



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

**PREDICTION OF SEDIMENT INFLOW TO GEFERSA RESERVOIR
(USING SWAT MODEL) AND ASSESSING SEDIMENT REDUTION METHODS**

Submitted in partial fulfillment for the degree of Masters of science in Civil Engineering

(Major in Water Supply and Environmental Engineering)

By

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Adviser: - Dr .Yilma Sileshi

March2012

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ABSTRACT

Sediment transport is a worldwide environmental problem that degrades soil productivity, water quality, causes sedimentation to the reservoirs and increases the probability of floods. Gefersa reservoir, one of the surface water supply sources of Addis Ababa city for the last 70 years, face this problem. The reservoir supplies an average of 30,000m³ of treated water per day to the city. Based on the 1979 and 1998 bathymetric surveys, with the assumption of linear yearly siltation rate there is 22,252 m³/year of sediment inflow to the reservoir. In terms of soil loss from the catchment area, this constitutes a loss of 575 tons/km²/year contributed by the catchment area. In this study, Soil and Water Assessment Tool (SWAT) was used to calibrate and validate a hydrologic component and sediment yield of Gefersa watershed. Back-calculation process was carried out to estimate the natural inflow to the Gefersa reservoir. Sensitivity analysis, model calibration and validation were also performed to assess the model performance. Nine highly sensitive parameters were identified of which curve number (CN2) was the most sensitive one. The coefficient of determination (R^2), Nash-Sutcliffe (E_{NS}) and the percent difference for a quantity (D) was used to evaluate model performance during calibration and validation. Results found were satisfactory and plausible for ungauged station i.e. $R^2 = 0.78$, $E_{NS} = 0.77$ and $D=-15.3$ for calibration and $R^2 = 0.72$, $E_{NS} = 0.70$ and $D=-20.7$ for validation period. Sediment were calibrated and validated on annual basis using D i.e.-1.37 for calibration and -6.9 for validation. Four scenarios are developed to observe the impact of land use changes. Based on this, change of 53% and 16% forest to agriculture resulted in 74.5% and 52.89% increase in sediment load. And change of 35% and 18% rangeland to agriculture land increase 40.47% and 29.51% increase in sediment load .Based on results of modeling, sediment reduction methods in the catchment as well as recovering storage capacity are proposed. Of the available reservoir sediment management approach, watershed management is the best method to reduce the yield of sediment and its entry into the reservoir. Periodic sluicing of sediments through operation of bottom outlet gates would also help to ease the problem.

Key words: - Gefersa, Sediment, SWAT Watershed, Bathymetric survey

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DEDICATED

To those who are always in my mind.

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Abbreviations

AAWSA	Addis Ababa Water and Sewerage Authority
DBF	Data base file
DEM	Digital Elevation Model
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GW_Q	Ground water flow (mm)
HNARC	Holeta National Agricultural Research Center
HRU	Hydrologic Response Unit
m.a.s.l	Mean above sea Level
mm	Millimeter
MoWR	Ministry of water and Energy
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Service Agency
SURQ	Surface Runoff
SWAT	Soil and Water Analysis Tool
t	tons
T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
T/ha/yr	tons per hectare per year
UTM	Universal Trans Mercator
USLE	Universal Soil Loss Equation
Y	year

CHAPTER ONE

INTRODUCCION

1.1. Background

Soil erosion is a process of detachment of soil particles due to raindrop energy and/or surface runoff, the transport of sediment by surface runoff and the deposition of sediments as the velocity of surface runoff decreases. Soil erosion causes worldwide environmental problems leading to degraded soil productivity and water quality, causes sedimentation in the reservoirs and increases the probability of floods as a result of reduction of flood storage capacity.

A river is not only conveying water, but has many other functions. One of these functions is transporting of erosion products (boulders, gravel, sand, silt and clay) from its catchment to downstream direction. If the transport capacity of a river is affected by diversion of water from the river or by storing water in a reservoir, deposition of sediment may occur. If not properly taken care of, harmful sedimentation and erosion may occur. 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 was underestimated, because of the lack of sufficient data. Also a change in sediment yield is due to changed in land use in the upstream catchment that can cause detrimental sedimentation

To model erosion, good quality sediment transport data that has been accurately measured are required for calibration and validation. Sediment transport rates are important as they can provide sediment yield data, which is the most effective indicator of the negative effects of soil erosion. However, as stated by Bradbury et al. (1993), the prediction of sediment yield in developing countries is usually difficult because of the lack of suitable data and an appropriate predictive technique.

Gefersa reservoir is one of the surface water sources providing clean drinking water to residents of the capital city Addis Ababa in addition to Legedadi and Dire reservoirs. The Geffersa catchment area (55.56 km², or 5,556 ha) is located in Oromiya region under the control of AAWSA. Geffersa III reservoir, which is constructed in 1966, is located upstream of Geffersa I

dam about 1km to the west. It is used as both storage and silt trap. The Gefersa River and its feeder streams are part of the Akaki river catchment. The reservoirs supply an average of 30,000m³ of treated water per day to Addis Ababa city. The high rate of siltation is a major long-term problem for the reservoirs, as it severely affects their capacity and results in shortage of usable water for Addis Ababa. It also increases the water treatment costs .Based on the 1979 and 1998 bathymetric surveys, with the assumption of linear yearly siltation rate, there is 22,252 m³/year sediment outflows from the basin. In terms of soil loss from the catchment area, this constitutes a loss of 575 tons/km²/year.

This study concentrates on of prediction sediment inflow to Gefersa reservoir using SWAT watershed model and assessing sediment reduction methods in the Gefersa catchment, and to simulate future trend under different landuse scenarios based on the study of the master plan and field visits.

1.2. Problem Statement

Sediment transport leads to degraded soil productivity that causes worldwide problems such as sedimentation in reservoirs. There are many reservoirs in existence today which cannot perform as designed because much of their storage has been filled by sediment. For a water supply scheme, any loss of live storage increases the risk of supply failure and this is often undesirable. These problems are pronounced in the Gefersa reservoir – the main water supply source of Addis Ababa city because of quick land use change particularly to intensive agriculture in the catchment. According to Bathymetric survey (1999), there is a loss of 0.36% of the main reservoir volume of 6.23MCM, which constitutes a soil loss of this basin averaging 575 tons/km²/year in addition increasing the treatment cost due to increase in turbidity of raw water. Therefore, care should be given to alleviate this problem. The chart in Fig1.1 demonstrates the flow of cause and effect among processes of water yield and related aspects.

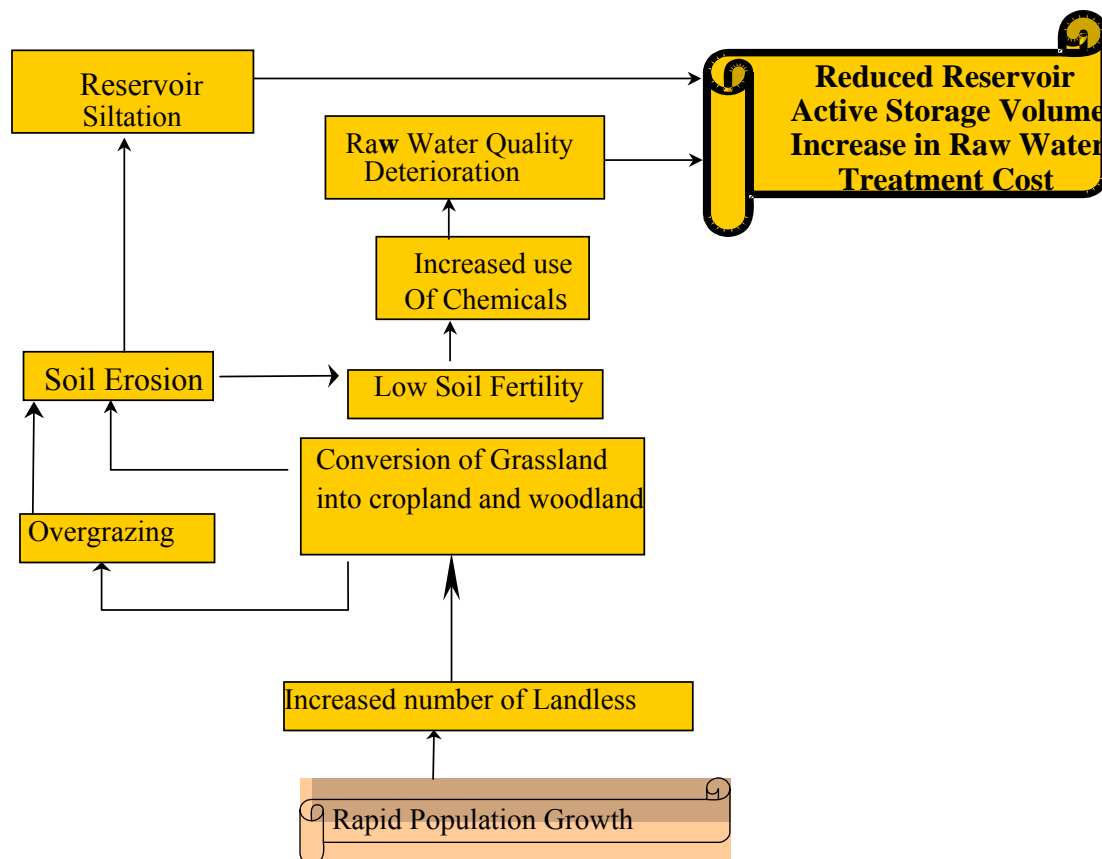


Figure 1-1 – The Problem tree

1.3. Objective of the study

The main objective of this study is prediction of sediment inflow to Gefersa reservoir and assessing sediment reduction methods in the catchment as well as in the reservoir using SWAT watershed model

Specific objective

- Generation of inflow Hydrograph for Gefersa Reservoir
- To assess sediment inflow to Gefersa Reservoir using SWAT
- To simulate future trend under different landuse scenarios.
- Assessment of Sediment reduction methods in the catchment as well as in the reservoir

1.4. Thesis layout

This thesis is divided into seven chapters.

Chapter one outlines the statement of the problem, specific aims and objectives of the present study. The chapter also provides some background information on the problems caused by sediment accumulation in reservoirs.

Chapter two deals with the location of study area and general catchment characteristics of the Gefersa catchment.

Chapter three briefly reviews the theory of sediment transport and erosion in rivers and reservoirs.

Chapter Four outlines the research methodology employed in this study. An overview of some of the erosion and sedimentation models is given. The application of the selected erosion model (SWAT) to Gefersa catchment is dealt with here.

Chapter Five Concentrates on SWAT model simulation results and discussion.

Chapter six Sediment reduction methods in the catchment as well as in the reservoir are assessed and appropriate techniques that may be used in order to remedy the sedimentation problem are proposed in this chapter.

Chapter seven summarizes the entire study by way of outlining the main conclusions, and recommendations.

CHAPTER TWO

DESCRIPTION OF STUDY AREA

2.1. Location of the study area

Gefersa reservoir is located 18 km west of Addis Ababa in West Shewa Zone, within Oromiya Region. Addis Ababa Water and Sewage Authority (AAWSA) have administrative control of the area. It is located between UTM grids 453,000 Km to 466,000 Km East and 997,000 m to 1,010,000 m north. The reservoir is in a shallow basin about 10 km wide, stretching between the Wechacha and Entoto mountains with a catchment area of 5,500 ha in Awash basin.

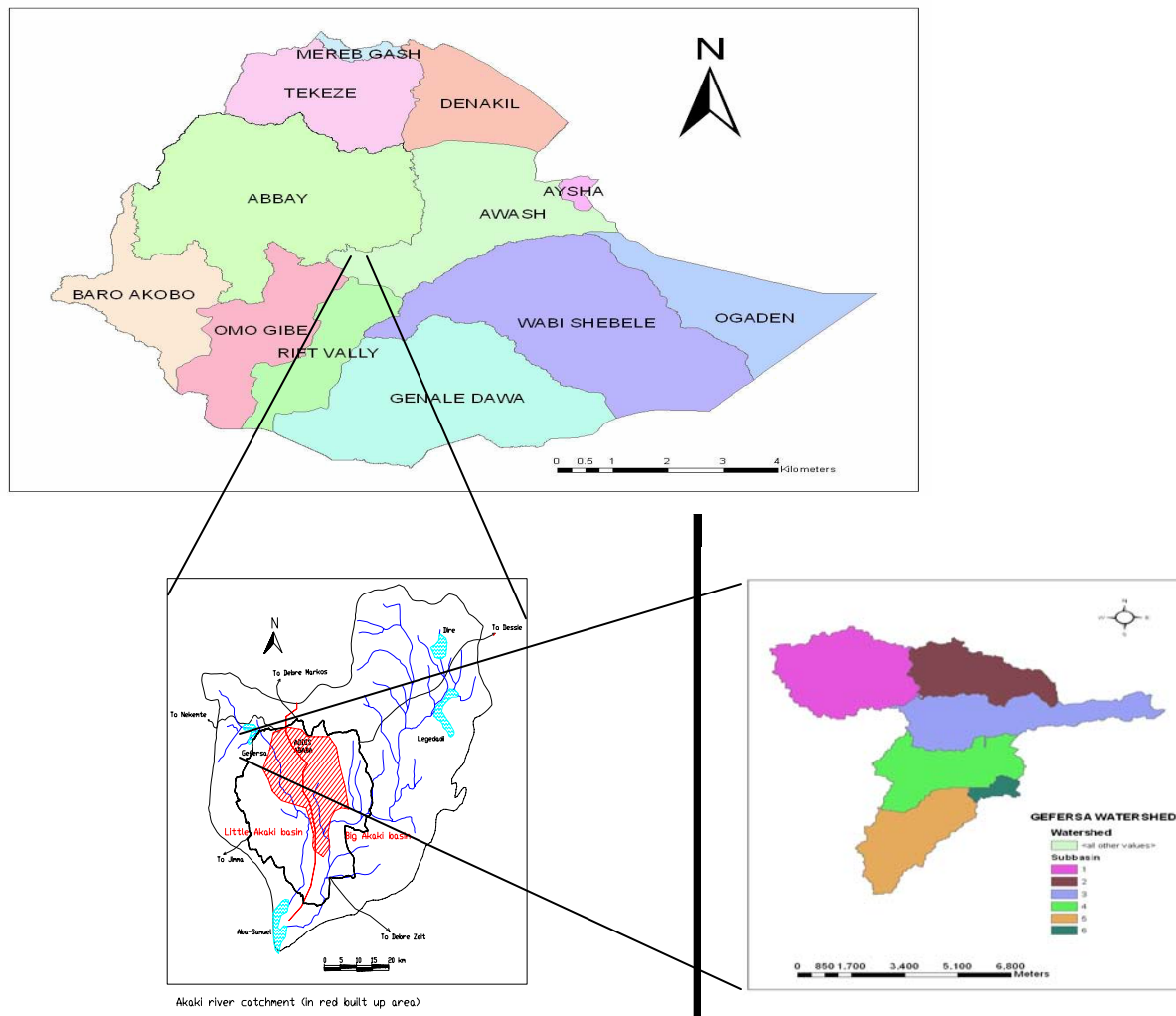


Figure 2.1:-Location map of Gefersa catchment

2.2. Topography

The altitude of the catchment area ranges from 2,580 to 2,940 m-amsl. The major physiographic units in this area are undulating plains, valleys, steep stream banks, hills and mountains.

2.3. Climate

The Gefersa catchment is located in a relatively high rainfall area with an annual rainfall of around 1,200 to 1,300 mm. There are two seasonal patterns in the region of Addis Ababa. The weather is relatively cool in the wet season of July to September when the main rain falls, while the rainless season of October to June has warmer temperatures.

No	Station name	Lat.	Long.	Elevation (m.a.s.l.)
1	Observatory	469224	995196	2408
2	Holeta	474073	1004349	2390
3	Entoto	442855	1002300	2900

Table2.1. Climatic Stations within and in the proximity to Gefersa catchment

Stations used as source of Precipitation data.

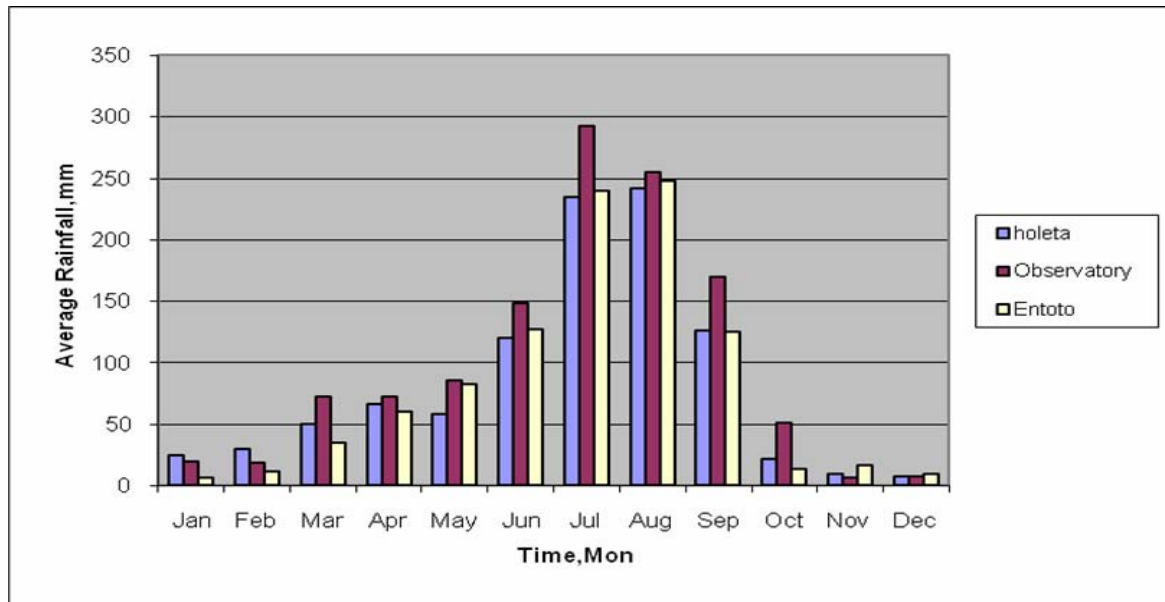


Fig 2.2 Mean monthly rainfall distribution

No	Station name	Lat.	Long.	Elevation (m.a.s.l.)
1	Observatory	472416	998334	2408
2	Holeta	474073	1004349	2390
3	Entoto	442855	1002300	2900

Table2.2. Climatic Stations within and in the Proximity to Gefersa catchment
 Stations used as source of minimum and maximum temperature data.

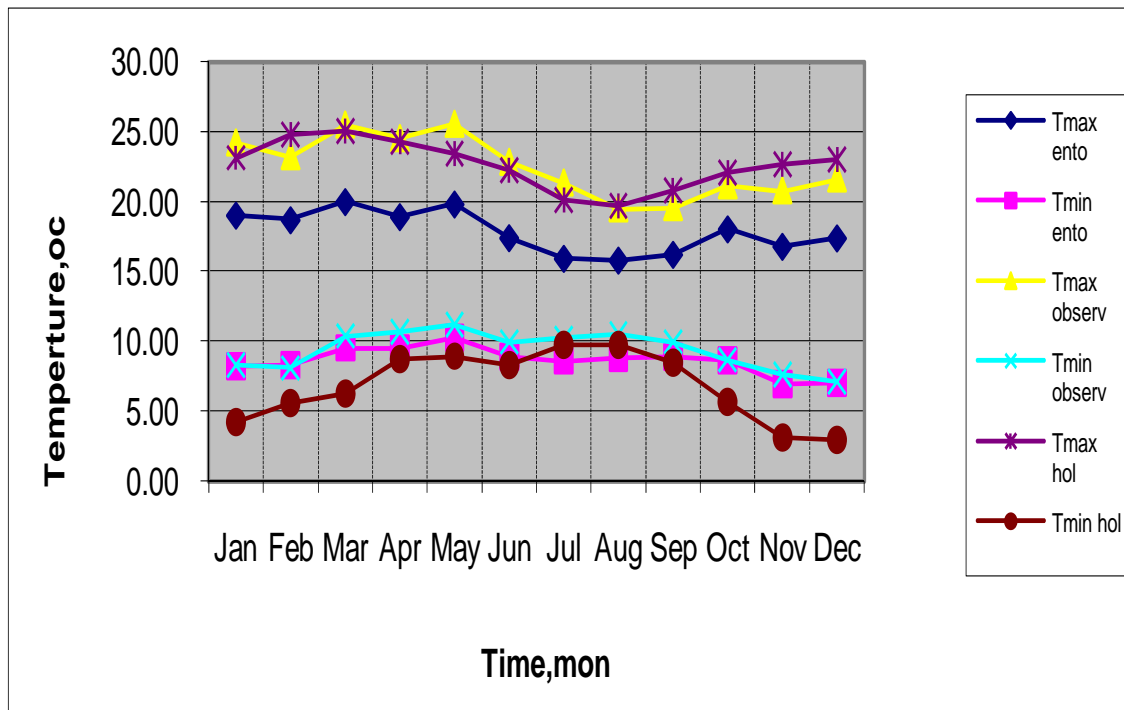


Fig 2.3 Mean monthly maximum and minimum temperature

2.4. Hydrology

The Gefersa River and its feeder streams are part of the Akaki river catchment. Most parts of the Akaki river basin is characterized by undulating topography steeper in the North, moderate in the middle and West; and relatively gentle and flat-laying in the South. In the South West, a flat grassland plain covered with thick black cotton soil covers the East of Addis Ababa –Jimma road and

it is swampy and extends in the Southeast direction. The catchment has been highly eroded by little Akaki river and its tributaries but in the Northern and Western parts the removal of topsoil is reduced due to the Eucalyptus tree that covers the area. Groundwater in this basin occurs in confined, unconfined and or semi-confined condition

2.5. Land Cover and Land Use

The land use and land cover types that were found in the catchment area are: cultivated fields, Eucalyptus woodland (mature and young), wooded shrub and grassland, pine woodland, grassland (wet and dry) bare soil, built-up areas (paved road, dam, concrete buildings) and a water body. The area surrounding the reservoir is covered by grasses and eucalyptus woodland, while the croplands are situated far from the reservoir area. The dominant land cover types found in the catchment area are: grassland, eucalyptus woodland (young and mature) and wooded – shrub-grassland which are important for environmental protection. The young and mature eucalyptus woodland covers the summit and sides of the mountain situated in the north-eastern part of the catchment area, the undulating plains and the steep sides of streams.(see section 4.2.2 for details)

2.6. Soil

Based on MoWE classification system, five soil types namely, chromic luvisol, chromic vertisols Eutric nitosols, Orthic soloncks and Vertic camisols are common soil types in the catchment (see section 4.2.3). The soil in the cultivated fields is yellowish-red and is intensively cultivated. The crop fields are cultivated for one year and left fallow in the next year. No continuous cropping is practiced on the same land because soil fertility is poor (according to the farmers of the area). Thus, only half of the land cropped each year (Bathymetric1999).

CHAPTER THREE

LITERAURE REVIEW

3.1 Watershed Hydrology

Beginning from the atmosphere water condenses to form drops of water. When they grow to a sufficient size, they fall as precipitation (rain, snow, hail etc). Part of the precipitation intercepted by natural vegetative cover is redistributed to runoff or may evaporate directly back to the atmosphere. Precipitation also moves into the soil in one of the most important process of the hydrologic cycle- Infiltration. Percolation is the downward movement of water through the soil profile after infiltration and it may be saturated (flow governed by gravity potential) or unsaturated (flow governed by capillarity potential). The movement of water from the liquid phase to the vapor phase and then to the atmosphere, occurring from any wet surface referred to as evaporation, effectively reduces the moisture in the soil. There may also be interception of the downward movement of water causing redistribution or it may also indicate the amount of water lost through evaporative process following precipitation.

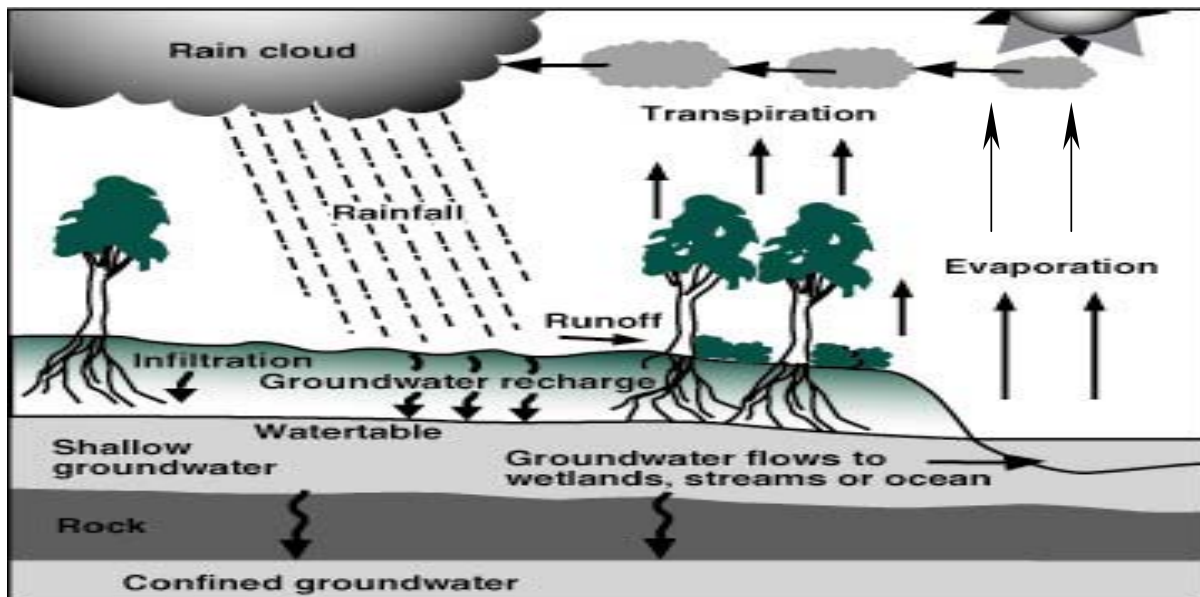


Figure 3.1: The hydrologic cycle or Water cycle (WRC, 2004).

Water also moves to the atmosphere through the stomata from the soil and roots via the plant's internal moisture supply system (transpiration). The combined evaporative processes are termed evapotranspiration. When the water reaches the stream it is referred to as streamflow, discharge and it may have been supplied by surface runoff, subsurface flow, storm flow and base flow (Black, 1991). Several locations serve as storage in the hydrologic cycle, water could be stored in the aerated unsaturated portion of the soil mantle and beneath the water table under saturated conditions. Huge amount can also be stored on top of the soil while a considerable amount could also be stored in vegetation. Surface storage could be in form of ponds, puddles, lakes and wetlands of all types as well as in rivers and stream channels. During the period immediately following a runoff-producing event, the amount of water on the watershed naturally diminishes. As this occurs the source of water for the streamflow reduces in size, with the distant upper slopes drying out first and according to Black (1991) in the last stages of runoff, if allowed to continue long enough, only the channel will be contributing to streamflow. The amount of water precipitating in any given year in the hydrosphere is about 0.00046% of the total water on earth (Black, 1991). This is what makes up the part of the hydrologic cycle with which man most commonly interacts forming links between various storages and serving as the source of floods or drought. Watershed runoff exhibits different characteristics, which are dependent on the storage from which it is derived.

3. 2. Soil Erosion and Sedimentation

The rapid erosion of soil by wind and water has been a problem ever since land was first cultivated. Consequences of soil erosion are both on and off-site. Onsite are particularly important on agricultural land where the breakdown of soil structure, redistribution of soil within field, the loss from a field, and the decline in organic matter and nutrient result in a reduction of cultivable depth and a decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity, which at first restricts, what can be grown and results in increased expenditure on fertilizers to maintain yield but later threatens food production and lead to land abandonment. Offsite problem result from sedimentation downstream or downwind.

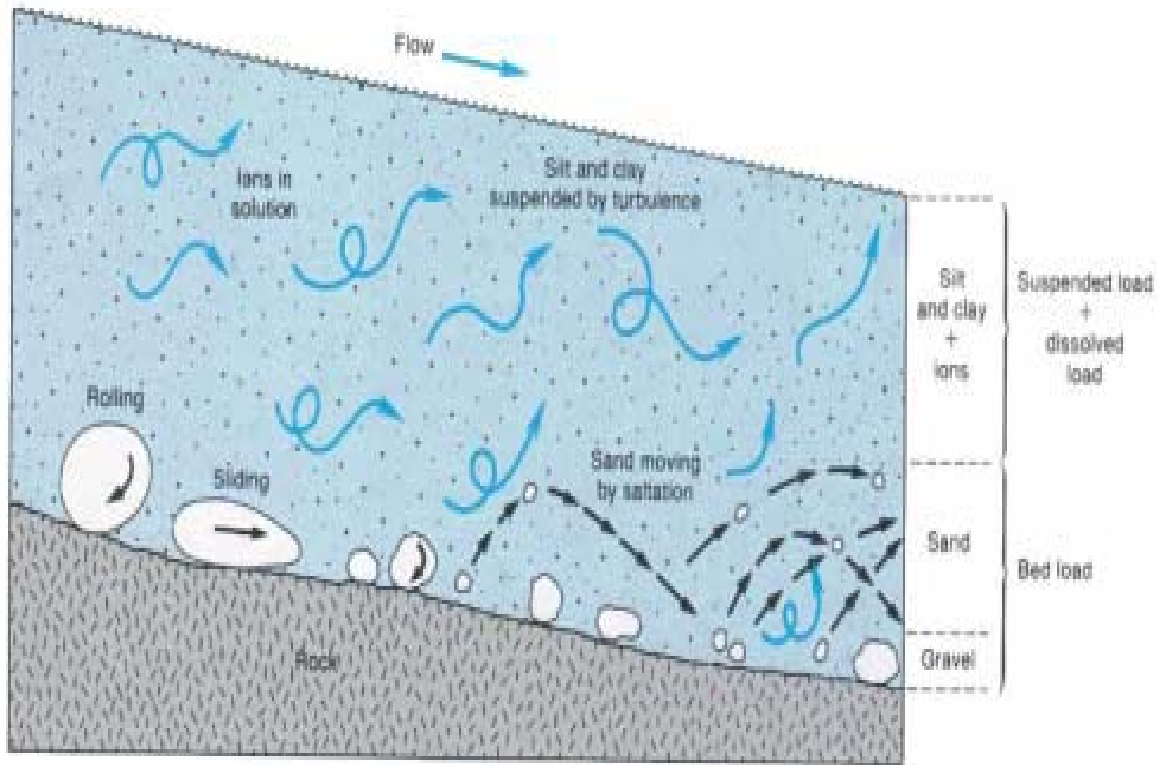


Figure 3.2 Composition and movement of sediment within the stream and along the Stream bed (Stoelting, 2004).

The impact of erosional processes can be summarized under three major headings namely a) soil productivity to crops, b) flood hazards and c) the life expectancy of water storage structures. But, environmental impact of delivered sediment also represents a major concern (El-Swaify & Dangler, 1982).

Peak rainfall seasons often produce uncontrolled runoff, which may result in floods. However, natural vegetation in high rainfall areas is most adequate to minimize runoff and erosional losses during those periods. Increasing human activities have been reported to disturb the natural hydrologic pattern, thus producing floods. These were previously unknown, increasing the destructiveness of existing floods, inducing water deficit at the locations of the disturbance due to excessive water losses by runoff and evaporation. The term sediment yield is the total sediment outflow from a watershed or drainage basin during a given time. It is the material, which is carried to some point of interest. As it is known, that not all soil loss is delivered to the

stream system – deposited at various locations in the watershed. Streams transport coarse sediments as bed load, while fine sediment is transported as suspended load (Fig. 3.2). Sources of sediment include soil erosion usually carried as suspended load and material eroded from the stream channel, which is transported as both suspended load and bed load. The major controlling factors for sediment yields are the climate and vegetation, basin size, elevation and relief, rock and soil type, land use and human activity all which in turns determines soil erosion rate and stream capacity.

3.3 Sediment Process

The process of sedimentation usually happens in the following stages:-

- i- Erosion,
- ii- Entrainment (drawing of particles into fluid),
- iii- Transportation,
- iv - Sedimentation/Compaction (deposition)

The processes are highly complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the flowing water. Once a particle has been eroded it must entrain before it can be transported away. Both entrainment and transport depend mainly upon the weight, shape, size and forces exerted on the particles by the flow. Deposition occurs when the forces are diminished enough leading to a reduction or cessation of transport. Therefore, when a river flow enters a reservoir, its velocity and transport capacity are reduced and its sediment load is eventually deposited. For example the amount and rate of deposition in a reservoir are determined mainly by:-

- Detention storage time
- The shape of the reservoir
- The operating procedure of the reservoir

The depositional pattern usually starts with the coarser material depositing towards the reservoir headwater, while finer sediment is transported further into the reservoir.

3.4. Overview of soil erosion and hydrological modelling

Many hydrological and soil erosion models are developed to describe the hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of sediments.

3.4.1. Soil erosion model

Soil erosion modelling is an important tool for viable conservation of natural, agricultural and built-up environments. Catchment-scale erosion modelling is particularly desirable, since it facilitates more efficient soil conservation planning (DeJong et al., 1999) by providing spatial data over large areas that may be used to decrease erosion related problems (Jetten et al., 2003; Cohen et al., 2008).

Erosion modeling is based on understanding of the physical laws of landscape processes that occur in the natural environment. Erosion models can provide a better understanding of natural phenomena such as transport and deposition of sediment by overland flow and allow for reasonable prediction and forecasting. Many different models have been proposed to describe and predict soil erosion by water and associated sediment yield. They vary considerably in their objectives, time and spatial scales involved. The models available in the literature for sediment yield estimation can be categorized in two main groups:

(1) Physical process based models and

(2) Empirical models

Physical process based models are intended to represent the essential mechanisms controlling erosion process by solving the corresponding equations. These models are the synthesis of individual components that affect the erosion processes and it is argued that they are highly capable to assess both the spatial and temporal variability of the natural erosion processes. The physical based models include WEPP and SHE . Physical based models are expected to provide

reliable estimates of the sediment yield. However, these models have the major draw back, since they require many parameters related with each processes as these models are organized in physical-based sub-models related to hydrology, hydraulics, meteorology and soil mechanics. As a result, the number of input parameters for some of the models may be as high as 50, as for instance in the case of the WEPP model (Nearing et al., 1989). Therefore, the practical application of these models is still limited because of uncertainty in specifying the values of the model parameter and due to the differences between the scales of application, which is a catchment versus field. The application of physical based models in many areas is further limited due to lack of data set required for the model simulation.

Empirical models are those that are based entirely on data not derived from relationship between variables and they are not based on physical parameters. Empirical models like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991), Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1975) and Agricultural Non point Source Pollution Model (AGNPS) (Young et al., 1987) are examples of commonly used watershed models based on USLE methodology to compute soil erosion. 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.. 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. 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.

3.4.2. Hydrological model

Why we need hydrologic models?

Hydrology is principally concerned with the study of the motion of the earth's waters through the hydrologic cycle, and the transport of constituents such as sediment and pollutants in the water as it flows (Maidment, 1996). Hydrological modelling is very important for prediction of runoff and soil erosion, and is a major tool for research hydrologists and water resources engineers for planning and management of water resources. Hydrological models can be used to estimate river flows at ungauged sites, fill gaps in incomplete data series or predict future runoff and river flows. The need for hydrological models is increasing both in aspects of coverage and functionality. Also more and more researchers and practitioners require access to hydrological models and in particular model simulation results. Hence, hydrological models need to be more robust, transparent and defensible as they are increasingly relied on to make informed decisions on sharing and managing of limited water resources (Chiew, 2007). Distributed hydrological models consider the spatial non-uniformity of hydrological characteristics and processes in the river basin. These models are based on our understanding of the physics of the hydrological processes which control catchment response and use physically based equations to describe these processes. These models can be applied for the study of the effects of land use changes and human intervention on the catchment behavior.

Hydrological models are tools that describe the physical processes controlling the transformation of precipitation to stream flows. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. The focus of these models is to establish a relationship between various hydrological components such as precipitation, evapotranspiration, surface runoff, ground water flow and soil water movement (infiltration). Many of these hydrological models describe the canopy interception, evaporation, transpiration, snowmelt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated subsurface flow. These models range from simple unit hydrograph based models to more complex models that are based on the dynamic flow equations. Simulation programs implementing watershed hydrology and river water quality models are important tools for watershed management for both applied and operational research purposes.

A hydrological model represents the water cycle of a drainage basin and studies the response of this basin to climatic and physical conditions. Three different categories of hydrological models can be distinguished: physically process based, empirical and statistically based.

Physically process based models are described by mathematically formulated fundamental physical laws, where each basin is represented by a concept; a reservoir for instance. They are useful for inferring the distribution, magnitude, and past, present and future behavior of a process with limited observations. These equations can relate the changes of water properties into the reach to those across the surface. These physical processes vary both temporally and spatially. They consider the spatial and temporal changes of different factors (Jaroslav et al., 1996). Physically based distributed watershed models play also a major role in analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds.

Empirical models are a synthesis and a summary of field or experimental observations. Their fundamental parameters are not compulsory physically related. Empirical models are based on defining important factors through field observation, measurement, experiments and statistical methods (Petter, 1992). They are useful in predicting the hydrology or soil erosion, but are site specific and require long-term data (Elirehema, 2001). Empirical models are the result of several years of research data and numerically evaluate the effects of climate, soil properties, topography and crop management.

Statistically based models use many observations to estimate the behavior of watersheds and their interactions. They can be physically or empirically based.

In addition to categorizing both soil erosion and hydrological models with respect to the way they are being synthesized, another distinction is the difference between distributed and global models. In global models, the watershed is one single entity and in distributed models, many units represent the variability of hydrological parameters on the surface. Spatial variability is handled by dividing a drainage basin into smaller geographical units, such as sub basins, land cover classes, elevation zones or a combination of them. The hydrological response units

(HRUs) represent areas where the modeling simplified and where the hydrological response is supposed to be homogeneous.

In recent years, distributed watershed models are increasingly used to study alternative management strategies in the areas of water resources allocation, flood control, impact of land use change and climate change, and finally environmental pollution control. Many of these models share a common base in their attempt to incorporate the heterogeneity of the watershed and spatial distribution of topography, vegetation, land use, soil characteristics, rainfall and evaporation. Some of the watershed models developed in the last two decades are CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel,, EPIC - Erosion Productivity Impact Calculator (Williams, 1995), AGNPS (Agricultural None Point Source model) (Young et al.,1987), SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998) and HSPF (Hydrologic Simulation Program – Fortran) (Bicknell et al., 2001), ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation) (Beasley and Huggins, 1982), EROSION-3D (SCHMIDT, 1995), EUROSEM (European Soil Erosion Model) (Morgan et. al., 1997), WEPP (Water Erosion Prediction Project) (Foster and Lane, 1987) etc.

Among the above mentioned models, the physically based distributed model SWAT is a well established model for analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds. It is one of the watershed models for long term impact analysis. It is widely applied in many parts of United States and many other countries like Ethiopia.

3.5 Previous Study

Sedimentation is an important issue for the Gefersa dams as it directly influences the reservoir capacities and satisfaction of the water demand. Several topographic survey or bathymetric survey of the Gefersa reservoirs have been carried out in 1955,1964,1979 and 1998 and have concerned Gefersa I/II (all studies) and Gefersa III(1998 study).

The 1955 topographic survey was made by USAOM. In 1964, Lahmeyer made a survey which give interesting results. Following the 1964 survey, the Gefersa III dam was built as a sediment trap upstream of the old Gefersa I/II dam (1966).Lahmeyer assessed that the 1964 sedimentation,

based on the 1955 lake level, amounted to about 380,000m³. This siltation is mainly located at the bottom of the reservoir since 90% of deposits are below 2596m (116.5 local scales) .They, found that 214,000m³ were deposited from 1939 to 1955 and 160,000m³ from 1956 to 1964. And there is 289,282m³ were deposit from 1966 to 1979.

BECOM and TAHAL performed bathymetric survey in 1979 and 1998 respectively. The loss of capacity between 1979 and 1998 is about 420,000 m³ (at elevation 121 i.e. the present sill elevation).

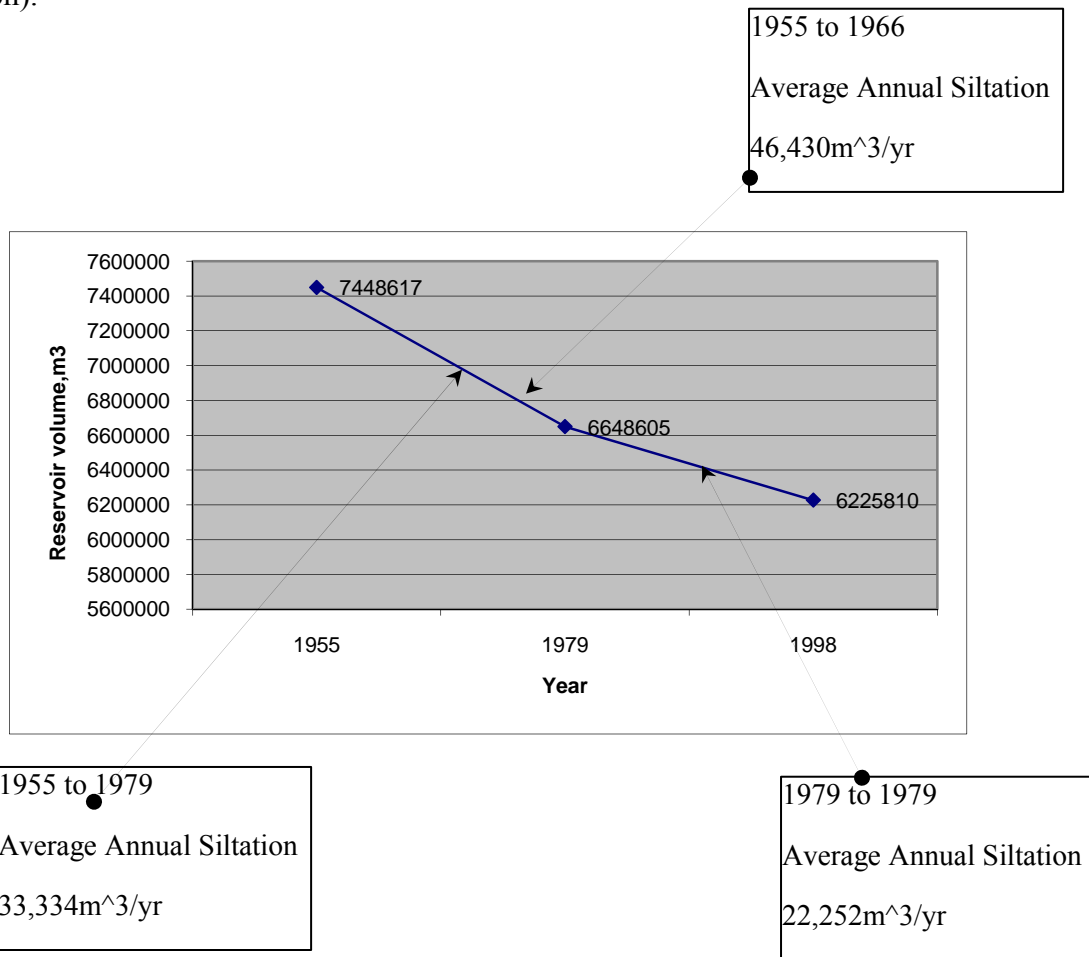


Figure3.3Geffersa Reservoir: Siltation rate estimate (Bathymetric survey, 1999)

CHAPTER FOUR

MATERIALS AND METHODS

4.0. Field Visit

A field visit to the study area was conducted for duration of several days. The objective was to become familiar with the topography, foremost land-use and land cover of the study area and to have better sense of its hydrology during hydrological modeling (SWAT).



Fig.4.1.Photo of Gefersa catchment (Photo taken Feb, 2011)

4.1. Modelling

4.1.1. Definition of modeling

A model in its broadest sense is a simplified depiction of a natural entity that in some way exhibits its important features while eliminating or suppressing matters of irrelevant detail. In science and engineering, an essential attribute of a model is that it be quantitative, that is, that it yields a numerical value for a feature of the natural entity, as a replacement for a measurement. A quantitative model can be used to explore cause-and effect relations and to determine values of physical variables that are too costly or difficult to measure directly. Models have long been used in water resources management to guide decision making and improve understanding of the system. It is essential that a model used in water-resources management be sufficiently accurate for its intended purpose. Because a model is a simplified depiction of the natural system, its accuracy is subject to question until proven the acceptability of a model can only be determined by a confrontation with observation. Therefore, the existence of a model does not obviate the need for data from the watercourse, but in fact imposes additional needs and requirements on the data base.

4.1.2. SOIL AND WATER ASSESSMENT TOOL (SWAT)

4.1.2.1 SWAT Theory

The SWAT model is a long-term, continuous simulation watershed model. It operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail by allowing the division of watersheds into smaller subwatersheds (Neitsch et al, 2005). SWAT models water flow, sediment transport, crop/vegetation growth, and nutrient cycling. The model allows users to model watersheds with less monitoring data and to assess predictive scenarios using alternative input data such as climate, land-use practices, and land cover on water movement, nutrient cycling, water quality,

and other outputs. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. Several model components have been previously validated for a variety of watersheds. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2 meters), shallow aquifer (typically 2-20 meters), and deep aquifer (more than 20 meters). The soil profile can be subdivided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. Flow, sediment, nutrient, and pesticide loadings from each HRU in a subwatershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. SWAT theoretical considerations were explained briefly in the following sections.

4.1.2.2. SWAT hydrologic simulation

The water balance is the driving force for the simulation of hydrology. SWAT uses two steps for the simulation of hydrology, land phase and routing phase. The land phase is the phase in which the amount of water, sediment, nutrient and pesticides loadings in the main channel from each subbasin are calculated.

$$SW_t = SW_o + \sum_{i=1}^t P_{day} - Q_{surf} - AET - Q_{seep} - Q_g \text{ -----(4.1)}$$

Where SW_t is the final water content in millimeters (mm), SW_o is the initial soil water content on day i (mm), P_{day} is the precipitation on day i (mm), Q_{surf} is the surface runoff on day i (mm), AET is the actual evapo-transpiration on day i (mm), Q_{seep} is the water entering the deep percolation from the soil profile on day i (mm), and Q_g is the return flow from lateral flow on day i (mm)

SWAT 2005 uses the concept that surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. Based on this assumption, SWAT uses two methods for estimating surface runoff: the Soil Conservation Service Curve Number technique (USDA Soil Conservation Service, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911). In the Soil Conservation Service (SCS) curve number method often called the

Curve-Number (CN) method, land use and soil characteristics are lumped into a single parameter. The initial value for CN is assigned by the user for each HRU then SWAT calculates the lower and upper limit. For this calculation, SWAT uses a soil classification based on the Natural Resource Conservation Services (NRCS). This classifies soil into four hydrologic groups (a soil group has similar runoff potential under similar storm and cover condition (NRCS, 1996)) based on infiltration characteristics of the soil (Neitsch et al. 2005). After this classification the model defines three antecedent moisture conditions to determine the appropriate CN for each day using the CN-AMC (Curve Number – Antecedent Soil Moisture Condition) distribution based on the moisture content of the soil calculated by the model (Neitsch et al., 2005). This daily CN then used to determine a theoretical capacity S (retention parameter) that can be infiltrated.

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

$$Q = \frac{(R - 0.2S)}{R + 0.8S} \quad R > 0.2 S \dots\dots\dots 4.2$$

$$Q = 0 \quad R < 0.2 S \dots\dots\dots 4.3$$

Where Q is the daily surface runoff (mm), R is the daily rainfall (mm), and S is a retention Parameter. The retention parameter, S , varies (a) among watersheds because soils, landuse ,management, and slope all differ from each other and (b) with time because of changes in soil water content. The parameter S is related to curve number (CN) by the SCS equation

$$S = 25.4 \left[\frac{1000}{CN} - 10 \right] \dots\dots\dots 4.4$$

The Green & Ampt method requires sub daily precipitation data and calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity. Water that does not infiltrate become surface runoff.

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

The rational formula is:

$$q = \frac{CIA}{3.6} \text{-----(4.5)}$$

Where: q_{peak} : is the peak runoff rate (m³/s),

C: is the runoff coefficient,

i- is the rainfall intensity (mm/hr),

A- is the sub basin area (km²) and

3.6 is a unit conversion factor

The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. The rate and velocity of flow is calculated by using the Manning equation. The main channels or reaches are assumed to have a trapezoidal cross section by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. While calculating the water balance in the channel flow, the transmission and evaporation losses are also considered by the model. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In the latter method, 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. For this study, the variable storage method was adopted. Storage routing is based on the continuity equation

$$\Delta V_{\text{storage}} = V_{\text{in}} - V_{\text{out}} \text{----- (4.6)}$$

Where: V_{in} is the volume of inflow during the time step (m³ water), V_{out} is the volume of outflow during the time step (m³ water), and V_{stored} is the change in volume of storage during the time step (m³ water). Detail of the equation was given in SWAT manual.

There are many methods that are developed to estimate potential evapotranspiration (PET). Three methods are incorporated into SWAT:

- the Penman-Monteith method (Monteith, 1965),
- the Priestley-Taylor method (Priestley and Taylor, 1972)
- the Hargreaves method (Hargreaves et al., 1985).

The Penman-Monteith method requires solar radiation, air temperature, wind speed and relative humidity. Priestley-Taylor method requires solar radiation, air temperature and relative humidity; where as Hargreaves method requires air temperature only. Priestley and Taylor (1972) used the following equation to estimate PET:

$$\lambda E_o = \alpha_{pet} * \frac{\Delta}{\Delta + \alpha} (H_{net} - G) \text{-----} (4.7)$$

Where: λ is the latent heat of vaporization (MJ/kg),

E_o is the potential evapotranspiration (mm/day),

α_{pet} is a coefficient, ($\alpha_{pet} = 1.28$ when the general surroundings are wet or under humid condition),

Δ is slope of saturation vapour pressure-temperature curve de/dT (kPa/°C),

γ is the psychrometric constant (kPa/°C),

H_{net} is the net radiation (MJ/m²day), and

G is the heat flux density to the ground (MJ/m²day).

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

$$\lambda E_o = 0.0023 * H_0 * (T_{max} - T_{min})^{0.5} * (\overline{T_{avg}} + 17.8) \text{-----} (4.8)$$

Where: λ is the latent heat of vaporization (MJ/kg),
 E_o is the potential evapotranspiration (mm/day),
 H_0 is the extraterrestrial radiation (MJ/m²day),
 T_{max} is the maximum air temperature for a given day (°C),
 T_{min} is the minimum air temperature for a given day (°C), and
 T_{av} is the mean air temperature for a given day (°C).

4.1.2.3. SWAT Sediment simulation

Erosion and sediment yield are estimated for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE)

$$Sed = 11.8(Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \text{-----} (4.9)$$

Where: sed- is the sediment yield on a given day (metric tons),

Q_{surf} is the surface runoff volume (mm H₂O/ha),

q_{peak} is the peak runoff rate (m³/s),

$area_{hru}$ is the area of the HRU (ha),

K_{USLE} is the USLE soil erodibility factor

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.

Channel routing consists of flood and sediment routing. The flood routing model uses a variable storage coefficient method developed by Williams. Channel inputs include the reach length,

channel slope, bankfull width and depth, channel side slope, flood plain slope, and Manning's n for channel and floodplain. Flow rate and average velocity are calculated using Manning's equation and travel time is computed by dividing channel length by velocity. Outflow from a channel is also adjusted for transmission losses, evaporation, diversions, and return flow. The channel sediment routing equation uses a modification of Bagnold's sediment transport equation that estimates the transport concentration capacity as a function of velocity:

$$CY_u = SPCON * V^{SPEXP} \dots\dots\dots (4.10)$$

Where, CY_u is sediment transport concentration capacity in g/m³; SPCON is the concentration capacity in g/m³ at a velocity of 1 m/s; V is flow velocity in m/s; and SPEXP is a constant in Bagnold's equation. The SWAT model either deposits excess sediment or reentrains sediments through channel erosion depending on the sediment load entering the channel.

4.2. SWAT Model Setup

SWAT is a comprehensive model that requires information provided by the user to simulate runoff and soil erosion. The first step in initializing a watershed simulation is to partition the watershed into subbasins. The user has the option of allowing SWAT to automatically delineate the watershed and subbasins using the Digital Elevation Model (DEM) or the user can provide predefined subbasins. The land area in a subbasin is divided into hydrologic response units (HRUs). Hydrologic response units (HRUs) are portions of a subbasin and possess unique land use, slope range, and soil attributes (Neitsch et al., 2004). SWAT has different components. Hydrologic components of the model work on the water balance equation, which is based on surface runoff, precipitation, percolation, evapotranspiration, and return flow data; Weather is one of the model component that needs data on precipitation, air temperature, solar radiation, wind speed, and relative humidity data; Sedimentation is another component of the model that needs information on surface runoff, peak rate flow, soil erodibility, crop management, conservation practices, slope length, and steepness; Soil temperature, crop growth, nutrient pesticides and agricultural management are also components of SWAT. Thus, the data required for the model are DEM, soil data, land use data, precipitation and other weather data. For calibrating the model and also for validation purposes, river discharge and sediment yield are required at the outlet of the watershed.

4.2.1. DEM setup and Watershed Delineation

DEM Setup

The digital elevation model (DEM) data was used to delineate the sub-watersheds in the arc SWAT interface. The DEM data with a resolution of 30mx30m was collected from MOWR ,then using Global mapper 8 export as DEM .To delineate the watershed Digital Elevation Map (DEM) grid, mask grid and digitized stream network files were loaded using the watershed delineation tool. Topographic information was obtained from DEM which has projection. Before the DEM data was loaded in to Arc SWAT interface, it was projected into projected coordinate system. The projection of the DEM data was done using the Arc tool box operation in ArcGIS 9.3. The projected coordinate system parameters of Ethiopia (study area) are: UTM other GCS— Adindan UTM zone 37N.prj. The masking was done to focus catchment area because DEM covers more area than the watershed to be modelled. Hence, only the portion of the DEM covered by the mask processed by the interface

Watershed delineation

SWAT allows the user to delineate the watershed and subbasins using the Digital Elevation Model (DEM). This tool uses and expands ArcGIS and Spatial Analyst extension functions to perform watershed delineation (Neitsch et al., 2002). The DEM of the area is loaded into an ESRI (Environmental System Research Institute) grid format. Stream network was defined for the whole DEM by SWAT using the concept of flow direction and flow accumulation. Before defining the stream network, the model processes the DEM map grid to remove all the non-draining zones (sinks). To define the origin of streams a threshold area was defined. The threshold area defines the minimum drainage area required to from the origin of a stream. The size and number of subbasins and details of stream network depends on this threshold area. The threshold area was taken to be 750ha.The threshold area, or critical source area, defines the minimum drainage area required to form the origin of a stream. The watershed outlet is added and selected for finalizing the watershed delineation. With this information the model automatically produced 6 subbasins.

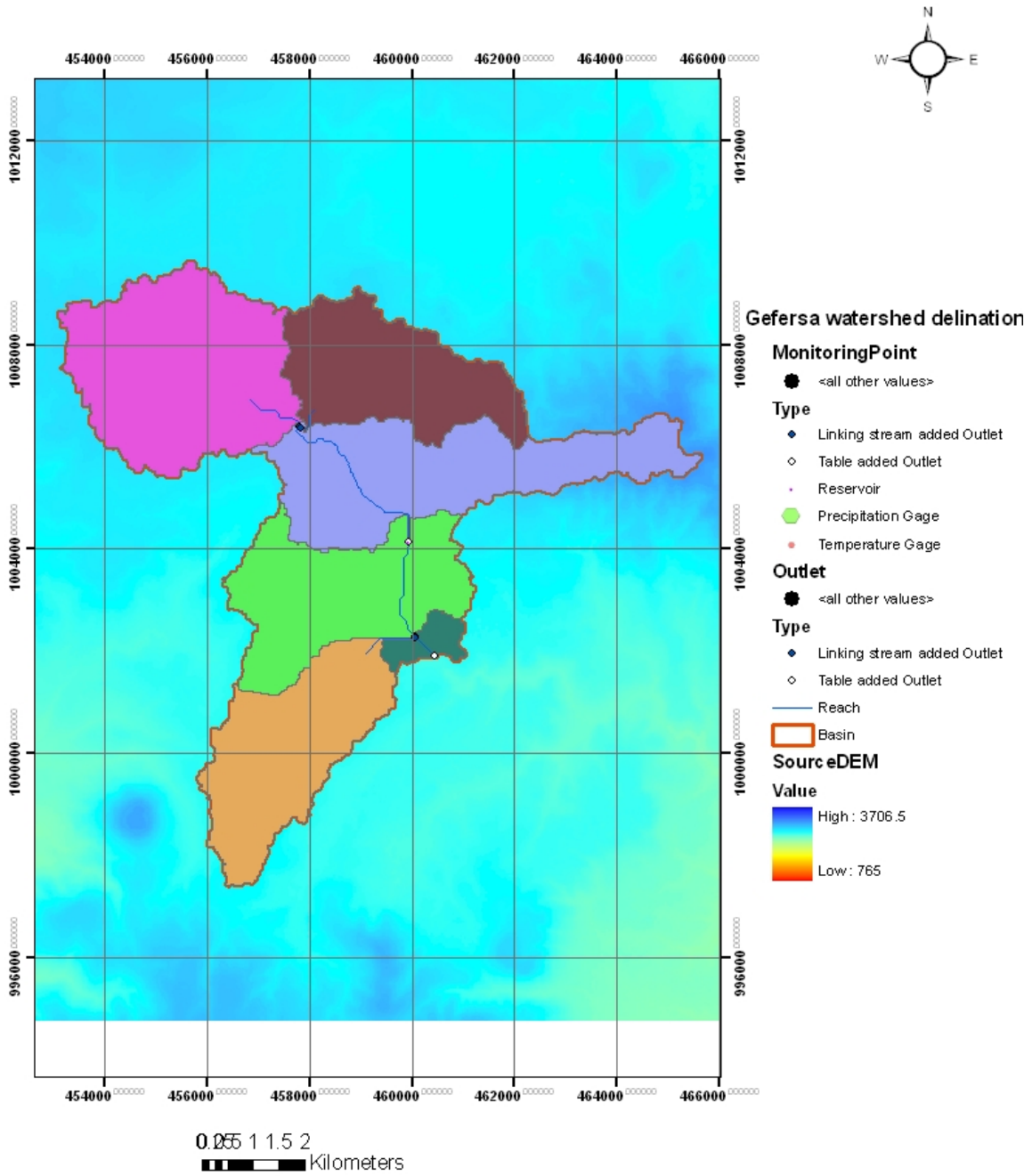


Figure4.3 Gefersa Watershed

4.2.2 Landuse/Landcover

Land use / Land cover are the one of the spatial input data required by SWAT model. Land use /Land cover data were collected from AAWSA, which was used during bathymetric survey from 1996-1999. The Land use /Landcover were collected in jpg (photo) format, so digitizing and georeferencing of the photo using arc catalog were done for each landuse and generate shape file and attribute table for each cover. Then, The land use/cover data reclassified according to the SWAT land use/cover type. A look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use were prepared so as to relate the grid values to SWAT land cover/land use classes. SWAT calculated the area covered by each land use.

No	Description	SWAT Code	Area(KM ²)	%Of Total area
1	Generic Agricultural Land	AGRL	12.919	23.494
2	Forest Mixed Deciduous and Evergreen	FRST	27.841	50.629
3	Rangeland Grass	RNGE	12.99	23.611
4	Water body	WATR	1.249	2.266
TOTAL			54.99	100

Table4.1 SWAT Landuse/Land covers of Gefersa Catchment

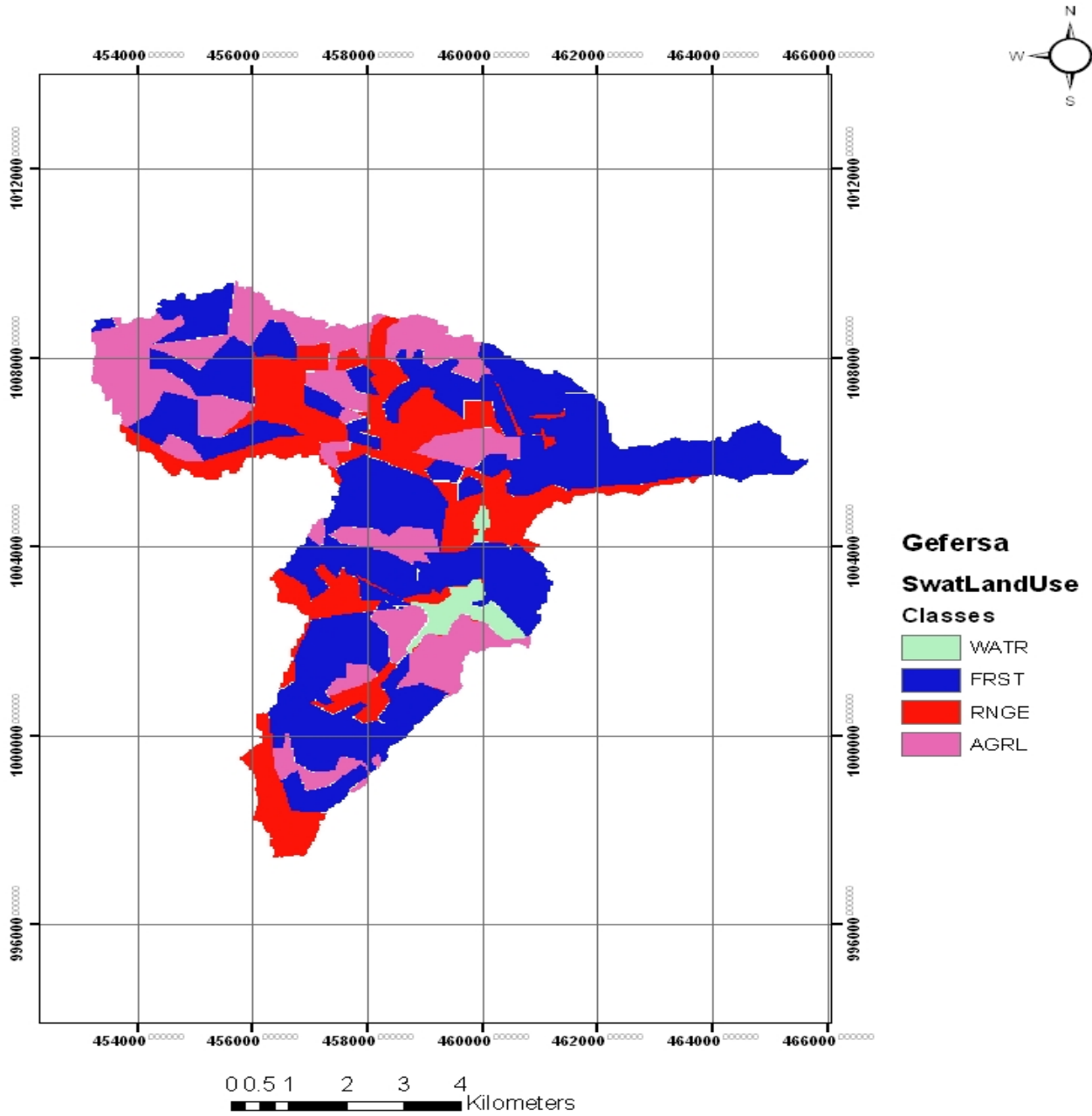


Figure4.4 Landuse/Landcover of Gefersa Catchment

4.2.3. Soil Data

Soil data are another spatial input required by SWAT. SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. The major aim of soil classification is to convert user's soils into SWAT database (or grid properties). The soil types found in Gefersa catchment is not found in U.S database. So that, SWAT does not recognize Stmuid for Gefersa catchment. To overcome this shorthand, instead of use the Stmuid to classify the soils, new soils and their properties were added to the soil database. That was done with the soil Database Editor. The soil characteristics were entered manually. To facilitate their manipulation they were rearranged in an EXCEL table. The data's were obtained mainly from the following sources: Awash River basin Soil database from the Ministry of Water and Energy and Harmonized soil database (FAO). Physical soil property calculator was used to calculate the available soil moisture content, bulk density and saturated hydraulic conductivity. Where as the soil erodibility (K) factor was calculated according to Williams (1995) by using equation 4.11 to 4.15

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand} \text{-----}(4.11)$$

Where f_{csand} is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand, f_{cl-si} is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The factors are calculated by using equation 4.12 to 4.14

$$f_{csand} = (0.2+0.3*exp(-0.256*ms*(1-msilt/100))\text{-----}(4.12)$$

$$f_{cl-si} = \left[\frac{m_{silt}}{m_c + m_{silt}} \right]^{0.3} \text{-----} (4.13)$$

$$f_{orgc} = \left[1 - \frac{0.25 * orgc}{orgc + exp[3.72 - 2.95 * orgc]} \right] \text{-----}(4.14)$$

$$f_{\text{hisand}} = 1 - \frac{0.7 * (1 - \frac{m_s}{100})}{(1 - \frac{m_s}{100}) + \exp\left[-5.51 + 22.9(1 - \frac{m_s}{100})\right]} \quad \text{-----(4.15)}$$

Where m_s is the percent sand content (0.05-2.00 mm diameter particles), m_{silt} is the percent silt content (0.002-0.05 mm diameter particles), m_c is the percent clay content (< 0.002 mm diameter particles), and $orgC$ is the percent organic carbon content of the layer (%).

No	Soil type	Area(KM ²)	%Of Total area
1	Vertic Cambisols	30.97	56.31
2	Orthic Solonaks	3.03	5.51
3	Chromic Vertisols	14.92	27.12
4	Eutric Nitosols	5.26	9.57
5	Chromic Luvisols	0.81	1.49
TOTAL		54.99	100

Table 4.2 Soil type of Gefersa Catchment

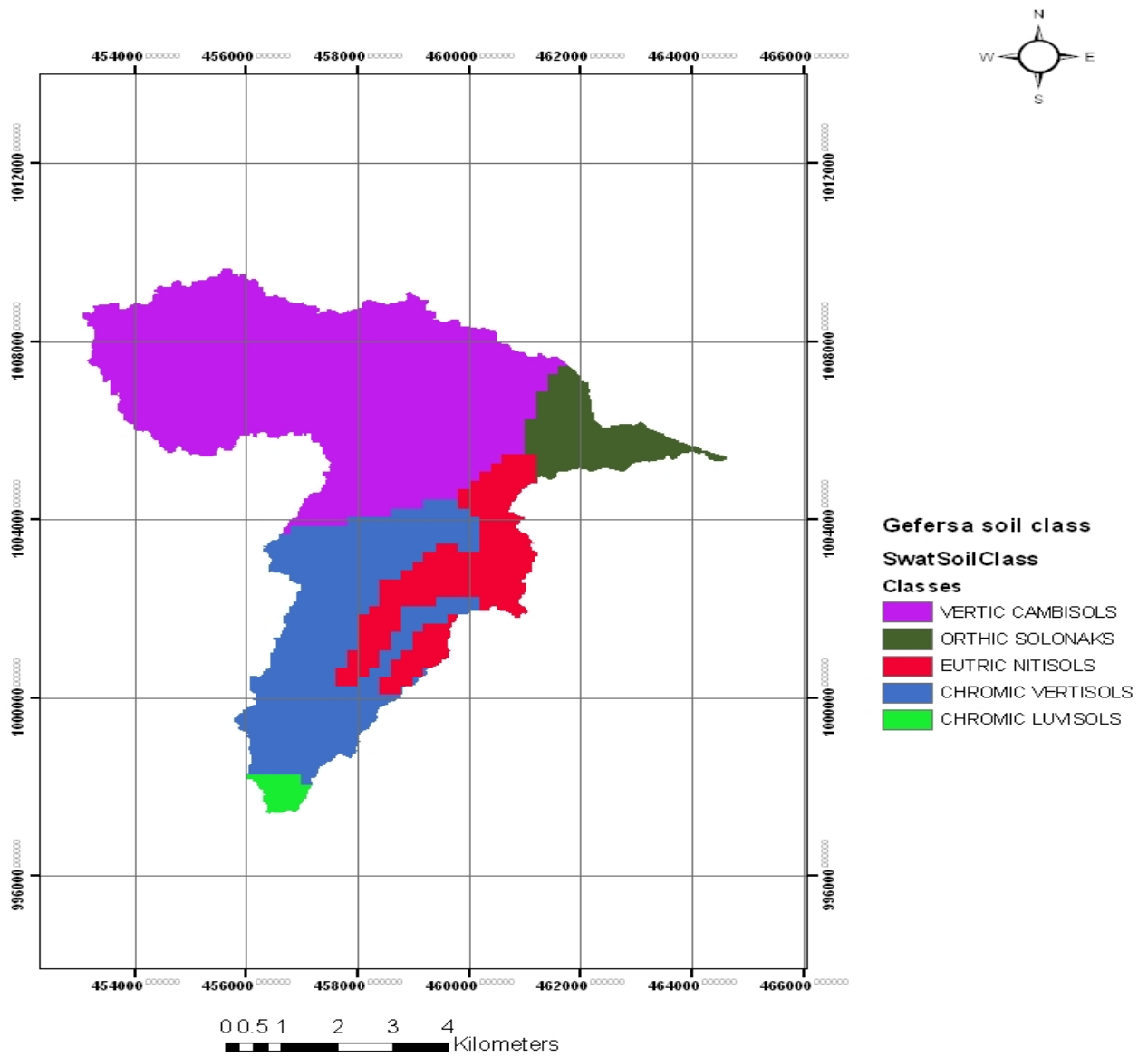


Figure.4.5. Soil map of Gefersa Catchment

HRU Definition

The Hydrologic Response Units (HRUs) Analysis tool in Arc SWAT helps to load landuse and soil layers to the project. The delineated watershed by Arc SWAT and the prepared land use overlapped analysis in Arc SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option for considering different slope classes for HRU definition) 20%, 20% and 20% for Landuse, soil and Slope class respectively was selected for this study .Based on the above classification, we have 46 hru in the Gefersa catchment.

4.2.4. Indirect method of Flow calculation

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and during any period of time, the difference between total input and Output will be balanced by the change of water storage within the volume. In general, therefore, use of a water-balance technique implies measurements of both storages and fluxes (rates of flow) of Water, though by appropriate selection of the volume and period of time for which the balance will be applied. The water balance equation for any natural area (such as a river basin) or water body indicates the relative values of inflow, outflow and change in water storage for the area or body. The tributaries, which contribute their flows to Gefersa reservoirs, have not been gauged. However with the effort to simulate the behavior of the watershed a back-calculation process has been implemented. The required information for the back-calculation is the water level – storage and water level –spillway relationship. This relationship of Gefersa Reservoir was provided by AAWSA. The water balance for any water body and any time interval in its general form may be represented by the following equation:

$$\text{Inflow} + ((\text{Rainfall-Evaporation}) * \text{Area}) = \text{Change in storage} + \text{Raw water supply} + \text{Spill} + \text{Process loss} + \text{Bottom Outlet} \text{-----} (4.16)$$

With

$$\text{Raw Water Supply} = \text{Treated water} + \text{Process Losses}$$

$$\text{Process loss} = 5\%-10\% \text{ of treated water}$$

Where A is surface area of reservoir

Therefore

$$\text{Inflow} = (\text{Change in storage} + \text{Raw water supply} + \text{Spill} + \text{Process loss} + \text{Bottom Outlet})$$

$$- (\text{Rainfall-Evaporation}) * \text{Area}$$

4.2.4.1. Methods of Computation of the main water balance components

A) Precipitation

Precipitation is usually the only source of moisture coming to the land surface and thus the accuracy of measurement and computation of precipitation determines to a considerable extent the reliability of all water-balance computations. The mean amount of precipitation, in a river basin or any other area, is determined by precipitation gauges, installed within the area under study.

B) Evaporation

Evaporation (EL) from lakes and reservoirs may be estimated from evaporimeter data by

$$EL = K E_p \text{-----} (4.17)$$

Where E_p is the evaporation from the pan or tank evaporimeter and K is an empirical coefficient. A pan coefficient of 0.7 is used in our case.

C) Volume of Reservoir

The volume of the Reservoir was calculated using elevation –storage curve of the Reservoir.

D) Spillway and Bottom outlet

The sill level of the reservoir is 2585.61m (121m local scale) above this level, there is spillway of water and at the same time bottom outlet also opened. The spillway discharge was calculated from Lake Level and the bottom outlet discharge is measured approximately in terms of duration of Gate opening..

E) Raw water supply

The water supply is measured on daily basis. Addis Ababa Water and Sewerage Authority supply an average of 30,000m³ per day of treated water for the city of Addis Ababa.

4.2.4.2. Checking indirect method of flow calculation

The generated inflows were checked using the area ratio method. This method considers only catchment areas by assuming that the catchment area is the dominant factors that control the volume of water as produced by rainfall by assuming the climate and physical catchment will be the same. In order to apply the above method a gauged river which is found downstream of Gefersa i.e. Little Akaki is used. The area ratio method is based on the assumption that the stream flow for a site of interest can be estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby stream flow-gauging station by the stream flow for the nearby stream flow-gauging station. Thus, the drainage-area ratio method is given by

$$Q_u = \left[\frac{A_u}{A_g} \right]^n * Q_g \text{----- (4.14)}$$

Where

Q_u is the estimated stream flow, in cubic meter per second;

A_u is the drainage area, in square kilometer, for the site of interest;

A_g is the drainage area, in square kilometer, for the stream flow-gauging station; and

Q_g is the stream flow, in cubic meter per second for gauging station i.e. Little Akaki

n Varies between 0.6-1.2

If the A_{site} is within 20% of the A_{gauge} ($0.8 \leq \frac{A_{site}}{A_{gaged}} \leq 1.2$), then $n=1$ to be used. The estimated discharge at the site will be within 10% of actual discharge

$$\text{For Gefersa catchment} = \frac{A_{site}}{A_{gaged}} = \frac{55}{131} = 0.419847$$

Since the ratio is lower than the range of the area ratio the value of n should be taken the minimum value i.e. 0.6

$$Q_{site} = Q_{gaged} * (0.419847)^{0.6} = Q_{gaged} * 0.5940935 \dots \dots \dots (4.15)$$

4.2.5. Weather Data

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, and relative humidity and wind speed. The Weather Data Definition dialog is divided in five sections: Weather Simulation data, Rainfall data, Temperature data, Solar Radiation data, Wind Speed data, and Relative Humidity data. The first one listed must be set prior to proceed with the next input data. Read these inputs from a file or generate the values using monthly average data summarized over a number of years. To generate the values, SWAT includes the WXGEN weather generator model (Neitsch, et al, 2001) that generates the climatic data and fill in gaps in measured records. This weather generator was developed only for the contiguous US and cannot be use for Gefersa catchment. Therefore, the only option was to collect the weather data available for the weather stations in the Reserve and analyzed them to make the required calculations. The data's were obtained from Ethiopian National Meteorological Agency (NMA), and Holeta National Agricultural Research Center (HNARC) for stations located within and around the watershed. Once collected, the daily values were rearranged, using EXCEL, and converted to dBase (.dbf) format. The daily values are used in the Weather Station into the SWAT Input menu.

4.2.6. Simulation approach

The ARCSWAT 2005 model was used in the watershed delineation process, which includes processing of DEM data for stream network delineation followed by subwatershed delineation. A total of six subwatersheds were delineated for the entire Gefersa catchment (see Figure 4.3). The

subwatersheds were then further subdivided into HRUs that were created for each unique combination of land use and soil. Thresholds values of 20 % for land cover and 20 % for the soil area were applied to limit the number of HRUs in each subwatershed. After the model setup, SWAT was executed with the following simulations options: (1) the Runoff Curve Number method for estimating surface runoff from precipitation, (2) the Hargreaves method for estimating potential evapotranspiration generation, and (3) the Variable storage method is used to simulate channel water routing. A simulation period of 2005 through 2009 was selected for the sensitivity analysis. Several model runs were executed for each input parameter with a range of values, keeping simulation options and other parameters' values constant. The analysis provided information on the most to least sensitive parameters for flow response of the watershed. Due to limitation of data, the model was calibrated for the period from 2005 to 2007 and validated for 2008 and 2009. For sediment, we use the Bathymetric survey data for calibration from 1979 to 1992 and from 1993 to 1999 for validation on annual basis. Three statistical approaches were used to evaluate the model performance: coefficient of determination (R^2), Nash-Sutcliffe simulation efficiency (E_{ns}) and the percent difference for quantity (D). The R^2 value is an indicator of the strength of relationship between the observed and simulated values; E_{ns} indicates how well the plot of observed versus simulated value fits the 1:1 line. If the R^2 value is close to zero and the E value is less than or close to zero, the model prediction is considered unacceptable. If the values approach one, the model predictions become perfect. And D indicates whether the model overestimates or underestimates the measured value

4.3. Evaluation of model prediction

The evaluation of the model was carried out to determine whether the model can accurately represent the physical processes occurring in a watershed. At present, statistical methods are the most commonly used form of evaluation and there are numerous statistical analysis methods available for evaluating the results of a model simulation. We used the correlation coefficient (R) Nash-Sutcliffe coefficient (E_{NS}) and the percent difference for a quantity (D)

The r^2 value is an indicator of strength of relationship between the observed and simulated values. It is calculated by the following equation:

$$r2 = \frac{\left[\sum_{i=1}^n (q_{si} - \overline{q_s})(q_{oi} - \overline{q_o}) \right]^2}{\sum_{i=1}^n (q_{si} - \overline{q_s})^2 \sum_{i=1}^n (q_{oi} - \overline{q_o})^2} \dots\dots\dots (4.18)$$

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

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

q_s is the average simulated value of the quantity in each model time step (in this case, monthly and yearly)

q_o -is the average measured value of the quantity in each model time step (in this case, monthly and yearly.)

Nash-Sutcliffe simulation efficiency, E_{ns} , indicates the degree of fitness of the observed and simulated plots with the 1:1 line (Santhi et al. 2002). It is calculated by the following equation:

$$E_{ns} = 1 - \frac{\sum_{i=1}^n (q_{oi} - q_{si})^2}{\sum_{i=1}^n (q_{oi} - \overline{q_o})^2} \dots\dots\dots (4.19)$$

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

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

The percent difference for a quantity (D) over a specified period with total days is calculated from measured and simulated values of the quantity in each model time step as:

$$D = 100 * \frac{\sum_{i=1}^n q_{oi} - \sum_{i=1}^n q_{si}}{\sum_{i=1}^n q_{si}} \dots\dots\dots (4.20)$$

Where: q_{si} is the simulated value and q_{oi} is the measured value

A value close to 0% is best for D. A negative value indicates model over estimation and a positive value indicate model under estimation.

Sensitivity Analysis

After the model set up (simulation), the results of the model output vs. the actual measurements, sensitivity analysis was carried out which is an important process in guiding the subsequent calibration process. The sensitivity analysis identified the effects of changing calibration parameters as given by Neitsch et al. (2002b) on stream flow Twenty-seven, (27) parameters were included in the analysis. The parameters selected are related to: runoff, groundwater and soil processes, and thus influence the hydrology of the system (Van Griensven, 2002). The sensitivity analysis was done for the whole simulation period with measured data record and model output data.

Calibration

The aim of model calibration is to achieve a reduction in model uncertainty by efficiently extracting information contained in the calibration data. It involves the comparison of model simulation with an observed data on predefined objective function and adjusting parameters to improve closeness. SWAT model can be calibrated both manually and automatically. For this study manual calibration was applied. The calibration was carried out using the out put of the sensitivity analysis of the model and by changing the sensitive parameter at a time while keeping of the rest of the parameters constant. Initial values were already assigned by the model itself and parameters which are then optimized manually. Calibration was performed until the predicted and observed results were visibly close. The manual calibration is used for this study.

Validation

The process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation. Calibration involve testing model with known input and output data in order to adjust some parameters, while validation involves comparison of the model results with different datasets from that used during calibration without any further adjustment of the calibration parameters.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Indirect Method of Flow Calculation into Gefersa Reservoir

Water balance studies provide an indirect evaluation of an unknown water balance component from the difference between the known components. The water balance equation for any natural area (such as a river basin) or water body indicates the relative values of inflow, outflow and change in water storage for the area or body. Reservoir data includes calculation the total outflow from the reservoir and inflow back – calculation processes. The daily total outflow was the sum of total water release through spillway and water consumption. Calculation methods were discussed in previous chapter. Figure 5.1 describe the generated inflow for five years from 2005 to 2009. Back calculation results were displayed in the Annex.

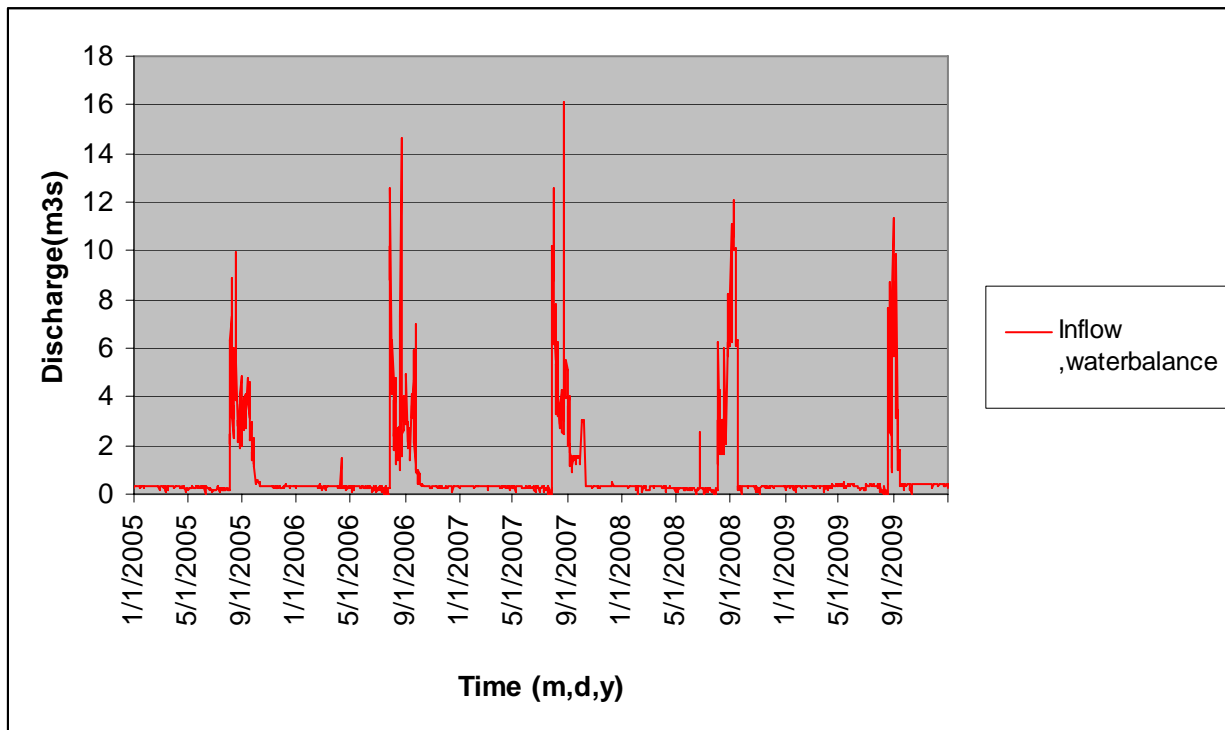


Fig 5.1 Generated daily inflow into Gefersa Reservoir

5.1.1. Checking indirect method of flow calculation

Streamflow data required for sites where no data were collected. Methods used to estimate streamflow for sites where no streamflow data were generated using indirect method of flow calculation. The generated inflows were checked using the area ratio method. In order to apply the above method a gauging river which is found downstream of Gefersa i.e. Little Akaki is used. The area ratio method is based on the assumption that the streamflow for a site of interest can be estimated by multiplying the ratio of the area for the site of interest and the area for a nearby streamflow-gaging station by the streamflow for the nearby streamflow-gaging station. Based on the above method, the average annual inflow was 28.5 MCM whereas using reverse water balance was 26.6 MCM. And mean annual inflow is about 25 MCM based on the Bathymetric survey study (1999). Figure 5.2 show the inflow generated using reverse water balance and area ration method. In year 2005 and 2008 the inflow generated using the area ration method exceed the inflow generated using reverse balance. Whereas in year 2006, 2007 and 2009 the inflow generated using both methods are somehow similar.

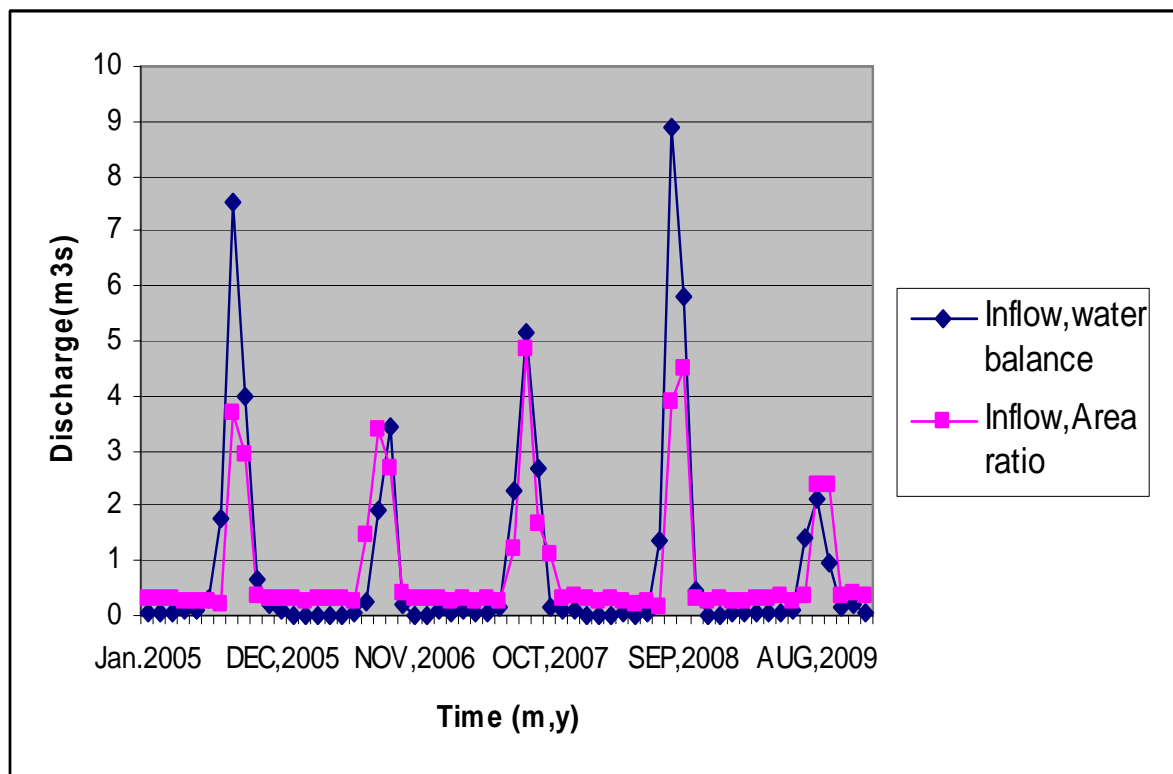


Fig 5.2 Checking Generated inflow into Gefersa Reservoir

5.1.2 Possible errors of indirect method of flow calculation

All the terms of the water balance equation which characterize inflow are determined from change in water storage and outflows. The following are some of the possible errors in reverse water balance calculation of Gefersa reservoir.

- Abstraction are not measured and the only way to estimate them is through the water production data at Gefersa water treatment plant
- Spillway volume calculated indirectly from water level and the spillway formula since no specific records are kept
- Also, bottom outlet operation is measured approximately in terms of duration of gate opening.

5.1.3. Uncertainty for area –ration method

This method is very simple and very rough approach; it relates the catchment area with runoff while there are a number of factors, which affect runoff. Actually, it is reasonable to use this approach by assuming the climate and physical catchment characteristics will be the same. But, if the ungauged and gauged catchments are far apart and different catchment characteristics you need to consider others characteristics such as climate and physical catchment characteristics (longest flow path, length, slope of the watershed, Landcover, soil type) to prepare the regional model.

5.2 Sensitivity analysis

Sensitivity analysis is useful to identify inputs parameters, which significantly affect the model outputs. Automatic sensitivity analysis was conducted using input daily flow. After simulating series of simulations, SWAT provides sensitivity of parameters in ranked order. The Initial SCS CN II value, which is a parameter related to runoff is a function of soil's permeability, land use and antecedent soil water conditions and Baseflow recession constant, a direct index of groundwater flow response to changes in recharge, are the most sensitive parameter. The flow was also found to be sensitive to soil properties: depth from soil surface to bottom of layer (SOL_Z) in mm. The flow was also sensitive to crop parameters: maximum potential leaf area index (BLAI) which is a parameter to quantify the density of the plant and maximum canopy storage (CANMX) in mm H₂O and Groundwater parameters: Aquifer for revap to occur (Revapmn) and

threshold water depth in the shallow aquifer for low (mm) (Gwqmn).The ranking of variables used in the sensitivity analyses for flow parameters are listed below.

Rank	Parameter	Max	Min	Relative sensitivity value	Class	Location	Description
1	Cn_2	35	98	1.8	Very high	*.mgt	Initial SCS CN II value
2	Alpha	1	0	0.899	High	*.mgt	Baseflow recession constant (days)
3	Canmx	10	0	0.425	High	*.hru	Maximum canopy storage
4	Revapmn	500	0	0.343	High	*.gw	Aquifer for revap to occur
5	Sol Z	3000	0	0.228	High	*.Sol	Depth from soil surface to bottom of layer
6	Blai	1	0	0.175	Medium	*.crop	Leaf index
7	Gwqmn	5000	0	0.0972	Medium	*.gw	Shallow aquifer required for return flow to occur(mm of water)
8	Sol_Awc	1	0	0.05	Medium	*.hru	Available water capacity of soil layer (mm/mm soil)

Table5. 1:- The most sensitive Parameters

5.5. Flow Calibration

Once the sensitive parameters for the model are identified, the next step is to calibrate and then validate the model. In the calibration we attempted to minimize model errors of the river flows. Thus model calibration involves modifications of model parameters values and comparison of predicted output to the measured data. Flow calibration for the Gefersa watershed was conducted for the years 2005 and 2007. These years were selected based on the availability of data. The model was calibrated on monthly basis. The model could reproduce peak flows quite well. Similarly, the model could capture dry period characteristics well. The over all performance of the model during calibration has been measured using R^2 and Nash-Sutcliffe (NS) as 0.78 and 0.77, respectively.

Parameter	Recommended range	Initial value	Values after calibration
Cn_2	-25% to 25%	Default	Reduce by 25%
Alpha_Bf	0-1	Default	0.2
Canmx	0-10	Default	0
Sol Z	-50% to 50%	Default	Reduce by 15%
Revapmn	0-500	Default	500

. Table 5.2 Values used for calibration

Time	Average Flow(m ³ /s)		Model Efficiency (Monthly)		
	Simulated	Measured	r ²	N _{SH}	D
2005-2007	26.2	30.9	0.78	0.77	-15.3

Table 5.3 simulated & observed flow Calibration

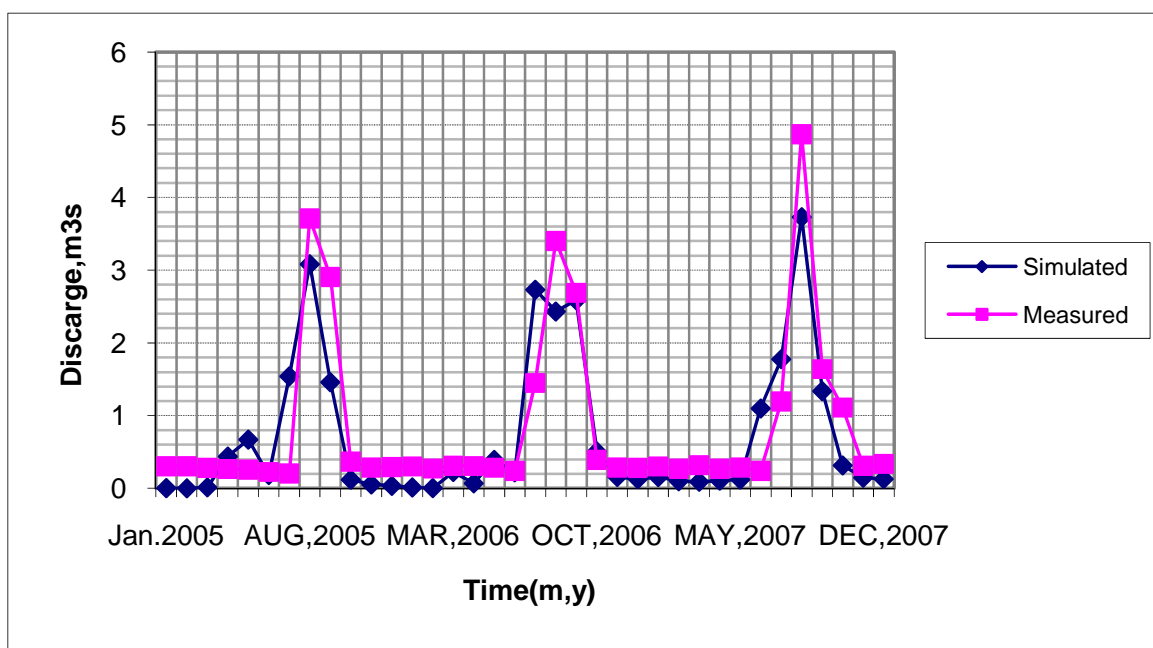


Figure.5.3 Measured and Simulated flow for calibration (Monthly)

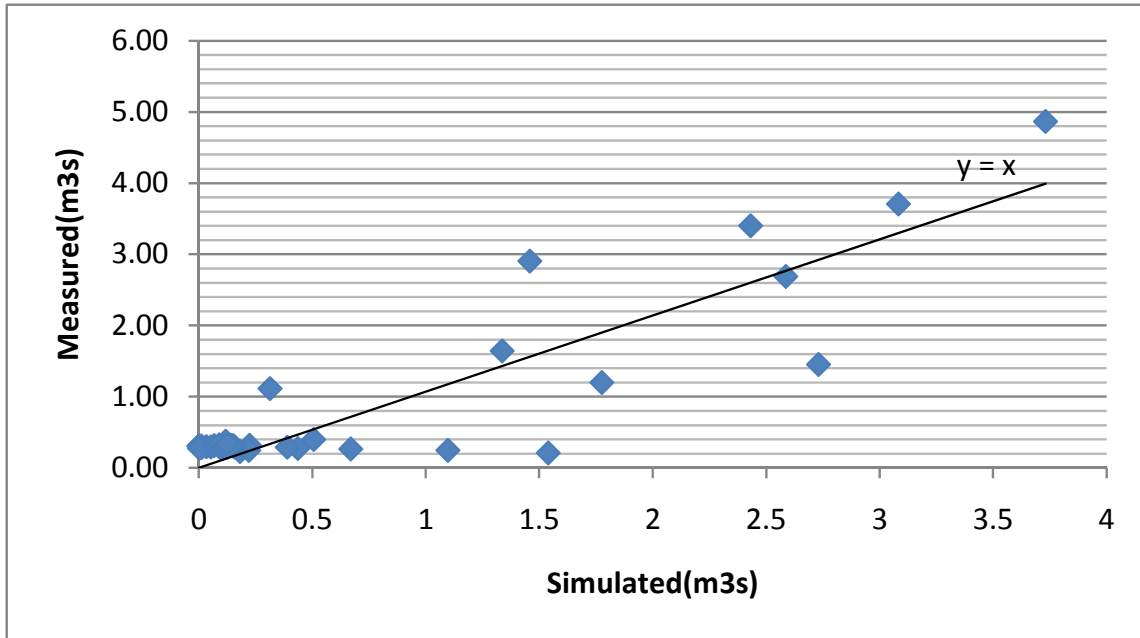


Figure 5.4 1: 1 fit line of measured & simulated flow for calibration

5.6. Flow Validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Thus, the model was validated with observed flow data at the same location, but for the period 2008 to 2009. Figure 5.5 presents the validation results. The over all performance of the model during validation has been measured using R^2 and Nash-Sutcliffe (E_{NS}) are 0.72 and 0.7 respectively. The peaks are underestimated in 2008, where as, the peak is nearly captured in 2009.

Time	Average Flow(m3/s)		Model Efficiency (Monthly)		
	Simulated	Measured	r^2	N_{SH}	D
2008-2009	15.04	18.9	0.72	0.7	-20.7

Table 5.4 simulated & observed flow Validation

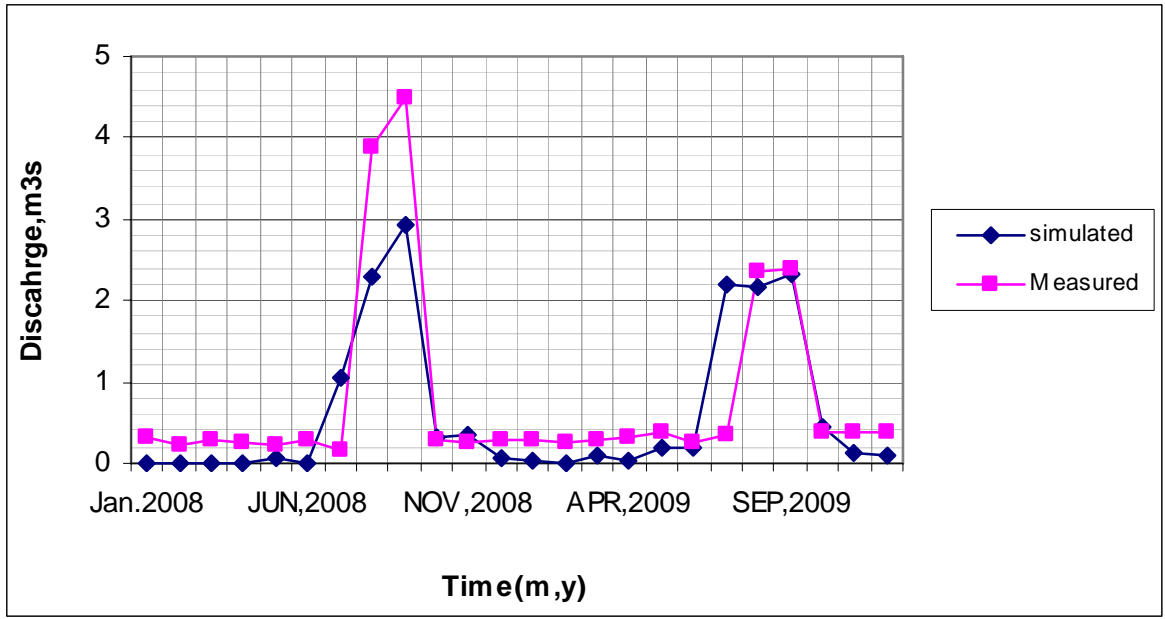


Figure 5.5 Measured and Simulated sediment flow for validation period (Monthly)

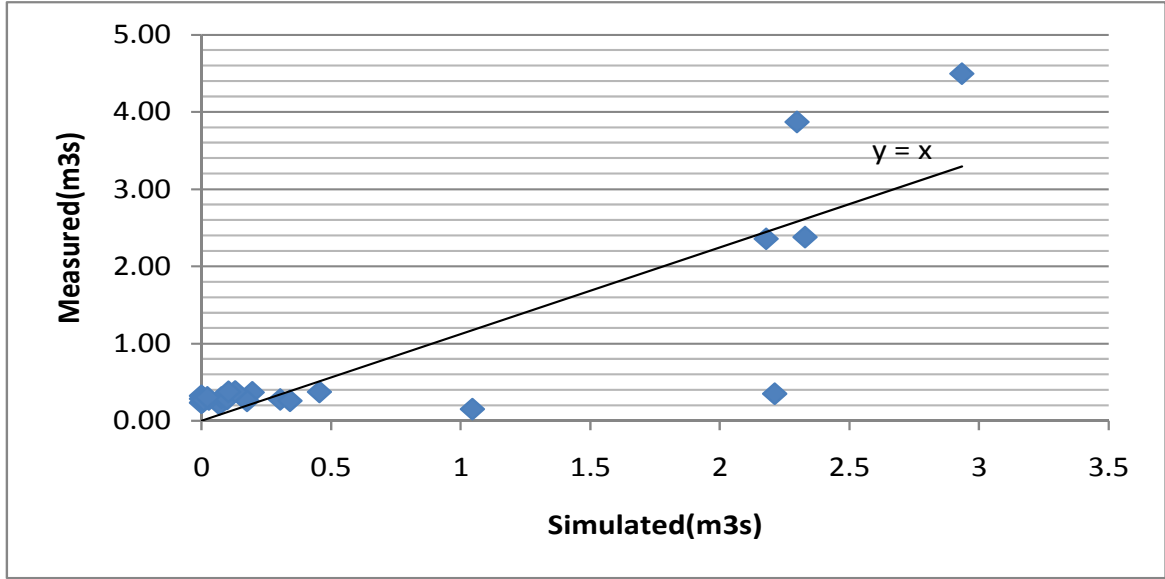


Figure 5.6 1: 1 fit line of measured & simulated sediment flow for validation

5.7 Sediment Calibration

SWAT model was first calibrated and validated to flows, then to sediment. The model was calibrated for sediment by comparing annual model simulated sediment load against annual measured sediment load for the period 1979 to 1992. BECOM and TAHAL have made two Bathymetric surveys in 1979 and 1999 respectively. Based on the analysis there is 5.75 t/ha/year of sediment inflow to the Reservoir i.e.31, 625 t/ year (assuming average annual sediment load equal). The model estimation result obtained during sediment calibration show that the SWAT model, overestimate the sediment load. All sediment calibration parameters were used to increase the sediment prediction. The overall performance of the model during calibration has been measured using D (the percent difference for a quantity) which is -0.014; means the model overestimate the average annual sediment by 1.4 %.

Parameter	Recommended Range	Initial value	Calibrated Value
USLE_P	-50 to +50%	Default	-50%
Slope	-50 to +50%	Default	-7%
SLSUBSN	-50 to +50%	Default	-50%
SPEXN	0.001-0.01	0.099	0.001

Table5. 5 Calibrated Parameters for Sediment (1979 -1992)

Time	Average Flow(tons/year)		Model Efficiency (Yearly)
1979-1992	Simulated	Measured	D
	32063.7	31625	-1.37

Table5. 6 Simulated & measured sediment Calibration (1979-1992)

5.8 Sediment Validation

The model was validated for the period 1993 to 1999 with adjusted values during calibration. Figure 5.4 presents the validation results. The overall performance of the model during validation has been measured using D (the percent difference for a quantity) which is -0.069; means the model overestimate the average annual sediment by 6.9%.

Time	Average Flow(tons/year)		Model Efficiency (Yearly)
1993-1999	Simulated	Measured	D
	33971.	31625	-6.9

Table 5.7 simulated & measured sediment Validation (1993-1999)

5.9 Scenario Development and analysis

5.9.1. Scenario Development

Scenarios are reasonable and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships. Many different activities are carried out in the catchment; mainly urbanization and farming activities. Farming activities are increasing in the area due to the population pressure and depletion of soil fertility to produce the intended demand of food crop for inhabitants. To analyze the effect of these different human activities in the catchment on sediment prediction in relation to demographic changes, development and management practices, we need to develop scenarios.

Therefore, in order to use the model as a tool for analyzing the effects of different activities in the study area, the following four different scenarios were simulated.

Scenario 1: 53 % of forest land is changed to agricultural land.

Scenario 2: 35 % of Rangeland Grass to agricultural land.

Scenario 3: 16 % of forest changes to agricultural land

Scenario 4: 18 % of Rangeland Grass changes to agricultural land

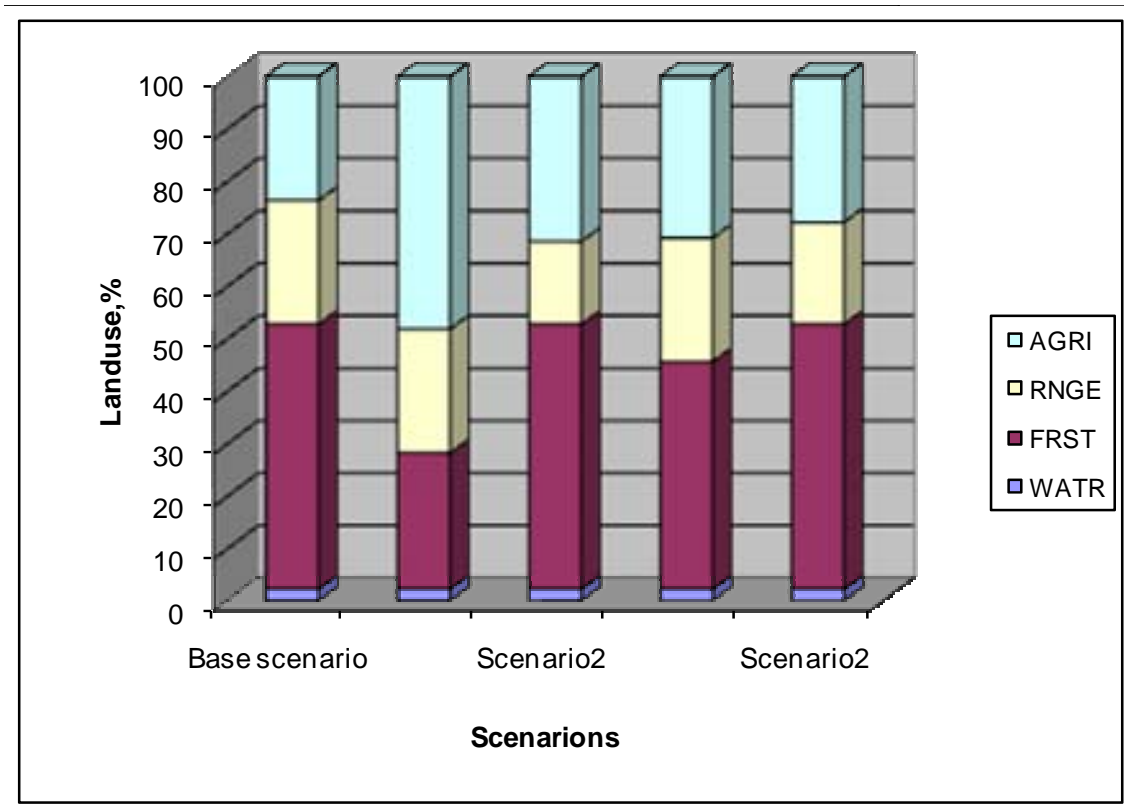


Fig 5.7 Landuse Scenarios

5.9.2. Scenario Analysis

The impact of different management practices was examined by applying different scenarios. The 1999 Landuse was used for each scenarios comparison (base scenario) and the results of four scenarios are presented below

Scenario number	Sediment yield (t/ha/year)	Sediment yield (t/year)	% of sediment change	Loss f storage (m3/ year)
Base Scenario	5.519	30354.5	0	21358.1
Scenario 1	21.699	119344.5	74.5	37269.8
Scenario 2	9.271	50990.5	40.47	30001.7
Scenario 3	11.715	64432.5	52.89	32590.3
Scenario 4	7.829	43059.5	29.51	27660.8

Table 5.7 Sediment yield using different Landuse scenario

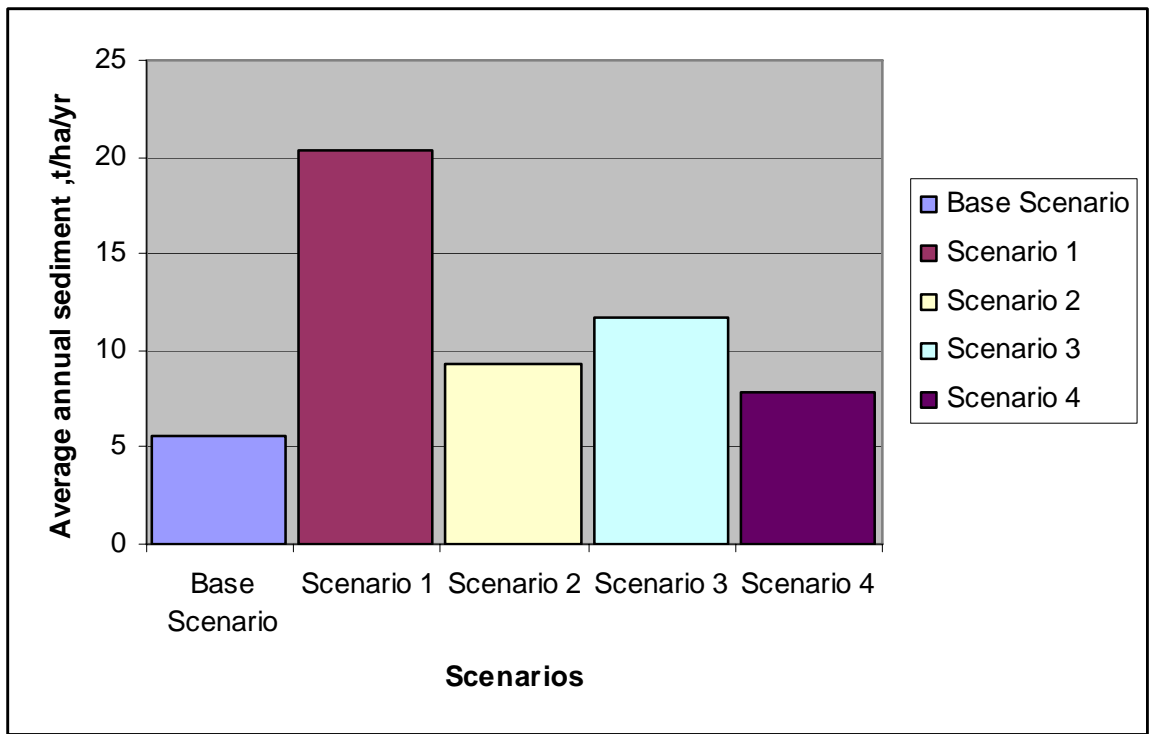


Fig5.8 Average annual sediment in ton/ha/year

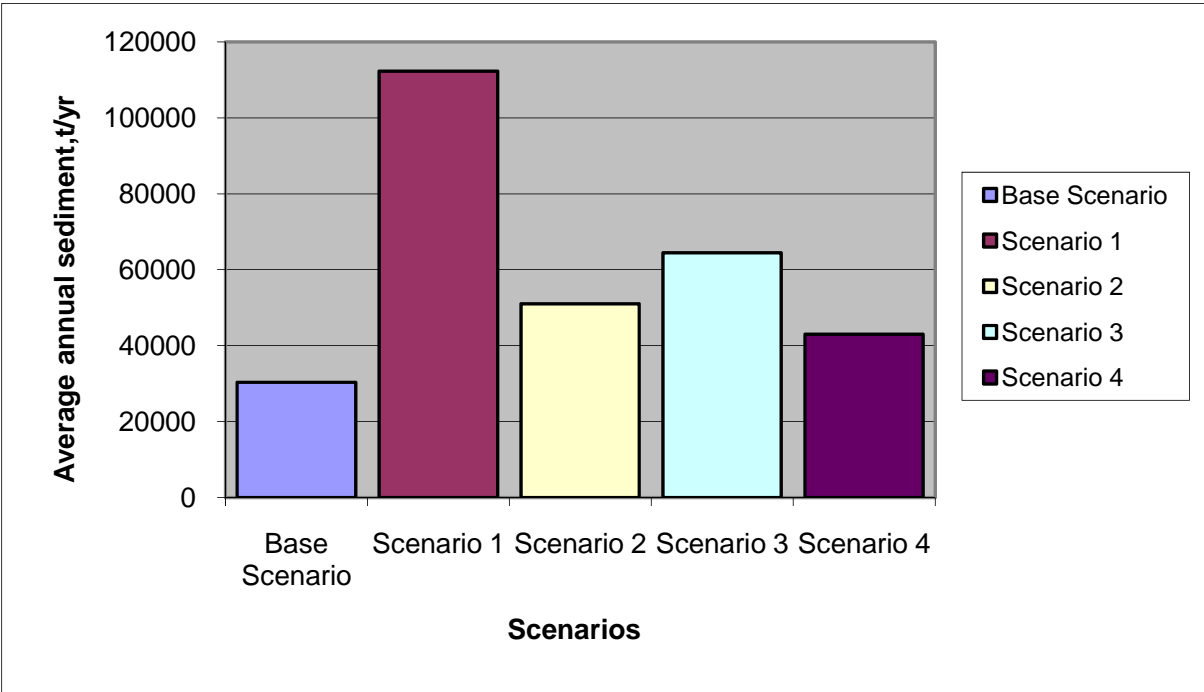


Fig 5.9 Average annual sediment in ton/year

CHAPTER SIX

ASSESSING SEDIMENT REDUCTION METHODS

6.0. Introduction

Reservoir sedimentation is a significant problem in Gefersa reservoir. In many water supply reservoirs, 50% or more of the original storage capacity is occupied by sediments. Sediment accumulation in reservoirs reduces their storage capacity and yield and limits their useful life if it is not controlled in some manner. When a dam is built across a stream, the flow cross section progressively increases and the flow velocity decreases toward the dam. This leads to a decrease in sediment transport capacity, causing deposition of sediments, first in the backwaters created by the reservoir and then in the reservoir. Coarse particles are deposited first, and silt and clay particles are deposited in the deep portions of the reservoir in the vicinity of the dam. Sediment deposition continues to reduce the useful storage capacity of the reservoir, so much so that after a certain number of years, the reservoir may not be able to meet the purposes it was designed for. Also Sediment deposition in a reservoir affects the water quality in two ways: 1) penetration of solar radiation into the water and photosynthetic activity are reduced because of turbid waters, and 2) recycling of nutrients and pollutants (carried with the sediments) from the lake bottom into the deep, overlying waters takes place, lowering the dissolved oxygen level to such an extent that these waters become inhospitable for fish and other aquatic life. Due to the above mentioned problems it is must to reduce sediment inflow to the reservoir and also reduce sediment deposition in the reservoirs. There are two basic approaches for reservoir sedimentation control: 1) controlling soil erosion through watershed management, and 2) handling sediment where it creates the problem, namely, in the reservoir

6.1. Reducing Sediment Inflow into the Reservoir

6.1.1. Watershed Management and Soil Conservation

The intent of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system. The distribution of

erosion over the watershed is investigated, and the areas contributing excessive sediment to the streams draining into the reservoir are demarcated. Conservation measures applied to these areas result in a significant reduction in sediment input to the reservoir. These measures include practices such as contour farming and terracing; strip cropping, crop rotation, no-till farming, grassed drainage ways, gully erosion control, and stabilization of critical areas by their return to grasslands or forests. Conservation measures take years to implement. Among the problems involved in instituting such measures are the relative costs of various measures to farmers, and the need for farmers to make significant changes in their usual style of farming. The efficiency of watershed management in reducing sediment inflow to the reservoir varies from a low of 5% to a high of 40% (Bruk, 1985; Mahmood, 1987).

6.1.2 Retention of Coarse Sediments in Upstream silt trap Dams

Silt trap dams are low dams built across the main sediment-contributing tributaries of reservoirs like dam 3 of Gefersa reservoir. These dams are designed to control sediment inflow into the reservoir. They create small reservoirs, which tend to silt up faster than the main reservoir. Silt trap dams retain the coarse fraction of the sediment and thus are helpful in reducing sediment deposits in the main reservoir. A small dam can be built a few meters upstream of the lake or reservoir to induce deposition of coarse sediments in the pool. In the case of Gefersa reservoir this silt trap dam has dual benefit i.e. silt trap and storage of water. Silt accumulation of the main dam in the period 1966 to 1998 declined by more than half to 22,250 m³/year. This decline is accounted for by the smaller contributing area due to the construction of the Geffersa III reservoir.

6.1.3. Bypassing of Heavily Sediment-Laden Flows

A great amount of sediment is carried by a stream or river during flood flows. A large part of such flow can be bypassed through a channel, tunnel, or pipes, significantly reducing silting in the reservoir. The bypass may consist of a barrage for diversion of floods and a bypass canal joining the main stream or river some distance downstream of the dam; or it may be a bypass tunnel instead of a bypass canal. Pipelines can be anchored in a low submerged weir near the stream/lake junction, can be placed along the lake bed or partially embedded in it, and can discharge downstream of the dam.. This technique has been successfully applied in Italy (Roveri,

1981). It has the ability of removing sediment quickly under the full head of water. The above measures can considerably reduce the input of coarse sediment to the reservoir, and this can reduce extensive delta formation. The site conditions, topography, dam foundation are feasible for Gefersa reservoir whereas economic analyses will determine the feasibility and practicality of this mitigative measure.

6.1.4. Trapping and Retention of Sediments by a Vegetative Screen

A vegetative screen at the head of a reservoir, whether artificial or natural, serves to reduce the velocity of incoming flow and to cause sediment deposition. . The vegetation does intercept the inflowing water, lowering the water supply to the reservoir by as much as 10%.

Set up buffer strips around the Gefersa reservoir to prevent sediments generated by area erosion and small stream erosion from reaching the reservoir directly and prevent the local inhabitants and grazing livestock from reaching the immediate vicinity of the reservoirs.

6.2. Methods of Maximising Sediment removal through flow

6.2.1. Reservoir drawdown and flushing

Drawing down the water level in a reservoir for the sake of reducing the amount of sedimentation, or in order to induce erosion of deposited sediment to recover storage capacity, is a method often used in reservoirs. The efficiency of sediment flushing depends on the topographic position of the reservoir, the capacity of the outlet, the outlet elevation, the characteristics of the inflow sediment, the mode of operation, the time duration of flushing, the flushing discharge, etc. Draw-down flushing has got some setbacks. The quantity which could have been evacuated is limited partly because the fine sediment deposits becoming consolidated, partly because deposition of the bed loads occurring in the upper part of the reservoir, and partly due to the high elevation of spillway through which the flushing discharge must pass. Sediment flushing must be done before the formation of considerable valley deposits. The outlet gates will require protection against abrasion by high sediment concentrations and blockage by sediment deposits.

6.2.2. Density Current Flushing

Gould defines a density current as a gravity flow of turbid water through, under or over water of different density (Fuat, 1994). The density difference being a function of the differences in temperature, salt content or silt content of the two fluids. The venting of density currents has long been considered an effective means of reducing the rate of reservoir silting, especially in impounding reservoirs. Following the recognition of the phenomenon of density currents, the method of density current flushing has been adopted in many reservoirs to reduce sedimentation (UNESCO, 1985)

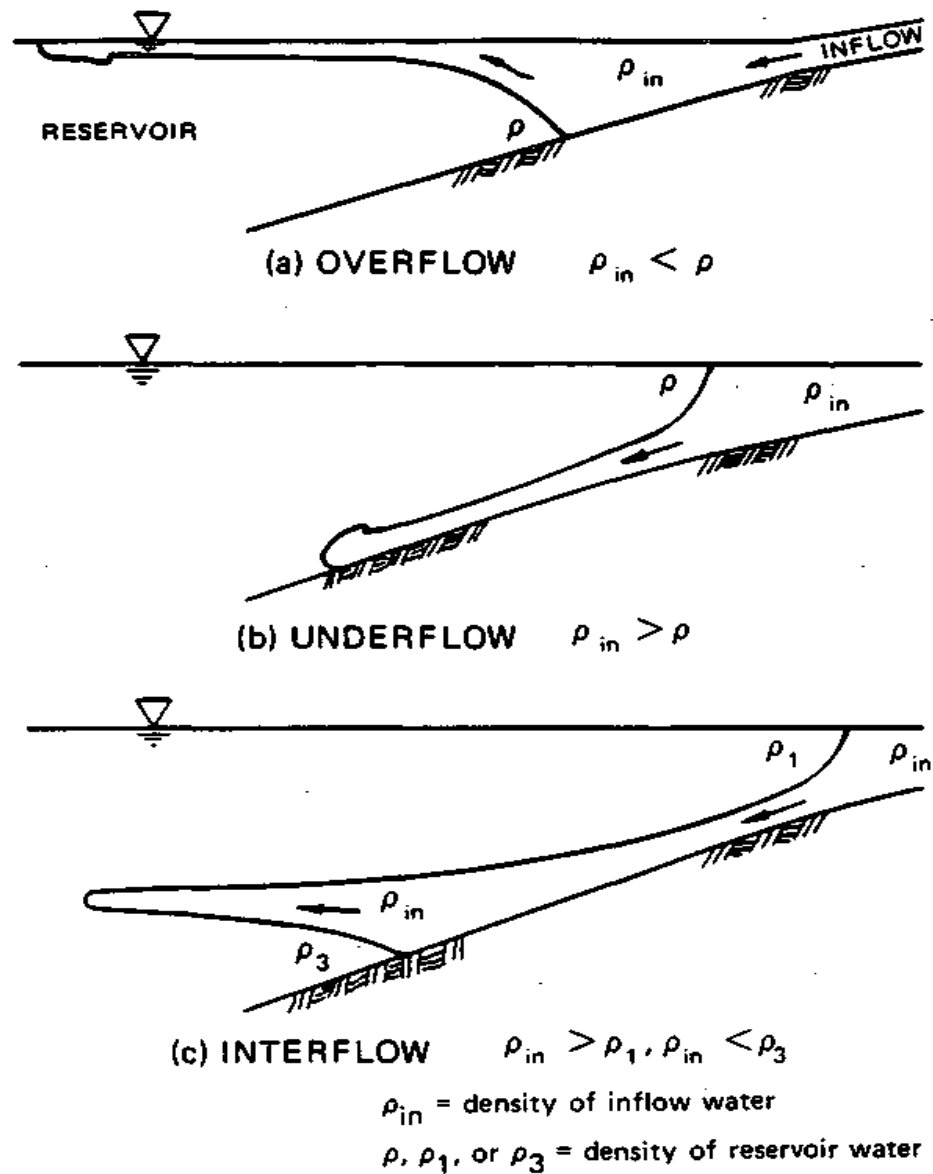


Figure 6.2. Schematic of overflow, underflow, and interflow patterns of incoming flow to a reservoir (after Wunderlich and Elder, 1973)

Density currents are very active during floods when sediment concentration loads are quite high. The topographic features of the reservoir and the hydraulic structures for sluicing are favorable for venting density currents. The original river channel has a steep slope, the inflowing sediments are composed primarily of fine materials, a relatively short distance of backwater

exists, and the locations of the bottom outlets just above the river bed are favorable to density current flushing or venting. Generally, more sediment will be vented from short and medium-length reservoirs with large incoming discharges; high density sediment concentrations; low, large-capacity outlets; and high outflow discharges. Provision of multilevel, multiple outlets improve the venting efficiency of the density currents.

6.2.3. Venting of Sediments through under sluices

Undersluices can be incorporated in the design of the impounding structure or dam. The total capacity of these sluices should lie in the range of 0.3 to 1.0 times the maximum daily flood inflow. Many sediment deposition models can be used in identifying the most suitable locations for the sluices. Knowledge of the expected sediment distribution pattern in the reservoir is useful in sizing and locating the gated outlets. Frequent venting of sediments may be resorted to during the high-inflow season when the excess flows may all be routed through the sluices. This operation not only greatly reduces the sediment entrapment by drastically reducing the residence time but also substantially reduces the surcharge in the reservoir that occurs with an overflow type of spillway. This leads to less flooding of lowlands around the reservoir. Release of water and sediment through the bottom outlets reduces degradation of the bed and caving-in of banks downstream of the dam (Singh, 1987). Sediment sluicing is distinct from sediment flushing because the main sediment load entering a reservoir is released downstream before it has time to settle down.

6.3. Recovering Reservoir Storage Capacity

6.3.1. General

Mechanical removal of silt/sediment from reservoirs is a costly operation. Nevertheless, it is a standard means of maintaining the operational volume free of sediments if no other alternatives exist. AAWSA will practice mechanical removal of sediments from the reservoirs at least at the mean annual sedimentation rate (with the addition of a safety factor) once the dead storage is filled with sediments. This would be justified in the absence of other alternatives to prolong the reservoir life span.

6.3.2. Dredging of Sediments

Dredging is an expensive means of restoring the storage capacity of a reservoir unless a large part of the cost can be recovered by beneficial use of the dredged material. Dredging is used if other methods (such as flushing, bypass construction, and drawdown flushing) are not successful or feasible, and the dam cannot be raised or replaced. The nature of the dredged materials namely liquid mud is such that it cannot be spilled freely and should be impounded in settling basins/reservoirs where the sediments will settle, while excess water flows back to the reservoirs. This would also prevent sediments from being washed back to the reservoirs during the wet season. The spillway and the excess water canal would be protected to allow conveyance of the original reservoir without erosion. The cost of dredging, including impoundment of the sediments in settling reservoirs, is estimated at 65-75 Birr/m³ (Bathymetric,1999).In the case of wide reservoirs hydraulic dredging can more efficiently remove over bank deposits than flushing and sluicing. It takes a smaller amount of water to remove a unit volume of deposits by dredging than by flushing. The dredging operation can be moved upstream from the dam to open a channel in the deposits to facilitate the movement of density currents toward the bottom outlet. Dredging may be done at fixed intervals for small or medium-sized reservoirs. It can also be an ongoing operation for some large reservoirs. It is a short-term remedial measure to alleviate the problem of sedimentation in the reservoir and does not provide a long-term solution to the problem. This method can restore storage to its maximum because it can remove bank deposits which flushing cannot handle.

6.3.3. Excavation

A large amount of sediments from incoming floods when reservoirs water levels are high settle in the flooded areas at the upstream end of the reservoirs. During the dry season, when water levels drop to supply and to losses, the sediments using heavy earthmoving and it is then possible to remove the sediments using heavy earthmoving equipment working in a downstream direction. The excavated material would be disposed of or spread in areas nearby (in order to lower the cost of disposal) .Spreading the material on agricultural and other lands would contribute to soil fertility. The sediment would be spread in such a way that most of them would be prevented from being washed back to the reservoirs in the subsequent wet seasons. However, excavations during the wet season at high levels would be more costly, while it would also

increase the turbidity of the water. The cost of sediment excavation and disposal /spreading at locations near the excavation site and away from the flooded area is estimated at about 24 Birr/m³ (Bathymetric, 1999)

6.4. Reservoir Operation Policy for Sediment control

The goal of reservoir operation and management is not only to adequately meet the design water demands, but also to release as much sediment as possible from the reservoir with the floodwaters so that the reservoir trap efficiency is reduced to as small a value as is economically and practically feasible. About 80 to 90% of the annual sediment load enters the reservoir during the flood season. Lowering pool levels during flood season further increases the efficiency of the operation. If reservoir sedimentation is perceived as a serious problem, the flow releases from the bottom outlets should be considered in dam design together with a reservoir operation that helps in maximizing flow-through of the incoming sediment. The outlets also help in drawing down reservoir levels during emergencies and repairs. These gates are part of the permanent hydraulic structure of the dam. In this case, the removal of sediments is through reservoir operation. This method makes use of the hydraulics of flow and mechanical means to remove sediments that have accumulated in the reservoir. Water is released through these low-level outlets leading to large flow velocities in the approach channel, providing a local concentration of flow that washes out the sediments downstream. This method could be the most appropriate for Gefersa reservoir because it is cost effective.

For more efficient operation of the bottom outlets the following guidelines should be followed in reservoir design and operation:

- lower the head on the sluices
- locate the sluices as deep as possible
- build wider sluices
- Increase the duration of flushing

- maintain steeper reservoir bottom slope
- maintain sufficient outlet capacity to release floodwaters
- flush towards the end of the high-flow season
- flush intermittently
- flush under pressure no more than 10 minutes

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

Gefersa reservoir, which is part of Akaki river catchment, supplies an average of 30,000m³ of treated water per day to Addis Ababa city. The high rate of siltation is a major long-term problem for the reservoir, as it severely affects the capacity of the reservoirs and results in a shortage of usable water for Addis Ababa as well as increasing the water treatment costs. A systematic approach to determine the rate of sediment yield from Gefersa catchment was done using SWAT watershed model. The main conclusions arrived at are summarized here.

1. The model performance efficiency indicators, regression coefficient (r_2), Nash-Sutcliffe (E_{NS}) and percent difference for quantity (D) are found to be 0.78, 0.77 and -15.3 in calibration and 0.72, 0.7 and -6.9 in validation for flow analysis. Similarly, Sediment model efficiency indicator D was -1.37 for calibration and -6.9 for validation. The model is therefore acceptable for use in modelling sediment inflow into Gefersa reservoir.

2. SWAT predicted annual sediment yield of the watersheds for the intervening period under different landuse scenarios. Change of 53 % of forest land to agricultural land ,change of 35 % of Rangeland Grass land to agricultural land, change of 16 % of forest changes to agricultural land and change of 18 % of Rangeland Grass changes to agricultural land result in 74.5 %,40.47 %, 52.89 % and 29.51% of sediment increased respectively.

3. Of the available reservoir sediment management approach, watershed management is the best method to reduce the yield of sediment and its entry into the reservoir. Vegetative screens at the upstream end of the reservoirs may withhold a significant part of the entering sediment. Construction of sedimentation basins at the mouths of the reservoir (like Gefersa III) may be the most feasible solution to sedimentation problems in Gefersa reservoir. Periodic sluicing of sediments through operation of bottom outlet gates may be another approach of sediment management in this reservoir.

7.2. Recommendation

- AAWSA must collect data on dam operations, especially bottom outlets on permanent basis.
- AAWSA must collect data on river flow and sediment data on daily basis.

- The database created in this study has paramount importance to conduct further research on water quality modelling. Therefore, it's recommended to use the database for further research work in the catchment.

- Bathymetric survey must carry out for the main dam every five years to monitor reservoir sedimentation rates. Since it is possible to dry up the Gefersa III reservoir by passing the water from this reservoir to the main Geffersa reservoir, it is recommended to carry out bathymetric surveys of Geffersa III reservoir by planned drying up this reservoir without affecting supply of water to Addis Ababa because there is only one Bathymetric survey for Gefersa III reservoir.

- After complete silting –up, reservoirs can be used for cultivation or a forestation. Sediments could also be used for other purposes such as material for the tile/ceramics/brick industry, improvement of poor agricultural lands, etc. If it is decided to dispose of sediment from a reservoir or silt /sediment trap, it will be necessary to determine the composition and properties of the settled sediments and identify possible users/uses.

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APPENDIX

Date	treated water, m3/day	Process loss,m3/d	lake level,m	Rainfall,mm	evaporation,m m	Actual evap	Spill+bottom outlet,m3/d	Available storage,MM 3	Change in Storage	Area,m2	(rain-Evap)*Area	INFLOW,M3/ DAY	INFLOW,m3/ s
1/1/2005	21350	1067.5	119.78	0	2.1	1.47	0	5.15884	0	1147500	-1686.825	24104.325	0.278985243
1/2/2005	22817	1140.85	119.78	0	4.34	3.038	0	5.15884	0	1147500	-3486.105	27443.955	0.317638368
1/3/2005	22778	1138.9	119.80	0	3.92	2.744	0	5.1764	0.01756	1150000	-3155.6	27072.51756	0.313339324
1/4/2005	22985	1149.25	119.82	0	4.16	2.912	0	5.19396	0.01756	1152500	-3356.08	27490.34756	0.318175319
1/5/2005	22849	1142.45	119.83	0	4	2.8	0	5.20274	0.00878	1153750	-3230.5	27221.95878	0.315068967
1/6/2005	22948	1147.4	119.85	0	4.64	3.248	0	5.2203	0.01756	1156250	-3755.5	27850.91756	0.322348583
1/7/2005	23032	1151.6	119.86	0	4.88	3.416	0	5.22908	0.00878	1157500	-3954.02	28137.62878	0.325667
1/8/2005	22693	1134.65	119.87	0	4.2	2.94	0	5.23786	0.00878	1158750	-3406.725	27234.38378	0.315212775
1/9/2005	22762	1138.1	119.88	0	3.5	2.45	0	5.24664	0.00878	1160000	-2842	26742.10878	0.309515148
1/10/2005	22893	1144.65	119.89	0	3.6	2.52	0	5.25542	0.00878	1161250	-2926.35	26964.00878	0.312083435
1/11/2005	22839	1141.95	119.90	0	3.7	2.59	0	5.2642	0.00878	1162500	-3010.875	26991.83378	0.312405484
1/12/2005	22962	1148.1	119.90	0	3.1	2.17	0	5.2642	0	1162500	-2522.625	26632.725	0.308249132
1/13/2005	22738	1136.9	119.91	0	3.4	2.38	0	5.27298	0.00878	1163750	-2769.725	26644.63378	0.308386965
1/14/2005	22693	1134.65	119.92	4.6	4	2.8	0	5.28176	0.00878	1165000	2097	21730.65878	0.251512254
1/15/2005	22706	1135.3	119.96	0	4.1	2.87	0	5.31688	0.03512	1170000	-3357.9	27199.23512	0.314805962

1/16/2005	22678	1133.9	119.98	3.1	3.32	2.324	0	5.33444	0.01756	1172500	909.86	22902.05756	0.265070111
1/17/2005	22816	1140.8	119.98	0	3.12	2.184	0	5.33444	0	1172500	-2560.74	26517.54	0.306915972
1/18/2005	22912	1145.6	119.99	0	3.39	2.373	0	5.34322	0.00878	1173750	-2785.30875	26842.91753	0.310681916
1/19/2005	22912	1145.6	120.00	0	4.08	2.856	0	5.352	0.00878	1175000	-3355.8	27413.40878	0.317284824
1/20/2005	22405	1120.25	120.01	0	4.05	2.835	0	5.36078	0.00878	1127000	-3195.045	26720.30378	0.309262775
1/21/2005	22608	1130.4	120.01	0	3.15	2.205	0	5.36078	0	1127000	-2485.035	26223.435	0.303511979
1/22/2005	22775	1138.75	120.01	0	3.02	2.114	0	5.36078	0	1127000	-2382.478	26296.228	0.304354491
1/23/2005	22733	1136.65	120.01	3.8	3.78	2.646	0	5.36078	0	1127000	1300.558	22569.092	0.261216343
1/24/2005	22814	1140.7	120.01	0	3.14	2.198	0	5.36078	0	1127000	-2477.146	26431.846	0.305924144
1/25/2005	22656	1132.8	120.01	0	4.09	2.863	0	5.36078	0	1127000	-3226.601	27015.401	0.312678252
1/26/2005	22585	1129.25	120.00	0	3.09	2.163	0	5.352	-0.00878	1175000	-2541.525	26255.76622	0.303886183
1/27/2005	22573	1128.65	120.00	0	4.07	2.849	0	5.352	0	1175000	-3347.575	27049.225	0.313069734
1/28/2005	22888	1144.4	119.98	0	4.12	2.884	0	5.33444	-0.01756	1172500	-3381.49	27413.87244	0.31729019
1/29/2005	22668	1133.4	119.96	0	3.18	2.226	0	5.31688	-0.01756	1170000	-2604.42	26405.80244	0.305622713
1/30/2005	22683	1134.15	119.96	0	4.04	2.828	0	5.31688	0	1170000	-3308.76	27125.91	0.313957292
1/31/2005	22799	1139.95	119.94	0	4.06	2.842	0	5.29932	-0.01756	1167500	-3318.035	27256.96744	0.31547416
2/1/2005	22940	1147	119.93	0	4.08	2.856	0	5.29054	-0.00878	1166250	-3330.81	27417.80122	0.317335662
2/2/2005	22475	1123.75	119.92	0	2.68	1.876	0	5.28176	-0.00878	1165000	-2185.54	25784.28122	0.298429181
2/3/2005	23011	1150.55	119.90	0	3.48	2.436	0	5.2642	-0.01756	1162500	-2831.85	26993.38244	0.312423408
2/4/2005	22792	1139.6	119.88	0	3.53	2.471	0	5.24664	-0.01756	1160000	-2866.36	26797.94244	0.310161371
2/5/2005	23022	1151.1	119.87	0	4.6	3.22	0	5.23786	-0.00878	1158750	-3731.175	27904.26622	0.322966044

2/6/2005	22743	1137.15	119.85	0	2.18	1.526	0	5.2203	-0.01756	1156250	-1764.4375	25644.56994	0.296812152
2/7/2005	22830	1141.5	119.83	0	3.19	2.233	0	5.20274	-0.01756	1153750	-2576.32375	26547.80619	0.307266275
2/8/2005	22819	1140.95	119.80	0	2.87	2.009	0	5.1764	-0.02634	1150000	-2310.35	26270.27366	0.304054093
2/9/2005	22875	1143.75	119.78	0	3.4	2.38	0	5.15884	-0.01756	1147500	-2731.05	26749.78244	0.309603963
2/10/2005	22838	1141.9	119.75	0	3.5	2.45	0	5.1325	-0.02634	1143750	-2802.1875	26782.06116	0.30997756
2/11/2005	22838	1141.9	119.73	0	3	2.1	0	5.11494	-0.01756	1141250	-2396.625	26376.50744	0.305283651
2/12/2005	22839	1141.95	119.71	0	3.5	2.45	0	5.09738	-0.01756	1138750	-2789.9375	26770.86994	0.309848032
2/13/2005	22709	1135.45	119.68	0	3.6	2.52	0	5.07104	-0.02634	1135000	-2860.2	26704.62366	0.309081292
2/14/2005	22725	1136.25	119.66	0	3.61	2.527	0	5.05348	-0.01756	1132500	-2861.8275	26723.05994	0.309294675
2/15/2005	22652	1132.6	119.64	0	3.7	2.59	0	5.03592	-0.01756	1130000	-2926.7	26711.28244	0.309158362
2/16/2005	22812	1140.6	119.62	0	4	2.8	0	5.01836	-0.01756	1127500	-3157	27109.58244	0.313768315
2/17/2005	22770	1138.5	119.58	0	3.8	2.66	0	4.98324	-0.03512	1122500	-2985.85	26894.31488	0.311276793
2/18/2005	23011	1150.55	119.55	0	4.1	2.87	0	4.9569	-0.02634	1118750	-3210.8125	27372.33616	0.316809446
2/19/2005	22801	1140.05	119.52	0	3.8	2.66	0	4.93056	-0.02634	1115000	-2965.9	26906.92366	0.311422728
2/20/2005	22890	1144.5	119.49	0	3.7	2.59	0	4.90422	-0.02634	1111250	-2878.1375	26912.61116	0.311488555
2/21/2005	22863	1143.15	119.46	0	4.3	3.01	0	4.87788	-0.02634	1107500	-3333.575	27339.69866	0.316431697
2/22/2005	22989	1149.45	119.43	0	4.18	2.926	0	4.85154	-0.02634	1103750	-3229.5725	27367.99616	0.316759215
2/23/2005	22901	1145.05	119.40	0	3.2	2.24	0	4.8252	-0.02634	1100000	-2464	26510.02366	0.306828978
2/24/2005	22931	1146.55	119.37	0	4.91	3.437	0	4.79886	-0.02634	1096250	-3767.81125	27845.33491	0.322283969
2/25/2005	23074	1153.7	119.34	0	4.22	2.954	0	4.77252	-0.02634	1092500	-3227.245	27454.91866	0.317765262
2/26/2005	22776	1138.8	119.31	11	3.16	2.212	0	4.74618	-0.02634	1088750	9567.935	14346.83866	0.166051373

2/27/2005	22916	1145.8	119.29	0	4.38	3.066	0	4.72862	-0.01756	1086250	-3330.4425	27392.22494	0.317039641
2/28/2005	22716	1135.8	119.26	0	3.2	2.24	0	4.70228	-0.02634	1085000	-2430.4	26282.17366	0.304191825
3/1/2005	22866	1143.3	119.22	0	3.61	2.527	0	4.66716	-0.03512	1077500	-2722.8425	26732.10738	0.309399391
3/2/2005	23066	1153.3	119.20	0	4.19	2.933	0	4.6496	-0.01756	1075000	-3152.975	27372.25744	0.316808535
3/3/2005	22595	1129.75	119.18	0	4.26	2.982	0	4.63204	-0.01756	1072500	-3198.195	26922.92744	0.311607956
3/4/2005	22953	1147.65	119.16	0	3.14	2.198	0	4.61448	-0.01756	1070000	-2351.86	26452.49244	0.306163107
3/5/2005	23015	1150.75	119.14	0	4.3	3.01	0	4.59692	-0.01756	1067500	-3213.175	27378.90744	0.316885503
3/6/2005	22949	1147.45	119.12	0	3.17	2.219	0	4.57936	-0.01756	1065000	-2363.235	26459.66744	0.306246151
3/7/2005	22579	1128.95	119.10	6.5	5	3.5	0	4.5618	-0.01756	1062500	3187.5	20520.43244	0.237505005
3/8/2005	22873	1143.65	119.08	0	4.41	3.087	0	4.54424	-0.01756	1060000	-3272.22	27288.85244	0.3158432
3/9/2005	22812	1140.6	119.06	0	2.92	2.044	0	4.52668	-0.01756	1057500	-2161.53	26114.11244	0.302246672
3/10/2005	22782	1139.1	119.04	0	3.4	2.38	0	4.50912	-0.01756	1055000	-2510.9	26431.98244	0.305925723
3/11/2005	22842	1142.1	119.02	0	4	2.8	0	4.49156	-0.01756	1052500	-2947	26931.08244	0.311702343
3/12/2005	23062	1153.1	119.00	21.5	4.02	2.814	0	4.474	-0.01756	1050000	19620.3	4594.78244	0.053180352
3/13/2005	22659	1132.95	118.98	0	3.41	2.387	0	4.45644	-0.01756	1047200	-2499.6664	26291.59884	0.304300913
3/14/2005	22901	1145.05	118.96	0	4.08	2.856	0	4.43888	-0.01756	1044400	-2982.8064	27028.83884	0.312833783
3/15/2005	22765	1138.25	118.94	0	3.45	2.415	0	4.42132	-0.01756	1041600	-2515.464	26418.69644	0.30577195
3/16/2005	22732	1136.6	118.92	10	4.61	3.227	0	4.40376	-0.01756	1038800	7035.7924	16832.79004	0.194823959
3/17/2005	22681	1134.05	118.90	10.2	4.58	3.206	0	4.3862	-0.01756	1036000	7245.784	16569.24844	0.191773709
3/18/2005	22788	1139.4	118.88	7	4.6	3.22	0	4.36864	-0.01756	1033200	3905.496	20021.88644	0.231734797
3/19/2005	22662	1133.1	118.87	10.6	4	2.8	0	4.35986	-0.00878	1031800	8048.04	15747.05122	0.182257537

3/20/2005	22756	1137.8	18.85	0	4.42	3.094	0	-83.4577	-87.81756	1029000	-3183.726	26989.70844	0.312380885
3/21/2005	22711	1135.55	118.83	0	4.5	3.15	0	4.32474	87.78244	1026200	-3232.53	27166.86244	0.314431278
3/22/2005	22741	1137.05	118.81	0	3.53	2.471	0	4.30718	-0.01756	1023400	-2528.8214	26406.85384	0.305634882
3/23/2005	22728	1136.4	118.79	0	4.36	3.052	0	4.28962	-0.01756	1020600	-3114.8712	26979.25364	0.31225988
3/24/2005	22721	1136.05	118.77	0	4.55	3.185	0	4.27206	-0.01756	1017800	-3241.693	27098.72544	0.313642656
3/25/2005	22803	1140.15	118.75	0	4.41	3.087	0	4.2545	-0.01756	1015000	-3133.305	27076.43744	0.313384693
3/26/2005	23006	1150.3	118.73	0	4.6	3.22	0	4.23694	-0.01756	1012200	-3259.284	27415.56644	0.317309797
3/27/2005	22863	1143.15	118.71	0	4.02	2.814	0	4.21938	-0.01756	1009400	-2840.4516	26846.58404	0.310724352
3/28/2005	22739	1136.95	118.69	0	4.1	2.87	0	4.20182	-0.01756	1006600	-2888.942	26764.87444	0.309778639
3/29/2005	22700	1135	118.67	0	4.12	2.884	0	4.18426	-0.01756	1003800	-2894.9592	26729.94164	0.309374325
3/30/2005	22944	1147.2	118.65	0	3.01	2.107	0	4.1667	-0.01756	1001000	-2109.107	26200.28944	0.303244091
3/31/2005	22762	1138.1	118.63	0	2.82	1.974	0	4.14914	-0.01756	998200	-1970.4468	25870.52924	0.299427422
4/1/2005	22090	1104.5	118.61	0	2.9	2.03	0	4.13158	-0.01756	995400	-2020.662	25215.14444	0.29184195
4/2/2005	18547	927.35	118.59	0	2.41	1.687	0	4.11402	-0.01756	992600	-1674.5162	21148.84864	0.244778341
4/3/2005	23136	1156.8	118.57	0	3.4	2.38	0	4.09646	-0.01756	989800	-2355.724	26648.50644	0.308431788
4/4/2005	23061	1153.05	118.55	0	4	2.8	0	4.0789	-0.01756	987000	-2763.6	26977.63244	0.312241116
4/5/2005	23292	1164.6	118.52	0	2.68	1.876	0	4.05256	-0.02634	982800	-1843.7328	26300.30646	0.304401695
4/6/2005	23031	1151.55	118.50	0	3.5	2.45	0	4.035	-0.01756	910000	-2229.5	26412.03244	0.30569482
4/7/2005	23082	1154.1	118.48	0	5	3.5	0	4.01744	-0.01756	907200	-3175.2	27411.28244	0.317260213
4/8/2005	23230	1161.5	118.45	0	2.52	1.764	0	3.9911	-0.02634	903000	-1592.892	25984.36566	0.300744973
4/9/2005	22988	1149.4	118.42	0	1.98	1.386	0	3.96476	-0.02634	898800	-1245.7368	25383.11046	0.293786001

4/10/2005	22941	1147.05	118.40	0	2.38	1.666	0	3.9472	-0.01756	896000	-1492.736	25580.76844	0.296073709
4/11/2005	22975	1148.75	118.37	0	2.37	1.659	0	3.92086	-0.02634	891800	-1479.4962	25603.21986	0.296333563
4/12/2005	22990	1149.5	118.35	0	2.4	1.68	0	3.9033	-0.01756	889000	-1493.52	25633.00244	0.296678269
4/13/2005	22992	1149.6	118.33	0	3.36	2.352	0	3.88574	-0.01756	886200	-2084.3424	26225.92484	0.303540797
4/14/2005	22964	1148.2	118.30	0	2.08	1.456	0	3.8594	-0.02634	882000	-1284.192	25396.36566	0.293939417
4/15/2005	22284	1114.2	118.26	1.2	2.48	1.736	0	3.82428	-0.03512	876400	-469.7504	23867.91528	0.276249019
4/16/2005	19928	996.4	116.24	1.1	5	3.5	0	2.05072	-1.77356	640750	-1537.8	22460.42644	0.259958639
4/17/2005	22818	1140.9	116.21	0	2.16	1.512	0	2.02438	-0.02634	635350	-960.6492	24919.52286	0.288420403
4/18/2005	22832	1141.6	116.18	0	3.66	2.562	0	1.99804	-0.02634	629950	-1613.9319	25587.50556	0.296151685
4/19/2005	22743	1137.15	116.15	0	5.32	3.724	0	1.9717	-0.02634	624550	-2325.8242	26205.94786	0.303309582
4/20/2005	22752	1137.6	116.12	0	2.52	1.764	0	1.94536	-0.02634	619150	-1092.1806	24981.75426	0.289140674
4/21/2005	22652	1132.6	118.10	0	2.62	1.834	0	3.6838	1.73844	854000	-1566.236	25352.57444	0.293432575
4/22/2005	22639	1131.95	118.07	3.2	3.38	2.366	0	3.65746	-0.02634	849800	708.7332	23062.19046	0.266923501
4/23/2005	22736	1136.8	118.04	2.3	2.12	1.484	0	3.63112	-0.02634	845600	690.0096	23182.76406	0.268319028
4/24/2005	22539	1126.95	118.02	3.2	3.32	2.324	0	3.61356	-0.01756	842800	738.2928	22927.63964	0.2653662
4/25/2005	22631	1131.55	118.00	16.6	3.35	2.345	0	3.596	-0.01756	910000	12972.05	10790.48244	0.124889843
4/26/2005	22611	1130.55	118.02	20.2	2.13	1.491	0	3.61356	0.01756	842800	15767.9452	7973.62236	0.092287296
4/27/2005	22567	1128.35	118.02	6.3	3.2	2.24	0	3.61356	0	842800	3421.768	20273.582	0.23464794
4/28/2005	22679	1133.95	118.01	8.1	2.66	1.862	0	3.60478	-0.00878	841400	5248.6532	18564.28802	0.214864445
4/29/2005	22746	1137.3	118.00	3.5	1.82	1.274	0	3.596	-0.00878	910000	2025.66	21857.63122	0.252981843
4/30/2005	22377	1118.85	117.99	6.4	2.23	1.561	0	3.58722	-0.00878	908650	4396.95735	19098.88387	0.221051897

5/1/2005	22491	1124.55	117.97	3.6	1.76	1.232	0	3.56966	-0.01756	905950	2145.2896	21470.24284	0.248498181
5/2/2005	22388	1119.4	117.95	10	1.76	1.232	0	3.5521	-0.01756	903250	7919.696	15587.68644	0.180413038
5/3/2005	22202	1110.1	119.96	6	1.08	0.756	0	5.31688	1.76478	1170000	6135.48	17178.38478	0.198823898
5/4/2005	22320	1116	117.97	3.1	1.05	0.735	0	3.56966	-1.74722	905950	2142.57175	21291.68103	0.246431493
5/5/2005	22275	1113.75	117.96	3.5	4.5	3.15	0	3.56088	-0.00878	904600	316.61	23072.13122	0.267038556
5/6/2005	22374	1118.7	117.95	7.2	5	3.5	0	3.5521	-0.00878	903250	3342.025	20150.66622	0.233225303
5/7/2005	22708	1135.4	117.96	8.3	5	3.5	0	3.56088	0.00878	904600	4342.08	19501.32878	0.225709824
5/8/2005	22263	1113.15	117.99	7.6	5	3.5	0	3.58722	0.02634	908650	3725.465	19650.71134	0.227438789
5/9/2005	22354	1117.7	118.02	3.6	2.2	1.54	0	3.61356	0.02634	842800	1736.168	21735.55834	0.251568962
5/10/2005	22612	1130.6	118.00	7.6	3.49	2.443	0	3.596	-0.01756	910000	4692.87	19049.71244	0.220482783
5/11/2005	22389	1119.45	117.97	8.6	4.01	2.807	0	3.56966	-0.02634	905950	5248.16835	18260.25531	0.211345548
5/12/2005	22338	1116.9	117.94	0	5.4	3.78	0	3.54332	-0.02634	901900	-3409.182	26864.05566	0.31092657
5/13/2005	22426	1121.3	117.92	5.5	4.02	2.814	0	3.52576	-0.01756	899200	2415.2512	21132.03124	0.244583695
5/14/2005	22498	1124.9	117.90	3.1	4.82	3.374	0	3.5082	-0.01756	896500	-245.641	23868.52344	0.276256058
5/15/2005	22320	1116	117.88	1.3	3.16	2.212	0	3.49064	-0.01756	893800	-815.1456	24251.12804	0.280684352
5/16/2005	22377	1118.85	117.86	0	2.1	1.47	0	3.47308	-0.01756	891100	-1309.917	24805.74944	0.287103581
5/17/2005	22424	1121.2	117.84	5	8.9	6.23	0	3.45552	-0.01756	888400	-1092.732	24637.91444	0.285161047
5/18/2005	22182	1109.1	117.86	6	4.5	3.15	0	3.47308	0.01756	891100	2539.635	20751.48256	0.240179196
5/19/2005	22285	1114.25	117.85	3.5	3.3	2.31	0	3.4643	-0.00878	889750	1058.8025	22340.43872	0.258569893
5/20/2005	22402	1120.1	117.83	5.4	4.74	3.318	0	3.44674	-0.01756	887050	1846.8381	21675.24434	0.250870884
5/21/2005	22374	1118.7	117.81	0.5	5.32	3.724	0	3.42918	-0.01756	884350	-2851.1444	26343.82684	0.304905403

5/22/2005	22389	1119.45	117.79	0	2.54	1.778	0	3.41162	-0.01756	881650	-1567.5737	25076.00614	0.290231553
5/23/2005	22493	1124.65	117.77	0	1.1	0.77	0	3.39406	-0.01756	878950	-676.7915	24294.42394	0.281185462
5/24/2005	22283	1114.15	117.75	0	2.38	1.666	0	3.3765	-0.01756	876250	-1459.8325	24856.96494	0.287696353
5/25/2005	22798	1139.9	117.72	0	0.86	0.602	0	3.35016	-0.02634	872200	-525.0644	24462.93806	0.283135857
5/26/2005	22426	1121.3	117.69	0	3.7	2.59	0	3.32382	-0.02634	868150	-2248.5085	25795.78216	0.298562294
5/27/2005	22647	1132.35	117.67	0	1.06	0.742	0	3.30626	-0.01756	865450	-642.1639	24421.49634	0.282656208
5/28/2005	22653	1132.65	117.65	0	2.04	1.428	0	3.2887	-0.01756	862750	-1232.007	25017.63944	0.289556012
5/29/2005	22800	1140	117.63	0	2.48	1.736	0	3.27114	-0.01756	860050	-1493.0468	25433.02924	0.294363764
5/30/2005	22517	1125.85	117.61	0	4.48	3.136	0	3.25358	-0.01756	857350	-2688.6496	26331.48204	0.304762524
5/31/2005	22821	1141.05	117.59	0	2.8	1.96	0	3.23602	-0.01756	854650	-1675.114	25637.14644	0.296726232
6/1/2005	22413	1120.65	117.57	0	0.94	0.658	0	3.21846	-0.01756	851950	-560.5831	24094.21554	0.278868235
6/2/2005	22430	1121.5	117.55	0	0.06	0.042	0	3.2009	-0.01756	849250	-35.6685	23587.15094	0.272999432
6/3/2005	22642	1132.1	117.52	0	0.92	0.644	0	3.17456	-0.02634	845200	-544.3088	24318.38246	0.28146276
6/4/2005	22579	1128.95	117.49	0	2.66	1.862	0	3.14822	-0.02634	841150	-1566.2213	25274.14496	0.292524826
6/5/2005	22303	1115.15	117.47	0	3.64	2.548	0	3.13066	-0.01756	838450	-2136.3706	25554.50304	0.295769711
6/6/2005	22524	1126.2	117.44	0	1.67	1.169	0	3.10432	-0.02634	834400	-975.4136	24625.58726	0.285018371
6/7/2005	22433	1121.65	117.41	0	2.32	1.624	0	3.07798	-0.02634	830350	-1348.4884	24903.11206	0.288230464
6/8/2005	22137	1106.85	117.38	3	3.28	2.296	0	3.05164	-0.02634	826300	581.7152	22662.10846	0.262292922
6/9/2005	2231	111.55	117.35	3.5	3.4	2.38	0	3.0253	-0.02634	822250	920.92	1421.60366	0.016453746
6/10/2005	22291	1114.55	117.32	0	2.4	1.68	0	2.99896	-0.02634	818200	-1374.576	24780.09966	0.286806709
6/11/2005	22469	1123.45	117.30	0	2.24	1.568	0	2.9814	-0.01756	815500	-1278.704	24871.13644	0.287860375

6/12/2005	22512	1125.6	117.26	0	2.2	1.54	0	2.94628	-0.03512	810100	-1247.554	24885.11888	0.288022209
6/13/2005	22249	1112.45	117.23	0	3.5	2.45	0	2.91994	-0.02634	806050	-1974.8225	25336.24616	0.29324359
6/14/2005	22033	1101.65	117.20	1.3	3.56	2.492	0	2.8936	-0.02634	802000	-955.984	24090.60766	0.278826478
6/15/2005	22457	1122.85	117.18	3.2	3.08	2.156	0	2.87604	-0.01756	799300	834.4692	22745.36324	0.263256519
6/16/2005	22354	1117.7	117.16	3.1	5.62	3.934	0	2.85848	-0.01756	796600	-664.3644	24136.04684	0.279352394
6/17/2005	22408	1120.4	117.14	4	0.82	0.574	0	2.84092	-0.01756	793900	2719.9014	20808.48104	0.240838901
6/18/2005	22292	1114.6	117.12	10.1	2.11	1.477	0	2.82336	-0.01756	791200	6822.5176	16584.06484	0.191945195
6/19/2005	22206	1110.3	117.10	9.2	1.5	1.05	0	2.8058	-0.01756	788500	6426.275	16890.00744	0.195486197
6/20/2005	21949	1097.45	117.08	11	1.5	1.05	0	2.78824	-0.01756	785800	7818.71	15227.72244	0.176246788
6/21/2005	22305	1115.25	117.10	9	5.6	3.92	0	2.8058	0.01756	788500	4005.58	19414.68756	0.224707032
6/22/2005	22120	1106	117.08	12.1	9.2	6.44	0	2.78824	-0.01756	785800	4447.628	18778.35444	0.217342065
6/23/2005	22147	1107.35	117.14	13.1	1.5	1.05	0	2.84092	0.05268	793900	9566.495	13687.90768	0.158424857
6/24/2005	22505	1125.25	117.12	15	1.46	1.022	0	2.82336	-0.01756	791200	11059.3936	12570.83884	0.14549582
6/25/2005	22628	1131.4	117.14	12	2	1.4	0	2.84092	0.01756	793900	8415.34	15344.07756	0.17759349
6/26/2005	22081	1104.05	117.12	18	2.96	2.072	0	2.82336	-0.01756	791200	12602.2336	10582.79884	0.122486098
6/27/2005	22299	1114.95	117.13	8	0.26	0.182	0	2.83214	0.00878	792550	6196.1559	17217.80288	0.199280126
6/28/2005	22267	1113.35	117.11	10.3	2.3	1.61	0	2.81458	-0.01756	789850	6863.7965	16516.53594	0.19116361
6/29/2005	21961	1098.05	117.10	10	3	2.1	0	2.8058	-0.00878	788500	6229.15	16829.89122	0.194790408
6/30/2005	22309	1115.45	117.13	12	2	1.4	0	2.83214	0.02634	792550	8401.03	15023.44634	0.173882481
7/1/2005	22087	1104.35	117.16	12	1.5	1.05	0	2.85848	0.02634	796600	8722.77	14468.60634	0.167460722
7/2/2005	22323	1116.15	117.17	10	2.6	1.82	0	2.86726	0.00878	797950	6527.231	16911.92778	0.195739905

7/3/2005	22394	1119.7	117.20	13	2.5	1.75	0	2.8936	0.02634	802000	9022.5	14491.22634	0.167722527
7/4/2005	22237	1111.85	117.25	15	2.9	2.03	0	2.9375	0.0439	808750	10489.4875	12859.4064	0.148835722
7/5/2005	22069	1103.45	117.38	16	3.6	2.52	0	3.05164	0.11414	826300	11138.524	12034.04014	0.139282872
7/6/2005	22236	1111.8	117.40	1.2	3.5	2.45	0	3.0692	0.01756	829000	-1036.25	24384.06756	0.282223004
7/7/2005	22468	1123.4	117.38	0	4.9	3.43	0	3.05164	-0.01756	826300	-2834.209	26425.59144	0.305851753
7/8/2005	22270	1113.5	117.38	3	5.6	3.92	0	3.05164	0	826300	-760.196	24143.696	0.279440926
7/9/2005	22427	1121.35	117.37	3.8	9.2	6.44	0	3.04286	-0.00878	824950	-2177.868	25726.20922	0.297757051
7/10/2005	22303	1115.15	117.40	9	3.6	2.52	0	3.0692	0.02634	829000	5371.92	18046.25634	0.208868708
7/11/2005	22198	1109.9	117.44	18	3.9	2.73	0	3.10432	0.03512	834400	12741.288	10566.64712	0.122299156
7/12/2005	22356	1117.8	117.48	8	4.87	3.409	0	3.13944	0.03512	839800	3855.5218	19618.31332	0.227063812
7/13/2005	22421	1121.05	117.47	6	6.5	4.55	0	3.13066	-0.00878	838450	1215.7525	22326.28872	0.258406119
7/14/2005	22491	1124.55	117.49	10	3.9	2.73	0	3.14822	0.01756	841150	6115.1605	17500.40706	0.202551008
7/15/2005	22458	1122.9	117.53	10	6.9	4.83	0	3.18334	0.03512	846550	4376.6635	19204.27162	0.222271662
7/16/2005	22760	1138	117.85	9	3.98	2.786	0	3.4643	0.28096	889750	5528.9065	18369.37446	0.212608501
7/17/2005	22512	1125.6	118.02	8	0.99	0.693	0	3.61356	0.14926	842800	6158.3396	17479.40966	0.202307982
7/18/2005	21559	1077.95	118.23	10	6.9	4.83	0	3.79794	0.18438	872200	4509.274	18127.86038	0.209813199
7/19/2005	20990	1049.5	118.46	10	6.9	4.83	0	3.99988	0.20194	904400	4675.748	17363.95394	0.200971689
7/20/2005	21574	1078.7	118.60	11	6.32	4.424	0	4.1228	0.12292	994000	6536.544	16116.27892	0.186531006
7/21/2005	21424	1071.2	118.77	8	9.82	6.874	0	4.27206	0.14926	1017800	1146.0428	21349.30646	0.247098454
7/22/2005	21232	1061.6	119.08	10	5	3.5	0	4.54424	0.27218	1060000	6890	15403.87218	0.178285558
7/23/2005	18806	940.3	119.20	11	4	2.8	0	4.6496	0.10536	1075000	8815	10931.40536	0.126520895

7/24/2005	19520	976	119.36	6	3.6	2.52	0	4.79008	0.14048	1095000	3810.6	16685.54048	0.193119681
7/25/2005	20547	1027.35	119.65	7	3.6	2.52	0	5.0447	0.25462	1131250	5068	16506.60462	0.191048665
7/26/2005	20587	1029.35	119.80	8	3.6	2.52	0	5.1764	0.1317	1150000	6302	15314.4817	0.177250946
7/27/2005	21464	1073.2	119.90	6	3.6	2.52	0	5.2642	0.0878	1162500	4045.5	18491.7878	0.214025322
7/28/2005	20916	1045.8	120.01	5	3.6	2.52	0	5.36078	0.09658	1127000	2794.96	19166.93658	0.221839544
7/29/2005	20832	1041.6	120.15	5	2.4	1.68	0	5.4837	0.12292	1155000	3834.6	18039.12292	0.208786145
7/30/2005	21020	1051	120.30	6	3.9	2.73	0	5.6154	0.1317	1185000	3874.95	18196.1817	0.210603955
7/31/2005	20858	1042.9	120.61	3.3	3.8	2.66	0	5.88758	0.27218	1236000	791.04	21110.13218	0.244330234
8/1/2005	21045	1052.25	120.87	10	3.9	2.73	0	6.11586	0.22828	1262000	9174.74	12922.73828	0.14956873
8/2/2005	21659	1082.95	121.00	9.1	3.9	2.73	0	6.23	0.11414	1275000	8121.75	14620.31414	0.169216599
8/3/2005	20891	1044.55	121.04	10	3.5	2.45	203004	6.23	0	1275000	9626.25	215313.3	2.492052083
8/4/2005	21074	1053.7	121.04	10	2.3	1.61	203340	6.23	0	1275000	10697.25	214770.45	2.485769097
8/5/2005	21042	1052.1	121.03	11	3.9	2.73	165856	6.23	0	1275000	10544.25	177405.85	2.053308449
8/6/2005	21177	1058.85	121.06	12	2.2	1.54	539964	6.23	0	1275000	13336.5	548863.35	6.352585069
8/7/2005	20906	1045.3	121.07	9	2.1	1.47	621352	6.23	0	1275000	9600.75	633702.55	7.334520255
8/8/2005	21672	1083.6	121.04	10	2.1	1.47	255216	6.23	0	1275000	10875.75	267095.85	3.091387153
8/9/2005	21322	1066.1	121.08	10	2	1.4	753708	6.23	0	1275000	10965	765131.1	8.855684028
8/10/2005	21139	1056.95	121.04	8	1.8	1.26	264996	6.23	0	1275000	8593.5	278598.45	3.224519097
8/11/2005	21912	1095.6	121.03	7	2.29	1.603	184661	6.23	0	1275000	6881.175	200787.425	2.32392853
8/12/2005	21322	1066.1	121.05	5	3.41	2.387	292044	6.23	0	1275000	3331.575	311100.525	3.600700521
8/13/2005	21274	1063.7	121.04	3	1.91	1.337	248450	6.23	0	1275000	2120.325	268667.375	3.1095761

8/14/2005	21141	1057.05	121.07	20	1	0.7	520541	6.23	0	1275000	24607.5	518131.55	5.99689294
8/15/2005	21231	1061.55	121.05	21	2.52	1.764	354204	6.23	0	1275000	24525.9	351970.65	4.073734375
8/16/2005	21113	1055.65	121.05	20.5	1.69	1.183	335144	6.23	0	1275000	24629.175	332683.475	3.850503183
8/17/2005	21501	1075.05	121.06	15.1	0	0	382716	6.23	0	1275000	19252.5	386039.55	4.468050347
8/18/2005	20960	1048	121.08	16	1.65	1.155	854304	6.23	0	1275000	18927.375	857384.625	9.92343316
8/19/2005	21049	1052.45	121.07	13.1	1.8	1.26	472119	6.23	0	1275000	15096	479124.45	5.545421875
8/20/2005	18552	927.6	121.04	19	2.1	1.47	242955	6.23	0	1275000	22350.75	240083.85	2.778748264
8/21/2005	21266	1063.3	121.04	10	2.18	1.526	254460	6.23	0	1275000	10804.35	265984.95	3.078529514
8/22/2005	21169	1058.45	121.04	11	3	2.1	214750	6.23	0	1275000	11347.5	225629.95	2.611457755
8/23/2005	21484	1074.2	121.03	9	2.88	2.016	201756	6.23	0	1275000	8904.6	215409.6	2.493166667
8/24/2005	21372	1068.6	121.03	0	2.92	2.044	160063	6.23	0	1275000	-2606.1	185109.7	2.14247338
8/25/2005	21180	1059	121.04	6	3.23	2.261	304980	6.23	0	1275000	4767.225	322451.775	3.732080729
8/26/2005	21484	1074.2	121.04	19	2.12	1.484	281023	6.23	0	1275000	22332.9	281248.3	3.255188657
8/27/2005	21404	1070.2	121.03	20	3.31	2.317	160063	6.23	0	1275000	22545.825	159991.375	1.851752025
8/28/2005	21125	1056.25	121.04	16	3.64	2.548	352428	6.23	0	1275000	17151.3	357457.95	4.137244792
8/29/2005	21452	1072.6	121.06	10	2.17	1.519	406908	6.23	0	1275000	10813.275	418619.325	4.845131076
8/30/2005	21471	1073.55	121.03	20	4.13	2.891	172932	6.23	0	1275000	21813.975	173662.575	2.009983507
8/31/2005	21364	1068.2	121.03	5	2.99	2.093	233417	6.23	0	1275000	3706.425	252142.775	2.918319155
9/1/2005	21489	1074.45	121.04	6	1.86	1.302	307467	6.23	0	1275000	5989.95	324040.5	3.75046875
9/2/2005	21562	1078.1	121.02	4	2.86	2.002	235577	6.23	0	1275000	2547.45	255669.65	2.959139468
9/3/2005	21514	1075.7	121.04	4.5	3.45	2.415	310817	6.23	0	1275000	2658.375	330748.325	3.828105613

9/4/2005	21405	1070.25	121.03	11	2.54	1.778	219926	6.23	0	1275000	11758.05	230643.2	2.669481481
9/5/2005	21467	1073.35	121.04	9	2.6	1.82	313169	6.23	0	1275000	9154.5	326554.85	3.779570023
9/6/2005	21484	1074.2	121.03	4.5	2.5	1.75	320340	6.23	0	1275000	3506.25	339391.95	3.928147569
9/7/2005	21455	1072.75	121.03	7.3	3.6	2.52	335805	6.23	0	1275000	6094.5	352238.25	4.076831597
9/8/2005	21549	1077.45	121.02	10	1.9	1.33	225473	6.23	0	1275000	11054.25	237045.2	2.743578704
9/9/2005	21626	1081.3	121.03	8	3.9	2.73	297444	6.23	0	1275000	6719.25	313432.05	3.627685764
9/10/2005	21791	1089.55	121.03	0	2.1	1.47	262409	6.23	0	1275000	-1874.25	287163.8	3.323655093
9/11/2005	21381	1069.05	121.04	19	4.8	3.36	406322	6.23	0	1275000	19941	408831.05	4.731840856
9/12/2005	31351	1567.55	121.02	20	4.6	3.22	351902	6.23	0	1275000	21394.5	363426.05	4.206320023
9/13/2005	21484	1074.2	121.04	16	2.2	1.54	320275	6.23	0	1275000	18436.5	324396.7	3.754591435
9/14/2005	21517	1075.85	121.03	15	3.8	2.66	358361	6.23	0	1275000	15733.5	365220.35	4.227087384
9/15/2005	21524	1076.2	121.03	11	3	2.1	324539	6.23	0	1275000	11347.5	335791.7	3.886478009
9/16/2005	21542	1077.1	121.03	12	3.6	2.52	262409	6.23	0	1275000	12087	272941.1	3.159040509
9/17/2005	21698	1084.9	121.03	10	3.9	2.73	381065	6.23	0	1275000	9269.25	394578.65	4.566882523
9/18/2005	21617	1080.85	121.03	12	3.2	2.24	336265	6.23	0	1275000	12444	346518.85	4.010634838
9/19/2005	21737	1086.85	121.02	5	3.3	2.31	174929	6.23	0	1275000	3429.75	194323.1	2.249109954
9/20/2005	21638	1081.9	121.02	0	4.9	3.43	230465	6.23	0	1275000	-4373.25	257558.15	2.980997106
9/21/2005	21580	1079	121.02	0	3.3	2.31	230175	6.23	0	1275000	-2945.25	255779.25	2.960407986
9/22/2005	21552	1077.6	121.01	0	3.5	2.45	97947	6.23	0	1275000	-3123.75	123700.35	1.431717014
9/23/2005	21709	1085.45	121.01	0	3.3	2.31	120082	6.23	0	1275000	-2945.25	145821.7	1.687751157
9/24/2005	21540	1077	121.01	2.1	3.1	2.17	124289	6.23	0	1275000	-89.25	146995.25	1.701333912

9/25/2005	21700	1085	121.01	0	1.9	1.33	97947	6.23	0	1275000	-1695.75	122427.75	1.416987847
9/26/2005	21568	1078.4	121.01	0	4.9	3.43	80621	6.23	0	1275000	-4373.25	107640.65	1.245840856
9/27/2005	21303	1065.15	121.02	0	2.7	1.89	175512	6.23	0	1275000	-2409.75	200289.9	2.318170139
9/28/2005	21565	1078.25	121.01	0	3.7	2.59	71880	6.23	0	1275000	-3302.25	97825.5	1.132239583
9/29/2005	21366	1068.3	121	0	4.92	3.444	9041	6.23	0	1275000	-4391.1	35866.4	0.41512037
9/30/2005	21540	1077	121	0	3.81	2.667	6546	6.23	0	1275000	-3400.425	32563.425	0.376891493
10/1/2005	21447	1072.35	121.00 0	0	3.4	2.38	24012	6.23	0	1275000	-3034.5	49565.85	0.573678819
10/2/2005	22222	1111.1	121.00 0	0	3.62	2.534	24130	6.23	0	1275000	-3230.85	50693.95	0.586735532
10/3/2005	21592	1079.6	121.00 0	0	3.6	2.52	25315	6.23	0	1275000	-3213	51199.6	0.592587963
10/4/2005	21638	1081.9	121.00 0	0	3.8	2.66	23240	6.23	0	1275000	-3391.5	49351.4	0.571196759
10/5/2005	21720	1086	121.00 0	0	3.95	2.765	24350	6.23	0	1275000	-3525.375	50681.375	0.586589988
10/6/2005	21825	1091.25	121.00 0	7.1	3	2.1	24660	6.23	0	1275000	6375	41201.25	0.476866319
10/7/2005	21710	1085.5	121.00 0	6.2	3.4	2.38	23536	6.23	0	1275000	4870.5	41461	0.479872685
10/8/2005	21660	1083	121.00 0	10.3	1.6	1.12	25288	6.23	0	1275000	11704.5	36326.5	0.420445602
10/9/2005	21993	1099.65	121.00 0	16.1	1.7	1.19	26475	6.23	0	1275000	19010.25	30557.4	0.353673611
10/10/2005	22057	1102.85	121.00 0	6.2	1.98	1.386	24763	6.23	0	1275000	6137.85	41785	0.483622685

10/11/2005	21867	1093.35	121.00	0	2.14	1.498	0	6.23	0	1275000	-1909.95	24870.3	0.287850694
10/12/2005	21610	1080.5	121.00	0	2.92	2.044	0	6.23	0	1275000	-2606.1	25296.6	0.292784722
10/13/2005	21612	1080.6	121.00	0	2.99	2.093	0	6.23	0	1275000	-2668.575	25361.175	0.293532118
10/14/2005	21864	1093.2	121.00	0	3.18	2.226	0	6.23	0	1275000	-2838.15	25795.35	0.298557292
10/15/2005	21790	1089.5	121.00	0	3.42	2.394	0	6.23	0	1275000	-3052.35	25931.85	0.300137153
10/16/2005	21758	1087.9	121.00	0	4.16	2.912	0	6.23	0	1275000	-3712.8	26558.7	0.307392361
10/17/2005	21679	1083.95	121.00	0	4	2.8	0	6.23	0	1275000	-3570	26332.95	0.304779514
10/18/2005	21692	1084.6	121.00	0	3.88	2.716	0	6.23	0	1275000	-3462.9	26239.5	0.303697917
10/19/2005	21820	1091	120.99	0	4.22	2.954	0	6.22122	-0.00878	1274000	-3763.396	26674.38722	0.308731334
10/20/2005	21601	1080.05	120.98	0	4.56	3.192	0	6.21244	-0.00878	1273000	-4063.416	26744.45722	0.309542329
10/21/2005	21748	1087.4	120.97	0	2.98	2.086	0	6.20366	-0.00878	1272000	-2653.392	25488.78322	0.295009065
10/22/2005	21814	1090.7	120.96	0	4.24	2.968	0	6.19488	-0.00878	1271000	-3772.328	26677.01922	0.308761797
10/23/2005	21881	1094.05	120.94	0	4.61	3.227	0	6.17732	-0.01756	1269000	-4095.063	27070.09544	0.31331129
10/24/2005	21774	1088.7	120.92	0	4.12	2.884	0	6.15976	-0.01756	1267000	-3654.028	26516.71044	0.306906371
10/25/2005	21852	1092.6	120.90	0	4.1	2.87	0	6.1422	-0.01756	1265000	-3630.55	26575.13244	0.307582551
10/26/2005	21691	1084.55	120.89	0	4.6	3.22	0	6.13342	-0.00878	1264000	-4070.08	26845.62122	0.310713209
10/27/2005	21741	1087.05	120.88	0	4	2.8	0	6.12464	-0.00878	1263000	-3536.4	26364.44122	0.305143996
10/28/2005	21745	1087.25	120.87	0	4.12	2.884	0	6.11586	-0.00878	1262000	-3639.608	26471.84922	0.306387144
10/29/2005	21800	1090	120.86	0	4.36	3.052	0	6.10708	-0.00878	1261000	-3848.572	26738.56322	0.309474111
10/30/2005	21720	1086	120.84	0	3.28	2.296	0	6.08952	-0.01756	1259000	-2890.664	25696.64644	0.297414889
10/31/2005	21793	1089.65	120.82	0	2.89	2.023	0	6.07196	-0.01756	1257000	-2542.911	25425.54344	0.294277123

11/1/2005	21500	1075	120.80	0	4.22	2.954	0	6.0544	-0.01756	1255000	-3707.27	26282.25244	0.304192737
11/2/2005	21586	1079.3	120.78	0	3.2	2.24	0	6.03684	-0.01756	1253000	-2806.72	25472.00244	0.294814843
11/3/2005	21714	1085.7	120.77	0	2.94	2.058	0	6.02806	-0.00878	1252000	-2576.616	25376.30722	0.293707259
11/4/2005	21550	1077.5	120.75	0	4	2.8	0	6.0105	-0.01756	1250000	-3500	26127.48244	0.302401417
11/5/2005	21592	1079.6	120.73	0	3.18	2.226	0	5.99294	-0.01756	1248000	-2778.048	25449.63044	0.294555908
11/6/2005	21806	1090.3	120.71	0	3.22	2.254	0	5.97538	-0.01756	1246000	-2808.484	25704.76644	0.297508871
11/7/2005	21539	1076.95	120.70	0	4.1	2.87	0	5.9666	-0.00878	1245000	-3573.15	26189.09122	0.303114482
11/8/2005	21517	1075.85	120.68	0	3	2.1	0	5.94904	-0.01756	1243000	-2610.3	25203.13244	0.291702922
11/9/2005	21570	1078.5	120.66	0	2.18	1.526	0	5.93148	-0.01756	1241000	-1893.766	24542.24844	0.284053801
11/10/2005	21821	1091.05	120.64	0	3.32	2.324	0	5.91392	-0.01756	1239000	-2879.436	25791.46844	0.298512366
11/11/2005	21654	1082.7	120.62	0	3.3	2.31	0	5.89636	-0.01756	1237000	-2857.47	25594.15244	0.296228616
11/12/2005	21767	1088.35	120.60	0	2.16	1.512	0	5.8788	-0.01756	1235000	-1867.32	24722.65244	0.286141811
11/13/2005	21767	1088.35	120.59	0	3.31	2.317	0	5.87002	-0.00878	1234000	-2859.178	25714.51922	0.29762175
11/14/2005	21561	1078.05	120.58	0	3.28	2.296	0	5.86124	-0.00878	1233000	-2830.968	25470.00922	0.294791773
11/15/2005	21840	1092	120.56	0	4.08	2.856	0	5.84368	-0.01756	1231000	-3515.736	26447.71844	0.306107852
11/16/2005	21519	1075.95	120.54	0	3.92	2.744	0	5.82612	-0.01756	1229000	-3372.376	25967.30844	0.300547551
11/17/2005	21472	1073.6	120.52	2	4.12	2.884	0	5.80856	-0.01756	1227000	-1084.668	23630.25044	0.273498269
11/18/2005	21734	1086.7	120.50	0	2.18	1.526	0	5.791	-0.01756	1225000	-1869.35	24690.03244	0.285764264
11/19/2005	21642	1082.1	120.49	0	3.31	2.317	0	5.78222	-0.00878	1223000	-2833.691	25557.78222	0.295807665
11/20/2005	21616	1080.8	120.48	0	3.94	2.758	0	5.77344	-0.00878	1221000	-3367.518	26064.30922	0.301670246
11/21/2005	21764	1088.2	120.46	0	2.28	1.596	0	5.75588	-0.01756	1217000	-1942.332	24794.51444	0.286973547

11/22/2005	21500	1075	120.44	0	3.48	2.436	0	5.73832	-0.01756	1213000	-2954.868	25529.85044	0.29548438
11/23/2005	21432	1071.6	120.42	0	3.41	2.387	0	5.72076	-0.01756	1209000	-2885.883	25389.46544	0.293859554
11/24/2005	21574	1078.7	120.40	0	2.22	1.554	0	5.7032	-0.01756	1205000	-1872.57	24525.25244	0.283857088
11/25/2005	21018	1050.9	120.38	0	3	2.1	0	5.68564	-0.01756	1201000	-2522.1	24590.98244	0.284617852
11/26/2005	20197	1009.85	120.36	0	2.24	1.568	0	5.66808	-0.01756	1197000	-1876.896	23083.72844	0.267172783
11/27/2005	19565	978.25	120.34	0	3.9	2.73	0	5.65052	-0.01756	1193000	-3256.89	23800.12244	0.27546438
11/28/2005	21240	1062	120.32	0	2	1.4	0	5.63296	-0.01756	1179000	-1650.6	23952.58244	0.277228963
11/29/2005	21158	1057.9	120.30	0	2.21	1.547	0	5.6154	-0.01756	1185000	-1833.195	24049.07744	0.278345804
11/30/2005	21046	1052.3	120.28	0	1.98	1.386	0	5.59784	-0.01756	1181000	-1636.866	23735.14844	0.274712366
12/1/2005	21424	1071.2	120.26	0	3.57	2.499	0	5.58028	-0.01756	1177000	-2941.323	25436.50544	0.294403998
12/2/2005	21673	1083.65	120.24	0	3.5	2.45	0	5.56272	-0.01756	1173000	-2873.85	25630.48244	0.296649102
12/3/2005	21857	1092.85	120.22	0	2	1.4	0	5.54516	-0.01756	1169000	-1636.6	24586.43244	0.28456519
12/4/2005	21386	1069.3	120.20	0	2.18	1.526	0	5.5276	-0.01756	1165000	-1777.79	24233.07244	0.280475375
12/5/2005	21101	1055.05	120.18	0	2.12	1.484	0	5.51004	-0.01756	1161000	-1722.924	23878.95644	0.276376811
12/6/2005	31356	1567.8	120.16	0	3.62	2.534	0	5.49248	-0.01756	1157000	-2931.838	35855.62044	0.414995607
12/7/2005	21809	1090.45	120.17	0	3.63	2.541	0	5.50126	0.00878	1159000	-2945.019	25844.47778	0.2991259
12/8/2005	21573	1078.65	120.15	0	3.6	2.52	0	5.4837	-0.01756	1155000	-2910.6	25562.23244	0.295859172
12/9/2005	21728	1086.4	120.15	0	2.61	1.827	0	5.4837	0	1155000	-2110.185	24924.585	0.288478993
12/10/2005	21646	1082.3	120.18	0	2.65	1.855	0	5.51004	0.02634	1161000	-2153.655	24881.98134	0.287985895
12/11/2005	21592	1079.6	120.19	0	2.92	2.044	0	5.51882	0.00878	1163000	-2377.172	25048.78078	0.289916444
12/12/2005	21581	1079.05	120.20	0	2.87	2.009	0	5.5276	0.00878	1165000	-2340.485	25000.54378	0.289358146

12/13/2005	21721	1086.05	120.18	0	3.32	2.324	0	5.51004	-0.01756	1161000	-2698.164	25505.19644	0.295199033
12/14/2005	21356	1067.8	120.19	0	4.48	3.136	0	5.51882	0.00878	1163000	-3647.168	26070.97678	0.301747416
12/15/2005	21651	1082.55	120.20	0	3.38	2.366	0	5.5276	0.00878	1165000	-2756.39	25489.94878	0.295022555
12/16/2005	21289	1064.45	120.19	0	4.5	3.15	0	5.51882	-0.00878	1163000	-3663.45	26016.89122	0.301121426
12/17/2005	17883	894.15	120.19	0	4.91	3.437	0	5.51882	0	1163000	-3997.231	22774.381	0.263592373
12/18/2005	21864	1093.2	120.19	0	3.36	2.352	0	5.51882	0	1163000	-2735.376	25692.576	0.297367778
12/19/2005	21978	1098.9	120.19	0	2.84	1.988	0	5.51882	0	1163000	-2312.044	25388.944	0.293853519
12/20/2005	21864	1093.2	120.19	0	2.96	2.072	0	5.51882	0	1163000	-2409.736	25366.936	0.293598796
12/21/2005	21989	1099.45	120.20	0	2.87	2.009	0	5.5276	0.00878	1165000	-2340.485	25428.94378	0.294316479
12/22/2005	22025	1101.25	120.19	0	2.3	1.61	0	5.51882	-0.00878	1163000	-1872.43	24998.67122	0.289336472
12/23/2005	21902	1095.1	120.18	0	2.9	2.03	0	5.51004	-0.00878	1161000	-2356.83	25353.92122	0.293448162
12/24/2005	22169	1108.45	120.19	0	2.21	1.547	0	5.51882	0.00878	1163000	-1799.161	25076.61978	0.290238655
12/25/2005	21835	1091.75	120.18	0	2.5	1.75	0	5.51004	-0.00878	1161000	-2031.75	24958.49122	0.288871426
12/26/2005	21937	1096.85	120.17	0	2.48	1.736	0	5.50126	-0.00878	1159000	-2012.024	25045.86522	0.289882699
12/27/2005	21988	1099.4	120.19	0	4.28	2.996	0	5.51882	0.01756	1163000	-3484.348	26571.76556	0.307543583
12/28/2005	21407	1070.35	120.17	0	5	3.5	0	5.50126	-0.01756	1159000	-4056.5	26533.83244	0.307104542
12/29/2005	21650	1082.5	120.16	0	5.18	3.626	0	5.49248	-0.00878	1157000	-4195.282	26927.77322	0.311664042
12/30/2005	22053	1102.65	120.17	0	3.38	2.366	0	5.50126	0.00878	1159000	-2742.194	25897.85278	0.299743666
12/31/2005	19419	970.95	120.16	0	3	2.1	0	5.49248	-0.00878	1157000	-2429.7	22819.64122	0.264116218

Table A- 1. Generated daily inflow using water balance for 2005 year

SUB	AREAKm2	PRECIPmm	PETmm	ETmm	SWmm	PERCmm	SURQmm	GW_Qmm	WYLDmm	SYLDt_ha
1	13.652	1131.633	2374.738	791.5887	51.387	11.05052	312.6943	11.08962	323.9908	6.73071429
2	8.6809	1103.99	2274.96	787.573	40.22224	8.207333	300.4915	8.41581	309.1736	2.98019048
3	12.209	1093.588	2102.781	703.88	50.30152	27.26819	399.8662	26.14819	429.5749	0.31071429
4	10.009	1269.429	2411.013	768.0301	4.988952	47.02567	432.4196	44.68986	477.9724	0.81614286
5	9.3979	1244.918	2365.317	757.5419	7.793571	40.0569	435.0748	38.5309	473.9791	15.7172381
6	1.047	1102.017	2007.646	812.3925	10.91805	52.32267	413.9833	49.76743	464.4307	24.9107619

Table A-2 Output of the sub-basins after SWAT

Subbasin	1	2	3	4	5	6
1979	7564	3139	1233	501.1	21750	1420
1980	6263	1589	1702	577.3	9444	1949
1981	12830	4786	2823	737.2	13450	2070
1982	13080	2857	2166	560.8	11970	1597
1983	8872	2652	2474	649	13420	1841
1984	9999	3302	2621	791.8	17720	2373
1985	6330	1753	1976	707.2	17110	2075
1986	12050	2831	2869	771	17890	1866
1987	7726	1497	2099	678.8	19040	1943
1988	11190	2319	2726	683	13390	2208
1989	7691	1555	2516	806.1	19060	2486
1990	12800	2788	2852	621.8	11010	1778
1991	11270	2157	2386	602.6	12790	1839
1992	7340	3145	2019	602.2	10480	1796
1993	7089	2971	3163	1075	16860	3013
1994	4590	1669	1906	588.5	8394	1535
1995	10520	1506	2035	595.3	16870	1674

1996	9024	1732	2682	1006	25390	2913
1997	4744	1289	1407	457.9	7266	1245
1998	7864	3646	3411	968.1	12790	2670
1999	14130	5146	2573	613.8	14100	1683

Table A-3 Yearly sediment yield from each sub-basin (unit: ton/year)

Layer 1

SNAM	CBN	Clay	Silt	Sand	f_{csand}	f_{cl-si}	f_{orgc}	f_{hisand}	K_{USLE}
Chromic Luvisols	0.63	27	22	51	0.463	0.78	0.9755	0.998	0.35
Chromic vertisols	0.75	55	29	16	0.491	0.72	0.964	0.999	0.34
Eutric nitosols	0.58	23	28	49	0.2	0.84	0.982	0.999	0.164
Orthic soloncks	0.53	21	43	36	0.2	0.88	0.985	0.999	0.175
Vertic Cambisols	0.78	42	28	30	0.2	0.76	0.96	0.956	0.14

Layer 2

SNAM	CBN	Clay	Silt	Sand	f_{csand}	f_{cl-si}	f_{orgc}	f_{hisand}	K_{USLE}
Chromic Luvisols	0.39	28	29	43	0.2	0.82	0.988	0.951	0.153
Chromic vertisols	0.97	51	28	21	0.206	0.73	0.927	0.999	0.14
Eutric nitosols	0.94	22	36	42	0.2	0.87	0.933	0.9989	0.16
Orthic soloncks	0.58	53	31	16	0.217	0.74	0.999	0.999	0.16
Vertic Cambisols	1.07	54	25	21	0.205	0.71	0.999	0.999	0.131

Layer 3

SNAM	CBN	Clay	Silt	Sand	f_{csand}	f_{cl-si}	f_{orgc}	f_{nisand}	K_{USLE}
Chromic Luvisols	2.45	49	27	24	0.203	0.73	0.753	0.999	0.112
Chromic vertisols	1.4	23	34	43	0.2	0.86	0.473	0.999	0.081
Eutric nitosols	1.4	23	34	43	0.2	0.86	0.473	0.999	0.081
Orthic soloncks	0.42	21	43	36	0.202	0.89	0.992	0.999	0.178
Vertic Cambisols	0.93	32	26	42	0.2	0.79	0.935	0.999	0.147

Table A-4 Soil Erodibility Factory (K_{USLE}) Calculation

Reservoir Area vs. Water Level

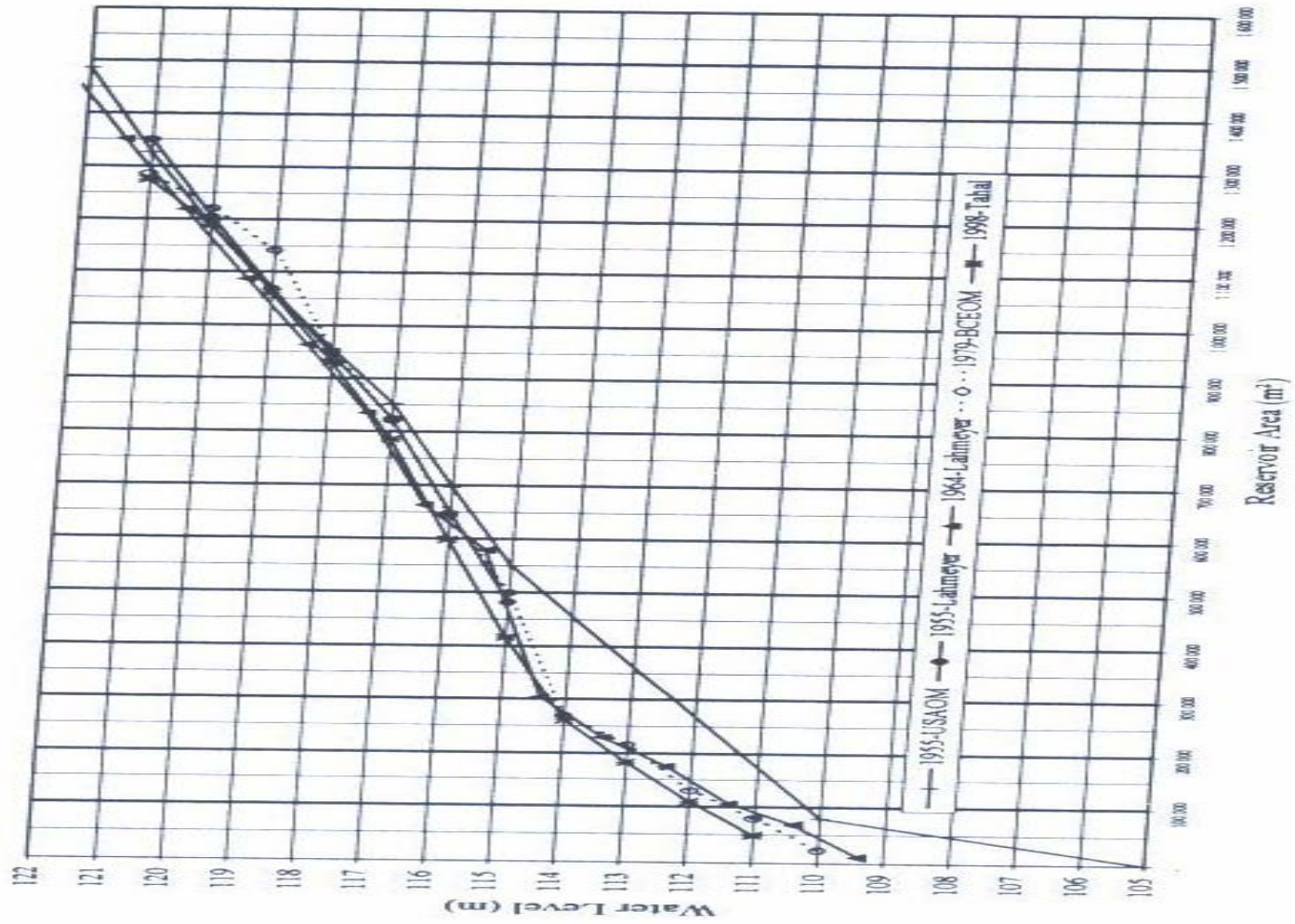


Figure 1 Reservoir Area vs Water level curve