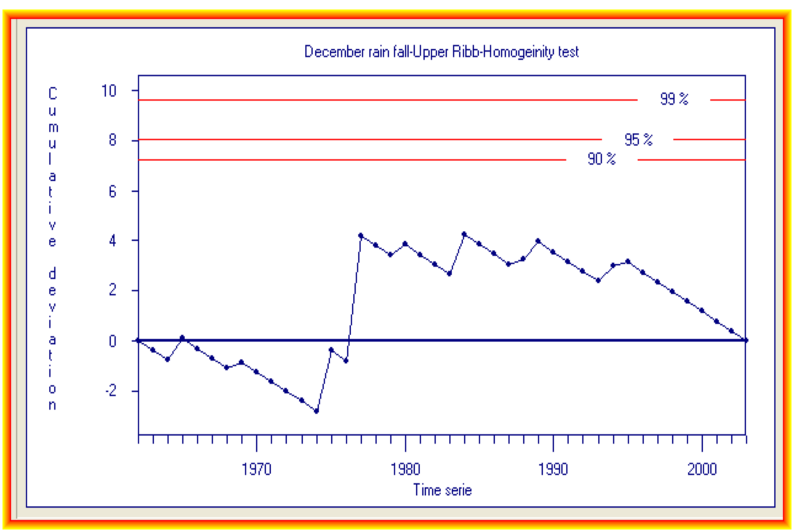

Figure B.20: December Rainfall Test

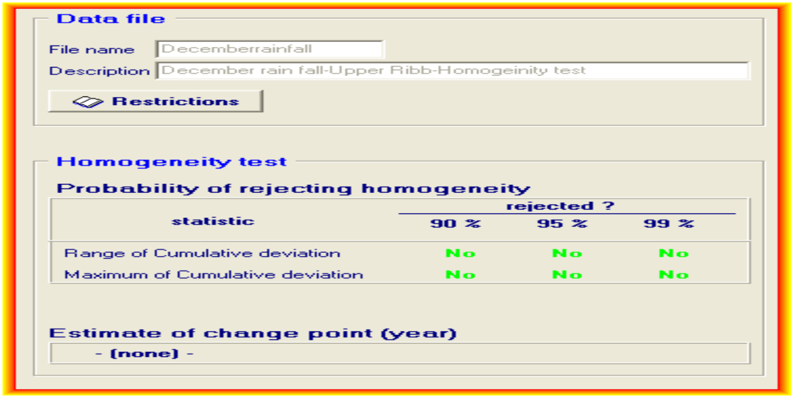

Figure B.21: December Rainfall Test

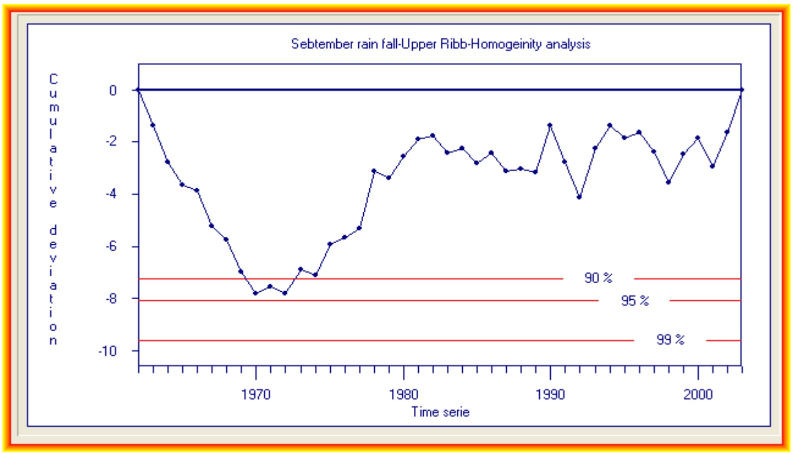

Figure B.22: September Rain fall Test

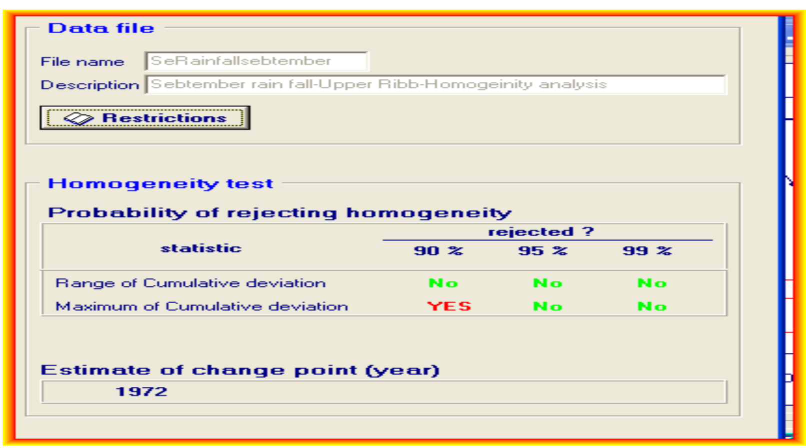

Figure B.23: September Rain fall Test

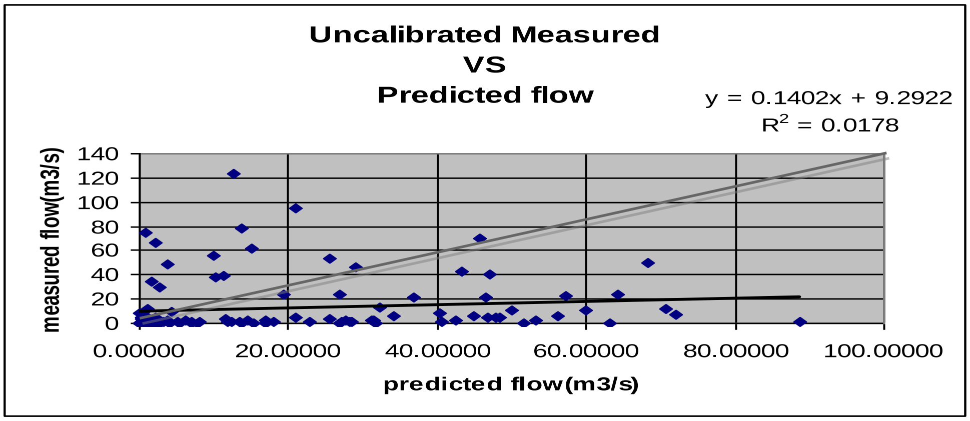

Figure B.24: Monthly Un Calibrated Flow Vs Predicted Flow

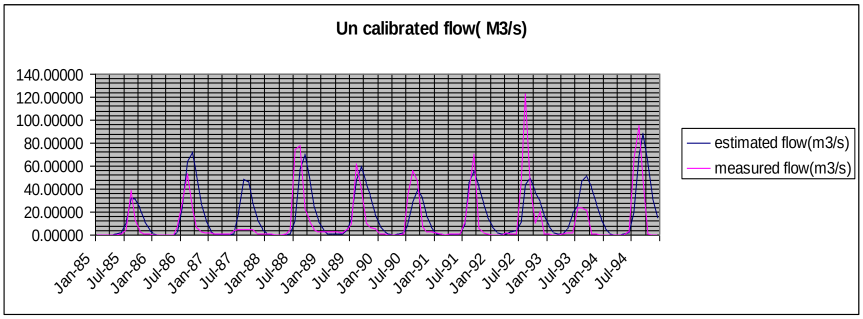

Figure B.25: Monthly Uncalibrated observed flow Vs predicted Flow

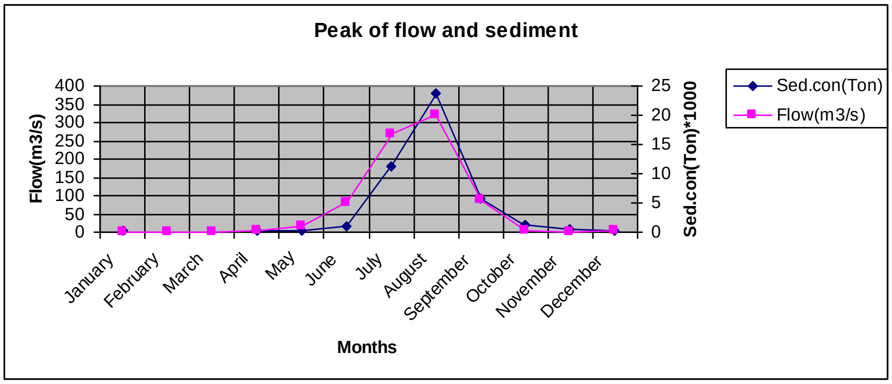

Figure B.26: Peak Flow and Sediment Load

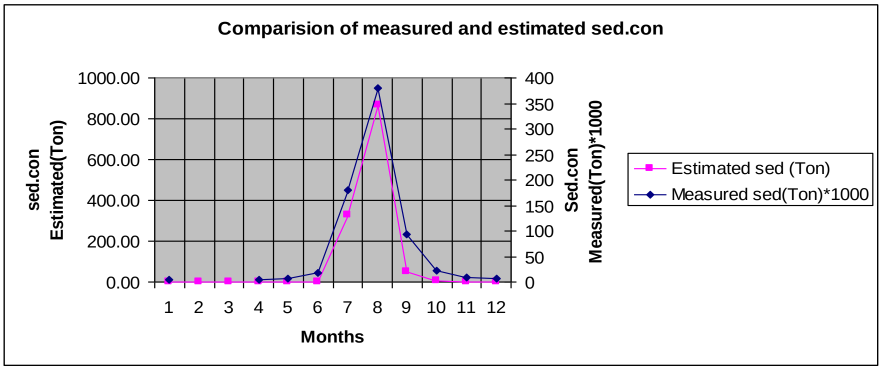

Figure B.27: Comparison of Measured and Estimated Sediment concentration

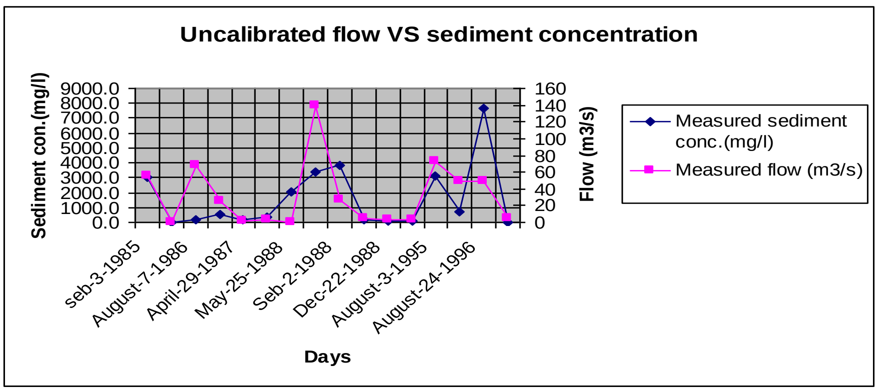

Figure B.28: Un Calibrated Flow VS Sediment Concentration

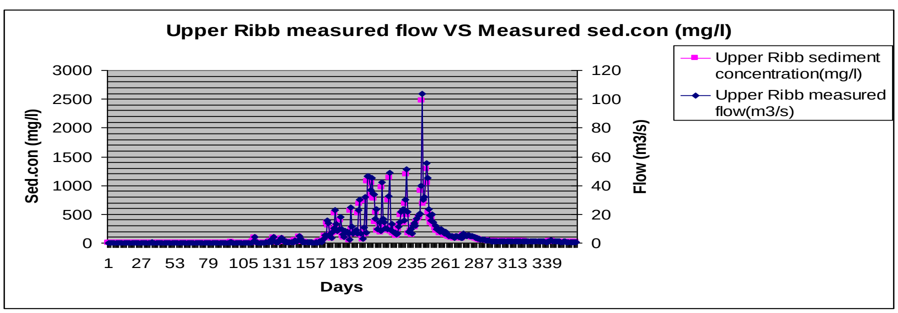

Figure B.29: Measured flow VS measured sediment concentration

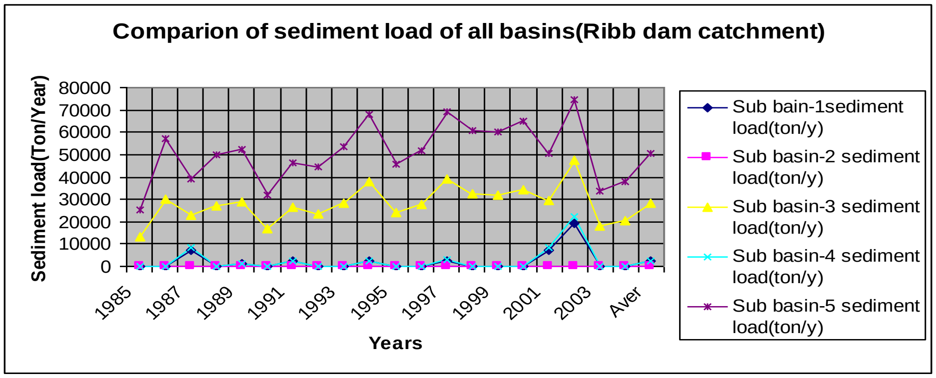

Figure B.30: Comparison of Sediment Yields

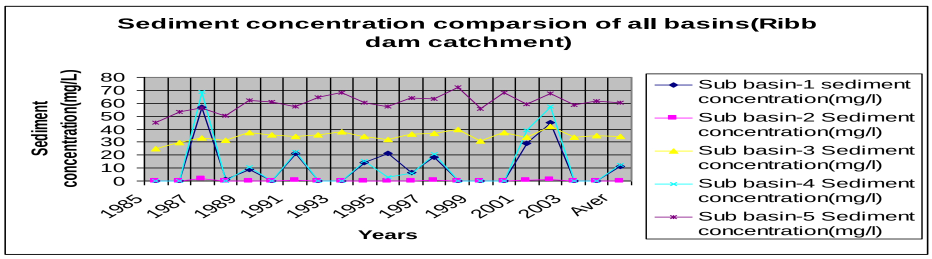

Figure B.31: Comparison of Sediment Concentration

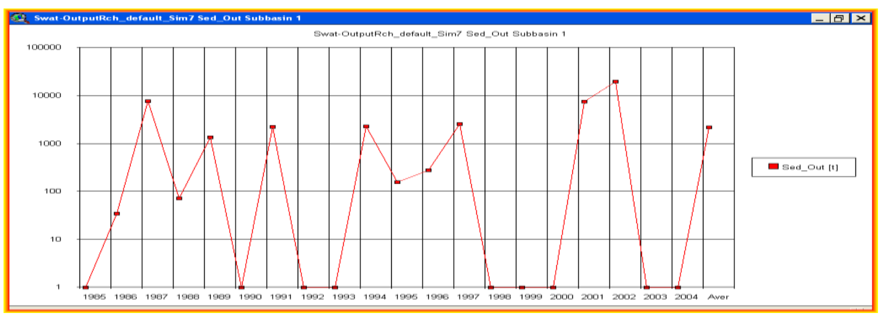

Figure B.32: yearly Sediment Yield of Sub Basin-1

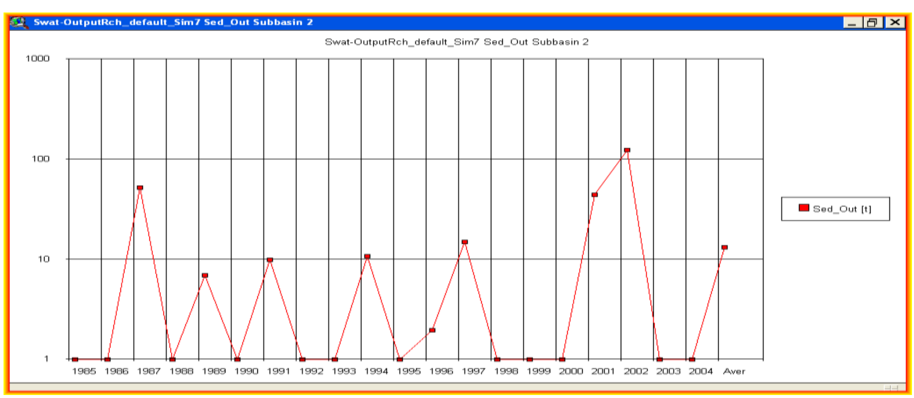

Figure B.33: yearly Sediment Yield of Sub Basin-2

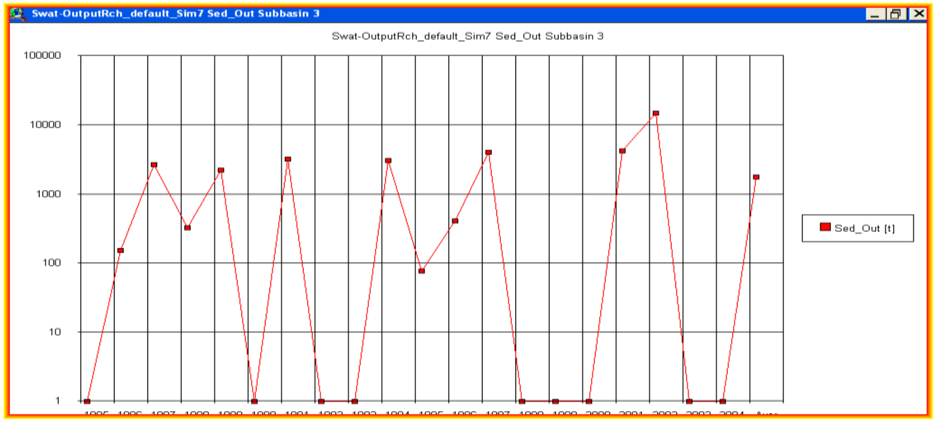

Figure B.34: yearly Sediment Yield of Sub Basin-3

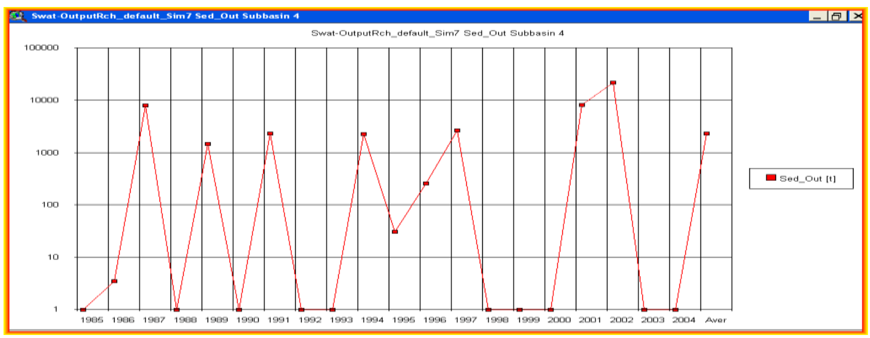

Figure B.35: yearly Sediment Yield of Sub Basin-4

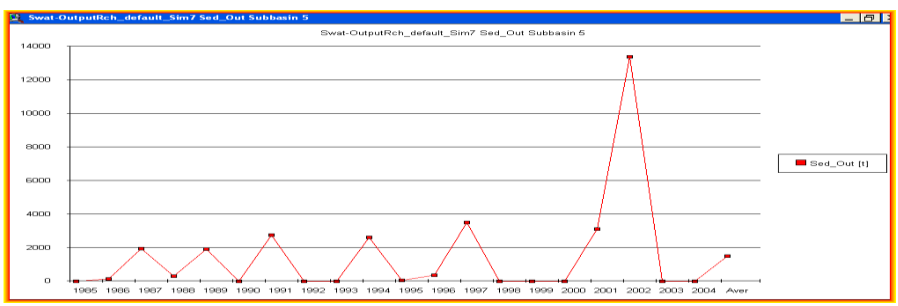

Figure B.36: yearly Sediment Yield of Sub Basin-5

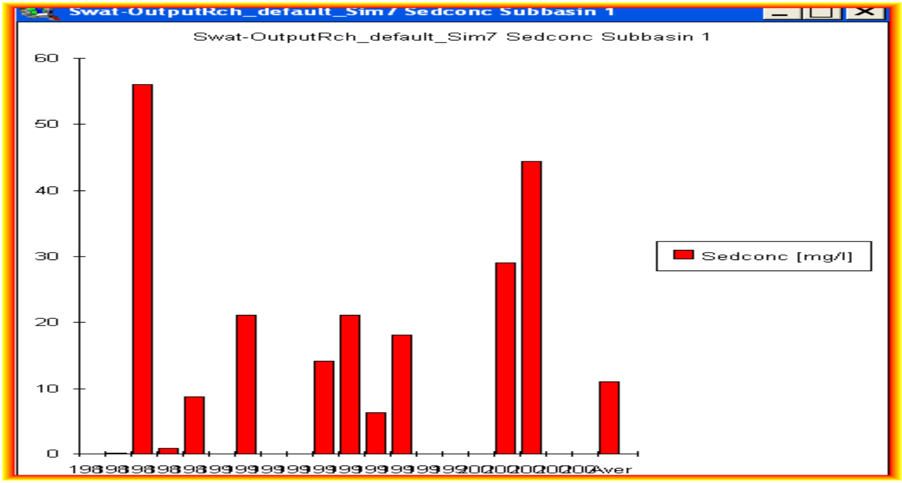

Figure B.37: Sediment Yield of Sub Basin-1

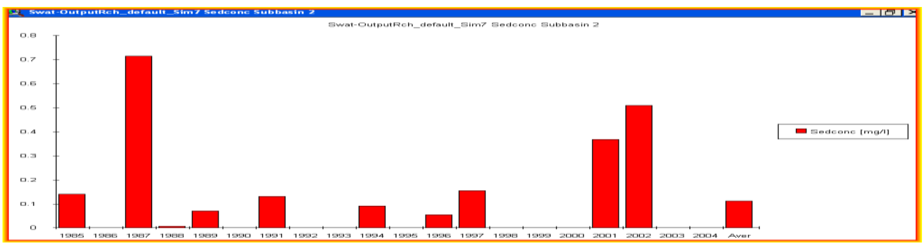

Figure B.38: Sediment Concentration of Sub Basin-2

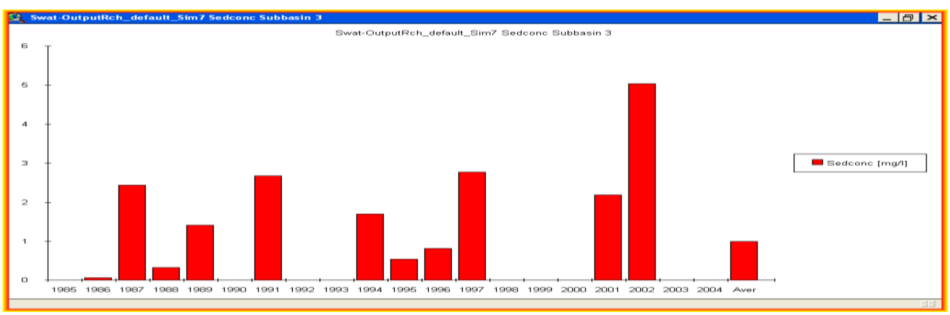

Figure B.39: Sediment Concentration of Sub Basin-3

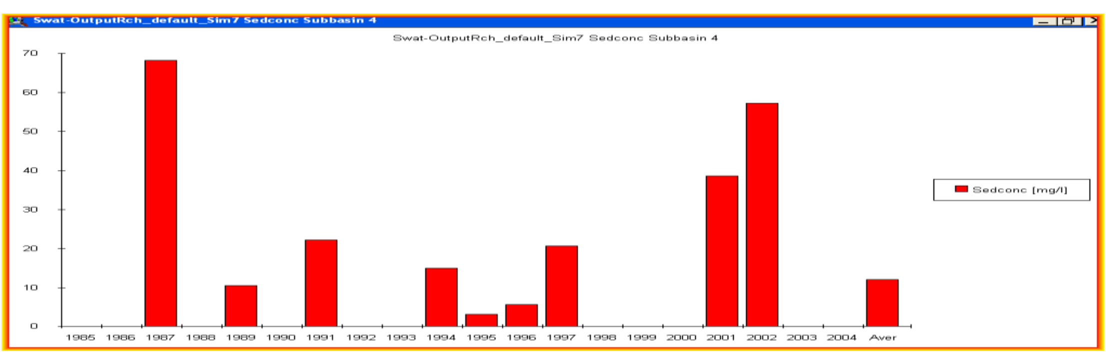

Figure B.40: Sediment Concentration of Sub Basin-4

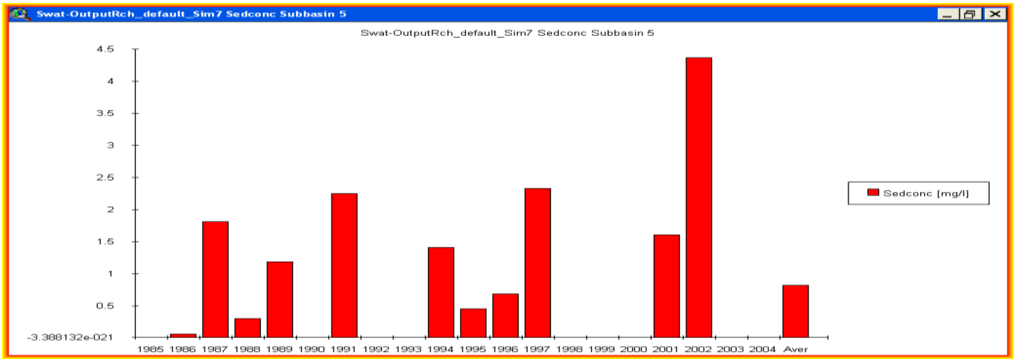

Figure B.41: Sediment Concentration of Sub Basin-5


Figure B.42: Msc Hydraulics students


Figure B.43: core of the dam

Figure B.44: geology of dam site

Figure B.45: geology of dam site

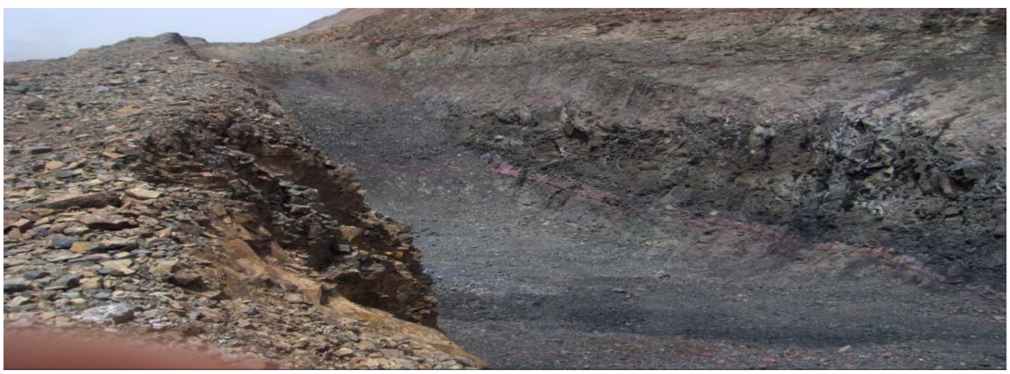

Figure B.46: geology of dam site

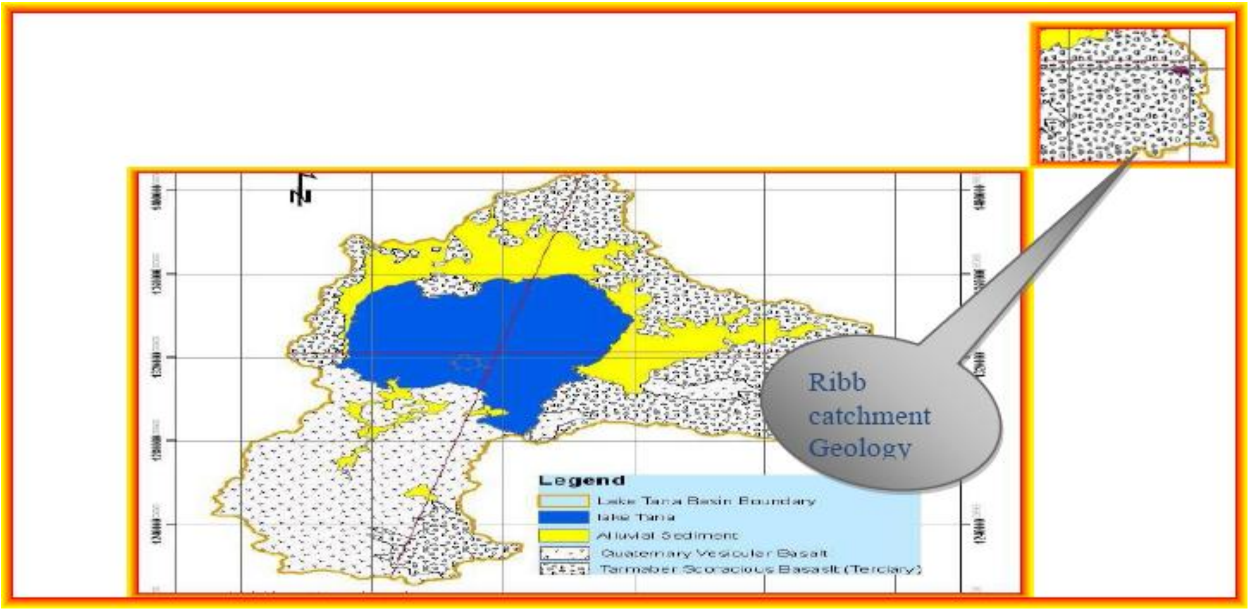

Figure B.47: geology map of study area

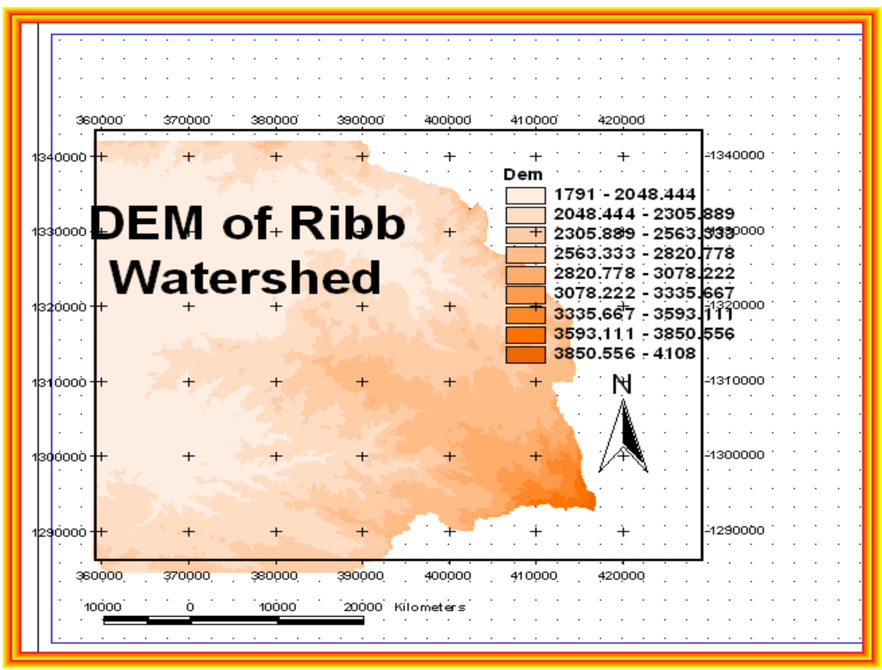

Figure B.48: Ribb Dam watershed catchment DEM

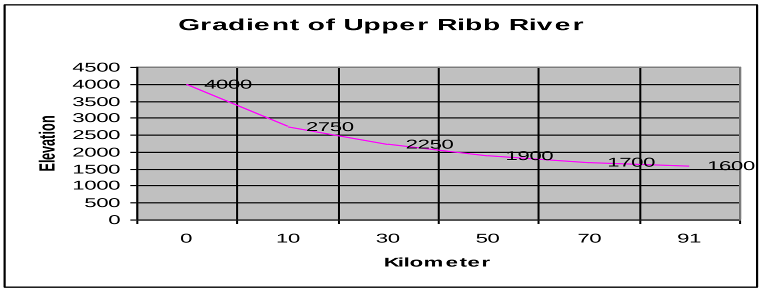

Figure B.49: Gradient of upper Ribb River

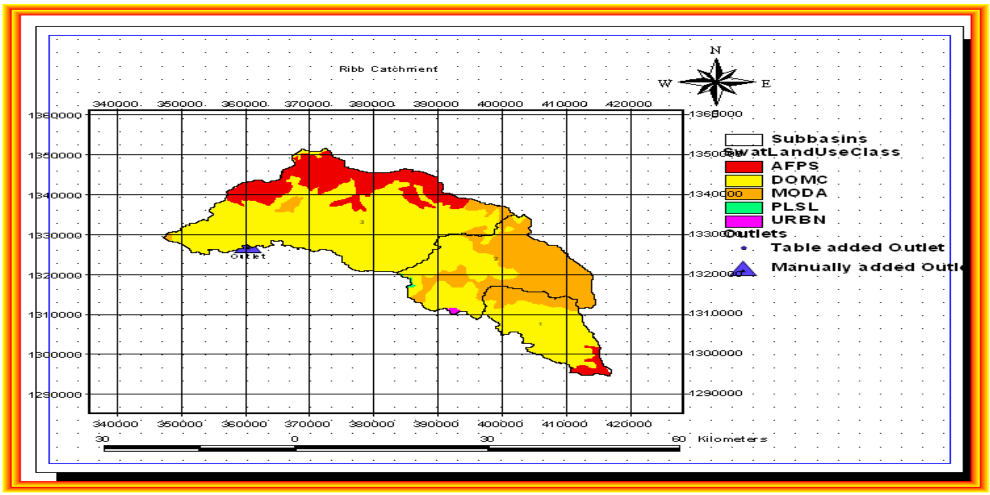

Figure B.50 Ribb Catchment land use classes

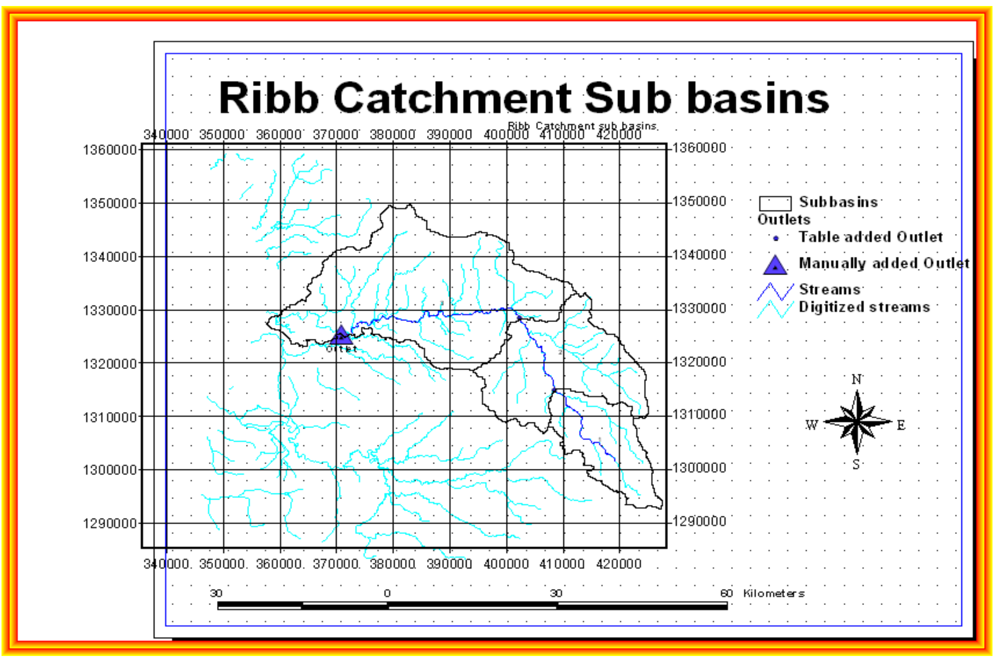

Figure B.51 Ribb Catchment Subbasins

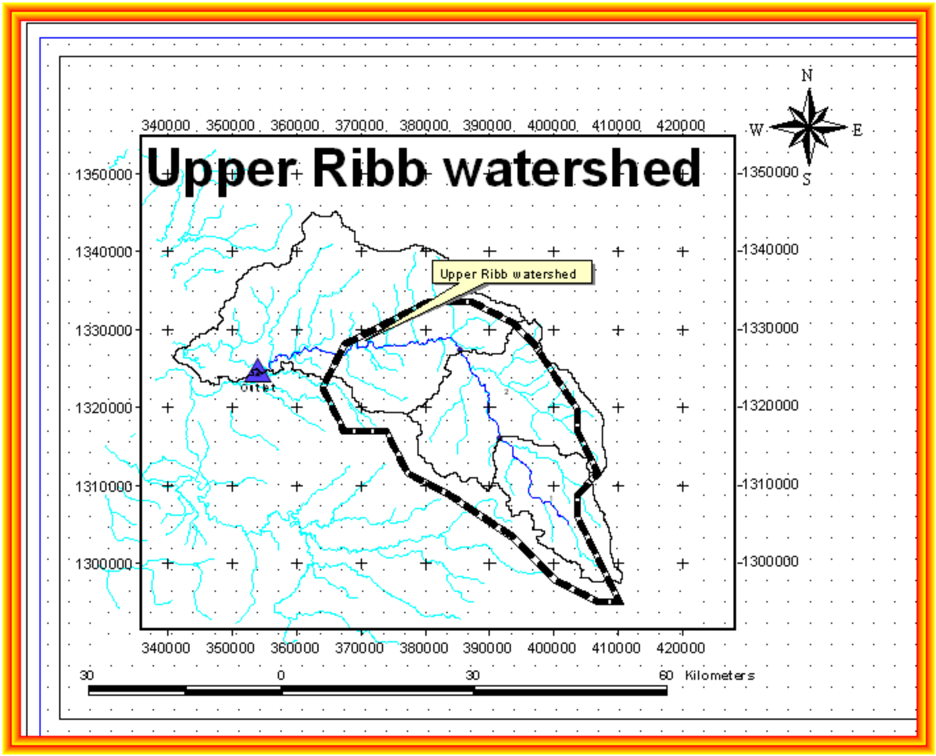

Figure B.52 Upper Ribb watershed

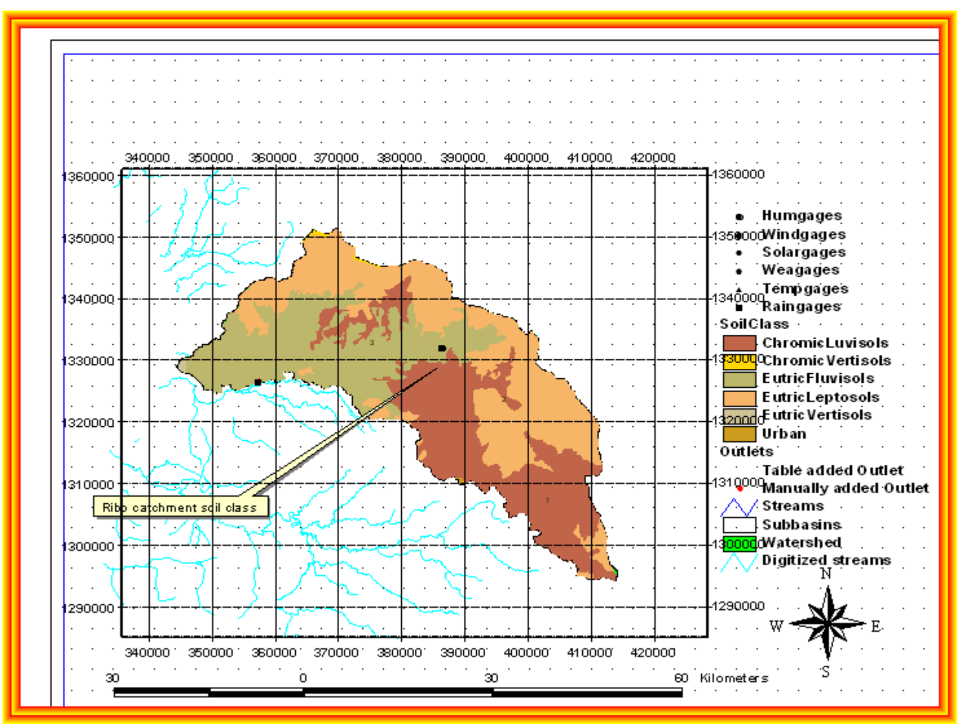

Figure B.53 Ribb Catchment Soil Classes