

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Civil and Environmental Engineering

Hydraulic Engineering Stream

Thesis on:

SEDIMENT PROBLEM OF GEFERSA RESERVOIRS AND THE APPROPRIATE MITIGATION.

Submitted in partial fulfillment for the degree of Masters of Science in Civil Engineering (Major in Hydraulic Engineering)

Done by: Tesfaye Daba

Advisor: Dr. Bayou Chanie

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Declaration

I, Tesfaye Daba, do hereby declare to the Senate of Addis Ababa University that this thesis entitled "Sediment problem of Gefersa Reservoirs and the appropriate mitigation", performed under the advisor of Dr. Bayou Chanie is submitted to the school of Civil and Environmental Engineering at the Addis Ababa Institute of Technology as a partial fulfillment of the requirements of the Master of Science in Hydraulic Engineering is my own work and all other materials are duly acknowledged properly. This work has not been submitted for any academic degree award at any University.

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ABSTRACT

In the world concerning dam construction the big problem and issue are sedimentation of reservoir because it consumes the reservoir volume which is designed to carry water and requires high amount of cost to handle from this problems.

The Gefersa reservoir which is used as the main water supply of 30,000m^3 per day to Addis Ababa is affected by sediment load from the watershed.

Soil and Water Assessment Tool model is used to analyze the daily data to calibrate and validate the hydrologic component and sediment of Gefersa catchment. According to the model output the high percentage of sediment of the catchment is from subbasin two and one respectively.

To check the performance of the model Sensitivity analysis, model calibration and validation of the area is done. According to global sensitivity analysis of the model the most sensitive parameters were curve number for flow calibration and Biological mixing efficiency for sediment calibration.

The coefficient of determination and the Nash-Sutcliffe efficiency for the daily runoff are obtained to be 0.57 and 0.52, respectively.

The coefficient of determination and the Nash-Sutcliffe efficiency for the daily runoff at the outlet of the watershed for validation is obtained to be 0.65 and 0.61 respectively.

The calibration of the model for the yearly sediment observed at Gefersa gives model efficiency of -4 which means 4% over estimation.

To manage the watershed area, in the future scenario, using Vegetation land change to 40% open broadleaved forest, 35% Rain-fed croplands and 30% Grass-land result in the reduction of sediment volume by 15.75%, 10.91% and 14.54% respectively.

Even if both structural and non-structural measures can reduce sediment load of an area, the non-structural measures are the best methods because they need small capital and can be applied easily according to the model scenario.

Key words: Gefersa Reservoirs, Sedimentation, SWAT model, Catchment

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ABBREVIATIONS

AAWSA	Addis Ababa Water and Sewerage Authority
DEM	Digital Elevation Model
ET	Evapo-Transpiration
FSL	Full Supply Level
GIS	Geographic Information System
GW_Q	Ground water flow (mm)
HRU	Hydrologic Response Unit
m	meter
m.a.s.l	meter above sea Level
Mcm	Million cubic meter
mm	millimeter
MoWIE	Ministry of Water, Irrigation and Electricity.
MUSLE	Modified Universal Soil Loss Equation
NMA	National Metrological Agency
SURQ	Surface Runoff
SWAT	Soil and Water Analysis Tool
SRTM	Shuttle Radar Topography Mission
t	tons
Tmax	Maximum Temperature
Tmin	Minimum Temperature
T/ha/yr	Tons per hectare per year
UTM	Universal Trans Mercator
USLE	Universal Soil Loss Equation
Y	Year

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Most natural rivers are approximately balanced with respect to sediment inflow and outflow. Dam construction dramatically alters this balance since the increased flow depth and decreased flow velocity of a reservoir reduces the sediment transport capacity and causes settling.
Sediments carried into a reservoir may deposit throughout its full length, thus gradually raising the bed elevation and causing aggradation. The pattern of deposition generally begins with a deltaic formation, mainly composed of coarser sediments in the reservoir headwater area. Density currents may transport finer sediment particles down to the dam.

Reservoir sedimentation is a complex process that varies with watershed sediment production, rate of transportation, and mode of deposition. Reservoir sediment depends on the river regime, flood frequencies, reservoir geometry and operation, flocculation potential, sediment consolidation, density currents, and possible land use changes over the life expectancy of the reservoir (H.M.Raghunath, 2006).

Addis Ababa was established as the capital city of Ethiopia in 1886 and has grown to become the largest urban and commercial center in the country. During its early years, the principal sources of water were the numerous springs located at the foot of the Entoto mountain range and hand dug wells located in the lower areas. The larger springs were tapped and fed into a number of small tanks for local distribution.

Continued growth necessitated the construction, in 1938, of a plant at the foot of Entoto to treat water from a number of springs and the nearby Kechene River, and in 1944 the original Gefersa dam located northwest of the city was completed.

The present state of the Gefersa main dam is the result of successive modifications. Originally built in 1943 as a 10m high masonry dam (Gefersa I), it was first modified in 1955 by raising its height by 6 m (Gefersa II). In 1966 a smaller dam (Gefersa III) was built about 800m upstream from the main dam to serve as a silt trap and additional water storage. Finally, in 2009, a major

rehabilitation project was finished which renovated the dam body and the hydraulic works (spillway, intake). There has been no new bathymetry conducted after the renovation of the dam, however, the design study by Tractebel & others (2002) states that the intended capacity of the reservoir according to the design finally chosen is 7.39 Mcm. The bathymetric survey of 1998 was conducted and that a reservoir volume at FSL was 6.23 Mcm. When this compared with the result of the 1979 survey which found a total volume of 6.65 Mcm at the same elevation there was a difference of 0.42Mcm. The FSL for Gefersa is 2,585.61 m.a.s.l.

Accordingly, the topographic map constructed during the raising of the dam in 1955, the total reservoir capacity at the time was 7.45 Mcm. Then back-calculated the reservoir volume in 1966, prior to the construction of Gefersa III to 6.94 Mcm assuming the average annual siltation rate between the 1979 and 1998 surveys to hold. The exact same calculation appears also in the Gefersa dam rehabilitation study of Tractebel & others (2002). According to these figures, the Gefersa reservoir was subject to a siltation rate of 46,400 m3 /yr between 1955 and 1966 (the year Gefersa III was constructed) and the reservoir was exposed to the full sediment load of the catchment. Between 1979 and 1998, the average annual siltation rate dropped more than 50% to 22,105 m^3/yr as a result of sediment trapping in the upstream Gefersa III reservoir. These results indicate that by 1966, Gefersa reservoir had lost 0.51 Mcm, i.e. about 6.8% of its 1955 capacity. This represents an average annual volume reduction rate of 0.62%/yr for the period 1955-1966. Since 1966 and the construction of Gefersa III dam, the Gefersa reservoir in 1998 had lost another 0.71 Mcm of its capacity, i.e. about 10.2% of its 1966 capacity, an average annual volume reduction rate of 0.32%/yr for the period 1966-1998 (22,188 m^3/yr). The influence of Gefersa III is clearly seen in the 50% decrease in the annual volume reduction rate since the construction of the dam. The total volume loss in 1998 compared to 1955 was 1.23 Mcm or 16.5% of the 1955 capacity, representing an average annual volume reduction rate of 0.38%/yr. The calculated sediment yield for the period up to 1966 was 1198 t/km^2/yr and since 1966, 574 t/km^2/yr. The sediment density that was assumed for these figures seems to be 1.45 t/m^3.

Bathymetric survey (in actuality, a topographical survey since it was conducted on dry land) of the small Gefersa III reservoir was conducted in 1999 at a time when the reservoir was dry and therefore accessible by conventional topographic equipment. The total volume at FSL found was 1.17 Mcm. This survey was intended to serve as a baseline for future surveys in order to estimate

the amount of silt captured by the dam and plan removal operations accordingly. It is suggested to conduct all future surveys of this reservoir on dry land since total emptying of the Gefersa III reservoir to Gefersa I/II is easily accomplished without loss of water stored.

Sedimentation reduces reservoir storage capacity for flow regulation and with it all water supply and flood control benefits, plus hydropower, navigation, recreation, and environmental benefits that depend on releases from storage. In addition to storage loss, many types of sediment-related problems can also occur both upstream and downstream of dams, and sediment entrainment can also interfere with the beneficial use of diverted water. Sediment can enter and obstruct intakes and greatly accelerate abrasion of hydraulic machinery, thereby decreasing its efficiency and increasing maintenance costs.

Aggradations in the upstream channel may occur over long distances above the reservoir, thus increasing flood risks on these areas.

The combination of sediment trapping and flow regulation also has dramatic impacts on the ecology, water transparency, sediment balance, nutrient budget and river morphology. The cutoff of sediment transport by the dam can cause streambed degradation, acceleration rates of bank failure and increase scour at structures such as bridges downstream of the reservoir. Coarsened and armored streambeds will degrade or eliminate spawning beds. Even coastal process can be affected; accelerated coastal erosion can occur because of sediment trapping in far upstream reservoirs and lack of sufficient downstream sediment supply.

The importance of sediment management has increased, as the number of dams and their ages increase. Regarding the above complex phenomena, the necessities for sediment management of reservoirs can be summarized below.

I. It prevents reservoir sedimentation from burying water intakes or outlets and causing harmful riverbed aggradations directly upstream of reservoirs, thereby guaranteeing safety of river and dam management.
II. It maintains the storage functions of the reservoir-to achieve sustained management of water resources for future generations.
III. As a key to integrated sediment management of sediment routing systems, dams must be able to discharge sediment.

1.2 Problem Statement

Worldwide reservoir sedimentation is a serious problem and considered as salient enemy. The gradual loss of reservoir capacity reduces the effective life of dams and diminishes benefits from irrigation, hydropower generation, flood control, water supply, navigation and recreation. On another hand sediment deposition propagates upstream and up tributaries, raises local groundwater table, reduces channel flood capacity and affects water division and withdrawals.

Gefersa reservoir is in a shallow basin stretching between the Wechacha and Entoto mountains and easily affected by siltation from this subbasin.

In Gefersa watershed, there are agricultural activities, deforestation and overgrazing in the catchment of the reservoir which is the main source of sediment. These and other related problems increase the sedimentation of Gefersa reservoir which is the only seasonal reservoir and loss in capacity. Therefore, understanding the impacts of soil erosion and looking for solutions to minimize is essential.

Sedimentation control is an important issue for the Gefersa dams as it directly influences the reservoir capacities and satisfaction of the water demand.

So unless, upstream catchment of the river and surrounding area are managed, the Gefersa reservoirs are affected by sediment problem and as a result the dam may be damaged because of load from sediment, the net water supply to the town may be reduced, flood may be occur at the downstream and design period of the dam may become short.

There are sediment control methods which may be applied easily and economical to reduce the all above risks of sediment.

1.3 Objective

1.3.1 General Objective

- Determining the sediment load of the reservoirs catchment by using different models such as PcpStat, Dew02 and recommend the appropriate mitigation measures to reduce its effect.

1.3.2 Specific Objectives

- Determine major sediment source of the reservoirs.
- Determine amount of inflow sediment to the reservoir.
- Decide the appropriate measures to control sediment problem of the area.

1.4 Thesis Layout

This thesis is organized in to eight chapters:

Chapter One outlines the introduction on sediment load problems on reservoirs, statement of the problem, general and specific objectives of the study.

Chapter Two deals with the location of study area and general characteristics of the Gefersa catchment such as topography, climate, hydrology, land use and soil of watershed.

Chapter Three briefly reviews related literature about sediment transport and erosion in rivers and reservoirs that sedimentation has often greatly reduced and endangered the live storage of many existing reservoirs.

Chapter Four deals with the methodology.

Chapter Five focuses on Results and Discussion.

Chapter Six deals with problems occurred due to sedimentation and appropriate mitigation**.**

Chapter Seven summarizes the entire study by outlining a brief conclusion, and forwarding some recommendations.

CHAPTER TWO

2. 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 Oromia region. Addis Ababa Water and Sewage Authority has 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 (Tahal, 1999).

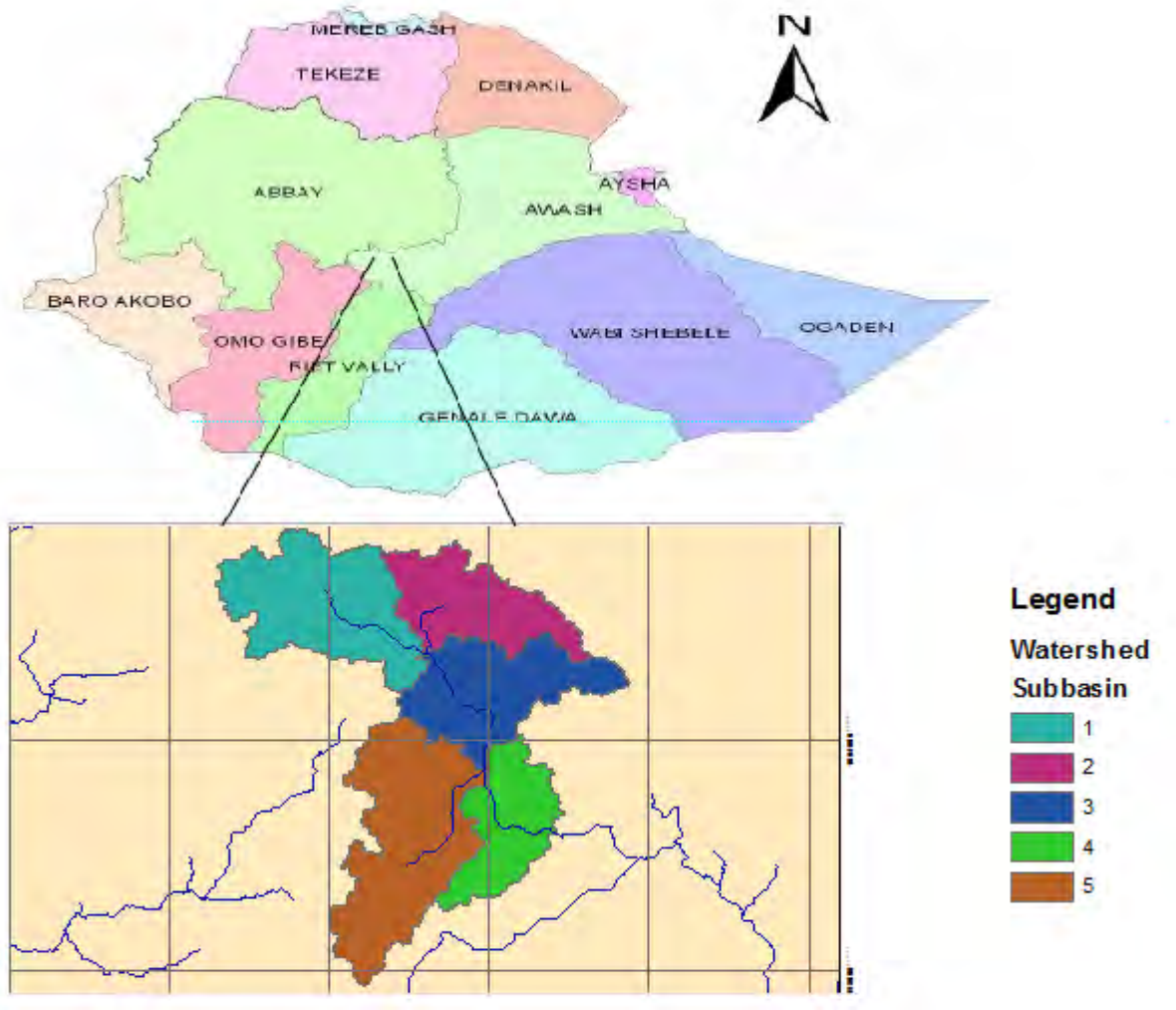

Figure 2.1 Map of Gefersa catchment.

2.2 Topography

The altitude of the catchment area ranges from 2,580 to 2,940 m-a.s.l. 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 1,350 mm. There are two seasonal patterns in the region of Gefersa catchment. 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.

Stations used as source of Precipitation data.

Table: 2.1. Rainfall and Temperature stations.

No	Station	Latitude	Longitude	Elevation (m.a.s.l)	Record period
1	Addis Ababa	9.033	38.75	2354	1986-2015
2	Debbrezeit	8.733	38.95	1900	1986-2015
3	Addis Alem	9.042	38.3833	2372	1986-2015
4	Sululta	9.183	38.733	2610	1986-2015
5	Holeta	9.070	38.5	2400	1986-2015
6	Gefersa	9.064	38.64	2603	1986-2015

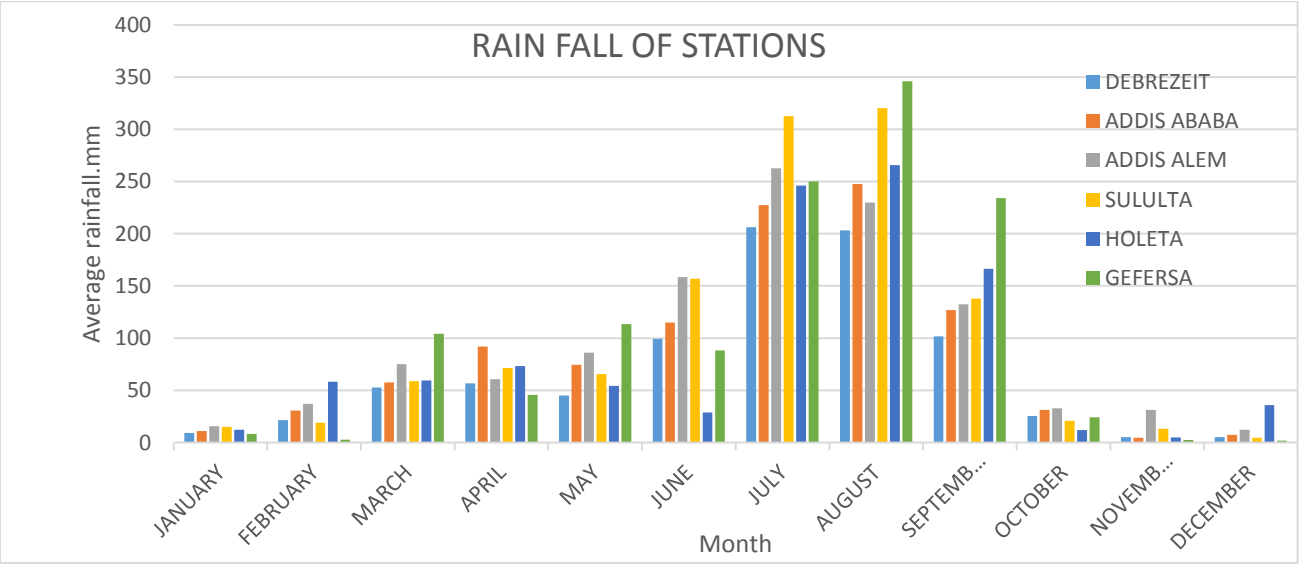

Figure.2.2. Rainfall station

Stations used as source of minimum and maximum temperature data.

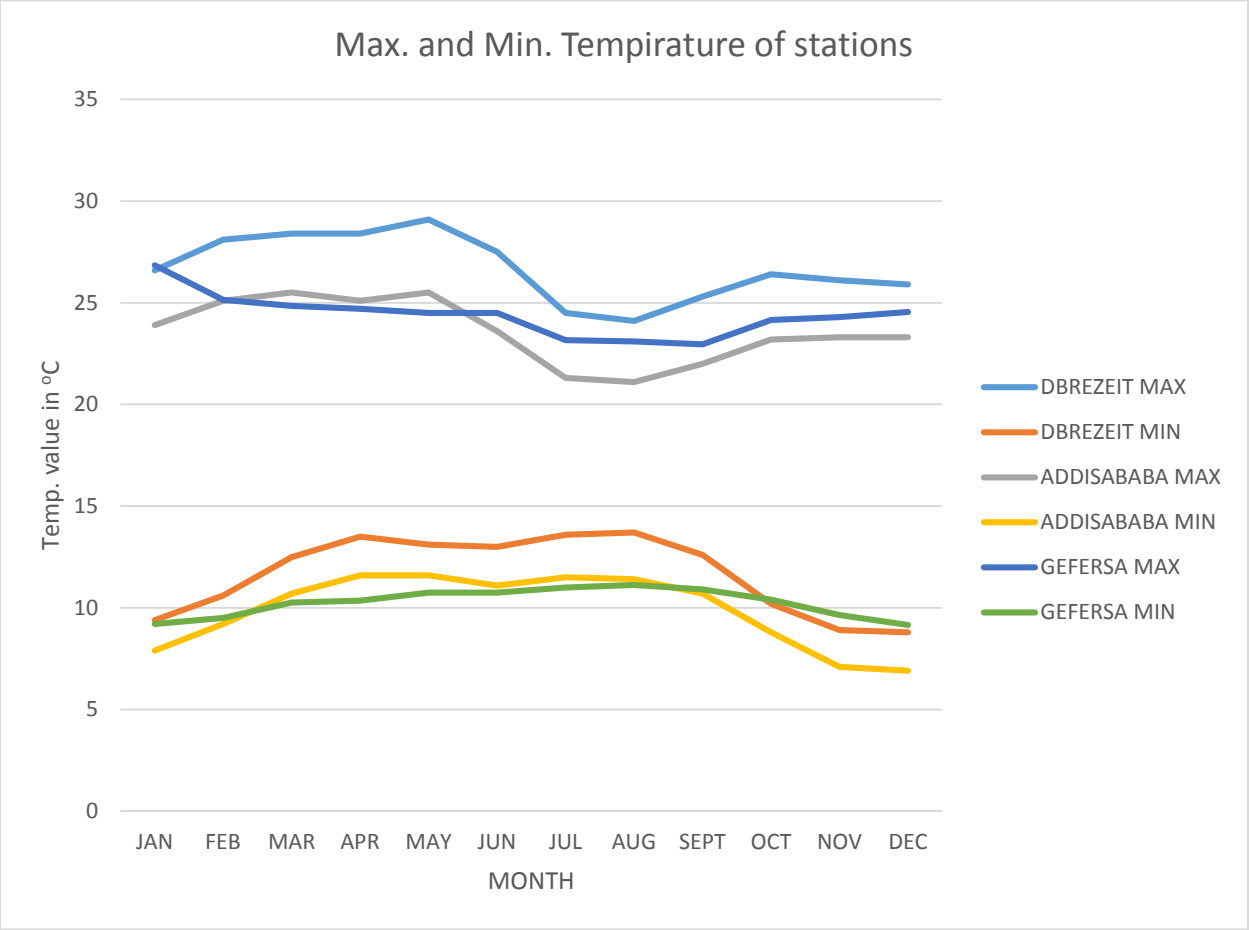

Figure.2.3 Maximum and Minimum temperature of stations.

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 Eculpatus tree that covers the area.

During site visiting I considered that the forests available above the reservoirs are used to reduce the soil erosion of the area. Groundwater in this basin occurs in confined, unconfined and or semi-confined condition (Daral, 2011).

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 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 (Daral, 2011).

2.6. Soil

Based on the data from MoWIE, three soil types namely, chromic luvisol, humic nitosols and vertic cambisols are common soil types in the catchment.

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. Thus, only half of the land cropped each year (Bathmetric, 1999).

CHAPTER THREE

3. LITERATURE REVIEW

3.0 Introduction

As the silt originates from the watershed, the characteristics of the catchment such as its areal extent, soil types, land slopes, vegetal cover and climatic conditions like temperature, nature and intensity of rainfall, have a great significance in the sediment production in the form of sheet erosion, gully erosion and stream-channel erosion. In regions of moderate rainfall, sheet erosion is the dominant source of total sediment load while in arid and semi-arid regions, gullying and stream-channel erosion furnish the greater part of the load (Chow, 1988).

Sediment moves in the stream as suspended load (fine particles) in the flowing water, and as bed load (large particles), which slides or rolls along the channel bottom. Sometimes, the particles (small particles of sand and gravel) move by bouncing along the bed, which is termed as 'saltation', which is a transitional stage between bed and suspended load. The material, which moves as bed load at one section may be in suspension at another section.

When the sediment-laden water reaches a reservoir, the velocity and turbulence are greatly reduced. The dense fluid-solid mixture along the bottom of the reservoir moves slowly in the form of a density current or stratified flows, *i.e.,* a diffused colloidal suspension having a density slightly different from that of the main body of reservoir water, due to dissolved minerals and temperature, and hence does not mix readily with the reservoir water.

Smaller particles may be deposited near the base of the dam. Some of the density currents and settled sediments near the base of the dam can possibly be flushed out by operating the sluice gates. The modern multipurpose reservoirs are operated at various water levels, which are significant in the deposition and movement of silt in the reservoir (H.M.Ranghunath, 2006).

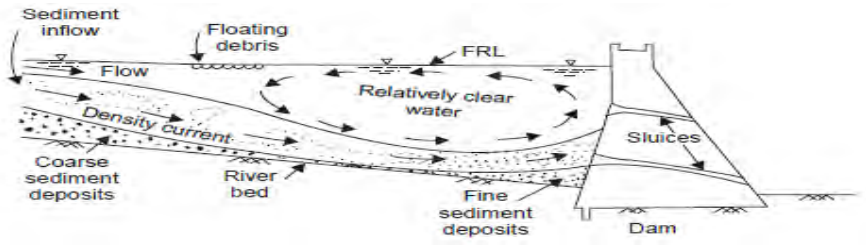

Figure. 3.1 Sediment accumulation in a reservoir (*(H.M.Ranghunath, 2006)*

3.1. Problems of Reservoir Sedimentation

3.1.1. Volume reduction

Sedimentation affects the storage capacity, which is the main asset of the reservoir. The loss of storage is particularly felt in connection with water supply for domestic use. 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 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 active and dead storage capacity of the reservoir so much. Sedimentation also affects the surface area of the reservoir, by reducing water depth and favoring the development of aquatic growth (H.M.Ranghunath, 2006). So that after a certain number of years, the reservoir may not be able to meet the purposes it was designed for.

3.1.2. Effects on the dam

Silt deposits may hinder the supervision of the dam. They can prevent the use of underwater means of supervision, such as submersibles, divers. They hamper visual observation after having emptied the reservoir, because the surface of the dam is soiled by mud and access from the side of the reservoir is made impossible.

And also if there is silt accumulation in the reservoir there may be the force which pulls the dam to the downstream and may affect the durability of dam (H.M.Ranghunath, 2006).

So when this force damages the dam, the dam may fail and affect the downstream lives. The flood may occur and may damage the cascade dams in the downstream.

3.1.3. Increase turbidity of water

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.

3.1.4. Treatment of water

When there is high amount of silt accumulation in reservoir the raw water become turbid and not suitable to drink. So the treatment of this turbid water is hard and costy. It needs high amount of chemicals, treatment structures and labors. When we use high amount of chemicals it may have another side effects on health.

3.1.5. Costy to remove and reduce

Due to the above mentioned problems it is a 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.

3.1.6 Dam life expectancy

The performance of the reservoir can also be reduced by sediment depositions. This occurs because the flow velocity decreases when the water passes through the reservoir.

The consequence is reservoir volume reduction, and the maximum life expectancy of a reservoir is therefore limited. The design of a dam is based on the, at that time, available demographic and hydrological data, but with the present evidence of climate change, such design could be insufficient if supply and demand condition changes.

One way of adapting if the reservoir is inadequate is to expand the reservoirs, if it is topographically and hydrologically feasible (Britanicca 2010).

3.1.7 Climate change and reservoirs

According to a report from United Nations Environment Programme (UNEP, 2000) called “Climate Change and Dams”, dams have a double role regarding climate change.

They can be a source of greenhouse gases; both carbon dioxide and, if the water at the bottom of the reservoir becomes anaerobic, they could also emit methane gas. Another aspect of dams is that they can be important as flood control infrastructures and if rainfall intensity increases due to climate change such infrastructure can save lives. The same report states that dams themselves are affected by climate change. Increased temperature increases the evaporation and increased rainfall

intensity will increase the sediment transport to dams. Both of these impacts reduce the capacity of the dam (UNEP, 2000).

3.1.7.1 Increased average rainfall

If the climate change results in increased average rainfall, which is a likely scenario for Addis Ababa, the piped water supply can be facing problems, especially since it is a surface water source system.

The same report states further that a potential problem with flooding can be the reduction of water quality through ingress in distribution pipes of flood water or overflowing sewerage water. Another potential problem can be that groundwater levels rises in the future due to increased rainfall, subsequently leading to polluted water ingress. Many household reservoirs that were standing on ground level were also contaminated when they got submerged (Nishat et al., 2000).

3.1.7.2 Increased rainfall intensity

Increased rainfall intensity is also a potential threat to the water distribution. A very intense rainfall leading to high runoff level can cause soil erosion, and capacity and water quality problem for the treatment plant due to sedimentation transport. Another problem with large intensity is infrastructure damage, especially if there is a flush flood (Howard et al., 2010).

3.2. Reducing Sediment Inflow into the Reservoir

Sediment deposition in reservoirs cannot be actually prevented but it can be reduced by adopting some of the following measures:

I. Reservoir sites, which are prolific sources of sediment should be avoided.
II. By adopting soil-conservation measures in the catchment area, as the silt originates in the watershed.
III. Agronomic soil conservation practices like cover cropping, strip cropping, contour farming, suitable crop rotations, application of green manure (mulching), proper control over graze lands, terracing and benching on steep hill slopes, etc. retard overland flow, increase infiltration and reduce erosion.
IV. Contour trenching and afforestation on hill slopes, contour bunding gully plugging by check dams, and stream bank stabilization by the use of spurs, rivetments, vegetation, etc. are some of the engineering measures of soil conservation.
V. Vegetal cover on the land reduces the impact force of rain drops and minimizes erosion.

VI. Sluice gates provided in the dam at various levels and reservoir operation, permit the discharge of fine sediments without giving them time to settle to the bottom.

VII. Sediment deposits in tanks and small reservoirs may be removed by excavation, dredging, draining and flushing either by mechanical or hydraulic methods and sometimes may have some sales value.

3.2.1. Bypassing of heavily sediment-laden flows

The construction of bypassing channels or conduits is one of the principal methods used to control the inflow of sediment to impounding reservoirs.

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. 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 where-as economic analyses will determine the feasibility and practicality of this mitigative measure.

3.3. Methods of Maximizing Sediment Removal through Flow

3.3.1. 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 the 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 inflowing sediment, the mode of operation, the time duration of flushing and the flushing discharge.

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 (Fasil, 2012).

3.3.2. Density current flushing

Density current is a gravity flow of turbid water through, under or over water of different density. The concentrations released by density currents depend on the topographic features of the reservoir (variation of width of the density current), the magnitude of incoming flood peak, incoming silt discharge and its sediment characteristics, the outlet elevation relative to the elevation of reservoir bottom, discharge capacity of outlets, flushing discharge, water level in the reservoir during the period of venting, and the length of the reservoir.

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.

3.3.3. Removing of sediments through under sluices

Under sluices 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. 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 (Fasil, 2012).

3.4. Recovering Reservoir Storage Capacity

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.

3.4.1. 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. 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 (Fasil, 2012).

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.

3.4.2. 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.
Reservoir sedimentation is a complex phenomenon from sediment yield to transport and deposition within reservoirs.

The seriousness of sedimentation and necessities for countermeasures are different in each reservoir or each river basin. Not only for tackling the traditional problems related to reservoir sedimentation, integrated reservoir sedimentation management should be considered both for sustainable management of water resources and sediment flow in the entire watershed. Reservoir sedimentation is one of the most crucial issues to be solved this century for sustainable water resources management. 'Do it now and do it quick' is the clue to success and this concept should be common sense for all responsible people.

3.5 Previous Study

Based on the 1979 and 1998 bathymetric surveys, with the assumption of linear yearly siltation rate of 22,252 m^3/year, the volume of the reservoir for 1966 (the time when Geffersa III started to serve as Silt-Trap) is 6.94 MCM, comparing the reservoir volume for period of 1966 to the 1955 volume shows on 46,400 m^3/year siltation for the period that the reservoir did not armed with silt trap. In terms of soil loss from the catchment area, this constitutes a loss of 1,200 tons/km^2/year contributed by the catchment area.

Silt accumulation in the period 1976 to 1998 declined by more than half to 22,250 m^3/year. This decline is accounted for by the smaller contributing area (with the same rate of 1200 ton//km^2/year) due to the construction of the Geffersa III reservoir.

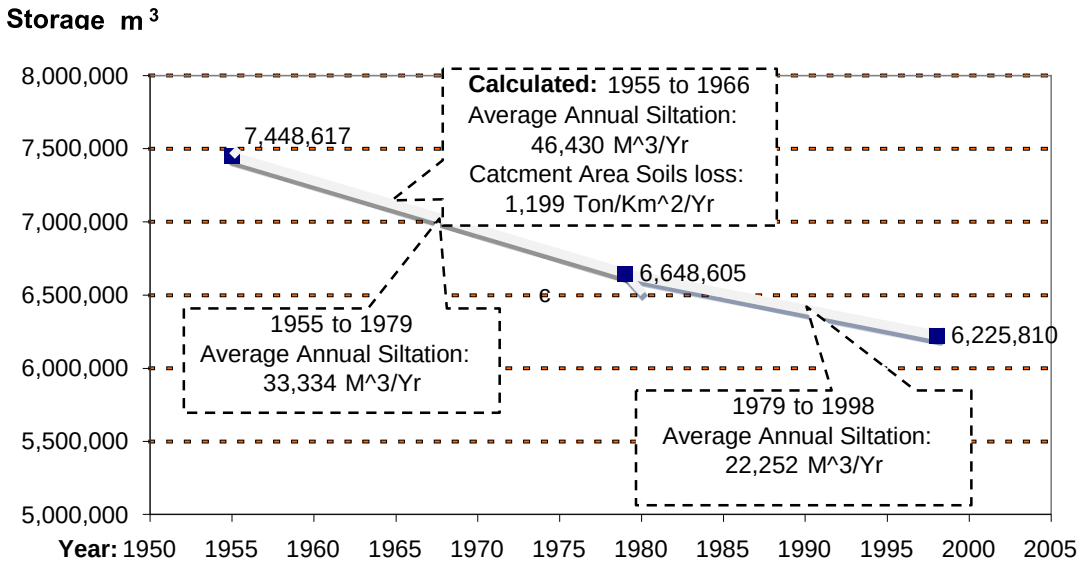

Figure. 3.2 Geffersa Reservoir Siltation Rate (Bathymetric survey, 1999)

Fasil Gebremeskel also done the research on gefersa reservoir with a title called Prediction of Sediment Inflow to Gefersa Reservoir (Using SWAT Model) and Assessing Sediment Reduction Methods and got average sediment load of 32063.7 tons/year for the period of 1979 to 1992.

CHAPTER FOUR

4. METHODOLOGY

4.0 Introduction

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.

For this specific project the SWAT model is selected. The reason for the selection of the SWAT model was that SWAT model is physically distributed and continuous time developed to predict the impact of land management practices on water, sediment and agricultural chemical yields from a watershed. After the objective is set and the suitable model is selected, the necessary data required to run the model was collected and prepared as to the requirement of the SWAT model format. The geospatial data such as the digital elevation map, land use/land cover map, soil map and the hydro-meteorological data such as the daily stream flow data, daily rainfall data, maximum and minimum daily air temperature data and sediment load/concentration data are all collected and processed as per the input requirement format of the model.

Tasks done to reach the aim of the research

- Data collection and preparation
  - ✓ Collect all necessary data required for the model to run
  - ✓ Prepare the collected data as per the requirement of the model (model input format)
- Import prepared data in to the model
- Model set up and run
  - ✓ Delineate the watershed
  - ✓ Create HRUs
  - ✓ Model Setup
  - ✓ Run the Model
- Sensitivity analysis
  - ✓ Identify Sensitive parameters prior to calibration to save time during calibration
- Calibration and validation
  - ✓ Calibrate the model for better prediction of the observed value
  - ✓ Validate the model outside the calibration period to see if the model is applicable

4.1 Data Collection and Preparation

To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modelling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of Digital Elevation Model (DEM), Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The length of period of weather and climatic data also affect the SWAT model performance. The output from the SWAT model can be affected by the DEM data resolution, mesh size, soil data resolution and soil map scale, watershed subdivision which on the other hand is affected by DEM data resolution. Bosch et al., (2004) found that SWAT stream flow estimates were more accurate when using high-resolution topographic data, land use/land cover data, and soil data. The required DEM data, soil data, land use/land cover data, flow data, climatic and sediment data was collected from different sources. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the upcoming sections.

4.1.1 Digital Elevation Model (DEM) Data

Digital Elevation model (DEM) is one of the main inputs of the SWAT (Soil and Water Assessment Tool) model. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRUs). The resolution of the Digital Elevation Model (DEM) is the most critical input parameter when developing a SWAT model (Gassman et al., 2007).

DEM resolution affects the watershed delineation, stream network and subbasin classification in the SWAT model. It affects the number of sub-basins and HRUs. The number of sub watersheds in the sub basin affects the predicted sediment yield for a watershed (Bingner et al. 1997).

SWAT sediment predictions were sensitive to HRUs and sub-watershed configurations. According to (Chaubey et al., 2005) a decrease in DEM resolution resulted in decreased stream flow and watershed area. Since the runoff volume and total sediment load depends on the watershed area, the decrease in the DEM resolution resulted in large error in the predicted output. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and sub basin classification.

In general, the quality of the DEM data strongly affect the final output of the hydrological model (Defourny et al., 1999). Therefore, it is wise to use the finest available DEM data for model application.

For this project a digital elevation model (DEM) was collected from MoWIE in the format of SRTM (Shuttle Radar Topography Mission) with a spatial resolution of 30 m x 30 m. In the original data there was a missing data which creates a hole in the DEM. But, the hole was edited and filled in the ArcMap using the Raster Editor. The edited DEM was projected to WGS1984 UTM Zone 37N using the raster projection in ArcMap toolbox before it was imported to ArcSWAT. The projected map was used in the watershed delineation in ArcSWAT which is the interface in the ArcMap to use it in SWAT model.

4.1.3 Soil data

Like the Digital Elevation Model, soil data resolution has also a significant impact on the modelling of stream flow, sediment load and nutrient content.

This on the other hand affected the runoff and sediment prediction. If the low resolution soil data is used to generate the HRUs it assigns same soil type for larger area of the watershed that actually may have different soil types. Different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity etc. which affects the water balance and sediment yield from the watershed. Therefore, using high spatial resolution soil map will increase the prediction accuracy of the model.

In this study the soil data was obtained from MoWIE. Therefore, all required soil properties were adopted from database since there was no possibility of measuring all soil properties in the field due to time constraint. The soil map obtained from MoWIE was projected to WGS1984 UTM Zone37N using the raster projection in ArcMap before it was imported to ArcSWAT.

Soils of Ethiopia is not available in SWAT data bases. So I compared the properties of Ethiopian soils with the SWAT data base soils then edit and represent with it in the look up table. Accordingly chromic luvisol is represented with Adams, humic nitosols with Enchanted and vertic cambisols with Munson

The soil map of Gefersa watershed used in the HRU definition in this study is shown in table 4.1 & Figure 4.1 below.

Table: 4.1 Percentage of soil at Gefersa catchment

No	Soil types	SWAT soils	Area(km^2)	% of coverage
1	Chromic Luvisols	Adams	1979.2	33
2	Humic Nitosols	Enchanted	520.0	10
3	Vertic Cambisols	Munson	2846.4	57

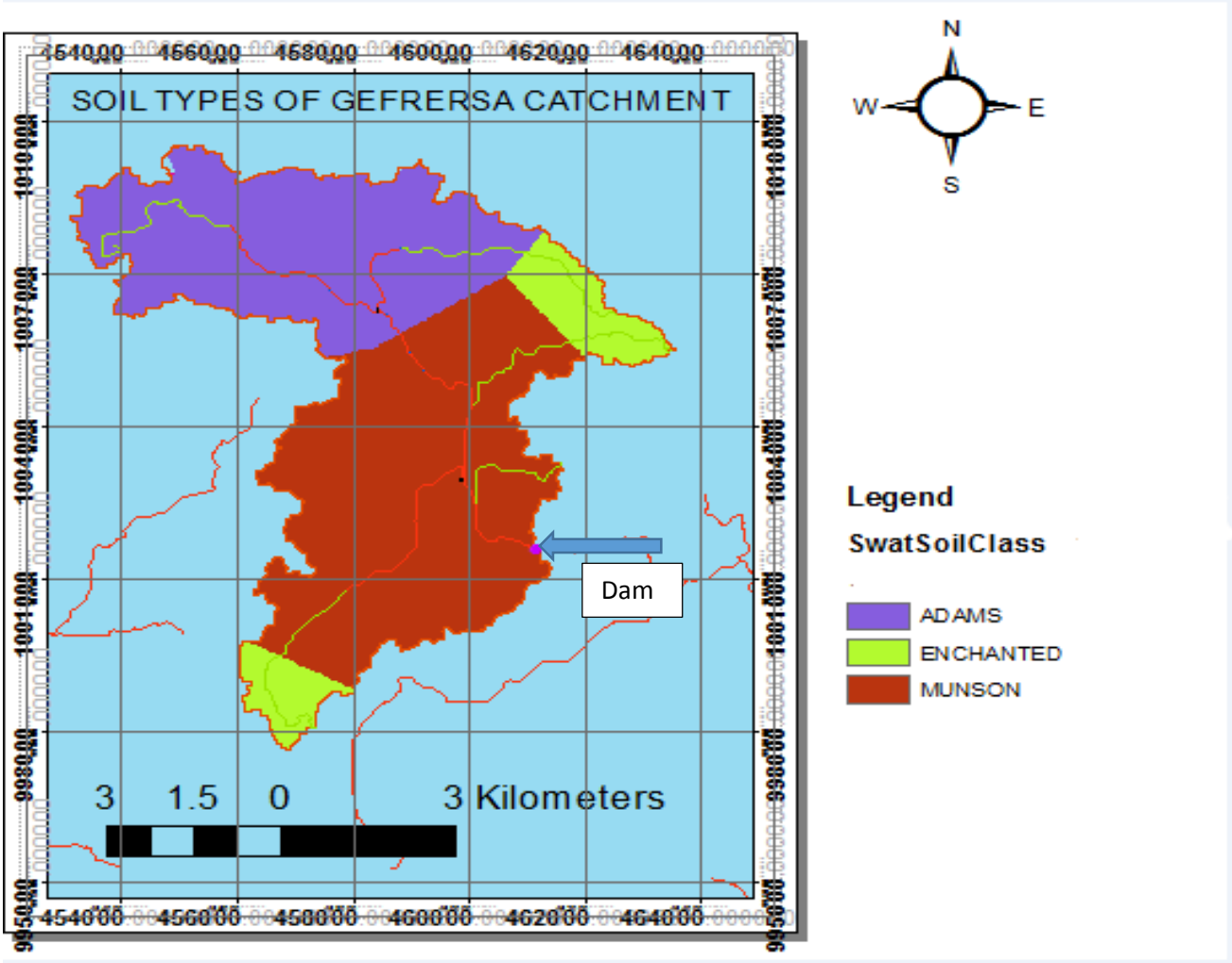

Figure. 4.1. Soil type of Gefersa catchment

4.1.4 Land use/land cover data

Land use/land cover data has also a significant effect on the hydrological modelling. Therefore, a detail analysis and mapping of the land use/land cover is crucial for proper hydrological modelling. Land use/land cover affects the runoff and sediment transport in the watershed.

Nine land use/land cover types were identified for Gefersa watershed: Rain fed croplands, Mosaic croplands, Mosaic vegetation, Closed to open broad leaved evergreen or Semi-deciduous forest, Open broad leaved deciduous forest, Mosaic forest-shrub land /grass land, closed to open shrub-land, Bare areas and water body. The land use for Gefersa watershed was projected to WGS1984 UTM Zone 37N using the raster projection in ArcMap before it was imported to ArcSWAT.

The land use map of the Gefersa watershed is shown in table 4.2 & Figure 4.2 below.

Table 4.2: Coverage of land use of Gefersa catchment (from model)

No	Land Use/Land Cover	Area(ha)	% of Coverage
1	Winter Wheat	340	6.4
2	Agricultural Land-Generic	3258	60.95
3	Agricultural Land-Row Crops	19	0.36
4	Forest-Mixed	22	0.42
5	Forest-Deciduous	163	3.07
6	Range-Grasses	524	9.81
7	Wetlands-Non-Forested	813	15.22
8	Range-Brush	39	0.73
9	Water	164	3.08

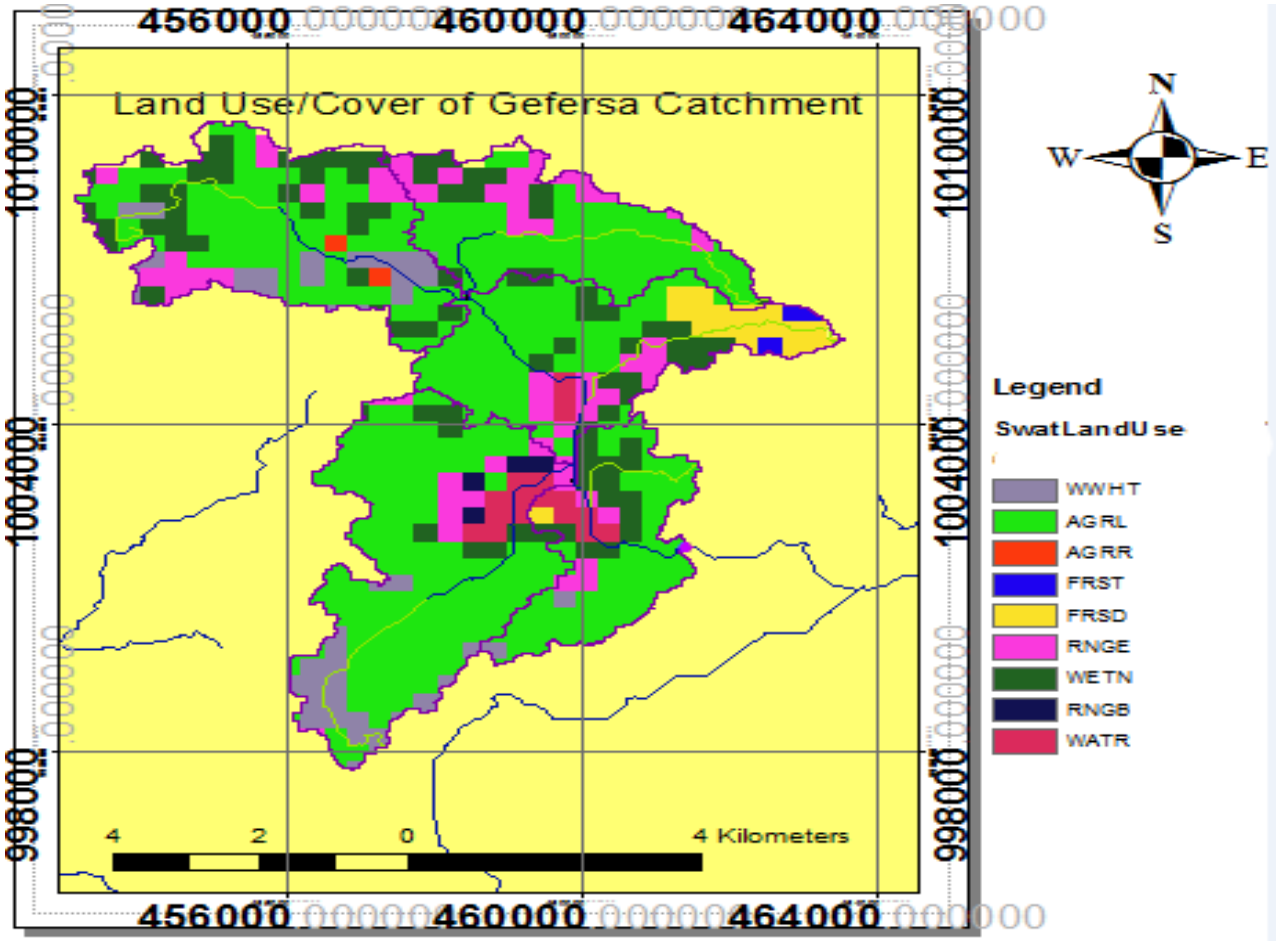

Figure. 4.2 Land use/cover of Gefersa catchment

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) 10%, 15% and 20% for Landuse, soil and Slope class respectively was selected for this study .Based on the above classification, we have 23 hru in the Gefersa catchment.

4.1.5 Flow data

Observed flow data of the reach was required for the Soil and Water Assessment Tool calibration and validation. The observed stream flow data was available from 1989-2004 at little Akaki river downstream of Gefersa Reservoirs. The flow was determined for the Gefersa Reservoir which is located at the downstream of the watershed of study.

This flow data was formatted as to the requirement of the SWAT model and used for model calibration and validation. The stream flow from 1989 to 1998 was used for model calibration and the 1999 to 2004 flow data was used for model validation. Here, it should be noted that the efficiency of the model during calibration and validation depends on the accuracy of the calculation. Any error during calculation may cause significant problem in model calibration and validation.

4.1.6 Climate Data/Weather Data

Climate data is among the most important data required for the SWAT model. Obtaining representative meteorological data for watershed-scale hydrological modelling can be difficult and time consuming. Land-based weather stations do not always adequately represent the weather occurring over a watershed, since they can be far from the watershed of interest and can have a missing data series, or recent data are not available (Fuka et al., 2014). It is beneficial to have a meteorological station within the watershed of interest. Rain gauge data are point measurements which may not represent the whole watershed. This problem can be reduced only when there is multiple rain gauges within the watershed. Otherwise, the problem exists specially for large watersheds which may have large hydro-climatic gradients. The problems related to each weather data will be stated under the following sections.

4.1.6.1 Rainfall data

The rainfall data was obtained from National metrology agency (NMA). There were six namely Addis Ababa, Debrezeit, Sululta, Addis Alem, Holeta and Gefersa meteorological stations located inside and outside the Gefersa watershed. The daily rainfall data of those stations are used in the model. The rainfall data for stations was available from 1986 to 2015.

4.1.6.1.1 Data quality control

The precipitation data must be checked for continuity and consistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any. This will help to identify if there are any gaps or unphysical peaks in data series and correct them before the data is used or input to the model. Otherwise, using the erroneous data as input to the model will give erroneous output from the model.

4.1.6.1.1.1 Visual inspection

After the rainfall data is obtained from NMA it must be checked for its quality. The first step in data quality control is by visual inspection. This can be done by checking if date and time record is complete, unphysical values (negatives), flat regions (sensor or transfer system fall out) and unphysical variation patterns (sensor malfunctioning).

4.1.6.1.1.2 Filling of missing data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. Here, the station whose data was missing is called interpolation station and gauging stations whose data are used to calculate the missing station data are called index stations.

There are methods to fill in missing data. These are: arithmetic mean method, normal ratio method and inverse distance weighing method. Arithmetic mean method can be used to fill in missing data when normal annual precipitation is within 10% of the gauge/station for which data are being reconstructed. The normal ratio method is used when the normal annual precipitation at any of the index station differs from that of the precipitation station by more than 10%. In the absence of normal annual rainfall for the stations inverse distance weighing method can be used to fill the missing data.

In this study by using Microsoft excel the regression formula is used to calculate the missing data of stations before the data is used by the model.

4.1.6.1.2 Statistical parameters calculation for precipitation data

After the precipitation data was checked for quality and the appropriate station selected, the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programme *pcpSTAT.exe*. This programme calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (Liersch, 2003). The result is shown in the table below.

Table 4.3: pcpSTAT output of weather generator station

```
Statistical Analysis of Daily Precipitation Data (1986 - 2015)
Input Filename = drainfall.txt

Number of Years =  30
Number of Leap Years =  7
Number of Records =    10957
Number of NoData values =         0
```

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	19.13	2	11	0.027	0.89	9
Feb.	28.39	4	10	0.056	0.83	9
Mar.	53.3	6	6	0.121	0.72	10
Apr.	59.93	5	4	0.176	0.68	12
May.	50.53	5	5	0.139	0.71	11
Jun.	94.65	6	5	0.393	0.71	18
Jul.	192.96	9	2	0.611	0.78	24
Aug.	192.03	9	3	0.672	0.79	25
Sep.	99.86	6	4	0.389	0.69	18
Oct.	30.54	4	10	0.052	0.8	8
Nov.	13.83	1	9	0.023	0.88	7
Dec.	15.58	2	13	0.025	0.89	8

```
PCP_MM = average monthly precipitation [mm]
PCPSTD = standard deviation
PCPSKW = skew coefficient
PR_W1  = probability of a wet day following a dry day
PR_W2  = probability of a wet day following a wet day
PCPD   = average number of days of precipitation in month.
```

Skewness is high in December, January February and October due to the high temperature and no cloud on the sky. The rain fall is also low during skewness is high.

4.1.6.2 Temperature data

The temperature data record was available from three weather stations: Addis Ababa, Debrezeit and Gefersa.

The daily maximum and minimum air temperature was available with some missing data. The missing data was filled using regression formula for checking the trend of the air temperature over time.

Statistical parameters calculation for temperature data

Again Dew02 software also calculates the temperature data to use in weather generator.

Table 4.4: dew02 output of weather generator station.

This file has been generated by the program 'dew02.exe'
Input Filename = dew02.txt
Number of Years = 30
Number of Records = 10957
Number of NoData Values
tmp_max = 0
tmp_min = 0
hmd = 0
Average Daily Dew Point Temperature for Period (1986- 2015)

Month	tmp_max	tmp_min	hmd	dewpt
Jan	26.73	9.46	53.88	10.33
Feb	27.91	10.86	48.11	9.68
Mar	28.47	12.36	51.32	11.34
Apr	28.21	13.29	54.13	12.26
May	28.80	12.87	54.33	12.58
Jun	27.34	12.79	62.82	13.93
Jul	24.49	13.28	74.15	14.93
Aug	24.10	13.30	76.63	15.21
Sep	25.21	12.35	70.79	14.34
Oct	26.27	10.19	54.31	10.30
Nov	26.14	9.01	52.50	9.44
Dec	25.96	8.86	52.85	9.39

tmp_max = average daily maximum temperature in month [°C]
tmp_min = average daily minimum temperature in month [°C]
hmd = average daily humidity in month [%]
dewpt = average daily dew point temperature in month [°C]

(written by Stefan Liersch, August, 2003)

The above table calculated by dew02 software using first class (Debrezeit) station maximum, minimum and humidity data. Then the output data was used in weather generator of the area in SWAT to calculate the missing data.

4.1.7 Sediment Data

The sediment data is collected from MoWIE which is recorded at different years (1990- 2001) at the reservoir and used to compare with the sediment data that is obtained by the model during the validation period.

4.2 SWAT model Description

The SWAT (Soil and Water Assessment Tool) model is a river basin model developed by US Department of Agriculture - Agricultural Research Service (ARS) in Temple, Texas.

The SWAT model is a physically based, continuous time, long term simulation, lumped parameter, deterministic, and originated from agricultural models with spatially distributed parameters operating on a daily time steps. SWAT incorporates features of several ARS models and is a direct outgrowth of the SWRRB model (Simulator for Water Resources in Rural Basins). Specific models that contributed significantly to the development of SWAT were CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems), and EPIC (Erosion-Productivity Impact Calculator).

SWAT is an operational or conceptual model that operates on a daily time step. The main objective of model development was to predict the impact of land management practices on water, sediment and agricultural chemical yields (nutrient loss) in large and complex watersheds with varying soils, land uses and management conditions over a long period of time (Lemma, 2015). To satisfy the intended objective, the model (a) is physically based (calibration is not possible on ungauged catchments); (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous in time and capable of simulating long periods for computing the effects of management changes (Neitsch et al., 2011). Therefore, the model is a computationally efficient simulator of hydrology and water quality at various scales. The model is semiphysically based, and allows simulation of a high level of spatial detail by dividing the watershed into large number of sub-watersheds (Abbaspour et al., 2007). It includes procedures to describe how CO_2 concentration, precipitation, temperature and humidity affect plant growth. It also simulates evapotranspiration, snow and runoff generation, and is used to investigate climate change impacts (Abbaspour et al., 2009).

A command structure is used for routing runoff and chemicals through a watershed. Commands are included for routing flows through streams and reservoirs, adding flows, and inputting

measured data on point sources. Using the routing command language, the model can simulate a basin sub-divided into sub-watersheds and further into hydrological Response units (HRUs) (Arnold et al., 1998).

4.2.1 Model components

SWAT includes the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, nutrient yielding, groundwater flow, crop growth, pesticide yielding, water routing and the long term effects of varying agricultural management practices.

The subbasin/sub-watershed components of SWAT can be classified into eight major components. They are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Figure 4.3*)*. Each of the components are described below.

Hydrology: The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, snow melt, transmission losses and ponds. The percolation and return flow or base flow considered in SWAT for hydrological modelling is only the percolation to shallow aquifer from vadose zone and base flow to the channel from the shallow aquifer. The groundwater flow from deep aquifer is not considered because the water that enters the deep aquifer is assumed to contribute to the stream flow somewhere outside the watershed.

The water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer. The water percolated to the deep aquifer is assumed to be lost from the watershed system and is not included in the water balance.

Weather: The weather variables required to run the SWAT are precipitation, air temperature, relative humidity, wind speed and solar radiation. These variables can be entered directly in to the SWAT model as daily or sub-daily values.

Sediment: SWAT generates the sediment from the watershed using Modified Universal Soil Loss Equation (MUSLE).

Soil Temperature: Soil temperature is important for movement of water through the soil since water cannot flow through the frozen soil.

Therefore, for the water to infiltrate through the soil layers and all the way to saturated zone, the soil temperature must be above the freezing point. Daily average soil temperature is calculated at the soil surface and the centre of each layer (Neitsch et al., 2011).

Crop Growth/Plant Growth/Land Cover: This SWAT component is a simplified version of the EPIC (Erosion-Productivity Impact factor) plant growth model. As in EPIC, the phenological plant development in SWAT, is based on daily accumulated heat units, Monteith's method for potential biomass, a harvest index to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen or phosphorus stress.

Nutrients: SWAT tracks the movement of different forms of Nitrogen and Phosphorus in the watershed. These nutrients are very important for plant growth. Amounts of $NO\,(N_3)$ contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. The amount of soluble phosphorous (P) removed in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor.

Pesticides: In SWAT, the movement of pesticides in to the stream network by runoff and percolation (in solution form) is modelled by equations adopted from GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Neitsch et al., 2011).

Agricultural Management: For the computation SWAT uses physically based inputs such as weather variables (precipitation, air temperature, relative humidity, wind speed and solar radiation), soil types and properties, topography, and land use/land cover of the catchment under study and directly models all the processes associated with water flow, sediment transport, crop growth and nutrient cycling, etc. (Arnold et al., 1998).

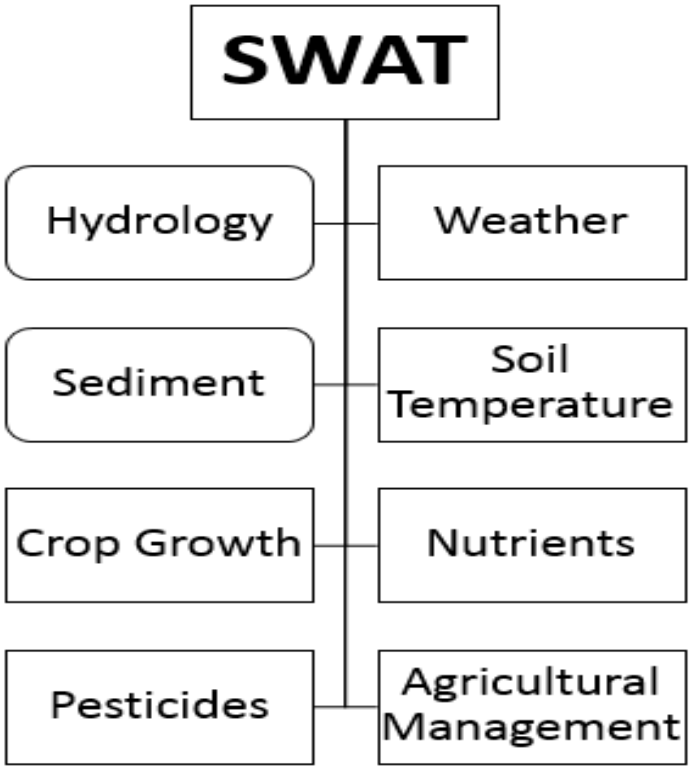

Figure 4.3 Main components of SWAT model

In this study, the ArcSWAT2012 was used, where the ArcGIS (version 10.2) environment was used for project development. Spatial parameterization of the SWAT model was performed by dividing a watershed into subbasins based on topography, soil, land use, and slope. This subdivision resulted in a smallest spatial unit in a watershed. This units, referred to as hydrologic response units (HRUs), are used as the basis of the water balance calculation. Water, sediment, and nutrient transformations and losses were determined for each HRU, aggregated at the subbasin level, and then routed to the associated reach and catchment outlet through the channel network (Abbaspour et al., 2009).

Some of the advantages of the SWAT model includes: modelling of ungauged catchments, prediction of the relative impacts of scenarios (alternative input data) such as changes in management practices, climate, and vegetation on water quality, quantity or other variables (Mulungu and Munishi, 2007).

4.3. Hydrological Processes in SWAT

SWAT allows a number of different physical processes to be simulated in a watershed (Neitsch et al., 2011).

SWAT simulates various hydrological processes. The simulated processes include surface runoff, infiltration, evapo-transpiration (ET), lateral flow, percolation to shallow and deep aquifers and channel routing (Arnold et al., 1998). All these hydrological processes are simulated in surface, soil, and intermediate (vadose) zone, shallow and deep aquifers. Among the mentioned hydrological processes, surface runoff, subsurface or lateral flow and return flow or baseflow contributed to stream flow in the main channel. As it was described earlier the water that enters the deep aquifer is assumed to be lost out of the system of the watershed under study. In SWAT, the local water balance is represented through four storage volumes.

These storage volumes are: snow, soil profile (0-2 m), shallow aquifer (2-20 m) and deep aquifer storage (>20 m) (Abbaspour et al., 2009). Since there was no significant snow fall in the catchment no process related to snow was considered in this study.

SWAT has a weather simulation model that generates daily data for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables of these data. This provides a useful tool to fill in missing daily data in the observed records.

SWAT first delineates a basin or a watershed and then, a basin is delineated into sub-basins, which are then further subdivided into hydrologic response units (HRUs). In this sub-division SWAT considers spatial variations in topography, land use, soil and other watershed characteristics.

Hydrologic Response Units (HRUs) are lumped land areas within the subbasin that are comprised of unique land cover, soil and management combinations and based on two options in SWAT, they may either represent different parts of the subbasin area or subbasin area with a dominant land use or soil type (also, management characteristics).

Therefore, each HRU is assumed to be spatially uniform in terms of slope, land use, soil type and climate. With this semi-distributed (subbasins) set-up, SWAT is attractive for its computational efficiency as it offers some compromise between the constraints imposed by the other model types such as lumped, conceptual or fully distributed, physically based models.

No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed.

To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be divided in to two major divisions. (1) The land phase of the hydrologic cycle and (2) the water or routing phase of the hydrologic cycle. The first division controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subbasin. And, the second division is related to the movement of water, sediments, nutrient and pesticide through the channel network of the watershed to the outlet (Neitsch et al., 2011).

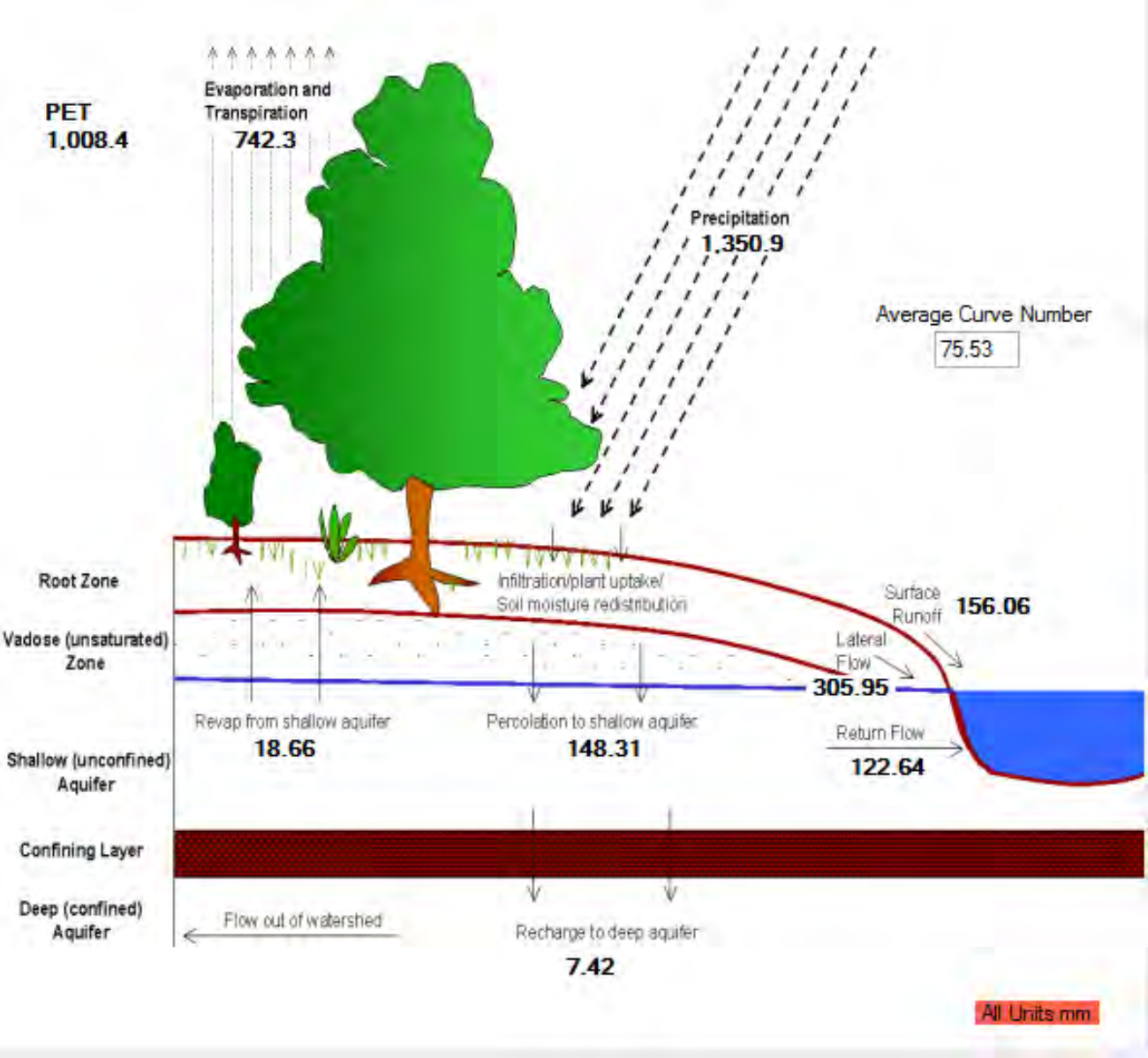

Figure 4.4 Schematic representation of the hydrologic cycle (from Model)

4.3.1 Land phase of the hydrologic cycle

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

That is the water contained in the soil is the sum of initial water in the soil and difference between Precipitation and Surface runoff, Evapotranspiration, Seepage and Return flow of day.

$$SWt = \mathrm{SWo} + \sum_{i=1}^{t}(\mathrm{Rday} - Qsurf - \mathrm{Ea} - \mathrm{Wseep} - \mathrm{Qgw}) \quad \text{.....4.1}$$

Where: SW_t -is the final soil water content (mm),

SW_o -is the initial soil water content on day *i* (mm),

t -is the time (days),

R_{day} -is the amount of precipitation on day *i* (mm),

Q_{surf} -is the amount of surface runoff on day *i* (mm),

E_a -is the amount of evapotranspiration on day *i* (mm),

W_{seep} -is the amount of water entering vadose zone from the soil profile on day *i* (mm) and

Q_{gw} -is the amount of return flow on day *i* (mm).

The subdivision of the watershed into sub-watersheds and further into HRUs enables the model to reflect the differences in evapotranspiration for various crops or land covers and soils.

Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy and gives much better physical description of the water balance.

4.3.1.1 Climate

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

Weather Generator

If there is no daily values for weather, SWAT generates from average monthly values. The model generates a set of weather data for each subbasin.

The values for any subbasin will be generated independently and there will be no spatial correlation of generated values between the different subbasins. Precipitation, temperature, wind speed, solar radiation and relative humidity of a given station in the watershed are generated in this way.

For this study the daily measured precipitation, air temperature, humidity, solar radiation and wind speed from 1986 - 2015 was used as input and the other variables were generated by SWAT.

Maximum and minimum air temperatures and solar radiation are generated from a normal distribution. A continuity equation is incorporated into the generator to account for temperature and radiation variations caused by dry and rainy conditions (Neitsch et al., 2011).

Snow

SWAT classifies precipitation as rain or freezing rain/snow using the average daily temperature. Snow is not significant in the watershed of study and was not considered in this study.

Soil temperature

The temperature of the soil affects the movement of water through the soil and the decay rate of the residue in the soil. Daily average soil temperature is calculated at the soil surface and centre of each soil layer (Neitsch et al., 2011).

4.3.1.2 Hydrology modelling

As the rain descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as surface runoff. Runoff moves relatively quickly toward a stream channel and contributes to short term stream response. Infiltrated water may be held in the soil profile and later evapo-transpired or it may slowly make its way to the surface water system through underground paths (Neitsch et al., 2011).

4.3.1.2.1 Surface runoff/overland flow

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the rate of application is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all the surface depressions have filled, surface runoff will commence (Neitsch et al., 2011).

SWAT provides two methods for estimating the surface runoff: the SCS curve number procedure and the Green and Ampt infiltration method.

The SCS curve number is a function of the soil's permeability, land use and antecedent moisture conditions whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity. SWAT uses the daily and

hourly time steps to calculate surface runoff. For daily time steps, SWAT uses an empirical SCS curve number (CN) method and for monthly time steps SWAT uses the Green and Ampt equation. For this project the SCS curve number was adopted for the simulation of surface runoff in SWAT since it requires the readily available daily data that can be obtained easily from government ministries and/or offices.

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

$$Qsurf = \frac{(Rday - Ia)^2}{(Rday - Ia + S)} \quad \text{.....4.2}$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm),

R_{day} is the rainfall depth for the day (mm),

I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm), and

S is the retention parameter (mm).

The retention parameter varies spatially due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad \text{.....4.3}$$

Where CN is the curve number for the day.

The curve number is a function of the soil's permeability, land use and antecedent moisture conditions: I – dry (wilting point), II – average moisture, and III – wet (field capacity).

The moisture condition I curve number is the lowest value that the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the equations:

$$CN1 = CN2 - \frac{20*(100 - CN2)}{(100 - \mathrm{CN2} + \exp[2.533 - 0.0636*(100 - \mathrm{CN2})])} \quad \text{..... 4.4}$$

$$CN3 = CN2 * \exp[0.00673 * (100 - CN2)] \quad \text{.....4.5}$$

Where, CN_1 is the moisture condition curve number 1,

CN_2 is the moisture condition curve number 2, and

CN_3 is the moisture condition curve number 3 (Neitsch et al., 2011).

The initial abstractions, I_a, is commonly approximated as $0.2S$ and the above equation becomes

$$\mathrm{Qsurf} = \frac{(\mathrm{Rday} - \mathrm{Ia})^2}{(\mathrm{Rday} + 0.8\mathrm{S})} \quad \text{..... 4.6}$$

Referring to the above equations, runoff will occur when $R_{day} > I_a$. Therefore, there is some amount of rainfall I_a (initial abstraction before ponding) for which no runoff will occur (i.e., runoff is zero) (Chow et al., 1988).

The peak runoff rate is the maximum runoff rate that occurs with a given rainfall event (Neitsch et al., 2011). The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT uses a modified rational method to calculate the peak runoff rate. q_{peak} is the ratio of the product of surface runoff and fraction of daily rainfall to time of concentration.

$$qpeak = \frac{\alpha tcQsurfArea}{3.6tconc.} \quad \text{.....4.7}$$

Where, qpeak is the peak runoff rate (m/s),

αtc is the fraction of daily rainfall that occurs during the time of concentration,

$Qsurf$ is the surface runoff (mm),

Area is the subbasin area (km^2),

tconc is the time of concentration for the subbasin (hr) and

3.6 is a unit conversion factor.

4.4. 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 Reservoir 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 (H.M.Raghunath 2006). Thus, the drainage-area ratio method is given by

$$Qu = Qg\left[\frac{Au}{Ag}\right]^n \quad \text{.....4.8}$$

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_{gauged} ($0.8 \leq \frac{Asite}{Agauge} \leq 1.2$) then n=1 to be used.

For Gefersa catchment = $\frac{Asite}{Agauge} = \frac{55}{131} = 0.4199$

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

$Q_{site} = Q_{gauged} * (0.419847)^{0.6} = Q_{gauged} * 0.5941$

4.5 Soil Hydrologic Group

The U.S. Natural resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS Soil Survey Staff (1996) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. This properties are depth to seasonally high water table, saturated hydraulic conductivity, and depth to a very slowly permeable layer. Soil may be placed in one of four groups, A, B, C and D, or three dual classes, A/D, B/D and C/D (Neitsch et al., 2011). These soil hydrologic groups are defined below.

A: (Low runoff potential). Soils in this group have high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

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

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

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

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

The Gefersa soils fall in the category of B (chromic luvisols & Humic Nitosols) and D (vertic cambisols).

4.6 Sediment Modelling

4.6.1 Introduction

For a watershed in which erosion and sedimentation process is significant, it is important to identify the source of erosion and what causes it. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied. In this study since there was a time limitation to conduct field investigation to the watershed of study, it aimed at applying SWAT (Soil and Water Assessment Tool) model to simulate the sediment yield from Gefersa watershed.

Therefore, a semi-distributed, physics-based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study. SWAT uses a Modified Universal Soil Loss Equation (MUSLE) developed by Williams (1975) to simulate sediment yield from the upland watersheds. MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978) (Neitsch et al., 2011).

$$Sed = 1.298*EI_{USLE}*K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.9$$

Where, Sed is the sediment yield on a given day (metric tons/ha),

EI_{USLE} is the rainfall erosion index (0.017 m-metric ton cm/ (m^2 hr)),

K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr / (m^3-mertic ton cm)),

C_{USLE} is the USLE cover and management factor,

P_{USLE} is the USLE support practice factor,

LS_{USLE} is the USLE topographic factor and

$CFRG$ is the coarse fragment factor.

The value of EI_{USLE} for a given rainstorm is the product, total storm energy (E_{storm}) times the maximum 30 minutes intensity (I_{30}). The storm energy indicates the volume of rainfall and runoff,

while the 30 minutes intensity indicates the prolonged peak rates of detachment and runoff (Neitsch et al., 2011).

$$Sed = 11.8(Q_{surf}*q_{peak}*Area_{hru})^{0.56}* K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG \quad \text{.....4.10}$$

Where, Q_{surf} is the surface runoff volume (mm),

q_{peak} is the peak runoff rate (m^3/s),

$Area_{hru}$ is the area of the HRU (ha), and the other variables in the equation carries the same meaning as described in USLE equation.

USLE predicts the average annual gross erosion as a function of rainfall energy. Whereas in MUSLE the rainfall energy is replaced with a runoff factor which improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events.

Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor used by USLE represents energy used in detachment only.

Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment (Neitsch et al., 2011). The detail of equations used to calculate K_{USLE}, C_{USLE}, P_{USLE}, LS_{USLE}, and $CFRG$ can be found in Neitsch et al (2011).

4.6.2 Sediment routing

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach. There are two options in SWAT to compute deposition and degradation in the reach. The first and traditional way is to keep the channel dimensions constant so that SWAT will compute deposition and degradation using the same channel dimensions throughout the simulation and the second is to activate channel degradation and allow channel dimensions to change and updated us a result of down cutting and widening. When channel down cutting and widening is simulated, channel dimensions are allowed to change during simulation period. Three channel dimensions are allowed to vary in channel down cutting and widening simulations: bankfull depth, channel width and channel slope. Channel dimensions are updated when the volume of water in the reach exceeds $1.4*10^6$ m^3 (Neitsch et al., 2011). In this study the former option was adopted in channel routing since the latter option is still in the testing phase.

4.6.3 Landscape contribution to subbasin routing reach

From the landscape component, SWAT keep tracks of the particle size distribution of eroded sediments and routes them through ponds, channels, and surface water bodies. The sediment yield from the landscape is lagged and routed through grassed waterway, vegetative filter strips, and ponds, if available, before reaching the stream channel. Thus, the sediment yield reaching the stream channel is the sum of total sediment yield calculated by MUSLE minus the lag, and the sediment trapped in grassed waterway, vegetative filter strips and/or ponds (Neitsch et al., 2011). There was no pond considered in this watershed of study.

4.6.4 Sediment routing in stream channels

Sediment routing is the function of peak flow rate and mean daily flow. When the watershed was delineated into smaller subbasin, each subbasins has at least one main routing reach.

Therefore, the sediment from upland subbasins is routed through these reaches and then added to downstream reaches. To do this, SWAT uses the simplified version of Bagnold equation (Bagnold, 1977) and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity (Neitsch et al., 2011).

$$Conc_{sed,ch,mx} = Csp * V_{ch,pk}^{spexp} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

Where, $Conc_{sed\ ch\ mx,}$ is the maximum concentration of sediment that can be transported by water (ton/m^3 or kg/L),

Csp and *sp*exp are coefficient and exponent of the equation defined by the user, and

$V_{ch\ pk,}$ is the peak channel velocity (m/s).

The exponent *sp*exp normally varies between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation. But, in SWAT2012 the value of this exponent varies between 1.0 and 1.5.

$$V_{ch,pk} = q_{ch,pk}/A_{ch,pk} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.12$$

Where, $q_{ch\ pk,}$ is the peak flow rate (m^3/s) and

A_{ch} *is* the cross-sectional area of flow in the channel (m^2).

$$Q_{ch,pk} = Prf * q_{ch} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.13$$

Where, *prf* is the peak rate adjustment factor, and

q_{ch} is the average rate of flow (m^3/s).

The routing in the river reach starts off by comparing the maximum concentration of sediment calculated to the concentration of sediment in the reach at the beginning of the time step, $Conc_{,sedchi.}$

If Conc.sed,ch,i > Conc.sed,ch,mx deposition is the dominant process in the reach segment and the net amount of sediment deposited is calculated as in equation below

$$Sed_{dep} = (Conc.sed,ch,i - Conc.sed,ch,mx)*V_{ch} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.14$$

Where, Sed_{dep} is the amount of sediment re-entrained in the reach segment (metric tons),

V_{ch} is the volume of water in the reach segment (m^3).

On the other hand, if Conc.sed,ch,i < Conc.sed,ch,mx degradation is the dominant process in the reach segment and the net amount of sediment re-entrained is calculated as in equation

$$Sed_{deg} = (Conc.sed,ch,mx - Conc.sed,ch,i)*Vch*K_{CH}*C_{CH} \quad \ldots\ldots\ldots\ldots\ldots 4.15$$

Where,Sed_{dep} is the amount of sediment re-entrained in the reach segment (metric tons),

K_{CH} is the channel erodibility factor (cm/ hr / pa) and

C_{CH} is the channel cover factor.

The channel erodibility factor is conceptually similar to the soil erodibility factor used in the USLE equation. Channel erodibility is a function of properties of the bed or bank materials. In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility. The channel cover factor can be defined as the ratio of degradation from a channel with a specified vegetation cover to the corresponding degradation from a channel with no vegetation cover. The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface (Neitsch et al., 2011).

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

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.16$$

Where, Sed_{ch} is the amount of suspended sediment in the reach (metric tons),

$Sed_{ch\,i}$, is the amount of suspended sediment in the reach at the beginning of the time period (metric tons),

Sed_{dep} is the amount of sediment deposited in the reach segment (metric tons) and

Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons).

Thus, the amount of sediment transported out of the reach is calculated using equation,

$$Sed_{out} = sed_{ch}*(V_{out}/V_{ch}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.17$$

Where,Sed_{out} is the amount of sediment transported out of the reach (metric tons),

V_{out} is the volume of outflow during the time step (m^3) and

V_{ch} is the volume of water in the reach segment (m^3).

SWAT incorporates a simple mass balance model to simulate the transport of sediment into and out of water bodies (ponds, wetlands, reservoirs and potholes) (Neitsch et al., 2011). In this study no wetlands and potholes are identified. But, Gefersa reservoir is located at the outlet of the catchment and it was not considered in the study as the area of interest for which the sediment yield is calculated from upstream of the reservoir.

4.7 Sensitivity Analysis, Calibration and Validation of SWAT Model

4.7.1 Sensitivity analysis

A complex hydrologic model is generally characterized by a multitude of parameters (Holvoet et al., 2005). SWAT (Soil and Water Assessment Tool) is known to have a large number of parameters. Over-parameterization is a well-known and often described problem in hydrological models, especially for distributed models such as SWAT. SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed (Abbaspour, 2013). Therefore, methods to reduce the number of parameters via sensitivity analysis are important for the efficient use of these models (Van Griensven et al., 2006). Sensitivity analysis is a process of testing and identifying model parameters that affects most the output from the model when changed. In other words, sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters) (Abbaspour, 2013). A parameter sensitivity analysis provides insights on which parameters contribute most to the output variance due to input variability (Holvoet et al., 2005). Therefore, a parameter is considered sensitive when the change in that parameter causes large change on model output.

In general identifying sensitive parameters prior to model calibration helps to allow the possible reduction in the number of parameters that must be calibrated thereby reducing the computational time required for model calibration. Once the sensitivity analysis is done calibration can be performed for limited number of influential parameters.

The current version of SWAT model, SWAT2012, provides the algorithmic techniques for sensitivity analysis. Two types of sensitivity analysis are allowed when using SUFI2 (Sequential Uncertainty Fitting version 2). Global Sensitivity and One-at-a-time sensitivity analysis. The two aforementioned sensitivity analysis methods may yield different results since the sensitivity of one

parameter depends on the value of other related parameters. In this study global sensitivity analysis were performed and the ranking of the parameters was determined.

4.7.1.1 Local (one-at-a-time) sensitivity analysis

The one-at-a-time sensitivity analysis is performed for one parameter at a time only by keeping the value of other parameters constant. One-at-a-time sensitivity analysis shows the sensitivity of a variable to changes in a parameter if all other parameters are kept constant at some reasonable value. This constant value can be the value of parameters from the best simulation (simulation with the best objective function value) of the last iteration. The drawback with the one-at-a-time sensitivity analysis is that the correct value of other parameters that are fixed are never known (Abbaspour, 2013). The objective function used in this project for ranking of the parameters based on one-at-a-time sensitivity analysis was the sum of the squares of the difference of the measured and simulated values after ranking (SSQR). The SSQR method aims at the fitting of the frequency distributions of the observed and the simulated series (Abbaspour, 2013).

After independent ranking of the measured and the simulated values, new pairs are formed and the SSQR is calculated as

$$\text{Minimize: SSQR} = 1/n\sum_{j=1}^{n}[Qj,m - Qj,s]^2 \quad \text{.....4.18}$$

4.7.1.2 Global sensitivity analysis

Global sensitivity analysis performs the sensitivity of one parameter while the value of other related parameters are also changing. Global sensitivity analysis uses t-test and p-values to determine the sensitivity of each parameters. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance. This type of sensitivity can be performed after an iteration. The main problem related to global sensitivity analysis is that it needs a large number of simulations (Abbaspour, 2013).

4.7.2 Model calibration and validation

Model calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold et al., 2012).

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions. This implies the application of the calibrated model without changing the parameter values that were set during the calibration, when simulating the response for a period other than the calibration period (Refsgaard, 1997).

The model calibration and validation process were conducted by using the SUFI2 (Sequential Uncertainty Fitting Version 2 programme) in SWAT_CUP.

SWAT_CUP is a computer programme for automatic calibration of SWAT models. The programme links SUFI2 procedures to SWAT. The auto-calibration procedure was supported by manual calibration for the values of parameters that were physically wrong. The values of parameters that are provided by SUFI2 during calibration as the best parameter value may not be physically correct or it may be outside recommended uncertainty range and needs to be adjusted manually to better match the existing situation.

The overall programme structure of SWAT_CUP is shown in Figure 4.5 below. The programme shows that the parameters of SWAT model should be edited in SWAT model after each iteration using SUFI2 or other programme. The SWAT model should be updated with a new set of parameters and then run the SWAT model. After the model was run using the new set of parameters, the new SWAT output must be used for the next iteration and so on.

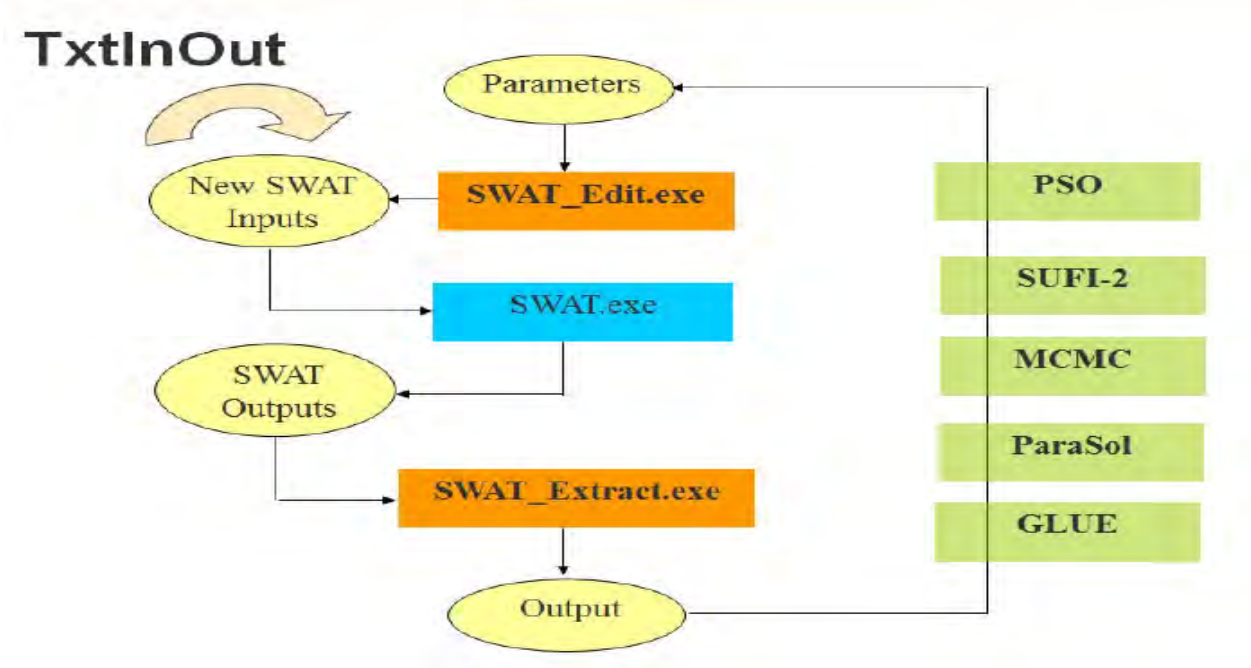

Figure 4.5 Overall programme structure of SWAT_CUP

4.7.3 Efficiency criteria

The systematic and dynamic behavior of the model can be visualized by plotting simulated flow and observed flow on the same coordinate system. By looking at the graph a modeler can understand whether the model over predicted or under predicted and also the timing of the rising and falling limb of the hydrograph and give subjective decision on the performance of the model. But, to quantitatively evaluate the model, we need mathematical measures of model performance. Reasons to evaluate model performance (Krause et al., 2005),

1) To provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior;

2) To provide a means for evaluating improvements to the modelling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information, and representation of important spatial and temporal characteristics of the watershed;

3) To compare current modelling efforts with previous study results.

To assess the goodness-of-fit of the model, two methods were used during the calibration and validation periods. These are: coefficient of determination (R^2) and the Nash-Sutcliffe efficiency coefficient (NS). These two statistical parameters are used to measure the model performance.

4.7.3.1 Coefficient of determination (R^2)

The coefficient of determination R^2 measures the fraction of the variation in the measured data that is replicated in the simulated model results.

The coefficient of determination R^2 is defined as (Krause et al., 2005) the squared value of the coefficient of correlation and is given by equation below.

$$R^2 = [\sum_i (Qm,i - \overline{Qm})(Qs,i - \overline{Qs})] \;/\; \sum_i (Qm.i - \overline{Qm})^2 \sum_I (Qs,i - \overline{Qs})^2 \text{.....4.19}$$

The value of R^2 ranges from (0-1) where a value close to 1.0 indicates good performance (good correlation) of the model and the value close to 0.0 indicates poor performance (poor correlation) of the model. The main drawbacks of R^2 is that it only quantifies dispersion. A model which systematically over-or under-predicts all the time will still result in good R^2 values close to 1.0 even if all predictions were wrong (Krause et al., 2005).

4.7.3.2 Nash-Sutcliffe efficiency coefficient (NS)

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) is used to assess the predictive power of the hydrological models. The value of NS varies from 1.0 (perfect fit) to 0.0. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al., 2005). The NS value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data. According to Krause et al, (2005) the major disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and simulated values are calculated as squared values.

This leads to an over estimation of the model performance during peak flows and an under estimation during low flows.

The Nash-Sutcliffe efficiency (NS) is calculated using equation below

$$NS = 1 - (\sum_i (Qm - Qs)^2 i) / \sum_i (Qm.i - \overline{Qm}) \quad \text{.....4.20}$$

This method is highly affected by a few extreme errors and it can be biased if a wide range of events is experienced.

4.8 Summary of Methods

The methods used in this project are summarized below.

1. **Creation of database**

Digital elevation model (DEM) was collected from MoWIE and then projected to WGS1984 UTM Zone37N using the raster projection in ArcMap.

Land use map that includes the study area was also collected from MoWIE and also projected to WGS1984 UTM Zone37N using the raster projection in ArcMap.

Soil map was also obtained from MoWIE and projected to the same coordinate system as above. Only three soil type was identified for the whole watershed area for further analysis.

The precipitation, temperature, humidity, solar radiation and wind speed data obtained from NMA was analyzed and processed as to the SWAT requirement format.

2. Model set up

The first step in model set up was creating the new SWAT project in ArcSWAT. Then the projected DEM map was imported in to ArcSWAT. Next the area of interest was delineated by selecting a point at the outlet of the watershed and found to be 5500 ha.

The drainage network, flow accumulation and flow direction all were automatically processed in ArcSWAT. A total 5 subbasin were delineated by SWAT for Gefersa watershed.

Land use and soil map in Arcshape format were imported in to the ArcSWAT model for HRU analysis. Both the maps were classified in ArcSWAT. The land slope of the study area was also classified in to two slope classes and made to overlay with land use and soil maps to subdivide the study watershed into hydrologic response units (HRUs).

Subdividing areas in to hydrologic response units enables the model to reflect the evapotranspiration and other hydrologic conditions for different land use, soils and slopes. The HRUs are the elementary units with unique land cover, soil and slope angle lumped together. A total of 23 HRUs were defined for the whole catchment.

After HRUs are defined, the next step in model set up is importing the climate data.

Climate data is one of the main sets of input for simulating the hydrological processes in SWAT. Precipitation, temperature, humidity, solar radiation and wind speed data are the climate data available for use. These available climate data were prepared in text (.txt) format and imported in to the SWAT model. Then the SWAT input tables were written into the model.

Some SWAT input files were edited before the model was run for simulation. Soil parameters were also edited. The statistical parameters of daily precipitation, minimum and maximum daily temperature, daily humidity, daily solar radiation and wind speed are also edited.

Hargreaves method was selected for calculating the potential evapotranspiration since it needs only daily minimum and maximum air temperature, SCS curve number was chosen to calculate surface runoff.

Finally, the model was run for the year 1986 to 2015 by fixing the warm up period of three years. The warm up period of (2-3) years is generally recommended for SWAT model to reach at hydrological equilibrium and 3 years warm up period selected in this project.

CHAPTER FIVE

5. RESULTS AND DISSCUSSIONS

5.1 Sensitivity analysis

The sensitivity analysis of flow and sediment was done separately since some parameters are sensitive to both flow and sediment, some sensitive to flow only and others sensitive to sediment only. Therefore, it is wise to test the sensitivity of the parameters for flow and sediment separately. Sensitivity analysis was carried out before calibrating the model to save time during calibration. Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. Some parameters does not have any influence on the model output while some may have little effect.

Automatic sensitivity analysis was conducted using input monthly 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, is the most sensitive parameter. The flow was also found to be sensitive to soil properties: Available water capacity of soil layer (AWC) mm/mm soil. The flow was also sensitive to hru: Average slope length (SLSUBBSN), Soil evaporation compensation factor (ESCO) 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.

Table: 5.1 Calibrated parameters for flow

Rank	Parameter	MIN	MAX	Relative sensitive value	Location	Description
1	Cn_2	35	98	0.21	mgt.	Initial SCS CN II value
2	SLSUBBSN	10	150	11.7718	hru.	Average slope length
3	CH_K2	-0.01	500	131.06	rte.	Effective hydraulic conductivity in the main channel alluvium
4	SOL-AWC	0	1	0.14772	sol.	Available water capacity of soil layer (mm/mm soil)
5	ESCO	0	1	0.46985	hru.	Soil evaporation compensation factor
6	GW-DELAY	0	500	260.021	gw.	Groundwater delay
7	GW-REVAP	0.02	0.2	0.2	gw.	Groundwater revap coefficient
8	BIOMIX	0	1	0.94261	mgt.	Biological mixing efficiency
9	REVAPMN	0	500	33.4292	gw.	Aquifer for revap to occur
10	CH_N2	-0.01	0.3	-0.0012	rte.	Manning's "n" value for the main channel
11	SURLAG	0.05	24	7.30388	bsn.	Surface runoff lag time
12	RCHRG-DP	0	1	0.13536	gw.	Deep aquifer percolation fraction
13	ALPHA-BF	0	1	0.83226	gw.	Baseflow recession constant (days)
14	GWQMN	0	5000	2261.18	gw.	Shallow aquifer required for return flow to occur(mm of water)
15	SOL-K	0	2000	4.07446	sol.	Saturated hydraulic conductivity (mm/hr)
16	LAT-TIME	0	180	23.6854	hru.	Lateral flow travel time.

5.2 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 1989 and 1998 on monthly basis. These years were selected based on the availability of data that is the flow data collected from MoWIE was on monthly basis. So 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 overall performance of the model during calibration has been measured using R^2 and Nash-Sutcliffe (NS) as 0.57 and 0.52, respectively.

Table: 5.2 Monthly Simulated & measured flow calibration

Time	Average Flow(m^3/s)		Model Efficiency(Monthly)		
1989-1998	Simulated	Measured	R^2	NS	PBIAS
	1.06	0.97	0.57	0.52	-9.3

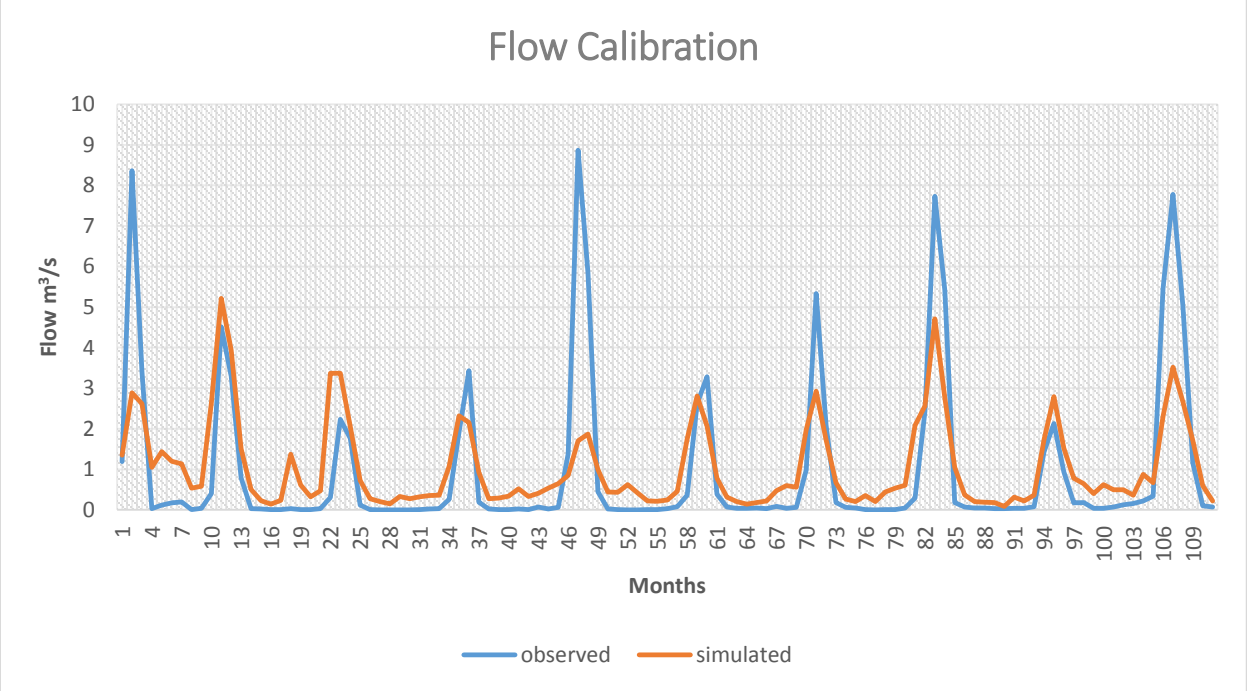

Figure. 5.1 Monthly Flow calibration of Gefersa catchment

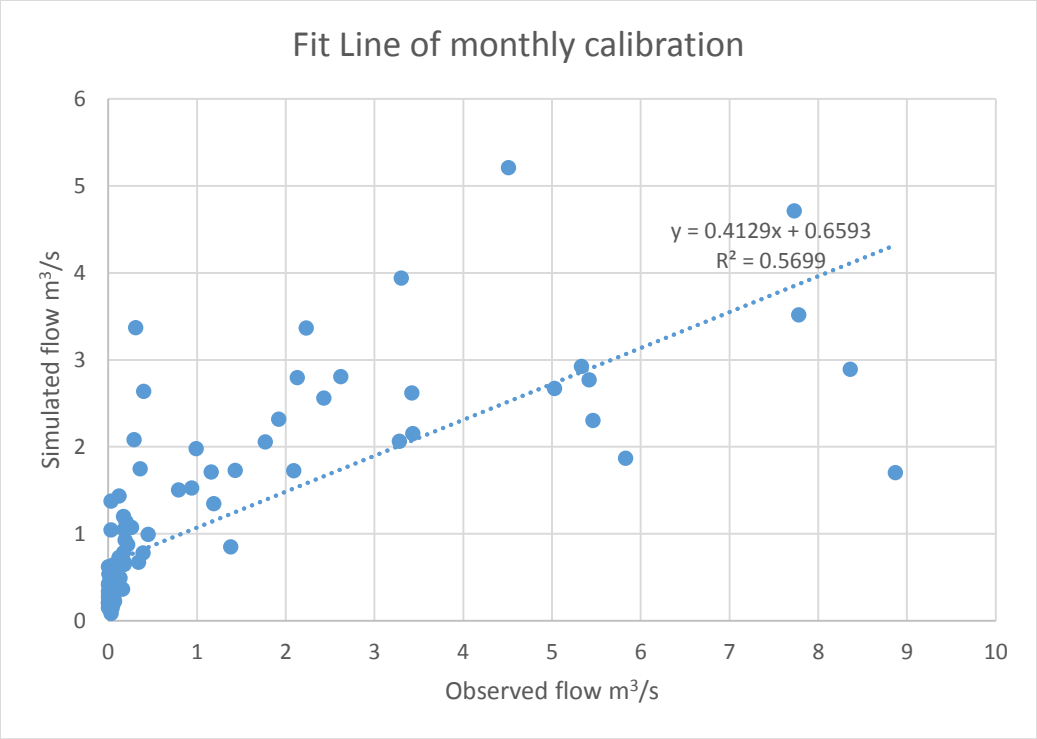

Figure: 5.2 Fit line of monthly measured & simulated flow for calibration

5.3 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 1999 to 2004. Figure 6.3 presents the validation results. The overall performance of the model during validation has been measured using R^2 and Nash-Sutcliffe (NS) are 0.65 and 0.61 respectively.

Table: 5.3 Simulated & measured flow validation

Time	Average Flow(m^3/s)		Model Efficiency(Monthly)		
1999-2004	Simulated	Measured	R^2	NS	PBIAS
	1.44	1.6	0.65	0.61	9.4

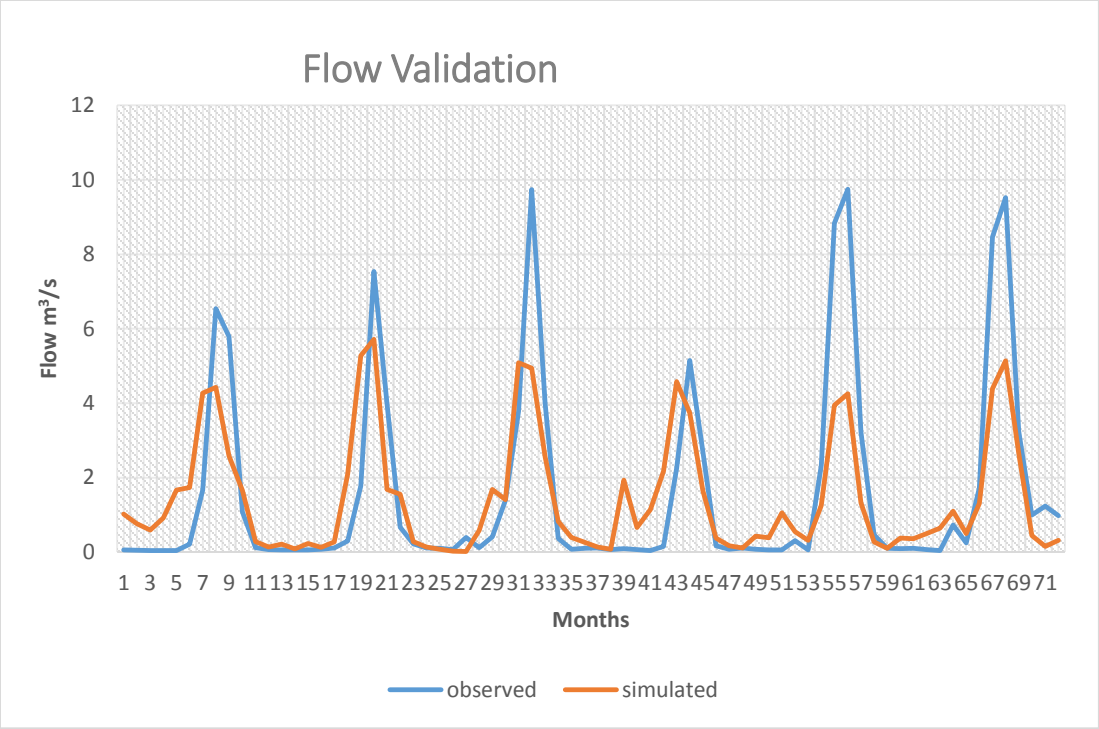

Figure: 5.3 Flow validation of Gefersa catchment

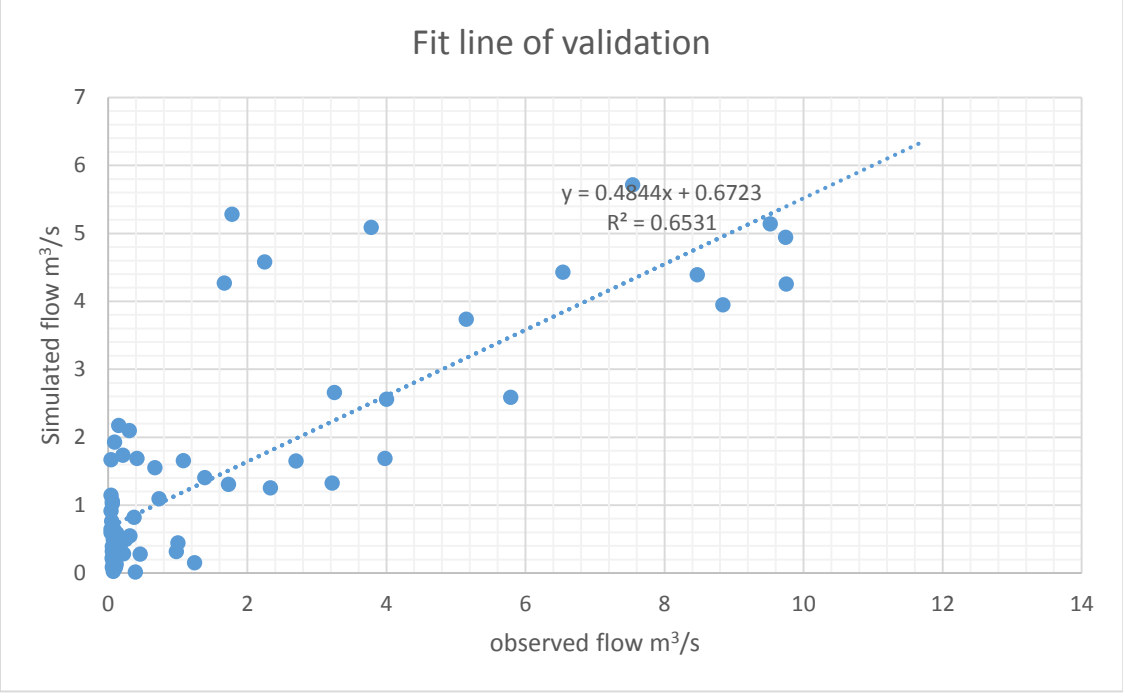

Figure: 5.4 Fit line of measured & simulated flow for validation

5.4 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 1990 to 1997.

According to the model output of the catchment, more of sediment of the area is from subbasin two and one, respectively. This shows that mitigation measures to these two subbasins may control the sedimentation problem of the Gefersa watershed easily.

Based on the analysis there is 27,288.75 t/year of sediment inflow to the Reservoir i.e. (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 -0.04; means the model overestimate the average annual sediment by 4 %.

Table: 5.4 Calibrated Parameters for Sediment

Rank	Parameter	Min	Max	Relative sensitive value	Location	Description
1	BIOMIX	0	1	0.228	.mgt	Biological mixing efficiency
2	SPCON	0.0001	0.01	0.017	.bsn	Linear re-entrainment parameter for channel sediment routing
3	CH-COV2	-0.001	1	0.443	.rte	Channel cover factor
4	SPEXP	1	1.5	1.240	.bsn	Exponential re-entrainment parameter
5	USLE-K	0	0.65	0.287	.sol	USLE soil erodibility factor
6	CH-COV1	-0.05	0.6	0.456	.rte	Channel erodibility factor
7	USLE-P	0	1	0.703	.mgt	USLE support practice factor
8	HRU-SLP	0	1	0.057	.hru	Average slope steepness

Table: 5.5 Simulated & measured Sediment Calibration

Time	Sediment load(ton/year)		Model Efficiency(yearly)
1990-1997	Simulated	Measured	D
	27288.75	26248.6	-4

When compared with Fasil G/Meskel research it indicates the reduction of siltation that is it reduced from 32063.7 t/year to 27288.75 t/year of sediment.

5.5 Sediment Validation

The model was validated for the period 1998 to 2001 with-adjusted values during calibration. The overall performance of the model during validation has been measured using D (the percent difference for a quantity) which is 0.5; means the model under-estimate the average annual sediment by 0.5%.

Table: 5.6 Simulated & measured Sediment validation

Time	Sediment load(ton/year)		Model Efficiency(yearly)
1998-2001	Simulated	Measured	D
	25460	25580	0.5

5.6 Scenario Development and Analysis for land use of the area

5.6.1 Scenario development

According to the output from the model among the land use/cover of the area Agricultural Land covers high amount of area and it is the source of the sediment of an area, and also the Forest-Deciduous, rain-fed crops and Range-Grasses covers small area and contribute little sediment to Gefersa Watershed. So to overcome this problem that is high amount of sediment is coming from the Agricultural Land let us change the percentage of coverage of land use/cover of Agriculture Land to reduce the sediment load of the watershed in future, because the cost needed to change is easy when compared with post treatment.

Accordingly let:

i. 40% area of Agricultural land is changed to Forest
ii. 35% area of Agricultural land is changed to Rain-fed crops
iii. 30% are of Agricultural land is changed to Grasses to reduce the production of sediment load from the above and compare them to select the best one to apply in the future.

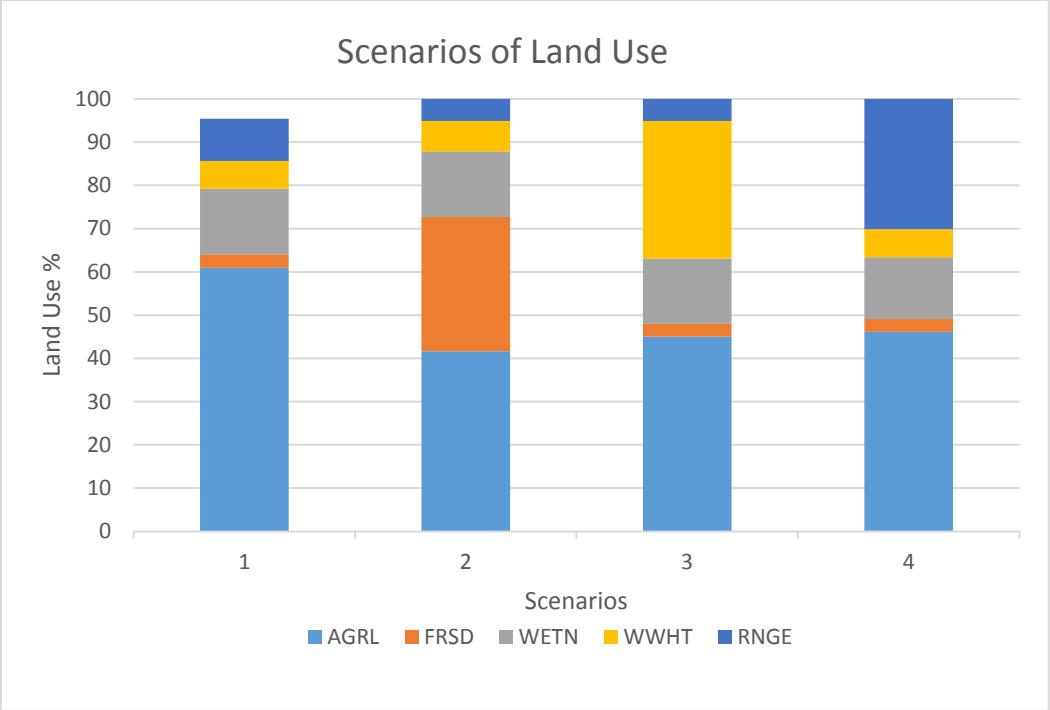

Figure 5.7: scenario of land use of Gefersa catchment.

5.6.2 Scenario analysis

The land use/cover is processed to decide the future management of the area to reduce the sediment load and easily protect the reservoir from failure.

Table 5.7: Scenario analysis of Gefersa catchment.

Scenario No	Sediment load (t/ha/year)	Sediment load (t/year)	% of sediment Change (reduced)	Volume to be saved t/year
0	4.98	27288	0	0
1	4.18	22990	15.75	4298
2	4.42	24310	10.91	2978
3	4.24	23320	14.54	3968

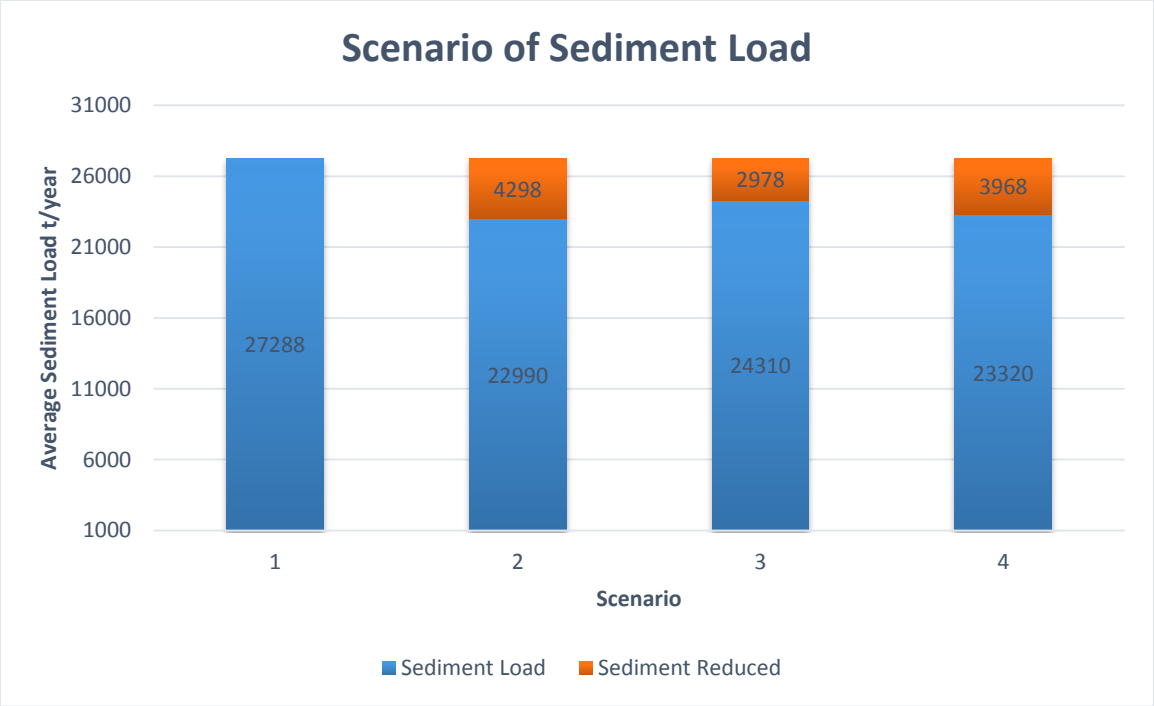

Figure 5.8 Scenario analysis of Gefersa catchment.

5.7 Scenario Development and Analysis for HRU

The multiple slope option 10%, 15% and 20% for Landuse, soil and Slope class respectively was selected in SWAT model as mentioned in methodology.

But by changing this HRU definition the sediment load of the area is also changed.

Table: 5.8: HRU Scenario analysis of Gefersa catchment.

Scenario No	% of Land use/soil/slope	Avg. Sediment load t/h (yearly)	Avg. sediment load t (yearly)	% of sediment Change (reduced)	Volume to be saved t/year
0	10:15:20	4.98	27288	-	-
1	05:15:20	4.50	24657.8	9.6	2630.2
2	10:05:20	4.88	26740	2.0	548
3	10:15:05	4.95	27123.6	0.6	164.4

From the above scenario the Land use percentage over sub-basin affects more the sediment load of the catchment. So to control the sediment load of the area by using buffer strips it is better to focus on land use percentage over area of the catchment.

CHAPTER SIX

6. MITIGATION MEASURES

6.1. At Gefersa reservoir sites sediment control

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.

So to reduce the sediment inflow to the reservoir there are three buffer strips. The main one, the exclusion zone, is the one near the reservoir. The other two buffer strips are the area of minimum activity and the supervised zone. The strips are running more or less parallel with the shore line of the reservoir, have a total width of 1,750 meters and would serve a dual purpose:

1. Preventing sediments generated by catchment erosion and small stream erosion from reaching the reservoir directly.

2. Preventing the local inhabitants and livestock from reaching the immediate vicinity of the reservoir

First Buffer Strip: Exclusion zone

The water body of the reservoirs and its nearest shore line will be totally separated from any kind of human/livestock direct contact by buffer strips. The proposed buffer strips surrounding the reservoirs will be fenced by strong barbed wire fence to be set up 2 to 3m above the reservoir maximum level and controlled by AAWSA. This roughly 250m wide buffer strip consist of: a fence, a protection canal, a rural road, an embankment and a green area (grassed areas, dense tree and bush plantings).

Second buffer strip: Area of Minimum Activity

This second buffer strip in which only minimum activity will be allowed and about 500m wide beginning from the boundary of the first buffer strip and consist of hardy grasses such as Cynadon, Digetaris, Bracharia, sedge grasses and others propagated by rhizome and non-seed producing

plants. These will serve as fine sediment trappers to obtain clean water. Heavy seeders and highly decomposing types or plants will be avoided to reduce organics.

Third buffer strip: Supervised zone

Trees and small shrubs will be planted in this area with natural vegetation or fodder plant to be harvested by cut and carry methods. Shrubs and grass in staggered pattern are acceptable in this zone. The kind of shrubs to be used in this zone are Agam, Kai apple (Koshim) Kega, Enjorey and other types of non-seed dispensing bushes. Similar shrubs can be staggered with non-shading trees like Acacia Abyssinica, Gravilea robusts Junperious, Podocarpus, Pine radiate, Shenis molle planted on the periphery. The third buffer strip will be about 1000m wide (Darman, 2011).

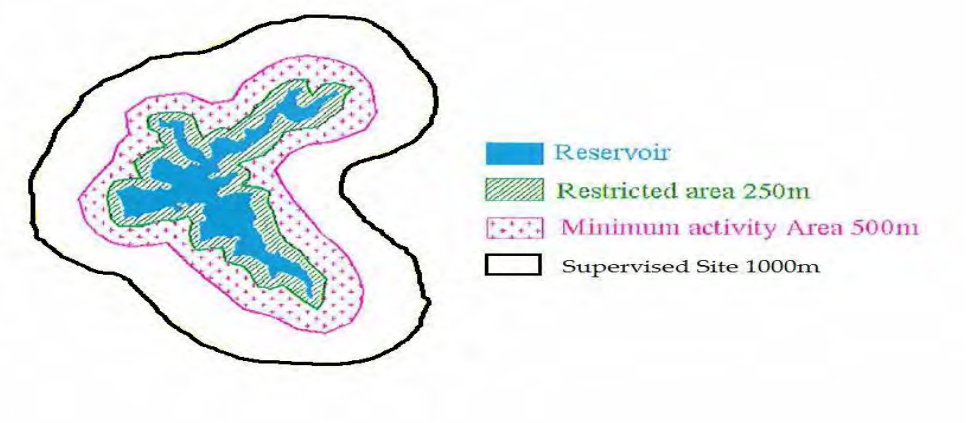

Figure.6.1: Buffer strip layout (Darman, 2011).

Protection canals could be excavated near and outside the green vegetative zone to prevent grazing and access to the reservoir, and acting as a belt of windbreaks. Such a canal would have to be bridged or discontinued where access is needed for inspection, maintenance, control, etc. The canal would also serve for collection of drainage and runoff water. This would be let into the reservoir by inlets (protected from erosion) about every 500 m or less. The steep sides and the sediments settling in the canal will call for regular maintenance, perhaps even during the wet season.

6.2. 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). More specifically three different soil conservation methods were examined.

The use of vegetative contour strips, consisting of grass or other permanent vegetation in a contoured field to help trap sediment and nutrients. Because the buffer strips are established following the contours, runoff flows slower and evenly across the grass strip, reducing sheet and rill erosion. Permanent vegetative contour strips are in fact an inexpensive substitute for terraces.



Figure: 6.2 Vegetative contour strips (Darman, 2011).

Applying mulching, requiring residues produced within the cropping area and/or residues collected from elsewhere. These residues are applied in the field by spreading them on top of the soil. They protect to a certain extent the soil from erosion and reduce compaction from the impact of heavy rains (Darman, 2011).



Figure: 6.3 Mulching (Darman, 2011).

Another technique which was examined consists of making soil ridges of varying width and height, average being 30 cm width and 20 cm height. At regular intervals, crossties are built between the ridges. The ties are about two-thirds the height of the ridges, so that if overflowing occurs, it will be along the furrow and not down the slope. This technique is applicable in the areas where subsistence crops are cultivated (Darman, 2011)



Figure: 6.4 Soil ridges (Darman, 2011).

6.3. 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 of Gefersa III 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 m^3/year. This decline is accounted for by the smaller contributing area due to the construction of the Gefersa III reservoir.

Constructing silt trapping structure needs high amount of invest, so the silt-trap zone is good to prevent silt transported with water that originates from the catchment close to the reservoir and from the silt-trap-zone itself to enter the reservoirs. It covers the perimeter of the reservoir and it is separated into three sub-zones:

The tree zone

The tree zone is the outer and upper part of the silt-trap zone. This is the zone which is meant to filter out and contain larger sediments that are mobilised with the runoff during heavy rains. It will also form a barrier discouraging human and cattle movements, if dense enough. The trees will be planted with a spacing of 1.0 or 1.5 meters.

The shrub zone

The shrub zone is the middle part of the silt-trap zone. This is the zone which is to filter out and contain sand and gravel that are rolling to the silt-trap zone from overlaying terrains.

The shrubs will be planted with a spacing of 1.0 meters. The difference between the tree zone and the shrub zone is that the individual shrubs have multiple stems which can densely fill up the line creating a good blockage that serves as a barrier to any gravel escaping the tree zone and passing through to this zone. It will also serve as an impassable barrier to cattle movements.

Between the shrub zone and the tree zone, a fence is proposed to be constructed along the perimeter. This fence will protect the reservoir and the grass zone from any human and livestock interferences.

The grass zone

The grass zone is the inner and lower part of the silt-trap zone. This is the zone which is to filter out and contain the silt that is escaping through the tree and shrub belt of the silt-trapping zones. This layer needs to be very thick to contain the silt and release only the filtered water downstream to the reservoir. In addition to protecting the reservoir from silt deposition, this zone serves as a buffer zone for protecting the dam (Darman, 2011).

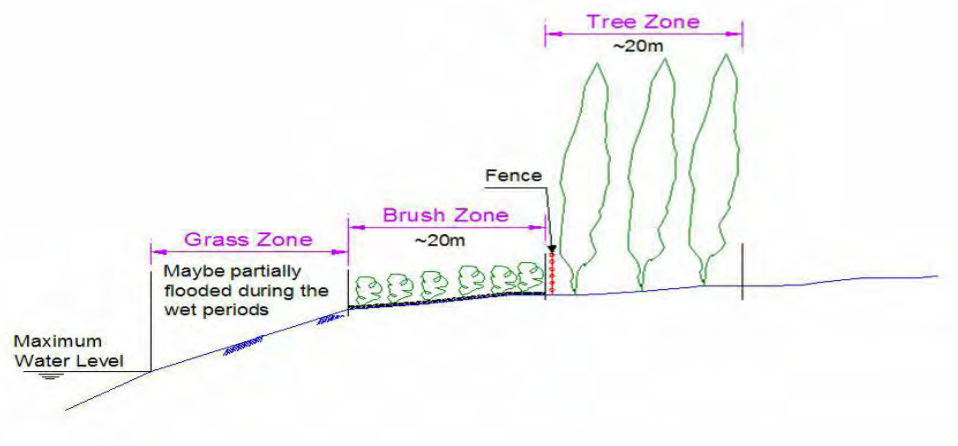

Figure: 6.5. Silt-trap zone (Darman, 2011).

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 (Fasil,2012). This method could be the most appropriate for Gefersa reservoir because it is cost effective.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Gefersa Reservoirs are structures used as water supply for Addis Ababa city by supplying an average of 30,000 m^3/day.

But due to poor upstream watershed management the reservoirs become silted. This siltation of reservoirs affects life of dam, reduce volume due to reduction of live storage, reduce quality of potable water and increase treatment cost.

To understand the amount of this siltation SWAT2012 was used to simulate runoff and sediment from Gefersa watershed of Little Akaki, Awash basin. The model operates on a daily time step and allows a basin to be subdivided into grid cells or natural sub-watersheds.

The objective of the study was to determine the sediment load of the reservoir catchments by using different models and recommend the appropriate mitigation measures to reduce its effect. A GIS interface was used to prepare and process a geospatial data required to run the model. Automatic calibration of SWAT model using Sequential Uncertainty Fitting version two was used together with enormous support of manual calibration.

Coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) have been used to measure the performance of the model.

The coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) for the daily runoff are obtained as 0.57 and 0.52 for the calibration period (1989-1998), respectively. The coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NS) for the daily runoff at the outlet of the watershed for validation period (1999-2004) are obtained as 0.65 and 0.61 respectively.

The calibration of the model for the yearly sediment observed at Gefersa gives (R^2) and (NS) value 0.29 and 0.28, respectively and model efficiency of -4 which means 4% over estimation.

In general, the daily stream flow and the yearly sediment yield predicted by SWAT corresponded well with observed values. However, the model seems to over predicted surface runoff and under predicted in some years. The reason for this was that the daily stream flow data used for calibration and validation are not reliable that is the flow data sometimes have an outlier record.

The global sensitivity analysis of the SWAT parameters showed that Gefersa catchment runoff is most sensitive to curve number (CN), average slope length (SLSUBBSN) and effective hydraulic conductivity in the main channel alluvium (CH_K2). The sensitivity analysis of the SWAT parameters showed that sediment yield is most sensitive to upland factors such as Biological mixing efficiency (BIOMIX), Linear re-entrainment parameter for channel sediment routing (SPCON), and Channel cover factor (CH-COV1).

Agricultural Land-Generic land use covers high percent of the area and it is the source of more of the sediment of watershed. So to reduce it scenario was done as change 40% area of Agricultural to Forest, 35% area to Rain-fed crops and 30% area to Grasses result in 15.75%, 10.91% and 14.54% of sediment volume reduction respectively.

So the stakeholder may reduce the sediment load of the area in future easily without expending high amount of cost simply by changing the land use and management of the area.

Even if both structural and non-structural measures can reduce sediment load of an area, the non-structural measures are the best methods because they need small capital and can be applied easily according to the model scenario.

7.2. Recommendations

This study of determining sediment problem of Gefersa Reservoirs and measures to be applied at watershed may be used for further research.

Since AAWSA has administrative control of the area it must collect all data of the area because to study the problem of area full, accurate, continuous, quality and updated data plays a great role.

Not only lack of data, but also there was documentation problem. Hence, responsible bodies should give due attention to minimize this problem.

SWAT uses daily based data, to compare the output results with the observed data, the stakeholders of the reservoir must collect the river flow and sediment data at inlet on daily basis.

When watershed management like afforestation and grass land are applied to reduce the sediment load they also reduce greenhouse gas effect by increasing the oxygen amount of the area. Therefore, watershed management shall be encouraged.

Further studies are necessary for the sediment monitoring techniques in order to have fast and periodic application of the measure since full and detail knowledge of sedimentation is essential for the life span of the dams.

Sediment has socio-economic, environmental and geomorphological impacts therefore; changes in sediment quantity and quality can have significant implications and impacts on a range of social, economic and environmental systems. It is, therefore important to study the socio-economic and environmental impacts that will be involved before monitoring sediment measure is applied.

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ANNEXES

A-Table 1: Flow and sediment of subbasin for 30 years from the model.

Sub basin											
SUB	**YEAR**	**AREA km2**	**PRECIP mm**	**PET mm**	**ETmm**	**SW mm**	**PERC mm**	**SURQ mm**	**GW_Q mm**	**WYLD mm**	**SYLD t_ha**
1	1989	12.641	1364.6	956.976	632.269	13.72	599.511	130.924	480.178	644.127	7.071
2	1989	8.2337	1382.75	969.759	650.126	13.595	592.126	116.361	476.897	638.391	7.887
3	1989	10.135	1402.064	982.396	665.172	19.084	598.018	19.984	489.927	632.499	0.909
4	1989	7.2187	1405.089	981.633	669.648	20.652	592.985	13.317	485.547	628.3	0.577
5	1989	15.227	1405.089	982.025	663.89	20.092	637.589	17.151	525.438	633.167	0.608
1	1990	12.641	1725.78	959.11	717.401	9.013	780.994	244.42	792.839	1084.936	18.573
2	1990	8.2337	1748.734	971.921	738.443	9.788	777.933	218.323	786.129	1068.789	20.549
3	1990	10.135	1773.16	984.588	759.67	8.448	836.474	49.336	834.389	1059.508	2.63
4	1990	7.2187	1776.985	983.832	766.753	8.826	831.987	39.872	829.92	1055.515	2.172
5	1990	15.227	1776.986	984.224	760.292	9.555	885.128	47.99	883.244	1062.663	2.149
1	1991	12.641	1335.965	965.747	599.286	10.161	572.209	172.11	527.471	738.047	10.16
2	1991	8.2337	1353.734	978.647	614.815	10.344	571.362	153.344	526.732	731.11	11.183
3	1991	10.135	1372.643	991.409	636.739	12.973	597.608	30.865	552.187	714.524	1.298
4	1991	7.2187	1375.604	990.671	643.815	14.334	591.452	23.288	546.396	707.917	0.883
5	1991	15.227	1375.604	991.062	638.841	14.791	632.834	28.728	585.896	713.477	0.905
1	1992	12.641	1096.485	964.065	578.34	11.318	429.928	92.67	361.006	479.585	7.616
2	1992	8.2337	1111.069	976.943	595.365	11.344	422.088	81.711	353.605	470.168	8.45
3	1992	10.135	1126.589	989.679	620.693	16.54	411.509	14.172	347.955	453.881	0.912
4	1992	7.2187	1129.019	988.93	630.639	18.091	402.53	9.411	340.739	446.404	0.53
5	1992	15.227	1129.019	989.323	624.162	17.576	437.893	12.213	371.94	452.012	0.54
1	1993	12.641	1261.434	960.636	802.701	13.518	415.108	45.704	381.898	453.782	3.148
2	1993	8.2337	1278.211	973.467	821.277	13.54	403.102	40.425	370.478	446.014	3.494
3	1993	10.135	1296.066	986.156	838.376	19.021	375.401	5.305	343.346	440.318	0.316
4	1993	7.2187	1298.862	985.404	844.037	20.592	369.956	1.749	336.657	434.885	0.096
5	1993	15.227	1298.862	985.796	835.764	20.02	407.534	2.234	372.586	442.99	0.097
1	1994	12.641	1170.134	950.159	675.832	10.058	416.638	86.379	396.12	508.664	5.728
2	1994	8.2337	1185.697	962.851	691.409	10.708	409.685	76.773	389.513	501.455	6.193
3	1994	10.135	1202.259	975.39	707.112	13.13	409.901	16.001	386.857	496.04	0.695
4	1994	7.2187	1204.852	974.609	712.311	14.982	404.665	12.067	382.408	492.808	0.497
5	1994	15.227	1204.852	975.002	707.686	15.806	435.785	14.553	414.123	497.996	0.502
1	1995	12.641	1244.076	969.475	696.436	13.303	468.766	81.435	421.272	530.743	5.151
2	1995	8.2337	1260.623	982.425	712.326	13.431	461.734	72.025	414.28	524.212	5.574
3	1995	10.135	1278.231	995.23	732.35	17.283	448.486	11.244	405.73	516.934	0.546
4	1995	7.2187	1280.989	994.467	739.863	18.887	441.952	6.298	400.138	511.924	0.287
5	1995	15.227	1280.989	994.863	736.935	19.069	476.976	7.924	432.673	514.779	0.293

Sub basin

SUB	YEAR	AREA km2	PRECIP mm	PET mm	ETmm	SW mm	PERC mm	SURQ mm	GW_Q mm	WYLD mm	SYLD t_ha
1	1996	12.641	1571.423	940.728	720.307	6.328	679.259	188.91	629.854	856.607	8.868
2	1996	8.2337	1592.324	953.293	735.961	6.217	678.87	168.855	629.733	851.027	9.631
3	1996	10.135	1614.566	965.729	760.7	7.092	707.146	38.08	651.73	834.531	1.099
4	1996	7.2187	1618.049	965.023	768.171	7.977	701.291	30.679	645.521	828.854	0.782
5	1996	15.227	1618.049	965.403	762.708	8.799	747.934	36.93	690.474	834.069	0.812
1	1997	12.641	1192.003	991.352	685.501	5.368	436.872	75.878	386.197	490.335	4.873
2	1997	8.2337	1207.857	1004.594	703.311	5.51	427.434	66.718	377.539	481.784	5.377
3	1997	10.135	1224.728	1017.682	724.161	9.713	411.265	10.137	363.102	469.136	0.569
4	1997	7.2187	1227.37	1016.891	732.205	11.301	403.659	5.435	355.859	462.057	0.297
5	1997	15.227	1227.37	1017.296	727.031	11.107	439.128	6.864	388.028	466.594	0.303
1	1998	12.641	1475.121	939.497	678.788	5.023	653.573	152.302	607.642	796.778	8.331
2	1998	8.2337	1494.741	952.045	699.228	5.627	646.407	133.623	600.612	784.595	9.183
3	1998	10.135	1515.62	964.468	723.311	7.145	660.631	21.566	613.305	771.986	0.958
4	1998	7.2187	1518.89	963.775	732.218	9.036	653.475	13.322	606.667	764.537	0.517
5	1998	15.227	1518.89	964.152	723.283	10.111	702.728	17.062	654.706	773.272	0.537
1	1999	12.641	1369.503	995.756	636.093	0.916	576.894	169.398	525.997	730.024	10.021
2	1999	8.2337	1387.719	1009.057	656.589	0.816	572.695	149.767	522.198	718.78	10.88
3	1999	10.135	1407.102	1022.208	675.378	2.517	603.766	31.001	551.318	708.493	1.23
4	1999	7.2187	1410.138	1021.422	683.235	3.288	598.491	24.095	546.53	703.515	0.871
5	1999	15.227	1410.138	1021.829	674.365	3.692	642.872	30.108	588.118	712.415	0.909
1	2000	12.641	1384.214	985.52	633.521	9.694	595.767	155.043	547.373	738.235	8.501
2	2000	8.2337	1402.624	998.684	651.127	9.668	591.259	137.556	543.174	729.022	9.295
3	2000	10.135	1422.216	1011.707	668.587	11.872	613.644	26.796	566.111	722.069	1.155
4	2000	7.2187	1425.284	1010.954	675.721	12.875	607.617	19.892	560.548	716.38	0.89
5	2000	15.227	1425.284	1011.354	670.871	12.813	650.194	24.468	601.643	722.34	0.903
1	2001	12.641	1329.59	980.803	661.952	0.913	552.297	131.704	509.405	677.051	6.428
2	2001	8.2337	1347.274	993.902	680.649	1.481	544.863	116.778	502.005	666.113	7.064
3	2001	10.135	1366.093	1006.892	704.883	3.187	553.276	21.301	508.94	650.735	0.816
4	2001	7.2187	1369.04	1006.233	715.113	4.381	544.784	14.722	500.641	641.626	0.529
5	2001	15.227	1369.04	1006.618	709.37	5.033	584.708	18.169	538.84	647.046	0.548
1	2002	12.641	1217.206	1000.209	635.755	13.625	485.147	89.971	418.286	536.976	4.201
2	2002	8.2337	1233.395	1013.568	650.814	13.665	479.167	79.234	412.835	530.872	4.594
3	2002	10.135	1250.623	1026.799	675.691	18.978	463.215	12.248	404.772	517.9	0.478
4	2002	7.2187	1253.321	1026.082	683.102	20.571	456.594	6.772	399.823	512.862	0.235
5	2002	15.227	1253.321	1026.48	676.413	19.993	496.25	8.477	435.596	519.265	0.243
1	2003	12.641	1346.066	958.351	635.305	8.982	579.273	144.37	548.443	726.257	6.887
2	2003	8.2337	1363.969	971.152	649.861	9.233	576.811	128.124	546.293	720.285	7.538
3	2003	10.135	1383.021	983.817	679.105	11.11	588.299	23.027	551.833	699.227	0.899

Sub basin

SUB	YEAR	AREA km2	PRECIP mm	PET mm	ETmm	SW mm	PERC mm	SURQ mm	GW_Q mm	WYLD mm	SYLD t_ha
4	2003	7.2187	1386.005	983.086	687.921	12.191	581.475	16.142	544.593	691.839	0.6
5	2003	15.227	1386.005	983.475	684.252	12.166	621.319	20.081	583.993	695.914	0.628
1	2004	12.641	1306.054	952.299	651.82	9.99	550.858	109.678	503.667	646.814	6.135
2	2004	8.2337	1323.425	965.019	668.066	10.236	544.466	96.875	497.575	639.22	6.728
3	2004	10.135	1341.911	977.595	695.288	11.756	537.781	14.548	491.194	621.902	0.706
4	2004	7.2187	1344.806	976.843	703.683	12.855	530.668	8.184	484.439	615.039	0.377
5	2004	15.227	1344.806	977.232	699.143	13.361	570.109	10.544	522.06	619.234	0.394
1	2005	12.641	1201.025	956.806	637.511	6.568	479.867	93.206	439.882	563.826	4.837
2	2005	8.2337	1216.999	969.586	652.577	7.526	472.791	82.697	432.963	556.298	5.341
3	2005	10.135	1233.998	982.222	678.805	8.512	461.727	14.482	421.045	538.455	0.616
4	2005	7.2187	1236.66	981.464	687.495	10.239	453.915	8.9	413.33	530.352	0.333
5	2005	15.227	1236.66	981.855	683.939	11.21	488.333	10.721	446.122	533.539	0.347
1	2006	12.641	1463.942	933.731	657.771	10.01	633.336	178.988	577.495	791.277	10.13
2	2006	8.2337	1483.413	946.203	678.459	10.736	626.931	160.09	571.213	779.279	11.37
3	2006	10.135	1504.133	958.547	703.721	14.433	642.792	41.547	587.196	761.703	1.782
4	2006	7.2187	1507.378	957.851	712.135	16.642	634.17	35.424	579.159	754.582	1.486
5	2006	15.227	1507.378	958.227	705.222	17.029	680.133	41.231	622.201	761.184	1.519
1	2007	12.641	1354.107	952.184	726.164	13.399	526.964	104.432	475.644	613.591	5.871
2	2007	8.2337	1372.117	964.903	746.846	13.418	517.618	91.939	466.794	603.166	6.481
3	2007	10.135	1391.283	977.487	765.803	18.92	512.432	16.006	462.479	593.008	0.694
4	2007	7.2187	1394.284	976.762	771.079	20.507	508.022	10.738	457.349	588.858	0.407
5	2007	15.227	1394.285	977.148	763.077	19.939	551.288	13.538	497.093	596.604	0.422
1	2008	12.641	1310.075	1000.076	618.957	9.358	572.058	131.073	519.466	682.378	7.778
2	2008	8.2337	1327.5	1013.434	642.349	7.468	561.841	116.076	513.815	673.45	9.271
3	2008	10.135	1346.042	1026.652	671.412	12.748	563.621	20.73	512.076	650.884	1.095
4	2008	7.2187	1348.946	1025.898	683.518	14.609	553.114	13.917	503.957	642.235	0.713
5	2008	15.227	1348.946	1026.302	677.531	14.907	593.766	17.196	542.923	647.414	0.751
1	2009	12.641	1218.285	1002.983	668.94	13.917	452.298	98.532	391.762	519.525	6.054
2	2009	8.2337	1234.488	1016.38	688.071	13.871	441.472	87.362	378.78	504.275	7.561
3	2009	10.135	1251.732	1029.641	710.042	19.389	438.707	16.58	375.089	489.312	0.884
4	2009	7.2187	1254.432	1028.903	718.446	20.939	431.294	12.091	366.51	480.995	0.633
5	2009	15.227	1254.432	1029.305	713.282	20.343	466.446	15.005	398.414	485.952	0.653
1	2010	12.641	1510.426	880.474	498.164	14.268	756.417	268.266	726.529	1037.122	17.396
2	2010	8.2337	1530.515	892.234	509.36	14.307	761.924	241.869	730.079	1030.631	20.04
3	2010	10.135	1551.893	903.877	536.212	18.194	822.037	60.334	792.073	1018.052	2.501
4	2010	7.2187	1555.241	903.226	545.281	19.602	813.824	51.974	785.328	1011.625	1.99
5	2010	15.227	1555.241	903.581	540.281	19.873	862.692	61.719	834.108	1017.818	2.027
1	2011	12.641	1345.379	936.546	514.107	3.38	649.521	202.728	600.849	843.222	14.183

Sub basin											
SUB	**YEAR**	**AREA km2**	**PRECIP mm**	**PET mm**	**ETmm**	**SW mm**	**PERC mm**	**SURQ mm**	**GW_Q mm**	**WYLD mm**	**SYLD t_ha**
2	2011	8.2337	1363.273	949.055	527.819	3.311	650.259	181.227	601.828	836.862	15.367
3	2011	10.135	1382.315	961.439	553.098	5.785	688.034	38.896	635.446	818.84	1.7
4	2011	7.2187	1385.298	960.748	562.231	6.633	680.792	31.176	628.344	811.343	1.268
5	2011	15.227	1385.298	961.124	556.555	6.788	725.976	38.13	671.72	817.334	1.303
1	2012	12.641	1318.705	966.002	432.378	2.23	664.951	233.745	612.097	884.911	13.65
2	2012	8.2337	1336.244	978.904	443.576	2.296	669.145	209.79	615.912	879.049	14.914
3	2012	10.135	1354.909	991.683	463.75	1.551	727.063	50.744	670.344	867.369	1.932
4	2012	7.2187	1357.832	990.984	471.621	1.447	721.207	42.889	664.726	861.43	1.595
5	2012	15.227	1357.832	991.371	467.426	1.864	764.889	50.723	705.876	864.997	1.666
1	2013	12.641	1358.324	979.396	423.753	0	583.754	365.687	535.236	937.747	23.235
2	2013	8.2337	1376.39	992.477	437.123	0	591.887	336.069	542.969	929.961	26.212
3	2013	10.135	1395.616	1005.435	467.457	0	688.707	123.947	634.588	904.007	5.116
4	2013	7.2187	1398.626	1004.737	479.934	0	676.377	118.062	623.002	892.742	4.797
5	2013	15.227	1398.627	1005.127	478.59	0.033	710.616	133.088	656.064	895.16	4.985
1	2014	12.641	1311.938	969.031	404.759	0	576.844	342.609	528.598	906.022	27.465
2	2014	8.2337	1329.388	981.974	416.264	0	587.342	312.483	538.609	899.901	31.208
3	2014	10.135	1347.957	994.784	444.745	0	683.221	106.029	630.108	878.053	4.994
4	2014	7.2187	1350.865	994.057	455.389	0	673.458	99.427	620.857	868.454	4.249
5	2014	15.227	1350.865	994.448	450.702	0.033	709.545	114.203	655.116	873.053	4.38
1	2015	12.641	988.023	975.025	329.653	0.078	417.606	249.477	377.955	654.467	25.661
2	2015	8.2337	1001.165	988.047	339.512	0	423.813	227.861	383.851	649.04	28.372
3	2015	10.135	1015.149	1000.945	364.6	0	492.463	73.731	449.103	628.898	4.386
4	2015	7.2187	1017.339	1000.243	374.907	0	484.408	67.331	441.52	619.524	3.569
5	2015	15.227	1017.339	1000.633	371.511	0.168	511.647	77.518	467.463	622.918	3.966

A-Table: 2 AVERAGE MONTHLY BASIN VALUES

MON	RIAN (MM)	SNOW FALL(MM)	SURF Q (MM)	LAT Q(MM)	WATER YIELD (MM)	ET (MM)	SED YIELD (T/HA)	PET (MM)
1	37.28	0.00	0.49	1.07	12.34	28.35	0.02	56.18
2	47.24	0.00	1.52	1.20	11.74	34.02	0.11	68.75
3	86.05	0.00	5.46	2.22	20.10	49.63	0.39	92.75
4	86.14	0.00	2.16	2.55	22.54	61.20	0.12	100.98
5	86.77	0.00	2.60	2.54	26.45	64.40	0.21	116.01
6	143.83	0.00	5.39	3.42	29.15	74.87	0.30	100.74
7	288.80	0.00	27.39	10.99	89.76	82.11	1.59	86.69
8	293.23	0.00	30.20	13.72	150.95	80.04	1.78	83.69
9	163.03	0.00	12.79	9.42	148.75	73.59	0.81	83.84
10	46.41	0.00	1.03	2.70	101.79	41.32	0.10	80.07
11	34.05	0.00	0.42	0.93	52.86	28.22	0.03	59.48
12	37.73	0.00	0.44	0.94	23.25	23.86	0.03	51.47

A-Table: 3 Land use summary

LULC	AGRL	FRSD	RNGE	WETN	WWHT
AREA Km^2	37.19	1.58	2.74	8.13	3.76
CN	80.34	66.00	77.21	77.43	78.03
AWC mm	19.42	15.00	18.17	18.07	16.20
USLE_LS	2.21	3.55	2.54	2.41	1.94
PREC mm	1350.93	1350.93	1350.93	1350.93	1350.93
SUR Q mm	96.24	11.46	79.49	82	85.23
GW Q mm	558.01	678.11	581.21	585.01	622.22
ET mm	649.68	610.90	641.88	635.36	591.79
SED th	5.89	0.36	6.66	6.39	1.30
NO3 Kgh	2.31	0.00	0.01	0.01	1.48
ORGN Kgh	10.90	0.66	5.04	5.09	4.39
BIOM th	0.00	0.09	0.10	0.13	7.69
YLD th	0.00	0.22	0.00	0.00	2.38

A-Table: 4 Land use summary after scenario I

LULC	AGRL	FRSD	RNGE	WETN	WWHT
AREA Km^2	22.27	16..58	2.73	8.11	3.76
CN	80.34	70.76	77.19	77.45	78.03
AWC mm	19.42	19.14	18.18	18.06	16.20
USLE_LS	2.21	2.37	2.54	2.41	1.94
PREC mm	1350.93	1350.93	1350.93	1350.93	1350.93
SUR Q mm	96.27	39.08	79.29	82.16	85.23
GW Q mm	558.01	628.75	581.37	584.88	622.22
ET mm	649.66	632.82	641.93	635.32	591.79
SED th	5.76	0.89	6.64	6.40	1.30
NO3 Kgh	2.2	0.01	0.01	0.01	1.48
ORGN Kgh	10.73	1.43	5.03	5.10	4.39
BIOM th	0.00	1.84	0.10	0.13	7.69
YLD th	0.00	0.44	0.00	0.00	2.38

A-Table: 5 Land use summary after scenario II

LULC	AGRL	FRSD	RNGE	WETN	WWHT
AREA Km^2	24.07	1.58	2.74	8.08	16.98
CN	80.35	66.00	77.21	77.48	76.94
AWC mm	19.41	15.00	18.17	18.04	18.57
USLE_LS	2.21	3.55	2.54	2.41	2.14
PREC mm	1350.93	1350.93	1350.93	1350.93	1350.93
SUR Q mm	96.4	11.46	79.49	82.43	71.38
GW Q mm	557.69	678.11	581.21	584.67	632.56
ET mm	649.33	610.90	641.88	635.27	595.86
SED th	5.84	0.36	6.66	6.43	1.17
NO3 Kgh	2.37	0.00	0.01	0.01	2.00
ORGN Kgh	10.69	0.66	5.04	5.11	4.45
BIOM th	0.00	0.92	0.10	0.13	8.68
YLD th	0.00	0.22	0.00	0.00	2.69

A-Table: 6 Land use summary after scenario III

LULC	AGRL	FRSD	RNGE	WETN	WWHT
AREA Km^2	24.66	1.58	16.12	7.65	3.45
CN	80.33	66.00	74.43	77.27	77.94
AWC mm	19.41	15.00	19.25	18.14	16.22
USLE_LS	2.21	3.55	2.32	2.41	1.94
PREC mm	1350.93	1350.93	1350.93	1350.93	1350.93
SUR Q mm	96.11	11.46	56.69	80.68	84.35
GW Q mm	558.16	678.11	598.74	586.00	623.05
ET mm	649.67	610.90	646.44	635.68	591.82
SED th	5.82	0.36	4.40	6.19	1.27
NO3 Kgh	2.20	0.00	0.01	0.01	1.49
ORGN Kgh	10.75	0.66	3.58	4.99	4.31
BIOM th	0.00	0.92	0.12	0.14	7.70
YLD th	0.00	0.22	0.00	0.00	2.39



A- Figure: 1 Gefersa Reservoir outlet structure