ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULITY OF TECHNOLOGY

FLOOD FREQUENCY ANALYSIS FOR LOWER AWASH SUBBASIN [TRIBUTARIES FROM NORTHERN WOLLO HIGH LANDS] USING SWAT 2005 MODEL

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Degree of Masters of Science in Civil Engineering (Major in Hydraulic Engineering)

By
Yidenkachew Argaw

Addis Ababa
Ethiopia
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Approval by Board of Examiners

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Internal Examiner Signature

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External Examiner Signature

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Contacts from the Halcrow, Awash Basin Flood Protection Project, were very instrumental in this modeling effort as Halcrow provided Land use map, DEM (57m resolution) that formed the basis for model inputs.

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ABSTRACT

Flood frequency analysis provides vital information for the planning and design of many hydraulic structures and risk assessment in flood plain use.

The objective of flood frequency analysis is to estimate a flood magnitude corresponds to any required recurrence interval. The resulting relation between flood magnitudes and return period is referred to as Q-T relation (Flood Frequency curve). This study is based on peak discharge, in particular the annual maximum flood

Flood frequency Analysis, the determination of flood flows at different recurrence interval, is a common problem in hydrology. The standard procedure to determine probabilities of flood flows consists of fitting the observed stream flow record to specific probability distributions. However, this procedure only works for basins: That have 'long enough 'stream flow records to warrant statistical analysis (gauged catchments) because a reliable estimates of the Q-T relationship cannot be obtained from small samples of at-site data because of the high variability involved and where flood flows are not appreciably altered by reservoir regulation, channel improvements (levees) or land use change.

The majority section of this study contains the procedure of generating stream flow data for Mille and logiya watershed using rainfall –runoff model approach for use in flood frequency analysis. This thesis describes a spatially distributed watershed model of Lower Awash basin (Mille and Logiya watersheds) that has been developed using SWAT 2005 to describe stream flow generation for Mille and Logiya watershed at Mille station (Gauge033021) and Logiya, (Gauge033027). The Soil and Water Assessment Tool 2005(SWAT2005) was developed by the Agricultural Research Service of the United States Department of Agriculture and distributed by the US Environmental Protection Agency for watershed management. SWAT2005 Simulates through time the daily soil water balance.

The spatially distributed nature of SWAT 2005 means that the hydrological surface runoff processes are represented independently in different regions across the basin. There are 52 and 29 different regions called HRU (hydrological response units) for Mille and Logiya river watershed respectively in this modeling application (shown at Appendix G and H for Mille and Logiya watershed respectively).

A set of SWAT2005 input representative of the basin has been developed from a wide array of data and the flow simulation is successfully tested against measured flow data. For the Mille and Logiya river basin, SWAT2005 model was calibrated and validated over a four year on a daily time base for daily peak surface runoff from January 1990 to December 1994 for calibration and January 1995 to December 1998 for validation period. Sensitive model parameters were adjusted within their feasible ranges during calibration to minimize model predictive error for daily peak flows.

Model performance testes were evaluated to test the model accuracy during the validation and calibration period .These measures included percent differences, coefficient of correlation (R^2) and Nash-sutcliffe measures (ENs). A summery of the statistical results for hydrological calibration and validation of Mille and Logiya watershed at Mille and Logiya stations is summarized in table5.9 and table5.11 for Mille and table5.10 and table5.12 for Logiya. The daily ENs , R^2, and the percentage difference values range from 0.69 to 0.79 , 0.71 to 0.83 and 15.8% to 27.5% respectively for both watersheds at the gauging stations during the calibration and validation period. These hydrology performance test results ranges indicate the model is effectively simulating in the watershed. The results fulfilled the requirements suggested by Santhi *et al.* (2001) for $R^2 > 0.6$ and $E_{NS} > 0.5$.

Continuous hydrologic simulation is a valuable tool to determine flood frequencies in Ungauged watershed and in gauged watersheds that have short stream flow records or are heavily regulated. Since hydrologic simulation models the rainfall-runoff relationship in the basin, it can also be used to check the validity of the probabilistic distribution selected for gauged unregulated watersheds with long stream flow records.

Stream flow records, if available at all, are often much shorter and most of the sub watersheds are unguaged. The SWAT2005 continuous hydrologic simulation was used the monthly metrological data as an input for weather generator input file (.wgn file) that contains the statistical data needed to generate representative daily climate data for the sub basins and soil, land cover and DEM data layers for simulation and extend the existing short stream flow records form a few years to 50 years data for the watersheds.

The objective of the research is to use the watershed (Mille and Logiya) SWAT2005 model generated Annual maximum flow data for determining the best fit distribution for each watershed and Comparative analysis of flood frequency results. The extended records were fitted to a probabilistic distribution using "Easyfit" Statistical application Software and the Gamma three parameter distribution was the best fit distribution for both Mille and Logiya watersheds among many distributions presented within the software.

1. GENERAL INTRODUCTION

The lower Awash River basin is mostly located in the arid lowlands of Afar Region in the north eastern part of Ethiopia. It frequently floods in August/ September following heavy rains in the eastern highland and escarpment areas of wollo high land .A number of tributary rivers draining the highlands eastwards can increase the water level of the Awash river in a short period of time and cause flooding in the low-lying alluvial plains along the river course. Tributaries of Awash river from wollo high lands such as Mille and Logiya rivers contributed most to the lowland flooding in Afar.

In the lower plains, the Dubit area plantation and most of Dubit town have been inundated with floods mainly coming from Logiya and Mille rivers such flows have also cause damage to the Afar pastoralist in the area between Dubit and Assaita isolating then and their livestock.

A dam at Tendaho is required for irrigation development downstream. Construction of a dam at Tandaho would absorb and flooding from mille and river Awash it self. Logiya being down stream from Tendaho dam site will continue to cause flooding if proper river training is maintained, the Awash rive channel can manage to contain any flow form Logiya river within its banks assuming that Tendaho dam is constructed.

In fact, in planning the water resource projects in the basin, the peak and magnitude of flood that have to be adopted in the design of irrigation, flood control projects are of great importance for the planners. The selected design flood is too high or small results in the conservation and unnecessary costly Structure, the loss of structure itself causing thereby untold miserly to the people residing down stream, be siding damaging valuable immovable properties. Thus the flood frequency provides vital information for the planning and design of many hydraulic structures such as culverts, bridges, spillway, reservoir, dike, road embankment and for risk assessment in flood plain use.

The objective of flood frequency analysis is to estimate a flood magnitude corresponds to any required recurrence interval. The resulting relation between flood magnitudes and return period is referred to as Q-T relation (Flood Frequency curve). This study is based on peak discharge, in particular the annual maximum flood. If data is readily available in the catchments (gauged catchments) and the result of such analyze can be related to characteristics of the catchments and there by transfer to other site, but no flood records available any where in the catchments, there is a site on a river some of the tributaries which are gauged at one or more upstream and downstream locations, a reliable estimates of Q-T relation can not be obtained therefore available information about flood peak at one catchments can be inferred from other catchments with hydrological similar characteristics (regional flood frequency analysis), synthetic unit hydrograph technique and runoff rain fall model.

1.1. Objective

The main objective of this thesis research is to find an appropriate procedure for analysis of flood frequency for use in the basin. The results from the analysis is used for the achievement of proper design and planning of water resource development projects that is under taken in the basin catchments.

The specific objective

- Drive flood frequency curve for Mille and Logia river.
- Provide information for effective flood management of Tendaho dam.
- Provide information for proper management of Lower plain down stream of Tendaho dam.

1.2. Statement of the problem

Flood frequency Analysis, the determination of flood flows at different recurrence interval, is a common problem in hydrology. The standard procedure to determine probabilities of flood flows consists of fitting the observed stream flow record to specific probability distributions. However, this procedure only works for basins:

- That have ‘long enough ‘ stream flow records to warrant statistical analysis;
- Where flood flows are not appreciably altered by reservoir regulation, channel improvements (levees) or land use change.

Continuous hydrologic simulation is a valuable tool to determine flood frequencies in ungauged watershed and in gauged watersheds that have short stream flow records or are heavily regulated. Since hydrologic simulation models the rainfall-runoff relationship in the basin, it can also be used to check the validity of the probabilistic distribution selected for gauged unregulated watersheds with long stream flow records.

Meteorological data in the study watersheds extend from15 to 30years. Stream flow records, if available at all, are often much shorter and most of the watersheds are unguaged Continuous hydrologic simulations can use the observed metrological data available to extend the existing stream flow record form a few years to 20 or 25 years . The extended record can then be fitted to a probabilistic distribution.

Hydrologic simulation can also be used to determine flood frequencies in unguaged stream. In this case, the model is calibrated to a near-by, hydrological similar gauged stream. The model parameters are then adjusted to reflect the physical changes between the calibrated watershed and the ungauged watershed. Finally, all the available observed meteorological data is used to create a long stream flow record for the ungauged stream, which can be fitted to a statistical distribution. This method produces much better results than alterative simplified approaches such as comparison to similar watersheds, or indirect approaches that equate runoff frequency to precipitation frequency (such as unit hydrograph of rational formula).

Land use changes can have a significant effect on flood flow frequencies. Historic stream flow records may be non-stationary for basins in which widespread urbanization is taking place. Hydrologic simulation uses historic flow records to calibrate to the historic conditions and it then incorporates the effects of future urbanization and land management.

In addition to creating or extending stream flow records, hydrologic simulation can be used to study the validity of assumed probabilistic distribution for peak flows. The calculated run off intensity above certain return periods greatly exceeds the precipitation for the same return period. Since continuous hydraulic simulation maintains a continuous accounting of soil moisture, it provides a unique tool to analyze the complex relationship between frequencies of precipitation, soil moisture and runoff.

The basic requirement for any watershed hydrology model is its capability to estimate surface runoff adequately because it influences the development of hydraulic structures. An accurate simulation of yield from a watershed is quite essential, as it is often required to determine the magnitude of flood from the watershed.

During the past two decades there has been a dramatic increase in the development and use of hydrological models to evaluate the complex environmental processes and to assess non-point source of water resources. However, in Ethiopia little use has been made of hydrological models to develop management plan for small agricultural watersheds using a systematic modeling approach. It is obvious that rainfall data for several years are required for developing the long term management plan of a watershed. Many process-based hydrological models, including SWAT, have the capability to generate rainfall and, there after, surface runoff, on daily, monthly and annual bases. An adequate procedure to calibrate and validate the SWAT modeling is an important research issue. A model should be tested adequately before using it to develop effective watershed management plans, specifically if generated rainfall is the basic input.

Weather data are frequently needed to evaluate the long-term effects of proposed anthropogenic hydrological changes. These evaluations are often undertaken using deterministic mathematical models of hydrological process. In addressing hydrological response to weather inputs it is seldom sufficient to examine only the response to observed weather events. Use of observed sequences gives a solution based on only one realization of the weather process. What would be the result if another series with the same properties as the observed series were used? To answer these questions, it is desirable to generate synthetic sequences of weather data based on the stochastic structure of the metrological process with an appropriate model developed for that purpose.

The weather variable needed for most of the hydrological models include precipitation, maximum and minimum temperatures, solar radiation and other (Knisel, 1980). These variables are usually recorded daily, and most deterministic models required daily values. Rainfall predication plays an important role in designing the water harvesting structures, erosion control measures and for developing the management plan for the critical erosion-prone areas of a watershed. Several research workers across the world have developed rainfall predication models to solve the foresaid problems (Buishand, 1978; Richardson, 1981; Georgica and Bars, 1984).

As precipitation is chosen as the primary variable and daily precipitation amounts are determined independently of the other variables, any precipitation models that produce daily precipitation values (subject to some criterion of quality) could be used for the component. In SWAT a first –order Markov chain model (Bailey, 1964) is used to describe the occurrence of wet or dry days. The Markov chain model for daily precipitation occurrence has been studied extensively by several investigators (Hopkins and Robilard, 1964; Smith and Schreiber, 1973; Haan et al., 1976).

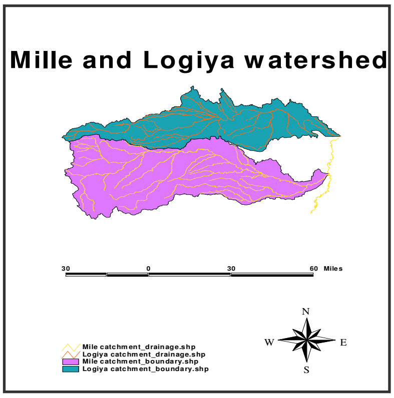
In developing countries, like Ethiopia rainfall generally is measured only in a few watersheds. In Ethiopia most of the watersheds selected for development and management purpose under various projects have only one rain gauge for the entire watershed. Sometimes it is almost impossible to gauge each and every sub watershed of all watersheds of the country.

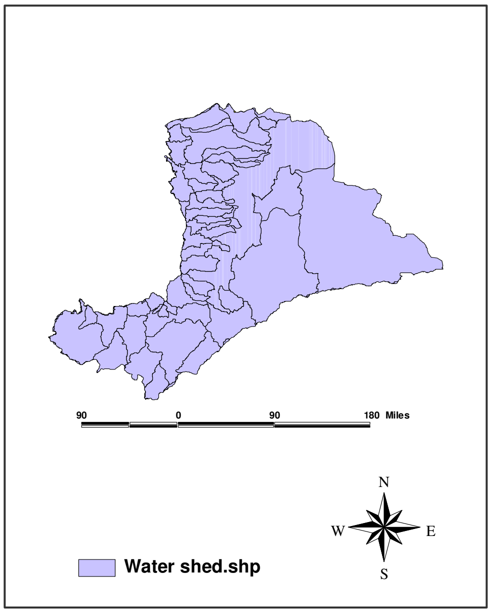
The ability to generate rainfall for predication of surface runoff and thereafter developing the management plan is essential keeping the above mentioned importance of the generated rainfall in estimation of runoff in mind. This study was undertaken to estimate runoff of a watershed and flood frequencies in Lower Awash sub basin (tributaries from the northern wollo highlands) using generated rainfall by the SWAT 2005 model.

2. DESCRIPTION OF THE STUDY AREA

2.1 Location

The Awash Basin is situated between latitudes 7°53'N and 12° N and longitudes of 37°57'E and 43°25'E in Ethiopia. It covers a total land area of 110,000 km²of which 64,000 km² is in Western Catchment of the basin. This catchment drains to the Awash main river or its tributaries. The remaining 46,00 km², most of which comprises the so-called Eastern Catchment drains into a desert area and does not contribute to the Awash main river course. The River Awash rises at an elevation of about 3,000m in the central Ethiopian highlands, west of Addis Ababa and flows through Koka Reservoir, to north-eastwards along the Rift Valley until eventually discharging into the wilderness of the Danakil Depression at Lake Abe 250meter above sea level (m.a.s.l) at the border to Djibouti. The main river length is about 1,200 km. (Figure 2.1)





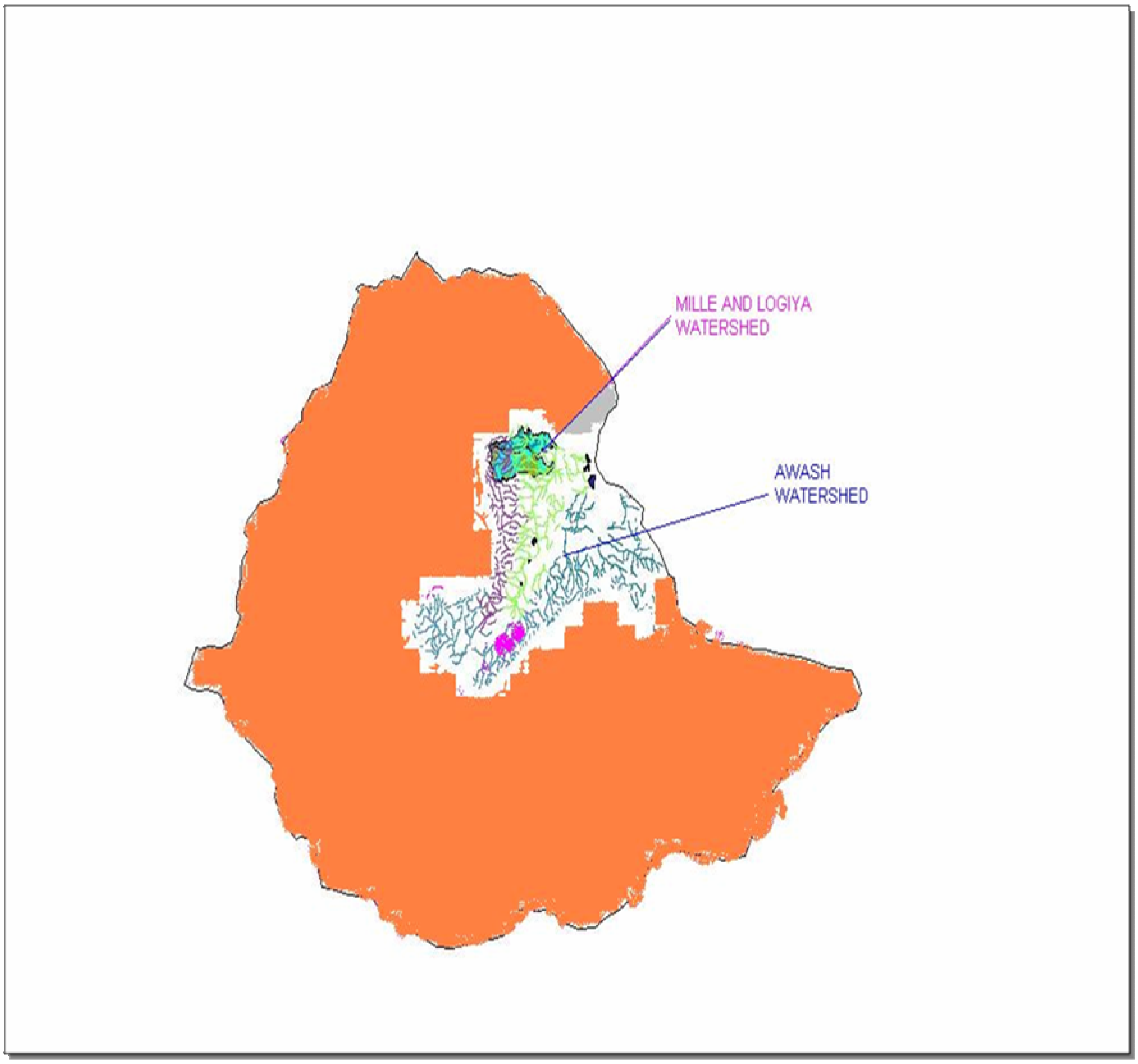


Figure 2.1 Map of Awash River Basin and the study area

The watershed bound it in the west between the Awash and the Blue Nile Basins, rising to a height of about 3000m. In the southeast, the boundary is the watershed between the Awash and the Wabi Shebele Basins, which lies at about 2000m and rising to 3600m at its western end. The Awash Basin boundary crosses the Rift valley along the divide with the Lakes Ziway Basin at a height of about 2000m. To the north the Awash basin is defined by a boundary containing the catchments of the terminal lakes. The boundary then joins the eastern end of the watershed with the Wabi Shebele (Figure 2.1). The Awash basin is narrow in the upper part and widens towards the north of the catchment. The catchment is characterized by its closed river system, which means it doesn't have outlet to the sea. The total length of the river is about 1200 km

This thesis on the Lower part of the Awash River Basin which drain from Northern Wollo highlands (Mille and Logiya).It's located between latitudes 11.45 and11.3 and longitudes 39.61667and 40.75(Figure 2.2). It covers about 11000 km^2 area

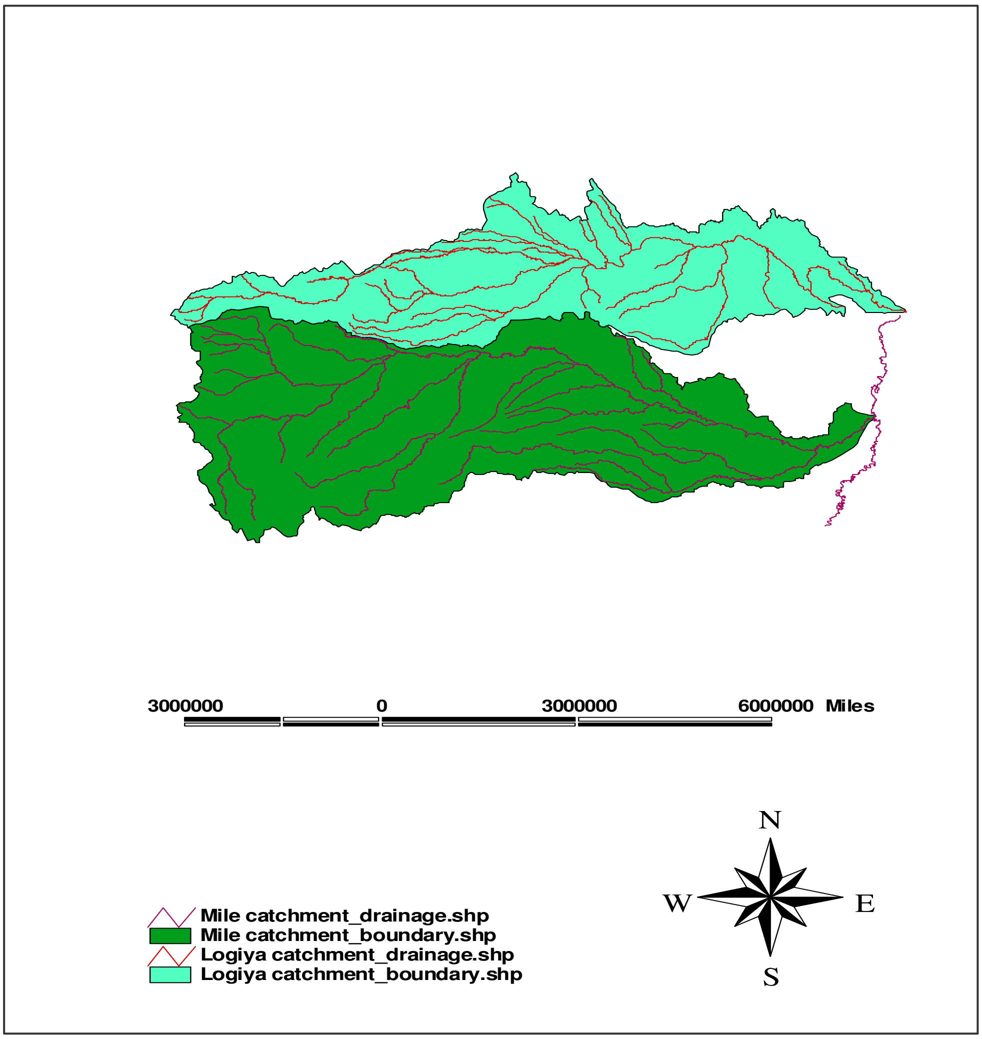


Figure 2.2 Map of Mille and Logiya watersheds

2.2. Physiographic

The main components of the Awash Basin are the Ethiopian platue and the rift valley which widens to the north in to the afar Triangle. The physiographic is an expression of the underlying geology with the Ethiopian plateau underlain by tertiary volcanic (basalt tuffs, agglomerates, and younger royalties, tuffs and the Rift valley floor Comprising basalts and ignimbrites near active volcanic such as Fantale, Dofan and Afrera in between thick, Quaternary-aged lacustrine, Fluvial and beach sediments.

The topography of the Ethiopia plateau is relatively flat with elevations generally between 2,000-2,500m. The lower elevation of the uplands is generally considered to be 1,500m. Exceptions to the flat plateau are the deeply incised river valleys, particularly associated with the western escarpment and the volcanic masses, which can rise to 3,000mm. Land drops steeply from the plateau to the Rift valley floor, which slopes in a north –easterly direction. On the south –eastern side of the valley, land rises sharply to the Ogaden Plateau, Which slopes south-east, draining to the Indian sharply to the Indian Ocean and as such most of the Awash tributaries rise in the Ethiopian plateau to the west.

The Awash basin can be divided in to five Zones, and the main valley is traditionally divided in to three areas. The upland zone is land over 1500m and can be subdivided in to the Western Escarpment running from around chole east of Addis Ababa to Dessie; the Eastern Escarpment from lteya to around AsbeTeferi where it abuts the uplands of the Eastern Catchments and the upper basin upland defined as draining in to koka reservoir. The Awash valley it self downs term of koka is divided in the uplands of eastern catchments and the upper Basin upland defined as draining in to koka reservoir. The awash valley it self down stream of koka is divided in to the upper valley between koka and Awash station (1,500-1,000m altitude), the Middle valley between Awash station and the Mille Confluence (1,000-600m) and the Lower valley or lower plains between the mille confluence and the Terminal lakes (600-250m). The final zone is that of the Eastern catchments as described above although a case could be made for including land above 1,500m as part of the Eastern Escarpment uplands despite the fact that runoff does not each the Awash River itself.

2.3 Geomorphology

It is generally recognized that the primary process responsible for driving geomorphologic change in the basin are: Rain Splash and sheet, wash, Gullying, Wind erosion.

Given the geology, topography, soils and climate of the region one would expect these geomorphic processes to be highly effective in eroding the landscape especially in the uplands, areas with steeper terrain and areas that are seismically active. Past studies identify sheet erosion (resulting from rain splash and overland flow) as the primary cases of erosion (Halcrow 1989), although the significance of wind erosion is also noted for drier areas of the basin. Field inspections undertaken as part of the study suggest that, in addition, riles ephemeral gullies and permanent gullies on agricultural land may have a much greater significance on catchments erosion and sediment dynamic in the Awash Basin than has been recognized to date.

2.4 Altitude and Slopes

Figures below shows the altitude range within the basin derived from a Digital elevation Model (DEM) created form digitized elevation map of 57 meter resolution.

Slop maps of the Awash Basin (as part of the whole of Ethiopia) have been produced both by the woody Biomass Project (WBISPP) and the University of BERN (also derived from a 200m resolution DEM) with slopes classified in to seven classes according to the FAO classification:

Class 1:0-2 % slope
Class 2: 2-5 slope
Class 3:5-8 slope
Class 4: 8-15 % slope
Class 5:15-30% slope
Class 6:30-60% slope
Class 7: >60% Slope

As can be seen the majority of slopes within the basin are in the 0-7.63% range corresponding to the flat rift valley floor bounded by much steeper slopes of the escarpments with a range largely between 15->60%.

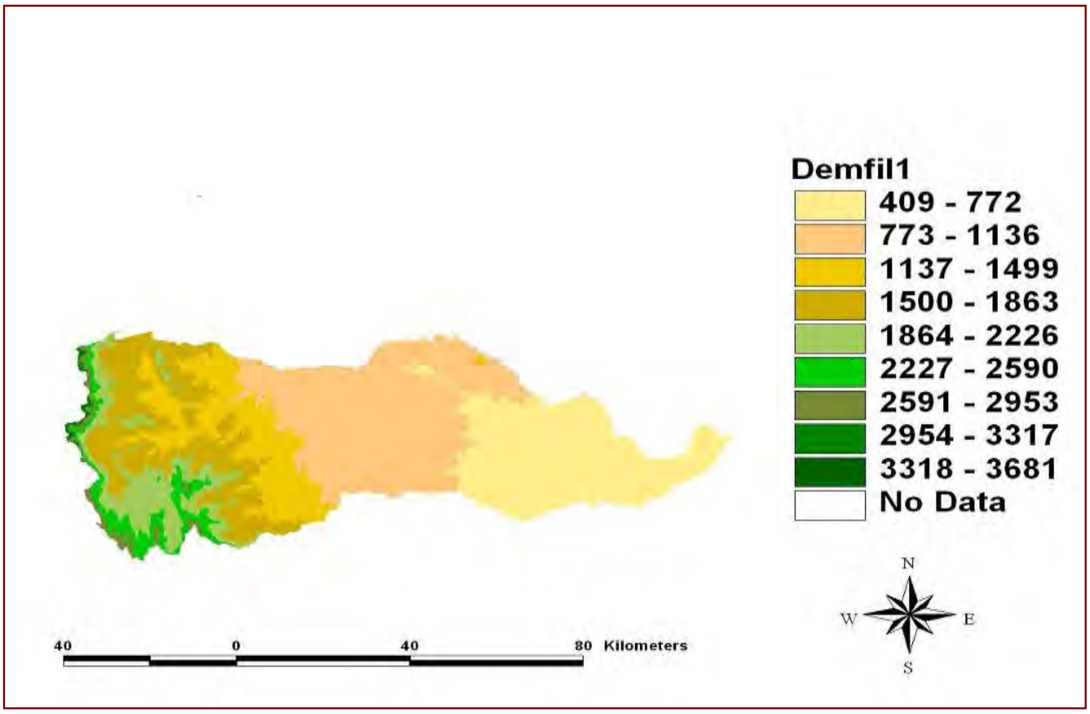


Fig.2.3 shows DEM for Mille watershed

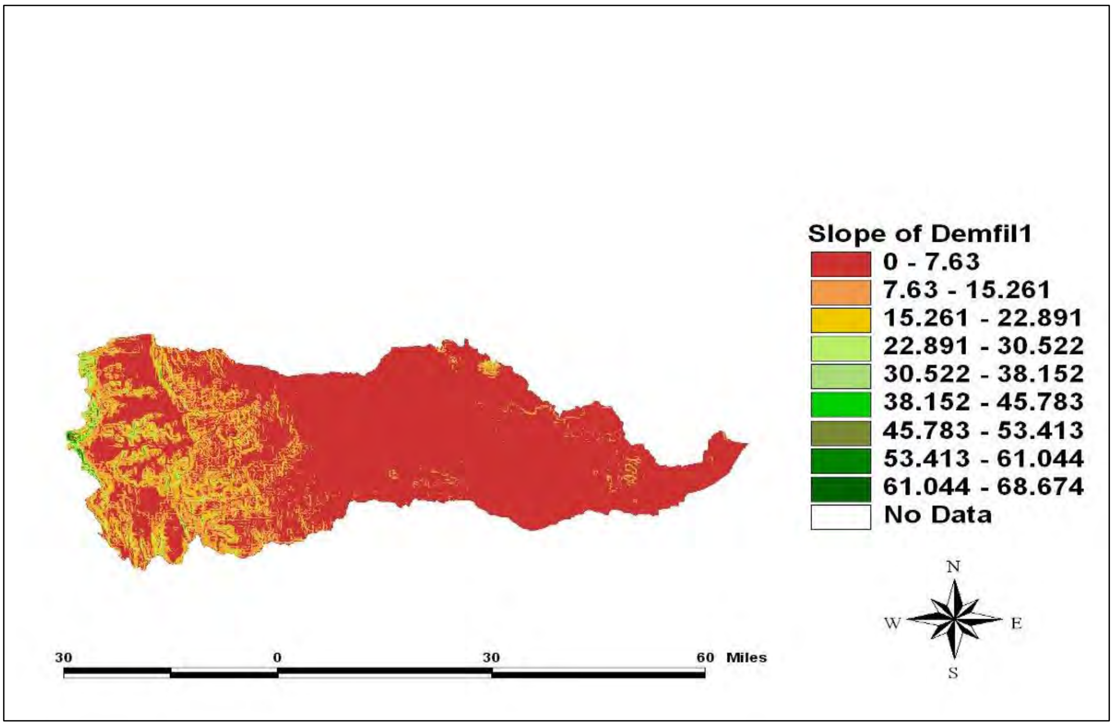


Fig.2.4 shows slope for Mille watershed

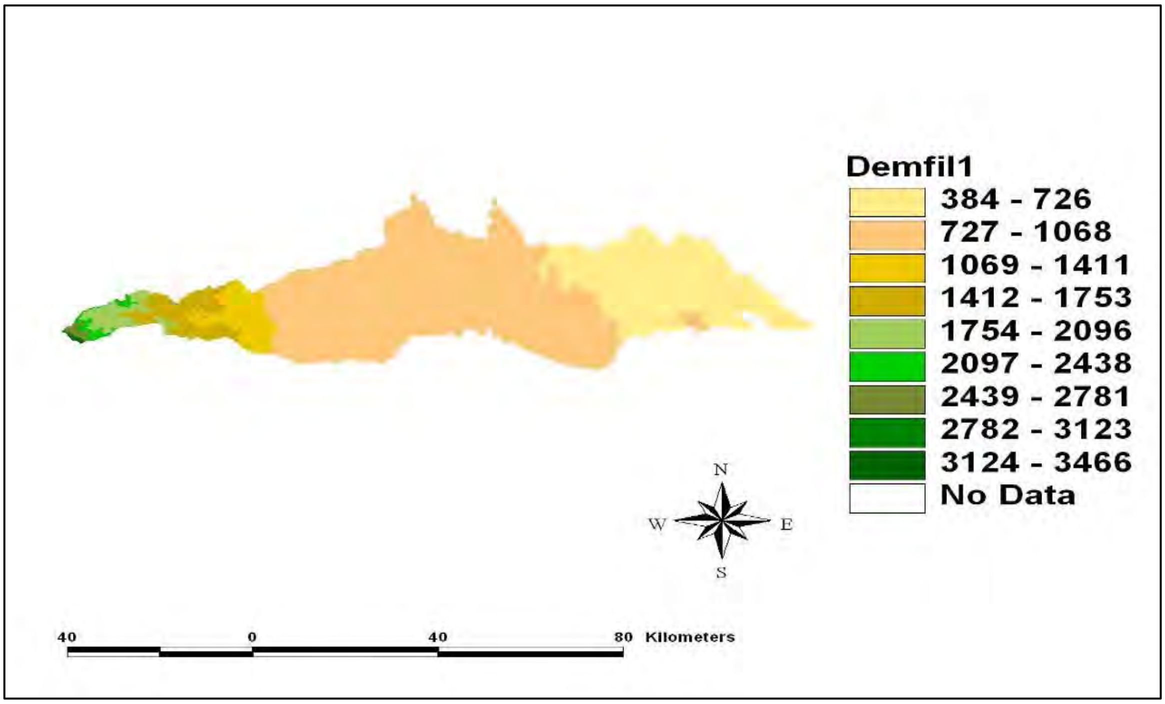


Fig.2.5showsDEMfor Logiya watershed

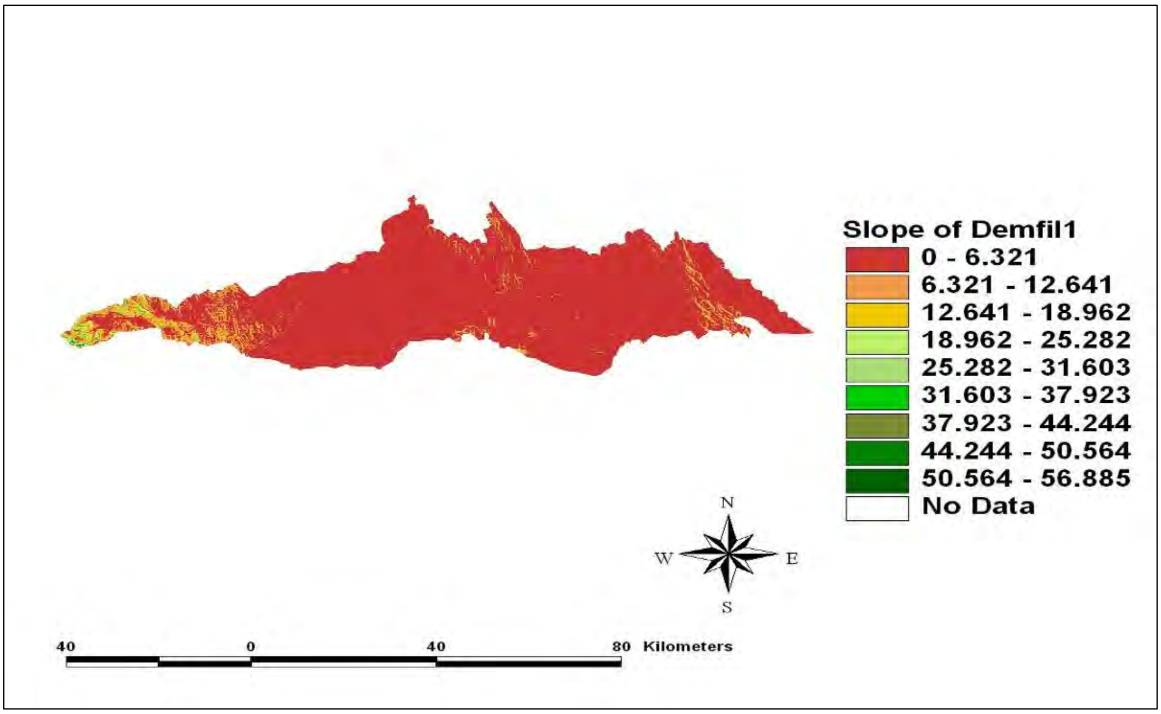


Fig. 2.6shows slope for Logiya watershed

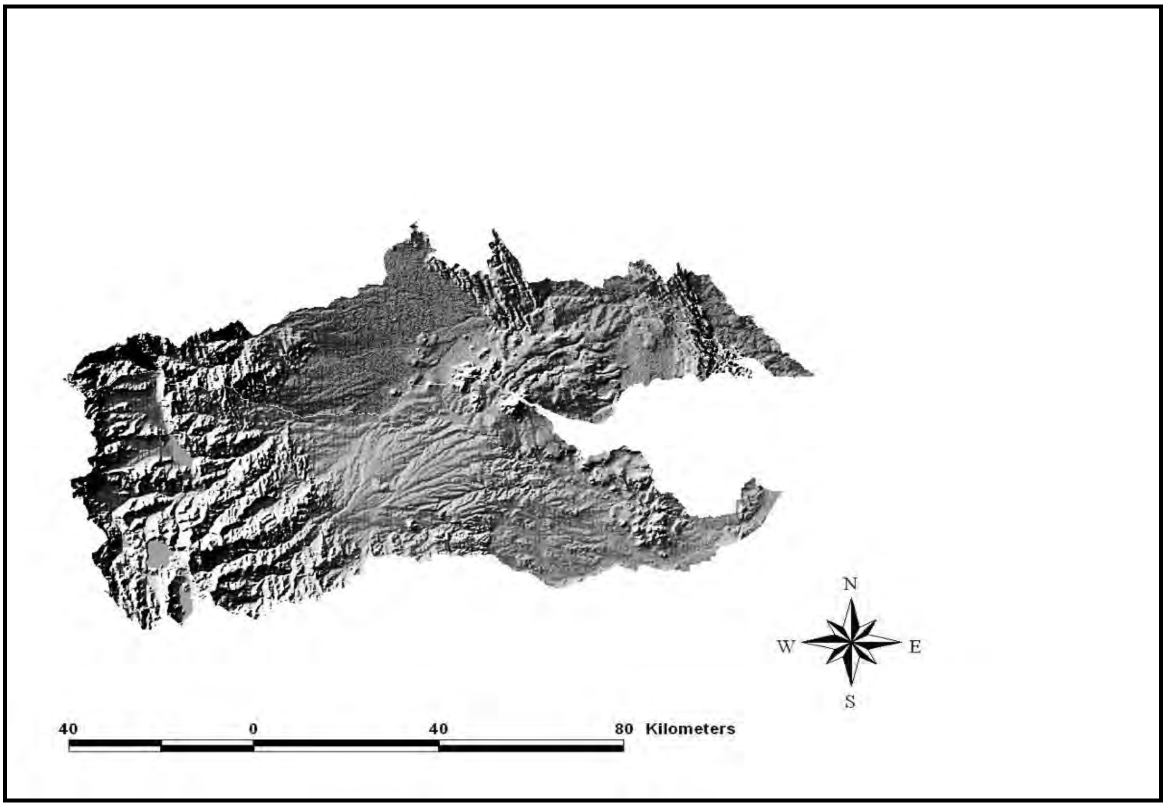


Fig. 2.7Shows Hilly shade for Logiya and Mille Watersheds

2.5 Climate

The climate of the Awash Basin is influenced by the Inter-Tropical Convergence Zone (ITCZ). As it migrates northwards across the basin it causes the small or spring rains in March and at its northern most extent it produced the heavy summer rains in July and August whilst it migration southwest from August to October results in drier weather caused by the easterly air flows between October and March.

2.6 Rainfall

The mean annual rainfall varies from a maximum of around 1,600mm at Ankober on the western escarpment to 160mm at Asaita near the Terminal Lakes. The mean annual rainfall over the western catchments is estimated to be 850mm and over the eastern catchments 465mm.

Classification of rainfall patterns in to wet (>1,400mm), Moist (900-1,400mm) and Dry (<900mm) has been used in the derivation of agro-ecological zones (see below).

2.7 Thermal Zones

The thermal or temperature zones of the basin derived for he DEM using the formula $T(C^{0})$=30.2-0.00591* altitude (m) as developed by the land use planning and Regulatory Department, Ministry of Agriculture (1984) and developed further by WBISPP in to ten thermal zones. These show the mean temperature in the growing season and approximate altitude.

Table 2.1: Thermal Zones for the study area

Thermal zone	**Mean Temperature ^{O}C**	**Altitude(m)**
T1	>27.5	<450
T2	25-27.5	450-900
T3	22.5-25	900-1400
T4	20-22.5	1400-1750
T5	17-20	1750-2250
T6	15-17	2250-2250
T7	12-15	2550-3100
T8	10-12	3100-3400
T9	7.5-10	3400-3850
T10	<7.5	>3850

2.8 Agro–Ecological Zone

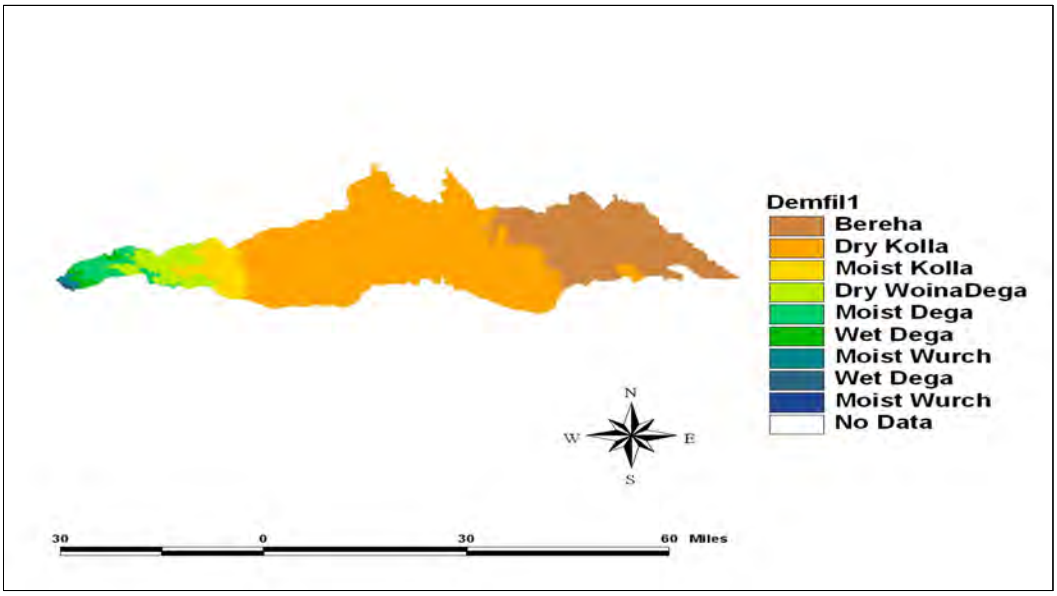
Figure 2.8 shows the agro-ecological zones within the Basin based on the traditional Ethiopia agro- climatic zones; wurch, Dega, WoinalDega, Kolla and bereha; combined with the Digital Rainfall Model developed by WBISPP and the thermal Zones. Table 2.2 shows the traditional agro-ecological zones defined by altitude mean temperature in the growing season and annual rainfall whilst table 2.3 shows this data reworked to include the ten thermal zones.

Table 2.2: Agro-Ecological Zones (after Hurini 1986)

Agro-climatic Zones	Altitude (m)	Mean Temperature in growing season (c)	Annual Rainfall (mm)
High Worth	>3700	<7.5	>1400
Wet Wurch moist Wurch	3200-3700	11.5-7.5	900-1400 >1400
Wet Dega Moist Dega	23-3200	16-11.11.5	900-1400 >1400
Wet Woina Dega Moist Woina Dega Dry Woina Dega	1500-2300	21-16	900-1400 >1400
Moist Kolla Dry Kolla	500-1500	27.5-21	900-1400 >1400
Bereha	<500	>27.5	<900

Table 2.3: Agro –ecological zones combined with ten thermal zones (WBISPP)

Agro-climatic Zones	Annual Rainfall(mm)	Altitude (m)	MeanTemperature in growing season (°C)
Wet Wurch	>1400	>3200	<12
Wet Upper Dega		2600-3200	12-15
Wet Dega		2300-2600	15-17
Wet Woina Dega		1500-2300	17-22.5
Wet Upper Kolla		500-1500	22.5-27.5
Wet Lower Kolla		<500	>27.5
Moist Wurch	900-1400	>3200	<12
Moist Upper Dega		2600-3200	12-15
Moist Dega		2300-2600	15-17
Moist Woina Dega		1500-2300	17-22.5
Moist Upper Kolla		500-1500	22.5-27.5
Moist Lower Kolla		<500	>27.5
Dry Wuch	<900	>3200	<12
Dry Upper Dega		2600-3200	12-15
Dry Dega		2300-2600	15-17
Dry Woina Dega		1500-2300	17-22.5
Dry Upper Kolla		500-1500	22.5-27.5
Dry Lower Kolla		<500	>27.5



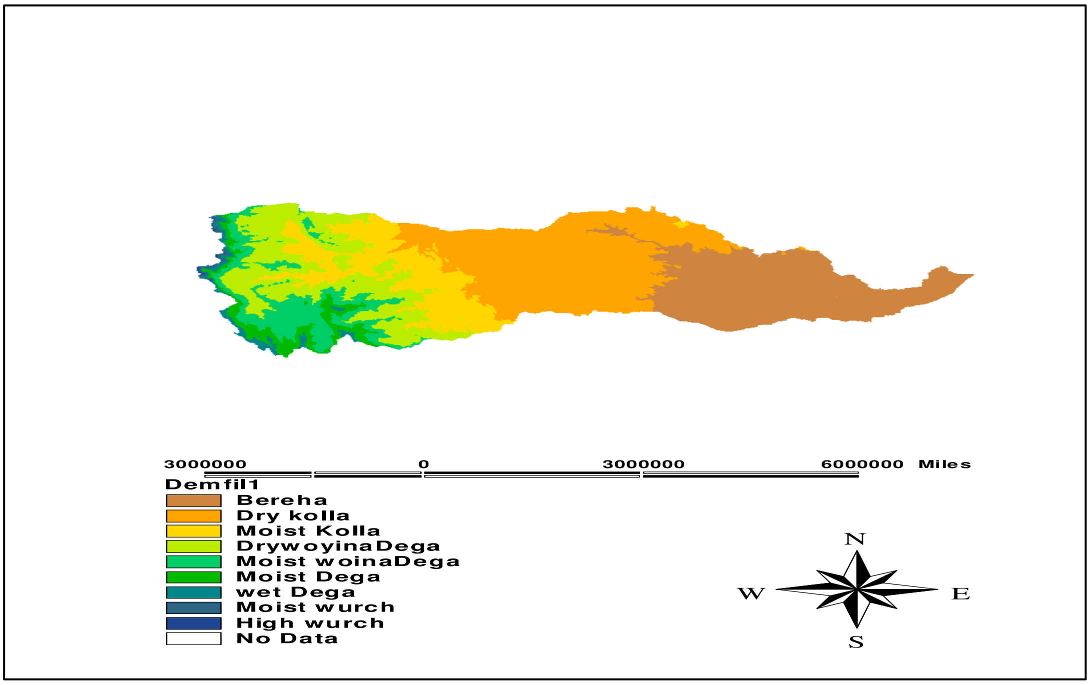


Fig.2.8 shows Agro ecological zone for mille and Logiya watershed

2.9 Agriculture

The Hal crow 1989 master plan study in its section on “Existing Agricultural Land Use’’ concentrated exclusively on irrigable and irrigated land without any mention of rain fed agricultural production which makes up the vast majority of agricultural land use in the basin.

In terms of changes in agriculture since the 1989 report it can be assumed that most change will have been in the rain fed sector but this is impossible to quantify due to the lack of any baseline data. The following section therefore indicates the changes in the irrigated agricultural sector since 1989.

2.9.1 Changes in Basin Irrigated Agriculture since 1989

The 1989 Halcrow Master Plan for the Development of surface Water Resources of the Awash Basin study assessed and evaluated the land and water resources of the basin and indicated that the land suitable for irrigation ranges form 150,000 to 175,000 ha without including potentials for medium and small-scale irrigation schemes in the highlands and isolated riverine areas However, the total land under irrigation, at that time, was estimated in the order of 68,000ha.

In the early 1990’ following the government’s new economic policy, Ownership of some schemes was transferred to local communities as compensation for lost cropping and grazing lands. How ever, in most cases, the communities did not use the land themselves for irrigation, either abandoning the land or leasing it to investors who are currently operating the farms growing cotton, broomcorn and other corps.

A total of 24,397ha, in eleven schemes, has been transferred to local communities in the Awash Basin. A number of the schemes are currently abandoned or left fallow with small Parts being operated either by private firms or used for intermittent cropping by the local communities. Many of these lands have now been covered with bushes and trees and will require significant rehabilitation work.

Table 2.4: Existing irrigation farms in the Lower Awash basin

Location in the valley	Scheme Name	Net Irrigated area (ha)
Lower Awash	Logiya	160
	Dubit	600
	Dit Bahri	950
	Dit Bahri (State Farm)	3.506
	Karadura	4,038
	Wonse	163
	Algana	397
	Kerbebuda	432
	Berga	514
	Bokayitu	518
	Total	11278

Source: Halcrow, 1989 and ministry of Water Resources 2004

3 LITERATURE REVIEW

3.1 Introduction

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

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

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

Hydrological models, which are simplified representation of complex hydrological system, can be: (a) physical, such as a scaled-down reproduction of a full-scale prototype built in a laboratory to assume dynamic similarity between model and real world; (b) mathematical, in which the behavior of the system is represented by a set of equations, together with logical statements, expressing relationships between variables and parameters. (Clarke, 1973).

If any of the variables is a random variable having a probability distribution, then the model is stochastic rather than deterministic. Conversely, if all the variables are free from random variations, then the model is deterministic. (Figure 3.1)

Hydrological models can be lumped or distributed. A lumped model ignores the spatial distribution of the input variables and parameters, which characterizes the physical process. Distributed models include data concerning the spatial distribution of variables together with computational algorithms to evaluate the influence of the distribution on simulated behavior.

Besides, models can be described as conceptual or empirical according to whether the form of the model equation is, or is not suggested by consideration of the physical processes acting up on the input variable to produce the output variables. Empirical models omit the physical laws and express relationships based upon field or laboratory experiments and the data collected from them. Regression models are empirical, being based on observation and not on an understanding of process. The term 'physically-based ' models is used to replace conceptual distributed models, because if models are physically based, meaning firmly based in our understanding of the physics of the processes, they are necessarily distributed because the equations on which they are defined generally involve one or more space coordinates (Beven, 1985). Physically based hydrological models thus have the capability of forecasting the spatial pattern of hydrological conditions within a catchment as well as simple outflows and storage pattern of hydrological conditions within a catchment as well as simple outflows and storage volumes. This distinction is, however artificial since many physical laws contain empirical constants. Also, hydrological models can be event models or continuous models. Event models represent a single runoff event occurring over a period of time ranging from an hour to several days. A continuous model is one that operates over an extended period of time determining flow rates and conditions, e.g. during runoff periods and periods of no runoff.

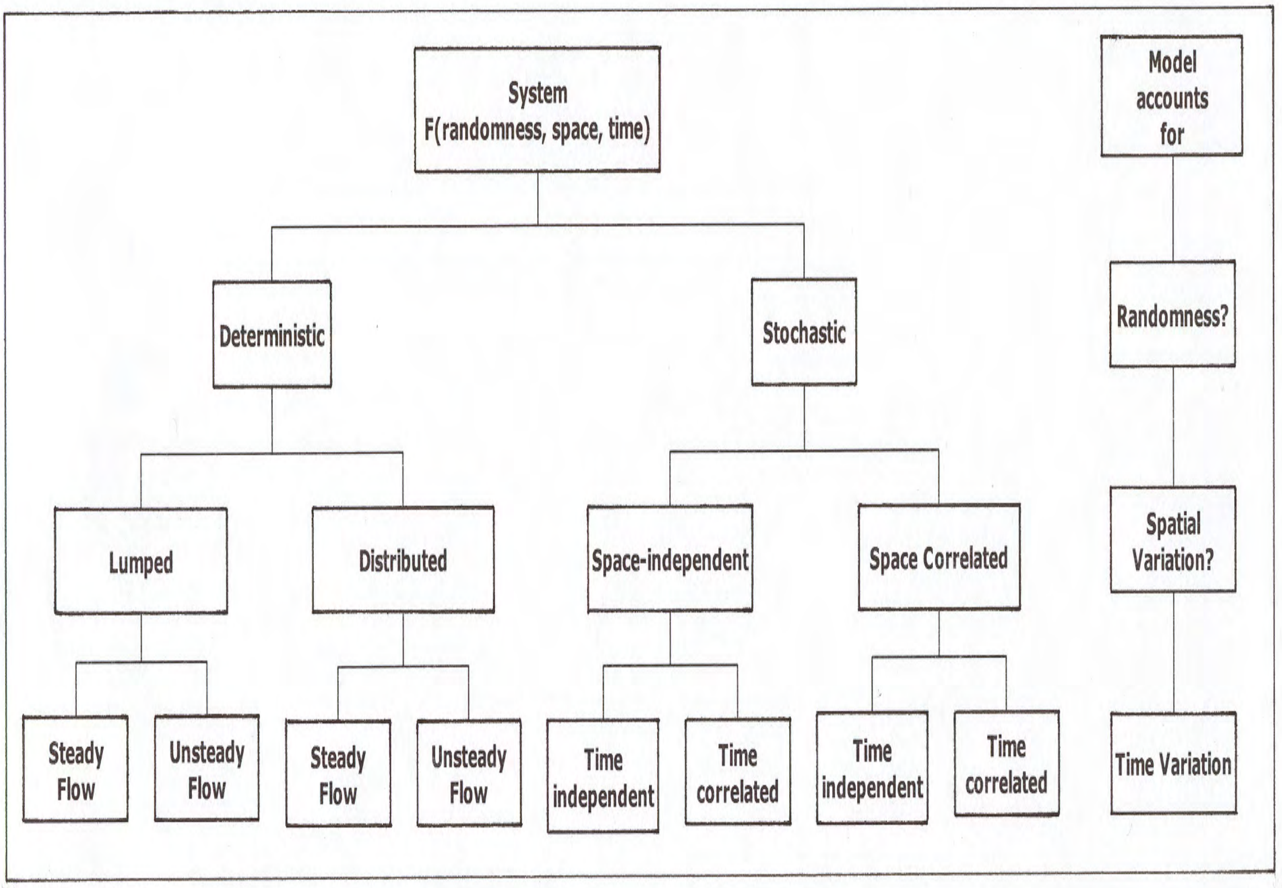


Figure3.1 Classification of models (Chw et al., 1988)

3.2 Formulation of Hydrological Processes

Water occurs on the earth in all its three states, viz. liquid, solid and gaseous, and in various degrees of motion. Evaporation of water from water bodies such as oceans and lakes, formation and movement of clouds, rain and snowfall, stream flow and groundwater movement are some examples of the dynamic aspects of water. These various aspects of water can be explained in terms of a cycle known as the *hydrologic cycle*.

The ***hydrologic cycle*** is the process where water is circulated through the earth-ocean-atmosphere system from the oceans to the air and then to the land in the form of rain or snow

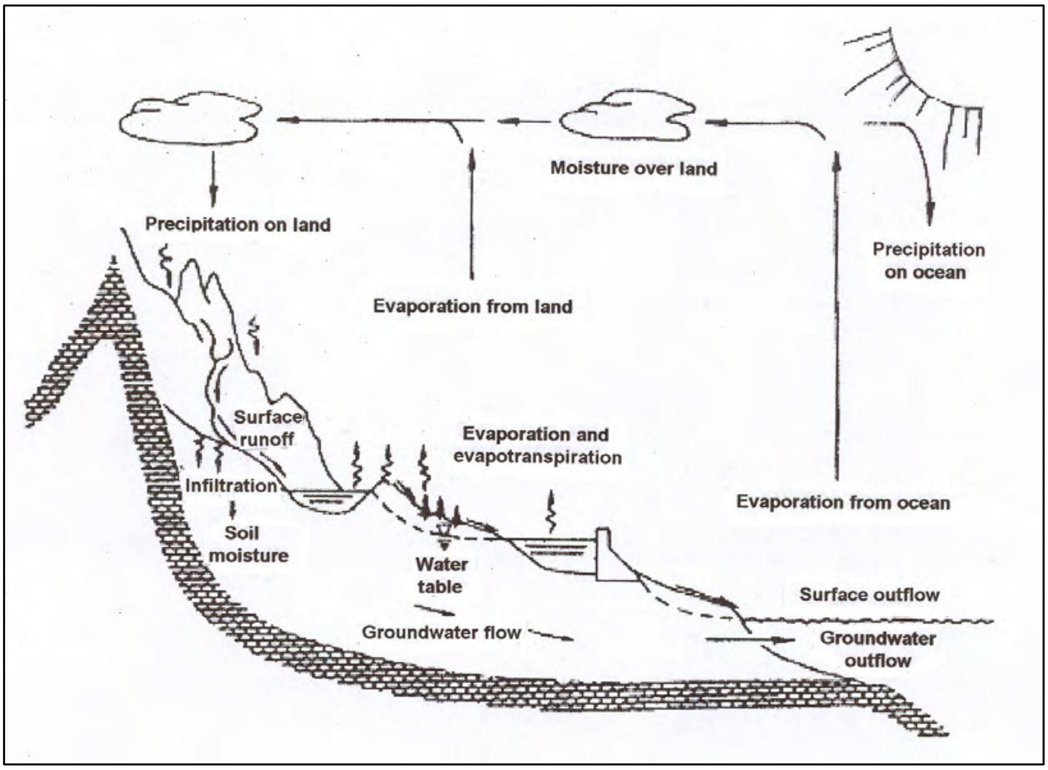


Figure3.2 Elements of Hydrological Cycle (Source: Chow et.al. 1988)

The hydrologic cycle shown in Figure 3.2 is the circulation of water evaporated from the sea and land surfaces, its transport through the atmosphere to the land and its return to the sea via surface, subsurface and atmospheric routes. Although called a cycle, the process is much more complex than a mere cycle. All kinds of short cut and parallel processes take place. Water precipitated over land passes through a number of storage media, which can be regarded as subsystems of the hydrological cycle. The hydrodynamics is the flow of water between and through the different storage media. A schematization of the flow components of the terrestrial part of the hydrologic cycle is given in Figure.3.3. The major achievement and objectives of the hydrological modeling is thus to study a part (section) of the hydrological cycle, namely the land phase of the hydrological cycle on a watershed scale.

In view of the terrestrial part of the hydrologic cycle, any conceptual model predicates its effort on an expansion of the basic water balance or continuity equation (see Chow et al. 1988) that is:

$$I - O = \frac{\Delta s}{\Delta t} \quad \text{---} \quad (3.1)$$

Where I is the input to the system (Precipitation), and O is output from the system (evaporation, stream and groundwater flow) and $\Delta s/\Delta t$ is the rate of change in the amount of water stored in the basin.

For the presented research, the water balance of a river basin will be applied and water balance is often applied to a river basin. A river basin (also called watershed, catchment, or drainage basin) is the area contributing to the discharge at a particular river cross-section. The size of the basin increases if the point selected as outlet moves.

The main processes of the land phase hydrologic cycle included are precipitation, evaporation, transpiration, interception, infiltration, subsurface flow and stream flow. It is evident that before any modeling effort can be executed, one has to understand the above physical processes, their extent of effect on the abstraction from or addition of water to a basin.

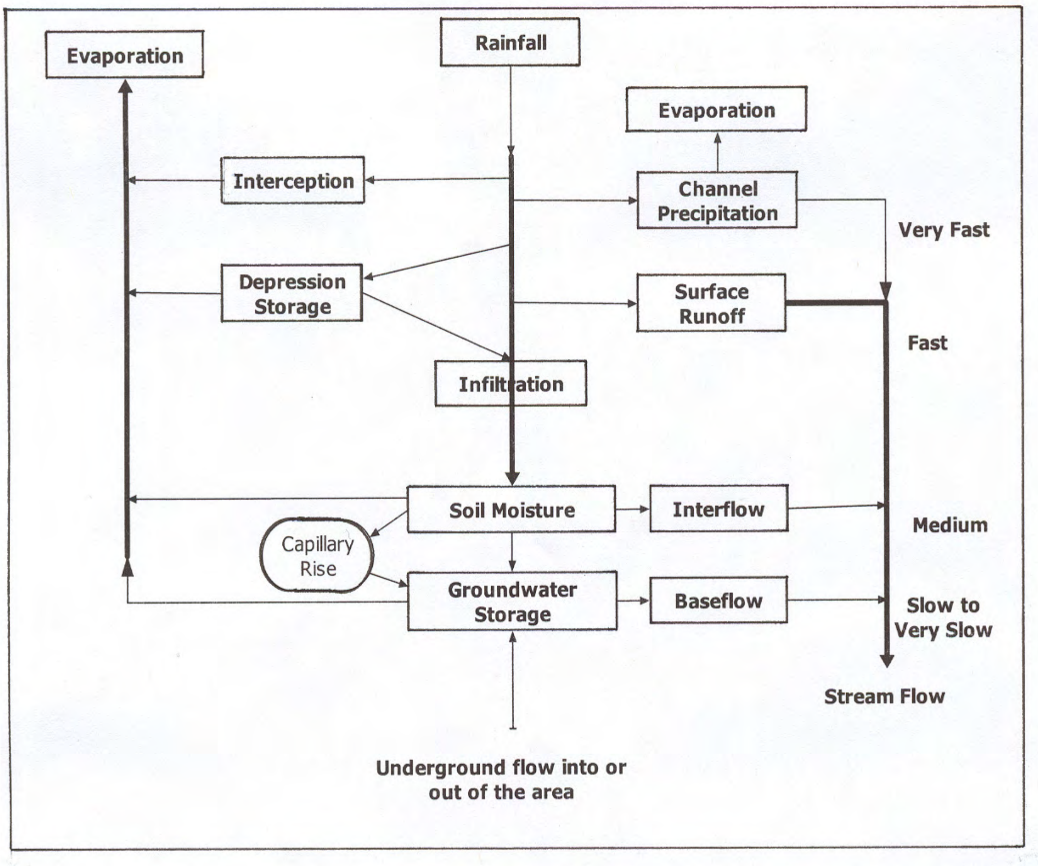


Figure 3.3 Schematic representation of the land phase of the water Cycle (after Starosolszky, 1987)

3.5 Soil and Water Assessment Tool (SWAT) Version 2005

The soil and Water Assessment Tool version 2005 (SWAT2005) is a continuous time, physically based, distributed watershed model developed by the Agricultural Research Service of the United States Department of Agriculture (USDA). SWAT, which was preceded by the Stimulator for Water Resources in Rural Basins, requires a significant amount of data and parameters for development and calibration. The principle purpose of SWAT is computation of runoff and loadings from rural watersheds, especially those dominated by agriculture (Williams and Arnold 1993, Arnold et al. 1998). Although the model time step is daily, SWAT was designed as a long-term yield model and is not designed to accurately stimulate detailed, single-event flood routing (Neitsch et al. 2001a).

SWAT was selected for this modeling because model predictions are distributed spatially. A simpler alternative to a spatially distributed model is a lumped watershed model. Lumped models make a single prediction that only applies at the watershed outlet and therefore provide no additional spatial information regarding the upstream sources of the modeled quantities.

SWAT 2005 allows for two different watershed discretizations. In this application, two levels of discretizations are used. First, the watershed is subdivided into a number of sub basins. This is the spatial scale at which the model routes constituents through the channel network. These sub basins are further divided into hydrologic response units (HRUs), which are units of unique intersections of land use and soils. For example, all the forest land on soil type A in a certain sub basin is one HRU. HRUs are not necessarily contiguous land areas and no channel routing is stimulated between HRUs. Most computations in SWAT occur at the HRU spatial scale where the state variables in each HRU, such as soil water, plant biomass are updated daily.

The model inputs for SWAT are developed with the aid of the SWAT2005 Arcview© Interface Program (DiLuzio at et al. 2001) that automatically assigns default model parameter values and creates inputs files based on various Geographic Information System (GIS) map layers provided to the interface. In addition, the SWAT2005Acrview © Interface Program (AVSWAT) can be used to run the model and map the results in within Arcview©.

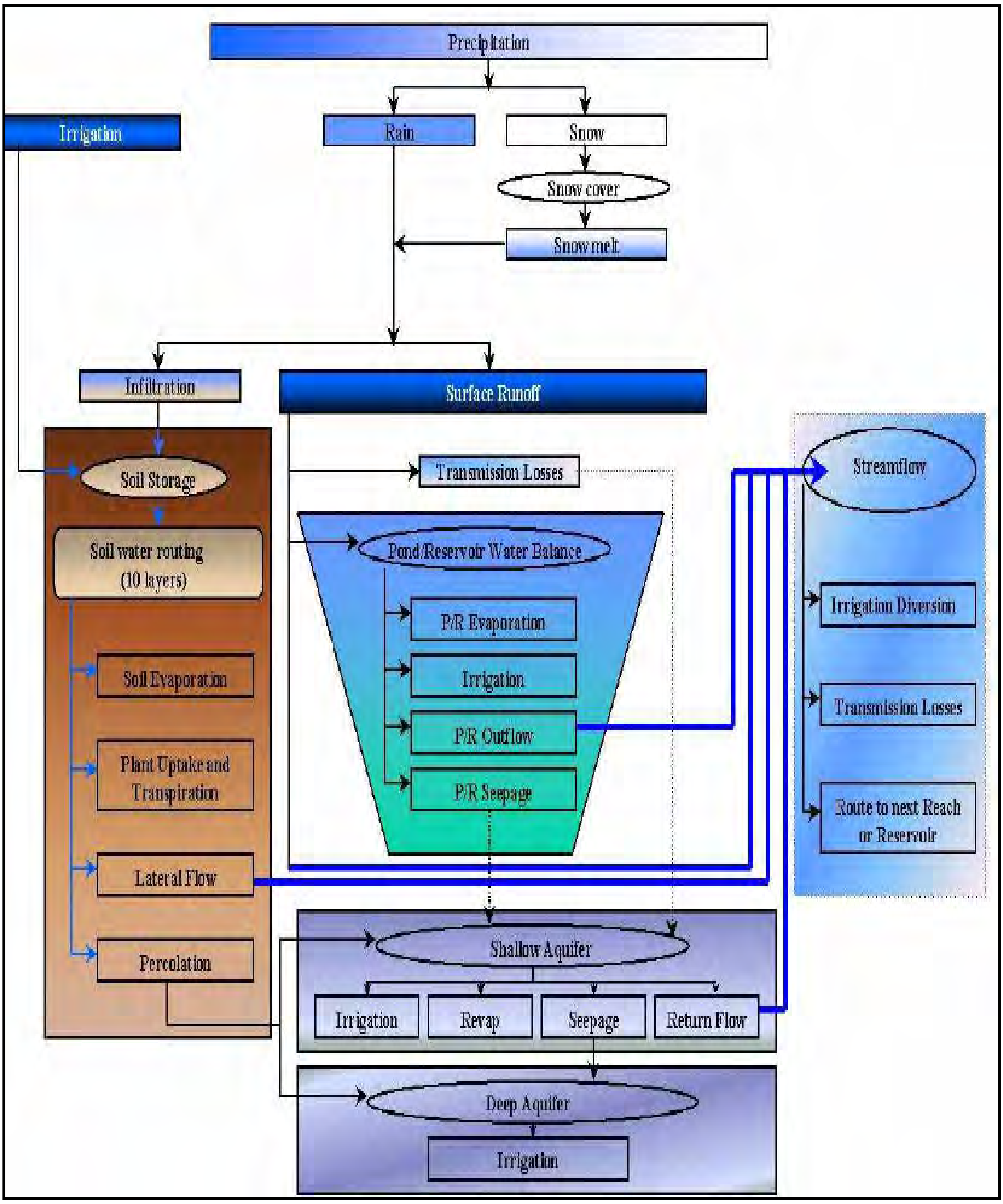
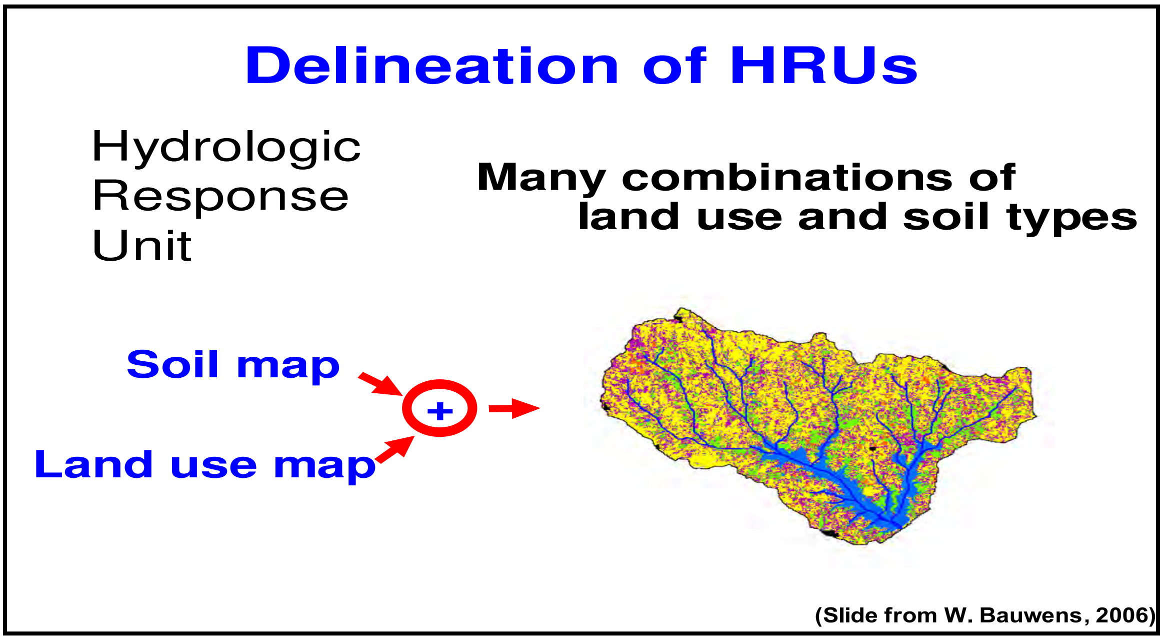


Figure 3.4 Shows Modules of SWAT 2005 Model



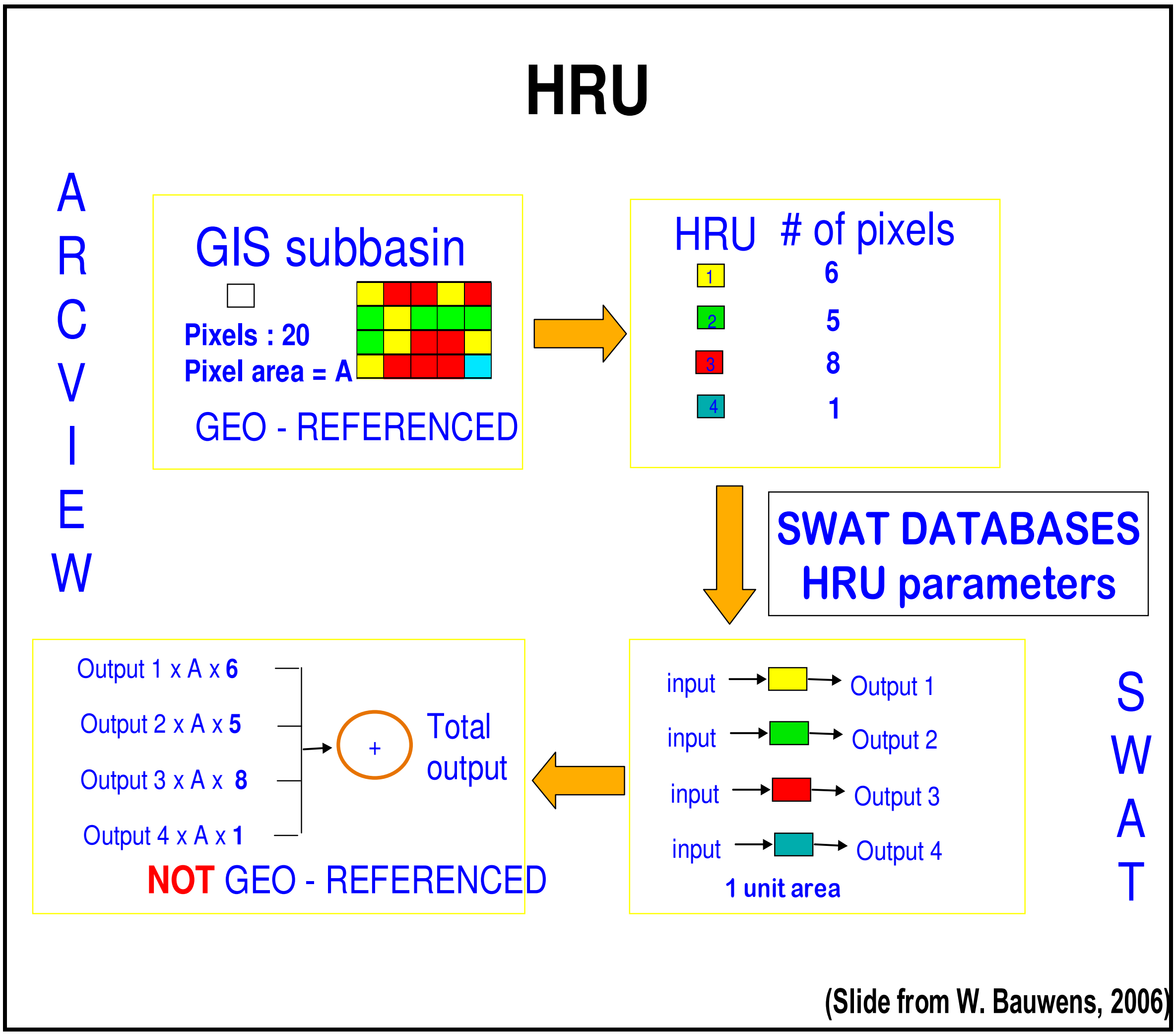


Figure 3.5Large spatial-temporal variability of HRU at catchment scale and how SWAT is distributed

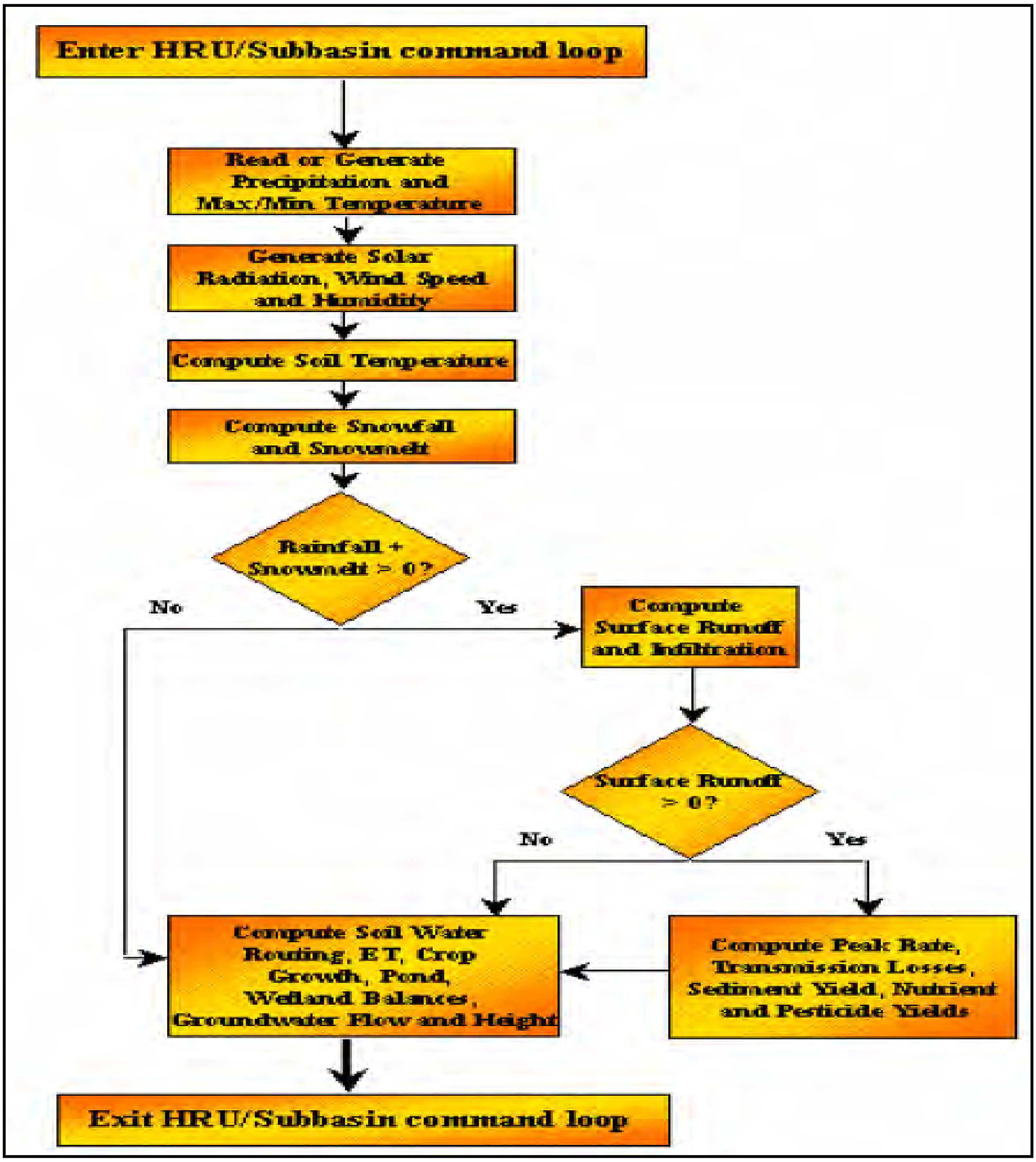


Figure 3.6 Shows Simulations at the sub-basin and HRU level

3.5.1Previous Applications of SWAT

Most of the applications of SWAT in the current literature are based on versions of SWAT that precede version 2005. Various versions of SWAT have been applied throughout the United States, primarily in Midwest and Southwest regions, including the Mississippi Riber basin, Illinois, Indiana, Texas, Oklahoma, and Wisconsin (Arnold and Allen 1996, Bingner 1996, Bingner et al. 1997, Mamillapalli 1998, Manguerra and Engel 1998, Srinivasan et al. 1998, Arnold et al. 1999, Arnold et al. 2000, Fitzhugh and Mackay 2000, Santhi et al. 2001, Kirsch et al. 2002). SWAT has also successfully been applied in Europe (Shepherd et al. 1999) and has been successfully adapted and modified for European conditions (Eckhardt and Arnold 2001). Most of the previous research has only focused on hydrology stimulation in these regions, with only a few recent publications on additional constituents such as sediment or nutrients (Bingner5 1996, Bingner et al. 1997, Srinivasan et al. 1998, FitzHugh and Mackay 2000, Santhi et al. 2001, Kirsch et al. 2002). The few studies applying SWAT in Northeastern climates have centered primarily in northeast Pennsylvania (Chow et al. 1995, Peterson and Hamlett 1998). SWAT was applied to a 250km^2 sub watered of the Delaware River in Northeast Pennsylvania (the ultimate receiving water for the Cannonsville Reservoir outflow) in order to stimulate hydrology and nitrogen (Chow et al. 1995). Peterson and Hamlett (1998) focused their work on modeling catchments in Pennsylvania that was dominated by fragipan soils and experienced severe snowmelt events throughout the winter and spring.

4 MATERIAL AND METHODS

4.1 Model Description

SWAT is a physically based, continuous time (Lenhart *et al.* 2002) and computationally efficient hydrological model, which uses readily available inputs. It was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch (a) *et al.* 2002). It enables users to study long-term impacts and hence is being used extensively in the US and Europe to assess the impact of global climate on water supply and quality (Rosenberg *et al.* 1999 cited KU Leuven E-manual[1]). The model can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds (Neitsch (a) *et al.* 2002). SWAT is used worldwide and has been chosen by the Environmental Protection Agency to be one of their better assessment science integrating point and non point sources (BASINS) models (Whittemore 1998 cited Lenhart *et al.* 2002). Thus, regulating environmental agencies will likely be using it increasingly (Lenhart *et al.* 2002).

The main reasons for the selection of SWAT2005 model are that the model is physically based, spatially distributed, and it belongs to the public domain. SWAT2005 simulates surface runoff outputs for the ungauged catchments for different land use /land cover changes. This makes the model suitable for the proposed task. Beyond that, the ArcView 3.2 integrated SWAT interface called the AVSWAT model provides a user friendly GUI that ease the use of the model. The model has also been tested in different tropical watersheds and reported to be able to well explaining watershed hydrological processes:, the study by Gosain *et al.* (2006) in Indian river basin, Benavides and Veenstra (2005) in tropical deforestation, Muthuwatta and Becht (2006) in Kenyan river basin, and Dilnesaw (2006) in Ethiopian Upper Awash River Basin can be sited as examples, which additionally justify the possible use of this model in the study area. A strong interest of testing suitability of different physically based models such as SWAT in different Ethiopian watersheds was also another ground for the selection.

AVSWAT (ArcView SWAT) is a complete preprocessor, interface and post processor of SWAT. It has been developed as an extension of ArcView GIS 3.2 by Backland Research Center, a Texas Agricultural experiment Station part of Texas A & M University System in Temple, Texas, in collaboration with Grassland Soil and Water Research Lab, a USDA-ARS laboratory in Temple, Texas http://www.brc.tamus.edu/swat/avswat.html). Being in the user friendly ArcView GIS 3.3 environment; the model provides the tools for delineating the watershed, defining the land use and soil, editing the model data bases, defining the weather stations, parameterize and editing the inputs, running the model, reading and mapping the results, and calibrating the simulation results. For this study the most recent version called "*AVSWAT-X for SWAT 2005 – Backland Research Center – Ver. Beta 0.04*" was used.

4.2 AVSWAT Model Approach

Watersheds can be subdivided into sub watersheds and further into hydrologic response units (HRUs) to account for differences in soils, land use, crops, topography, weather, etc. The model has a weather generator that generates daily values of precipitation, air temperature, solar radiation, wind speed, and relative humidity from statistical parameters derived from average monthly values. The model computes surface runoff volume either by using modified SCS curve number method or the Green & Ampt infiltration method. Flow is routed through the channel using a variable storage coefficient method or the Muskingum routing method. SWAT has three options for estimating potential evapotranspiration: Hargreaves, Priestley-Taylor, and Penman-Monteith. The model also includes controlled reservoir operation and groundwater flow model. The important equations used by the model are discussed as follows. The detailed and complete descriptions are given in the SWAT theoretical documentation (Neitsch (a) *et al.* 2002).

SWAT splits hydrological simulations of a watershed into two major phases: the land phase and the routing phase. The difference between the two lies on the fact that water storage and its influence on flow rates is considered in channelized flow (Neitsch (a) *et al.* 2002).

The land phase of the hydrologic processes (figure 4.1) is simulated based on the following water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \text{----------------Eq 4.1}$$

Where: SW_t is the final soil water content (mm water),
SW_0 is the initial soil water content on day (mm water),
t is the time (days),
R_{day} is the amount of precipitation on day i (mm water),
Q_{surf} is the amount of surface runoff on day i (mm water),
E_a is the amount of evapotranspiration on day i (mm water),
W_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on day i (mm water), and
Q_{gw} is the amount of return flow on day i (mm water).

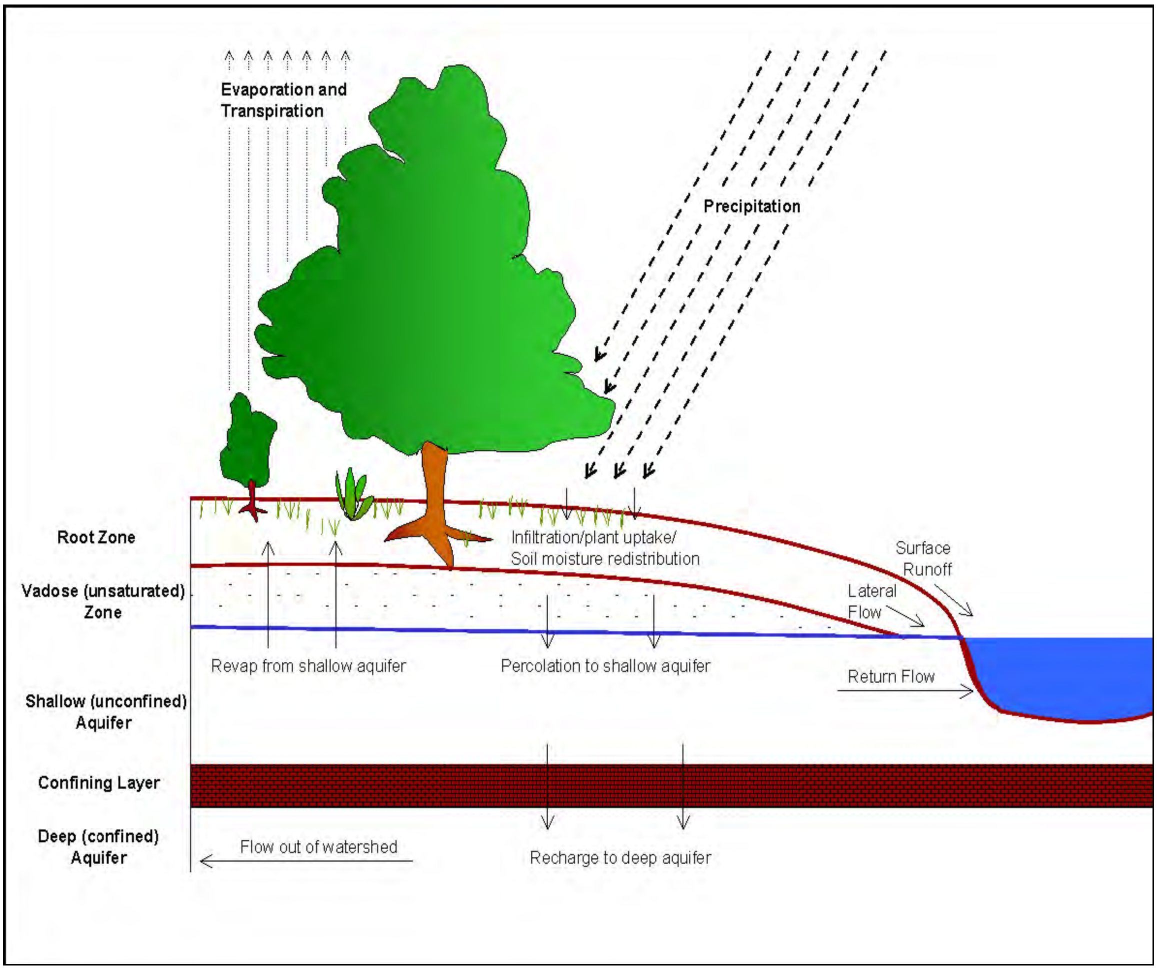


Figure4: 1Schematic representation of the hydrologic cycle (Neitsch et al. (b) 2000

4.2.1 Weather Generator

SWAT requires daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. Values for all these parameters may be read from records of observed data or they may be generated.

The weather generator input file contains the statistical data needed to generate representative daily climate data for the sub basins. Ideally, at least 20 years of records are used to calculate parameters in the .wgn file. Climatic data will be generated in two instances: when the user specifies that simulated weather will be used or when measured data is missing.

Lack of full and realistic long period climatic data is the problem of developing countries. Weather generators solve this problem by generating data having the same.

statistical properties as the actual ones (Danuso 2002). The weather generator first independently generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently. For the sake of data generation, weather parameters were developed by using the weather parameter calculator WXPARM (Williams, 1991) and dew point temperature calculator DEW02 (Liersch, 2003), which were downloaded from the SWAT website (http://www.brc.tamus.edu/swat/soft_links.html). The WXPARM program reads daily values of solar radiation (calculated from daily sunshine hours), maximum and minimum temperatures, precipitation, relative humidity, and wind speed data. It then calculates monthly daily averages and standard deviations of all variables as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month. The DEW02 programs reads daily values of relative humidity, and maximum and minimum temperature values and calculates monthly average dew point temperatures. In this study weather generated parameters calculated for five stations. solar radiation determination for swat input from sunshine hours and AVSWAT requires the solar radiation inMJ/m^2day daily time step but solar radiation data available from national metrological agency is in sunshine hours The weather generator parameters used and their values are shown in *Appendix C.*

4.2.2 Watershed Delineation

The ArcView GIS tool in AVSWAT partitions watersheds into a number of hydrological connected sub basins based on flow directions and accumulations. The watershed and sub basins delineation was carried out based on an automatic delineation procedure using a Digital Elevation Model (DEM) and digitized stream networks. The model fills all of the non-draining zones (sinks) to create a flow vector, and superimposes the digitized stream networks into the DEM to define the location of the stream network.

The AVSWAT interface proposes the minimum, maximum, and suggested size of the sub basin area (in hectare) to define the minimum drainage area required to form the origin of a stream. Generally, the smaller the threshold area, the more detailed are the drainage networks, and the larger are the number of sub basins and HRUs. In this study the threshold area of 25,000 ha is used because to reduce the number of hydrological response units for the case easy for the calibration processes and to delineate the water shed according to Ethiopian water shed code.

In addition to those defined by the model itself, two sub watershed outlets at mille and Logiya were added by table at the gauging stations, which were later used for the calibration and validation of the simulated flows and flood frequency analysis at the two stations.

4.2.3 Determination of Hydrologic Response Units (HRUs)

The sub basin delineation was followed by the determination of HRUs, which are unique soil and land use combinations within a sub basin modelled regardless of their spatial positioning. This describes better the hydrologic water balance and increases the accuracy of load predictions (Luzio *et al.* 2002). SWAT predicts the land phases of the hydrologic cycle separately for each HRU and routes to obtain the total loadings of the sub watershed

The HRUs can be determined either by assigning only one HRU for each sub watershed considering the dominant soil/land use combinations, or by assigning multiple HRUs for each sub watershed considering the sensitivity of the hydrologic process based on a certain threshold values of soil/land use combinations. For this study, the latter method was adopted as it better describes the heterogeneity within the watershed and as it accurately simulates the hydrologicprocesses.

The AVSWAT manual (Luzio *et al.* 2002) recommends the threshold levels for multiple HRUs to be set based on the project goal and the amount of detail desired. Default threshold values of 20% land use and 10% soil type are recommended to be adequate for most applications. After testing different scenarios of land use/soil type threshold values for the Upper Awash River Basin in Ethiopia, an adjacent river basin of the study area, Dilnesaw (2006) recommended 2% land use and 5%

soil type threshold values to be optimum values. However, this has resulted in more than 60 HRUs in each of the sub watersheds. This makes the automatic calibration trial impossible, where this tool is limited to watersheds with less than or equal to 60 HRUs. Thus, 20% land use and 10% soil type threshold values were adopted for the study area and results 53 HRUs and 29 HRUs for Mille and Logiya watershed. These threshold values were quite appropriate to represent the watershed's heterogeneity and to produce less than 60 HRUs.

4.2.4 Surface Runoff Simulation

4.2.4.1 Surface Runoff Volume

SWAT provides two methods for estimating surface runoff: the SCS curve number method (SCS 1972) and the Green & Ampt infiltration method (1911). Even though the latter method is better in estimating runoff volume accurately, its sub-daily time step data requirement makes it difficult to be used for this study. Hence, the SCS curve number method was adopted.

The method is an empirical model, which is based on the following equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R - I_a + S)} \text{ --------------------------Eq.4.2}$$

Where: Qsurf is accumulated runoff or rainfall excess (mm water),

Rday is rainfall depth for the day (mm water),

Ia *is* an initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water),

S is a retention parameter (mm water).

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

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

Where: CN is the curve number for the day.

CN = f (land use, practice, soil permeability, soil hydrologic group)

For the definition of the soil hydrologic groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification, which classifies soils into four hydrologic groups (A, B, C, & D) based on infiltration characteristics of the soils. Group A, B, C and D soils have high, moderate, slow, and very low infiltration rates with low, moderate, high, and very high runoff potential, respectively. The initial abstraction, Ia, is commonly approximated as 0.2S and the equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$ ------------------------Eq.4.4

4.2.4.2 Peak Discharge

The peak discharge or the peak surface runoff rate is the maximum volume flow rate passing a particular location during a storm event. SWAT calculates the peak runoff rate with a modified rational method. In rational method it assumed that a rainfall of intensity i begins at time $t = 0$ and continues indefinitely, the rate of runoff will increase until the time of concentration, $t = t_{conc}$. The modified rational method is mathematically expressed as:

$$q_{peak} = \frac{\alpha_{tc} * Q_{surf} * Area}{3.6 * t_{conc}}$$ --------------------Eq.4.5

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

α_{tc} is the fraction of daily rainfall that occurs during the time of concentration

Q_{surf} is the surface runoff (mm)

Area is the sub-basin area (km^2)

t_{conc} is the time of concentration (hr), and 3.6 is a conversion factor.

SWAT estimates the value of α using the following equation:

$$\alpha_{tc} = 1 - \exp[2 * t_{conc} * \ln(1 - \alpha_{0.5})]$$ -----------Eq.4.6

Where: t_{conc} is the time of concentration (h), and

$\alpha_{0.}$is the fraction of daily rain falling in the half-hour highest intensity rainfall.

Maximum half-hour rainfall is required by SWAT to calculate the peak flow rate for runoff. The user has the option of using the monthly maximum half-hour rainfall for all days in the month or generating a daily value. The variable ISED_DET in the basin input file (.bsn) defines which option the user prefers. The randomness of the triangular distribution used to generated daily values can cause the maximum half-hour rainfall value to jump around. For small plots or micro watersheds in particular, the variability of the triangular distribution is unrealistic.

Daily precipitation data are used by the model, the maximum half-hour rainfall may be calculated from the monthly maximum half-hour rainfall for all days in the month. The maximum half-hour rainfall is calculated only on days where surface runoff has been generated. For each month, provided the maximum half-hour rain observed over the entire period of record. These extreme values are used to calculate representative monthly maximum half-hour rainfall fractions. Prior to calculating the representative maximum half-hour rainfall fraction for each month, the extreme half-hour rainfall values are smoothed by calculating three month average values.

$$R_{0.5sm(mon)} = \frac{R_{0.5x(mon-1)} + R_{0.5x(mon)} + R_{0.5x(mon+1)}}{3}$$

Where: $R_{0.5sm(mon)}$ is the smoothed maximum half-hour rainfall for a given month (mmH_2O)

$R_{0.5x}$ is the extreme maximum half-hour rainfall for the specified month

(mm H_2O).

Once the smoothed maximum half-hour rainfall is known, the representative half-hour rainfall fraction is calculated using the equation;

$$\alpha_{0.5mons} = adj\ 0.5\alpha . \left[1 - \exp\left(\frac{R_{0.5sm(mon)}}{\mu_{mon}.\ln\left(\frac{0.5}{yrs.days_{wet}}\right)} \right) \right]$$

Where $\alpha_{0.5mon}$ is the average half-hour rainfall fraction for the month,

$adj_{0.5\alpha}$ is an adjustment factor

$R_{0.5sm}$ is the smoothed half-hour rainfall amount for the month (mm H_2O)

μ_{mon} is the mean daily rainfall (mm H_2O) for the month

yrs is the number of years of rainfall data used to obtain values for monthly extreme half-hour rainfalls

$days_{wet}$ are the number of wet days in the month.

SWAT input variables that pertain to generation of maximum half-hour rainfall fraction and SWAT input variables that pertain peak rate calculations are presented at Appendix C.

4.2.4.3 Time of Concentration

The time of concentration, t_{conc}, is a time within which the entire sub basin area is discharging at the outlet point. It is calculated by summing up both the overland flow time of the furthest point in the sub basin to reach a stream channel (t_{ov}) and the upstream channel flow time needed to reach the outlet point (t_{ch}):

$$t_{conc} = t_{ov} + t_{ch} \text{----------------------------Eq.4.7}$$

The overland flow time (t_{ov}) is computed as:

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \text{ --------------------------Eq.4.8}$$

Where: L_{slp} is the average subbasin slope length (m),

V_{ov} is the overland flow velocity (m/s), and 3600 is a unit conversion factor.

The overland flow velocity for a unit width along the slope is calculated by using the Manning's equation:

$$V_{ov} = \frac{q_{ov}^{0.4} * Slp^{0.3}}{n^{0.6}} \text{ ----------------------------Eq.4.9}$$

Where: q_{ov} is the average overland flow rate (m^3/s),

Slp is the average slope of the sub basin (m/m),

n is Manning's roughness coefficient of the sub basin.

Assuming an average flow rate of 6.35 mm/hr and substituting the equation of V_{ov} into t_{ov}, the simplified equation of the overland flow becomes:

$$t_{ov} = \frac{L_{slp}^{0.6} * n^{0.6}}{18 * Slp^{0.3}} \text{ ------------------------Eq.4.10}$$

Channel flow time is computed as:

$$t_{ch} = \frac{L_c}{3.6 * V_c} \text{ ------------------------------Eq.4.11}$$

Where: L_c is the average flow channel length (km),

V_c is the average flow velocity (m/s), and 3.6 is a unit conversion factor.

The average flow channel length is calculated as:

$$L_c = \sqrt{L * L_{cen}} \text{ --------------------------------Eq.4.12}$$

Where: L is the channel length from the furthest point to the sub basin outlet (km

L_{cen} is the distance along the channel to the sub basin centroid (km).

Assuming L_{cen} = 0.5L, and using the Manning's equation for V_c for a trapezoidal channel with side slope of 2:1 and bottom width to depth ratio of 10:1, channel flow time becomes:

$$t_{ch} = \frac{0.62 * L * n^{0.75}}{Area^{0.125} * Slp_{ch}^{0.375}} \text{ ------------------------Eq.4.13}$$

Where: t_{ch} is the time of concentration for channel flow (hr),

L is channel length from the most distant point to the sub basin outlet (km),

n is Manning's roughness coefficient for the channel,

Area is the sub basin area (km^2), and

Slp_{ch} is the channel slope (m/m)

4.2.4.4 Surface Runoff Lag

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated. SWAT incorporates a surface runoff storage feature to lag a part of the surface runoff release to the main channel. Once surface runoff is calculated, the amount of surface runoff released to the main channel is calculated as:

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1}) * \left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \text{ ----------------Eq.4.14}$$

Where: Q_{surf} is amount of surface runoff discharged to main channel in a day (mm),

Q'_{surf} is amount of surface runoff generated in a sub basin in a day (mm),

$Q_{stor,i\text{-}1}$ is the surface runoff stored or lagged from the previous day (mm),

$surlag$ is the surface runoff lag coefficient, and

t_{conc} is the time of concentration for the sub basin (hrs)

4.2.5 Potential Evapotranspiration (PET)

According to Penman (1956), PET is defined as "*the amount of water transpired by a short green crop, completely shading the ground, of uniform height and never short of water*". Even though, there are numerous methods for PET estimation, SWAT provides three alternatives for its calculation: Penman-Monteith (Monteith 1965, Allen 1986, Allen *et al.* 1989), Priestley-Taylor (Priestley and Taylor 1972), and Hargreaves (Hargreaves *et al.* 1985) methods. As an option, measured values can also be used as an input data. The methods have various needs for a number and type of climate variables: Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed; Priestley-Taylor method requires

solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only.

In this study, Hargreaves method was considered for PET estimation due to the data availability at most stations.

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

$$\lambda E_o = 0.0023 * H_o * (T_{\max} - T_{\min})^{0.5} * (\bar{T}_{av} + 17.8) \text{ ----------Eq.4.15}$$

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

E_o is the potential evapotranspiration (mm/day),

H_0 is the extraterrestrial radiation (MJ/m^{2}day),

T_{max} is the maximum air temperature for a given day (°C),

T_{min} is the minimum air temperature for a given day (°C), and

T_{av} is the mean air temperature for a given day (°C).

4.2.6 Soil Water - Percolation, Bypass Flow and Lateral Flow

Soil water may follow different paths of movement: vertically upward (plant uptake), vertically downward (percolation), or laterally-contributing to stream flow. The vertical movement as plant uptake removes the largest portion of water that enters the soil profile.

Percolation is the downward movement of water in the soil. SWAT calculates percolation for each soil layer in the profile. Water is allowed to percolate if only the water content exceeds the field capacity of that layer (Neitsch *et al.* (a) 2002).

Bypass flow is the vertical movement of free water along macro pores through unsaturated soil horizons and occurs in areas dominated by Vertic soils when the rate of rainfall or irrigation exceeds the vertical infiltration rate. While simulating the bypass flow, SWAT calculates the crack volume of the soil matrix for each day of simulation by layer. On days in which precipitation events occur, infiltration and surface runoff are first calculated for the soil. Part of the surface runoff equivalent to the cracks volume enters the soil profile as bypass flow, and the rest remains overland flow. Cracks are filled in accordance with their presence in the consecutive layers: those at the bottom layers are filled first (Neitsch *et al.* (a) 2002).

Lateral flow is common in areas with high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturated zone stored above this layer. This is called a perched water table, which is the source of water for lateral subsurface flow. SWAT incorporates a kinematic storage model for subsurface flow (Neitsch *et al.* (a) 2002). Lateral flow occurs when water stored in the shallow aquifer exceeds a threshold value.

4.2.7 Channel Routing

The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. As an optional process, the change in channel dimensions with time due to down cutting and widening is also included.

Similar to the case for the overland flow , the rate and velocity of flow is calculated by using the Manning's equation. The main channels or reaches are assumed to have a trapezoidal shape by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model.

The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In the latter method, when a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave recedes, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length.

For this study, the variable storage method was adopted. The method was developed by Williams (1969) and used in the HYMO (Williams and Hann 1973) and ROTO (Arnold *et al.* 1995) models. Storage routing is based on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \quad \text{--------------------------Eq.4.16}$$

Where: *Vin* is the volume of inflow during the time step (m^3 water),

Vout is the volume of outflow during the time step (m^3 water), and *ΔVstored* is the change in volume of storage during the time step (m^3 water).

This equation can also be detailed as follows:

$$V_{stored,2} - V_{stored,1} = \Delta t * \left(\frac{q_{in,1} + q_{in,2}}{2} \right) - \Delta t * \left(\frac{q_{out,1} + q_{out,2}}{2} \right) \quad \text{----Eq.4.17}$$

Where: *Δt* is the length of the time step (s),

qin,1 is the inflow rate at the beginning of the time step (m^3/s),

qin,2 is the inflow rate at the end of the time step (m^3/s),

qout,1 is the outflow rate at the beginning of the time step (m^3/s),

qout,2 is the outflow rate at the end of the time step (m^3/s),

$V_{stored,1}$ is the storage volume at the beginning of the time step (m^3 water)

and $V_{stored,2}$ is the storage volume at the end of the time step (m^3 water).

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

$$TT = \frac{V_{stored}}{q_{out}} = \frac{V_{stored,1}}{q_{out,1}} = \frac{V_{stored,2}}{q_{out,2}} \text{ ------------------Eq.4.18}$$

Where: *TT* is the travel time (s),

Vstored is the storage volume (m^3 water), and

qout is the discharge rate (m^3/s)

4.2.8 Flow Separation

For calibration of simulated flows, the total gauged stream flow data should be separated into surface and base flow components. The automated base flow separation and recession analysis techniques (Arnold *et al.* 1999), (http://pasture.ecn.purdue.edu/~what/) are among the several methods available to separate base flows. Due its simplicity, this technique was applied.

The automated base flow separation and recession analysis technique uses a dos based software called Base flow-program found from the SWAT website It is developed based on the recursive digital filter techniques (Nathan and McMahon 1990), and filters surface runoff (high frequency signals) from base flow (low frequency signals). The filter can be passed over the stream flow data three times (forward, backward, and forward). The details of the methodology are explained in Arnold *et al.* (1995). In cases of lack of knowledge about the local conditions, the authors recommended the use of only one filter pass as a default value. Furthermore, they suggested that in general the fraction of water yield contributed by base flow should fall somewhere between the value for the fraction of stream flow contributed by base flow that is estimated in first pass (Fr1) and in second pass (Fr2). This is true if the base flow in the watershed is from aquifers recharged by precipitation falling in the watershed. So the value between these two was adopted for the calibration of

SWAT simulated flow. In addition to the alpha factor, the base flow days (number of days for the base flow recession to decline through one log cycle) was also calculated.

4.3 Evaluation of Model Simulation

4.3.1 Model performance statistics

The three numerical model performance measures used in this study are the percent difference (D), coefficient of determination (r2 coefficient) and the Nash-suttcliffe simulation efficiency (ENS)(Nash and Sutticliffe1970).

The percent difference measures the average difference between the simulated and measured values for a given quantities over a specified period (usually the entire calibration or validation period in this study). The percent difference for quantity (D) over a specified period with N total months calculated from the measured and simulated values of the quantity in each model time step as:

$$D = \frac{100x(\sum_{j=1}^{n} Simulated_j - \sum_{j=1}^{n} Measured_j)}{\sum_{j=1}^{n} Measured_j} \text{-------------------------------Eq.4.19}$$

A value close to 0% is best for D how ever, higher values for Dare acceptable if the accuracy in which the measure data were gathered is relatively poor.

The r^2 coefficient and ENs simulation efficiency measure how well the trends in the measured data are reproduce by the simulated result over a specified time period and for a specified time step .for example, in this study, these measures were computed for a, monthly time steps.

The r^2 coefficient for n time step is calculated as:

$$r^2 = \frac{\left[\sum_{i=1}^{n}(Simulated_{i\_}Simulated_{avg})(Measured_i - Measured_{avg})\right]^2}{\sum_{i=1}^{n}(Simulated_i - Simulated_{avg})^2} \text{-------4.20.}$$

The range of values for r^2 is 1.0(best) to 0.0.The r^2 coefficient measures the fraction of the variation in the measured data that is replicated in simulated model results. A value of 0.0 for r2 means that none of the variance in the measured data is replicated by the model predictions. The ENs simulation efficiency for n times step is calculated as:

$$ENs = 1 - \frac{\sum_{i=1}^{n}(measured_i - simulated_i)^2}{\sum_{i=1}^{n}\left[measured - \frac{1}{n}\sum_{i=1}^{n} measured_i\right]^2} \qquad \text{------Eq.4.21}$$

ENs values range from 1.0(best) to negative infinity. ENs is a more stringent test of performance than r^2 and is never larger than r^2.ENs measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. A value of 0.0 for ENs means that the model predictions are just as accurate as using the measured data average to predict measured data .ENs Values less than0.0 indicate the measured data average is a better predictor of the measured data than the model prediction while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average.

4.3.2Calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated.

Refsgaard and Storm (1996 cited Dilnesaw 2006) distinguished three types of calibration methods: the manual trial-and-error method, automatic or numerical parameter optimization method; and a combination of both methods. According to the authors, the manual calibration is the most common and especially recommended in cases where a good graphical representation is strongly demanded

for the application of more complicated models. However, it is very cumbersome, time consuming, and requires experience. Automatic calibration makes use of a numerical algorithm in the optimization of numerical objective functions. The method undertakes a large number of iterations till it finds the best parameters. The third method makes use of combination of the above two techniques regardless of which comes first. For this study, at first, the third approach was considered. However, afterwards, due to the very extensive time and computer capacity requirements of the automatic calibration, only the manual calibration was applied.
As discussed in the previous section the gauged flow was separated into surface flow and base flow components for the water balance calibration. The calibration was commenced by the monthly average of the surface runoff. Sensitive parameters found from the sensitivity analysis were varied within their ranges till the volume is adjusted to the required quantity. The parameters varied were taken according to their relative sensitivity. This process continued by taking consecutive parameters till the volume simulated is within ±15% of the gauged volume. The curve number (CN), and the soil evaporation compensation factor (ESCO) are the most sensitive among the parameters used in the surface runoff calibration.
For parameters such as CN and the average HRU slope steepness (SLOPE), which vary among HRUs, their average values were taken.

The surface runoff adjustment was then followed by that of the base flow. The same approach was followed as above being the adjustment made to the most sensitive parameters affecting the base flow: the threshold water depth in the shallow aquifer for flow (GWQMN), the deep aquifer percolation fraction (rchrg_dp), and the groundwater revap coefficient (GW_REVAP). Each time the base flow calibration is finalized, the surface runoff volume was also checked as adjustment of the base flow parameters can also affect the surface runoff volume. The procedure followed for themanual calibration is presented in figure 4.2. After each calibration, the regression coefficient (R^2), and the Nash and Suttcliffe (1970) simulation efficiency (E_{NS}) were also checked in accordance to Santhi *et al.* (2001) recommendation ($R^2 > 0.6$ and $E_{NS} > 0.5$).

After the water balance calibration was completed, calibration was continued for its temporal trend to take care of the inconsistency occurred in the patterns of the simulated and gauged flows. This is more of an adjustment made to have similar hydrograph shapes and flow time lag. SLOPE and GW_DELAY were among the parameters considered at this step.

The calibration was carried out at two gauging station (at mille and logia) of the watersheds independently.. The calibration was done using historical records of Mille and Logiya watershed.

4.3.3 Validation

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation-period stream flows confirm that the model performs satisfactorily. In the validation process, data for a period of three years was used in both Mille and Logiya watersheds to evaluate the model accuracy. The statistical criteria used during the calibration procedure were also checked.

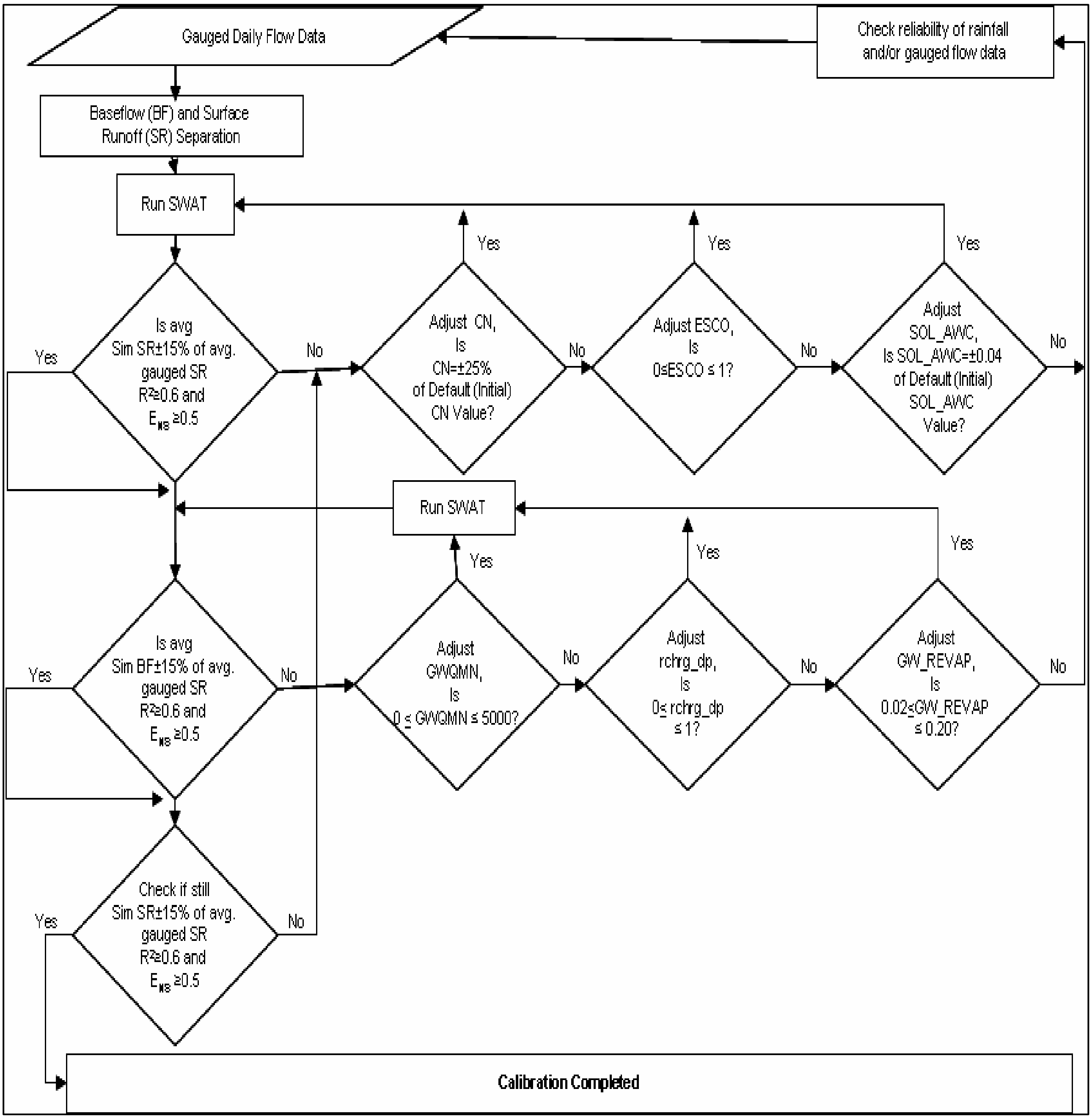


Figure4.2 The manual flow calibration procedure used in this study (diagram extended from that developed by Santhi et

4.4 AVXSWAT Model Data Inputs and Analysis

This section of the thesis outlines the development of the model inputs. Specifically, this section outlines the raw data sources utilized, translation of these raw data inputs to original SWAT 2005 input files, deviations from default model settings, initial conditions in the model and any optional physical processes selected for simulation in SWAT. A considerable effort was made to generate the most representative model inputs as possible given available data for the mille and logiya watershed in the lower Awash River Basin. Much of this derived input data will be beneficial to any future watershed models of the mille and logiya Basin.

4.4.1 Inputs for Delineation of Stream Network

4.4.1.1 Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) was used to model the geography of the study area. A DEM is a grid of square cells where each cell represents the elevation value at that location. The size of each cell determines the resolution of the DEM. Larger the cell coarser the resolution. For large areas coarser resolutions are preferred over finer resolutions due to lower computational times and availability issues. The elevation value for each cell is an average over all the elevations inside the cell. The assumption here is that for the extent of the study area this approximation is not a cause of a significant error. The user ultimately needs to make a decision regarding the resolution to be adopted for the DEM for the study area under consideration. In this study, a 57meter DEM was used.

The projection of the DEM should be noted so that henceforth all spatial representation is in the same projection. Therefore, the geographic locations files will be imported into a GIS and reprojected. The projection of the DEM is according to the information in table 4.1 below to the appropriate coordinate system for the area. The DEM was also checked for its accuracy by overlaying digitized stream networks of the study area on the DEM-based delineated watershed area and defined stream networks in ArcView GIS 3.2.

The DEM used in this study was taken from Land sat7Consortium for Spatial Information (CGIAR_CSI) website (http://srtm.csi.cgiar.org/), which provides the NASA Shuttle Radar Topographic Mission (SRTM) 3 arc second (≈90m) resolution Digital Elevation Data for the entire world and it is resampling to 57m resolution (byHalcrow).

Threshold area value applied for delineating the watershed is 25,000ha to create a stream network that shows all the streams that drain the area greater than the threshold area. This represents main sub watersheds of the study area.

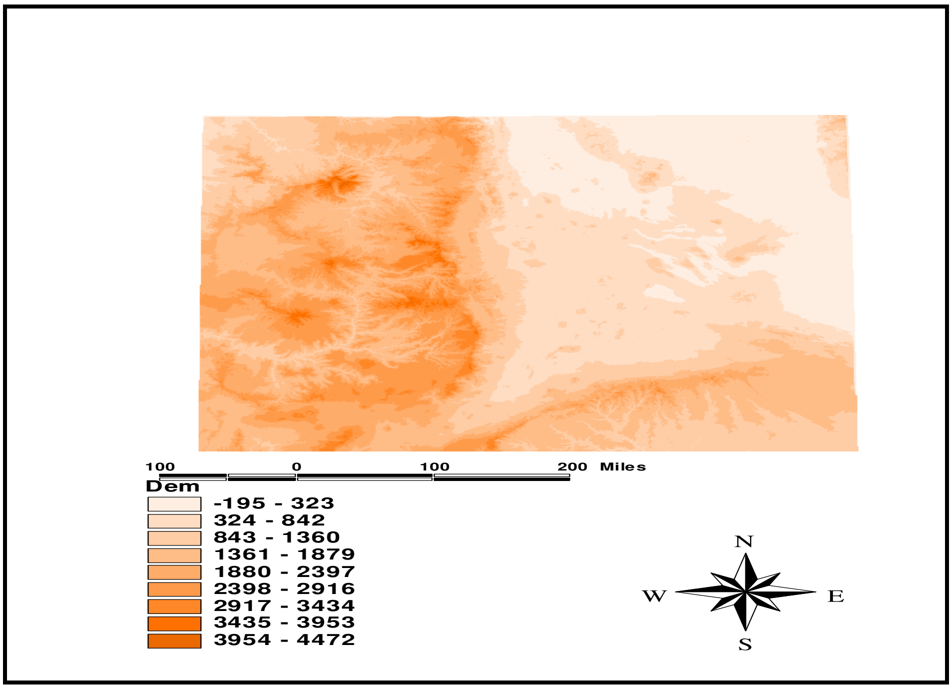


Figure4.3 DEM used in the area

Table4.1: Transverse Mercator projection parameters for Ethiopia (Dilnesaw **2006**)

Projection	Transverse_Mercator
Projected coordinate system	Adindan_UTM_Zone_37N
Geographic Coordinate System	GCS_Adindan
Datum	D_Adindan Prime Meridian: 0
False_Easting	500000.000
False_Northing	0.000
Central_Meridian	39.000
Scale_Factor	0.9996
Latitude_Of_Origin	0.000
Linear Unit	Meter (1.000)

4.4.1.2 Digitized Stream Networks

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

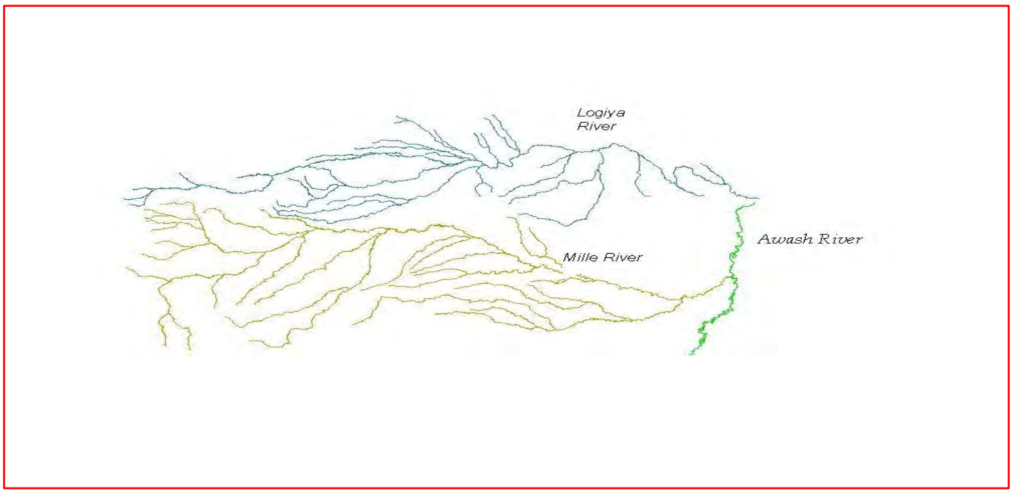


Figure4.4 Digitalized stream network in the basin

4.4.2 Land uses

Woody biomass inventory and strategic planning project provided a land use coverage map derived by supervised classification of Landsat TM imagery of various dates between 1999 and 2000 during phase I study for Ethiopia and these land cover digitalized map is available for the whole awash basin at separate map for the regions in the Awash Basin(Amhara ,Afar,Oromiya,Deridewa,Somalia regions in the basin).The digitalized land cover map and shape file formats for the above regions are available at Halcrow ,Awash basin Master plan project, was used as a benchmark in producing the land use map of the study area. As land use/land cover is not static in nature and only current ground conditions can accurately explain the hydrologic process, recent maps were used as a model inputs for the specified study.

SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use map of the study area to SWAT land use databases in the GIS interfaces. Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model. Information collected from the digitalized land use map shape file was used in renaming the land uses (Table 4.3). A due attention was given to represent the actual land use of the area with the predefined land use code of SWAT.

Table4.2: Original land use/land cover types redefined according to the SWAT code

Original Landuse(According to woody biomass classification)	Redefined Landuse according to the SWAT Database	SWAT_Code
Cultivable land(Reinified cerial land cover system) –CRCL,CRCM	Agricultural land	AGRR
Afro-Alpine Belt(PLANTATION FOREST)-FPD,FRD	Forest-Evergreen	FRSE
Bareland, TS,TR	Urban	URHD
Bush/Shrub Land-SHD,SHO	Range-Brush	RNGB
Grass land light and moderate stocke-GL,GM	Range -Grasses	RNGE
Cultivable land-CRCL	Durum Wheat	DWHT
Wood land,WD,WO	Forest mixed	FRSE
Lakes	Waterbody	WATR
Swamp perinnal seasonal-HSP,HSS	Wetland non forested	WETN
	pasture	PAST
Natural forest FCD,FPD,FPC	Forest decidicious	FRSD

Table4.3: SWAT land use of the study area with their aerial coverage (for mille watershed)

Landuse	**SWAT Code**	**Area [ha]**	**% age Watershed Area**
Cultivable land(Reinified cerial land cover system) –CRCL,CRCM Corn	AGRR	127.482	2.2870
Afro-Alpine Belt(PLANTATION FOREST)-FPD,FRD	FRSE	80.8582	1.4506
Bareland, TS,TR	URHD	995.729	17.862
Bush/Shrub Land-SHD,SHO	RNGB	1661.47	29.806
Grass land light and moderate stocke-GL,GM	RNGE	241.270	4.3283
Cultivable land-CRCL	DWHT	684.360	12.277
Wood land,WD,WO	FRSE	380.163	6.8199
Lakes	WATR	42.3853	0.7604
Swamp perennialand seasonal-HSP,HSS	WETN	1.6302	0.0292
Grass land fewstock-GB,	PAST	1342.63	24.086
Natural forest FCD,FPD,FPC	FRSD	16.3021	0.2925

Table4.4: SWAT land use of the study area with their aerial coverage (for logiya watershed)

Landuse	**SWAT Code**	**Area [ha]**	**% Water shed Area**
Cultivable land(Reinified cereal land cover system) – CRCB,CRCM	AGRR	63.639	1.99
Afro-Alpine Belt(PLANTATION FOREST)-FPD,FRD	FRSE	573.396	17.93
Bare land, TS,TR	URHD	853.857	26.70
Bush/Shrub Land-SHD,SHO	RNGB	56.924	1.78
Grass land light and moderate stocke-GL,GM	RNGE	14.711	0.46
Cultivable land-CRCL	DWHT	749.604	23.44
Swamp perennial and seasonal-HSP,HSS	WETN	256.477	8.02
Grass land fewstock-GB,	PAST	7.995	0.25
Natural forest FCD,FPC	FRSD	621.365	19.43

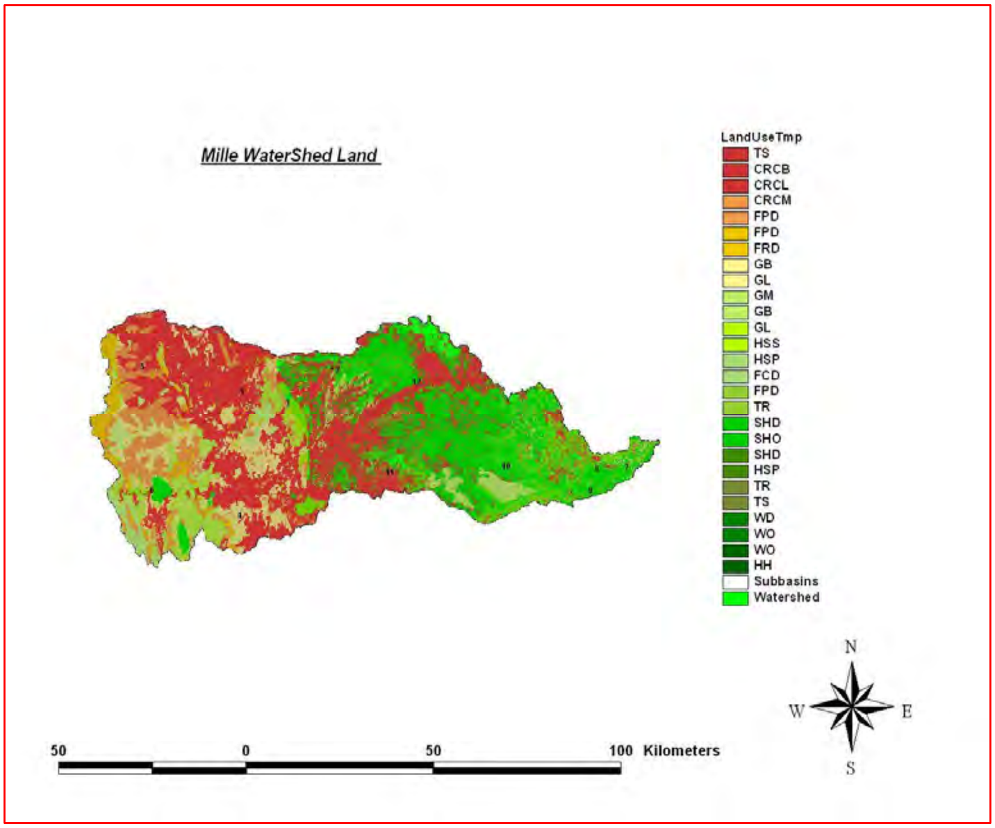


Figure4.5: Land use map of Mille watershed

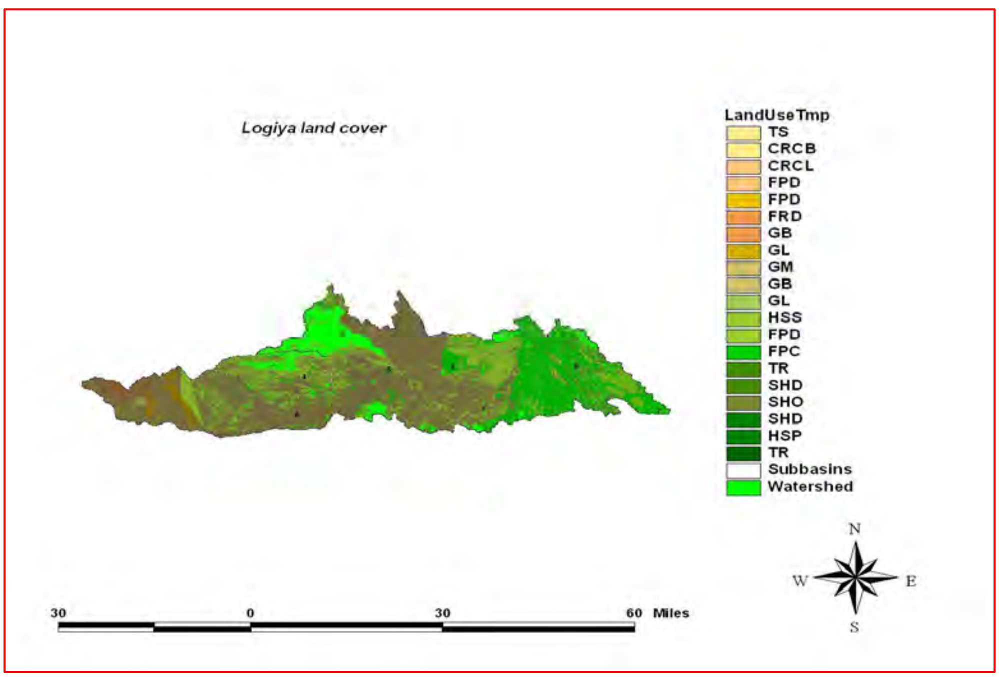


Figure 4.6: Land use map of the logiya watershed

4.4.3 Soil Data Input

The soils database describes the surface and upper subsurface of a watershed and is used to determine a water budget for the soil profile, daily runoff and erosion. SWAT model requires textural properties and physical-chemical-properties for each soil and the required parameters are shown in Table 4.6

The classification was made according the FAO-UNESCO Soil Classification System. The majority of the information was extracted from this database, but the database doesn't contain all soil properties, which are required by SWAT model.

In addition to the above source some of the soil properties which were not found from the above sources, were adopted already prepared by Dilnesaw (2006). The value of different soil parameters, which were adapted from the above soil data sources, and the estimated soil parameters for the adopted values are listed in Appendix B.

In order to integrate the soil map within the SWAT model, it is necessary to make a User Soil Database, which contains physico-chemical-properties for each soil. In this database all the soil in the area are represented, and coupled with its characteristics.

The major soil classification map of the study area according to the FAO-UNESCO Soil Classification System is shown in Figure 4.7and Figure 4.8 .The areas of all soil types in the study are summarized in Table 4.7 and Table 4.8.

Table4.5 Soil parameters required by the SWAT

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

The spatial distribution of different soil types is one of the very important factors affecting the overall hydrology of a watershed. SWAT model basically needs the soil data in defining lumped land areas, HRUs. SWAT's soil database needs all physical and chemical properties of each soil types in the watershed.

Table4.6: Soil types of the logiya watershed with their aerial coverage (FAO-UNESCO Soil Classification System)

Soil Type	Symbol	Area [km^2]	% Watershed Area
Mollic Andosols	Aco	0.544	0.01701
Mollic Andosols	ANm	54.143	1.693
Eutric Cambisols	CMe	2.075	0.06490
Calcaric flubisol	FLc	506.872	15.8498
Leptosol	LP	1870.536	58.4914
Utric Nitisol	NTu	436.555	0.13651
Haplic Luvisols	LVx	1.928	0.06028
Eutric regesol	RGe	562.983	17.6045
Ortic solonchalks	SCo	190.011	5.94162
Haplic Luvisol	LVh	4.513	0.14113

Table4.7: Soil types of the Mille watershed with their aerial coverage (FAO-UNESCO Soil Classification System)

Soil Type	Symbol	Area [km^2]	% Watershed Area
Mollic Andosols	ANm	381.004	6.8401
Eutric Cambisols	CMe	6.333	0.1137
Calcaric flubisol	FLc	184.4778	3.3119
Leptosol	LP	2.3612	0.0424
Utric Nitisol	NTu	30.725	0.5516
Lithic Leptosols	LVx	11.959	0.2435
Eutric regesol	RGe	11.959	0.2147
Ortic solonchalks	SCo	4896.923	87.9137
Haplic Luvisol	LVh	9.597	0.1723
Luvic Phaeozems	waterbody	25.617	0.4599

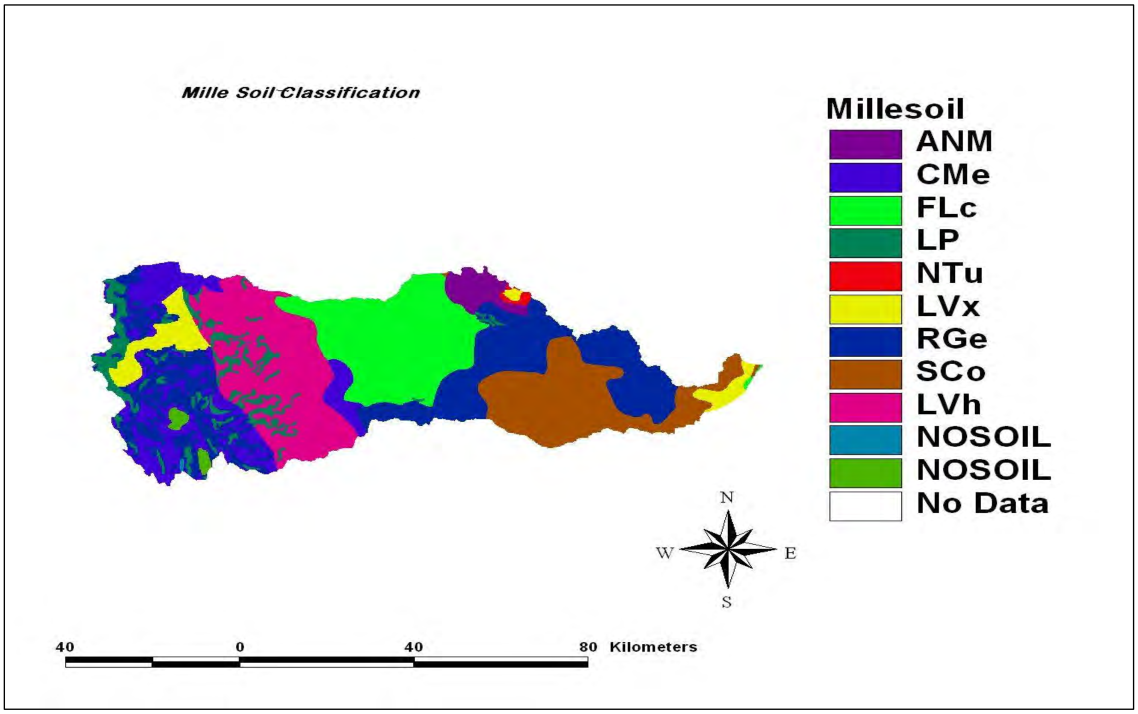


Figure4.7 Soil map of mille watershed

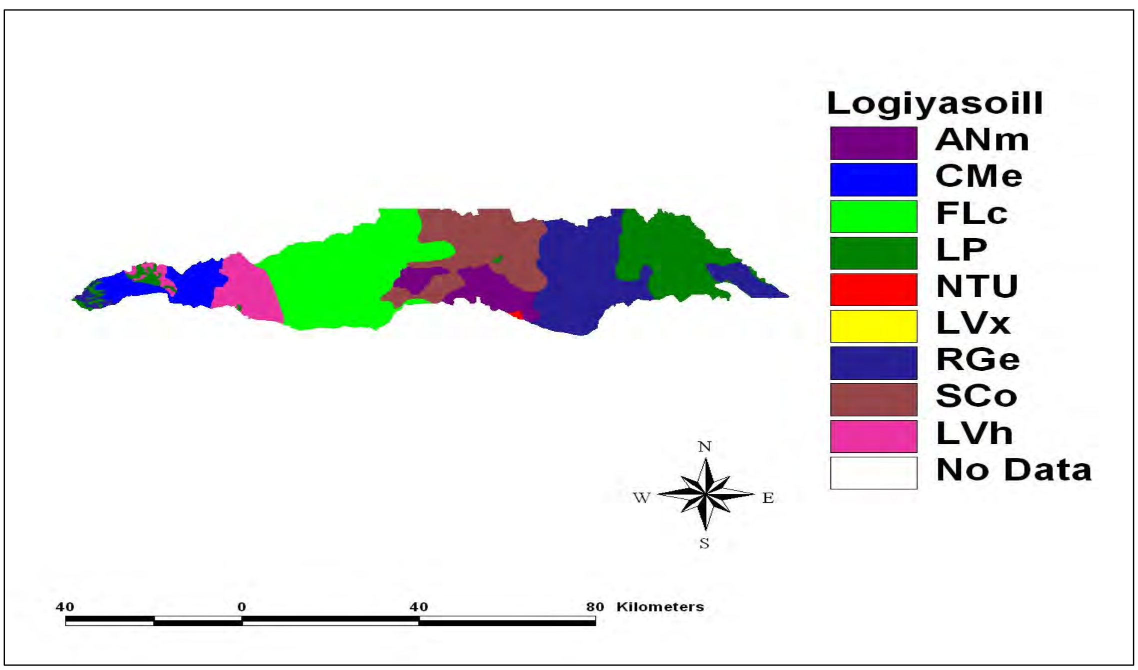


Figure 4.8 Soil map of Logiya watershed

4.4.4 Meteorological Records

SWAT also needs long years of climate data for the simulation of hydrological processes. For this study, the necessary climate data were collected from the National Meteorological Services Agency (NMSA) of Ethiopia. Data of precipitation, maximum and minimum temperature, sunshine hours, relative humidity, wind speed were collected for ten meteorological stations within and around the watershed. The locations of the stations and the details of the data collected are presented at appendix A.

Table4.8: Details of meteorological data collected from the NMSA

	Data was collected for the following years					
Station	***Precipitation***	***Max. Temp***	***Min. Temp***	***Sunshine Hours***	***Relative Humidity***	***Wind speed@2 m***
Assaita	1955-2005** 1957-1964*,1998-1993*,1996-1997*,1987*	1955-2004** 1957-1971*, 1986-1998*	1955-2004** 1957-1971*, 1986-1998	1997-2006**	1971-2005** 19887-1999*	1979-2005** 1987-1999*
Bati	1964-2005**	1964-2005** 1985-1987*	1964-2005** 1985-1987*	1987-2006**	1987-2005**	1987-2003**
Dubti	1986-2003**	1968-2003** 1971-1984* 1987*	1968-2003** 1971-1984* 1987*	1988-2002**	1962-2003** 1981-1985* 1991-2000*	1979-2002**
Combolcha	1952-2005**	1970-2005**	1970-2005**	1964-2006**	1953-2005**	1979-2005**

Sirinka	1966-2003** 1970-1979* 1990*	1966-2003** 1970-1979* 1990*	1966-2003** 1970-1979* 1990*	1987-2006** 1999-2002* 1996*,1990*,2005*	1980-2004**	1980-2004** 1984-1985*,1998-199*,1991*,1996*
Mersa	1968-2005**	1962-2004**	1962-2004**	-	-	-
Tendaho	1970-2005** 1963*,1973*	1962-1987** 1984*-1985*	1962-1987** 1984*-1985*	-	-	-
Haike	1962-1986**	-	-	-	-	
Mille	1962-2005**	1986-1996** 1996***	1986-1996**, 1996***	-	-	-
Wurgessa	1962-2004**				1970-2004**	-

➢ *daily data, monthly data*; * missing data*

As the result of any simulation depends of the quality of the available data, data-checking were made for their reliability. Excel manipulations were applied for this task. Data that seemed unreliable were discarded. SWAT normally uses solar radiation values rather than daily-sunshine-hours data, and hence conversion of these variables was made. Statistical analysis of the daily data (monthly daily averages, standard deviations, probability of wet and dry days, skew coefficient) were carried out, which were latter used as an input for the data generator. Finally, all the data were prepared in *.dbf* format as an input into the SWAT model. All the missing data were filled with a missing data identifier of -99. As discussed in previous SWAT has a built-in weather generator that is used to fill these gaps. SWAT takes data of each climatic variable for every sub basin from the nearest weather station measured from the centroid of the sub basin.

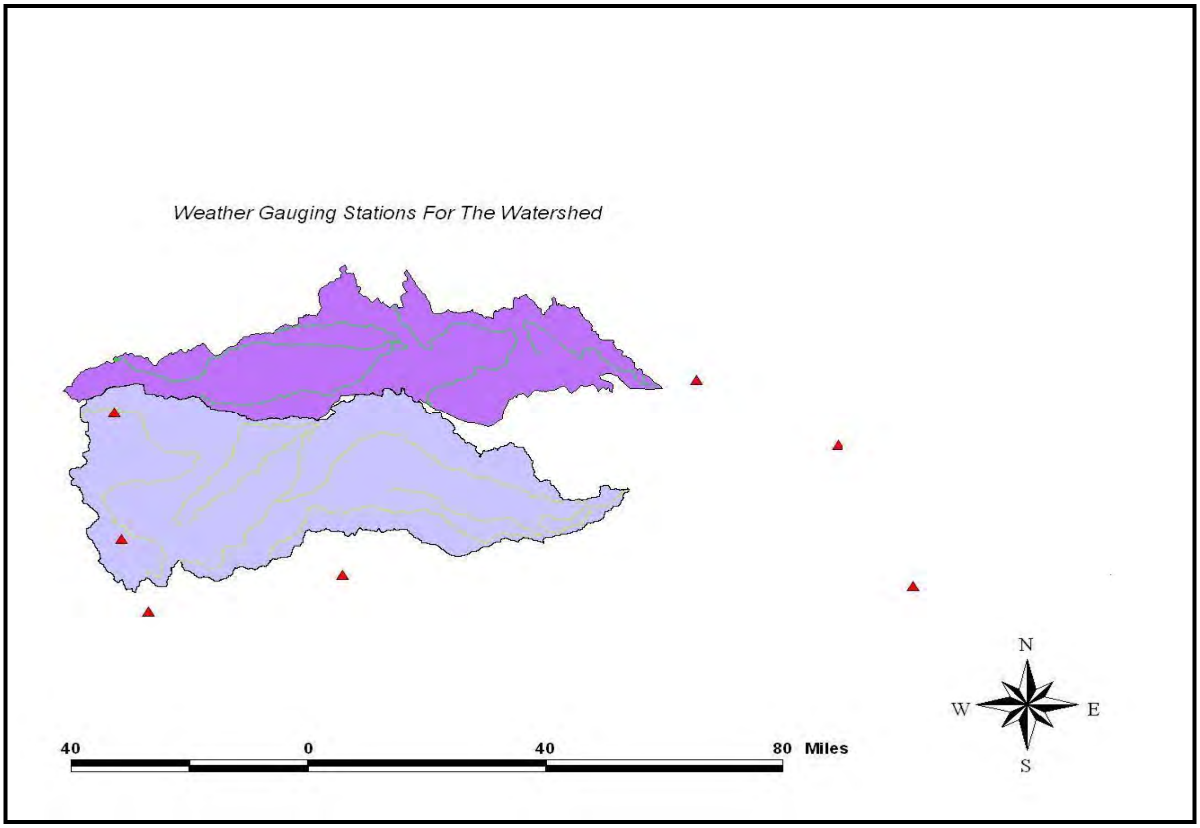


Figure 4.9 Weather gauging station for the watershed

4.4.5 River Flow Data

The watershed has two main rivers: flowing into the Awash river (Mille and Logiya) and other tributaries. Hence flow data of these rivers were collected, which were used in the calibration and validation process.

All these data were gathered from the Ministry of Water Resources (MoWR) and their details are presented in table 4.9 and Appendix J. Data were checked for their reliability and their monthly and yearly statistics were calculated for use in the calibration and validation of the simulated flows.

Table4.9: Details of hydrological data collected from theK Minstry of water resourse(MoWR)

Station	Daily Data Collected for the following years		
	River	Station code	Discharge
Mille	Mille	033021	1977-2004
Logiya	Logiya	033027	1985-2000

4.5 Model Input File Generation using the SWAT 2005 Arc view Interface (AVSWAT)

AVSWAT (DiLuzio et al. 2005) was used to create the initial model input files. AVSWAT processed mapped land use and soil data as well as a Digital Elevation Map (DEM) to create a set of default model input files. The DEM can be utilized by AVSWAT to delineate the stream basin (or watershed) and sub basin boundaries, calculate sub basin average slopes and delineate the stream network. The stream network was defined using the AVSWAT 'burn in' option based on Ethiopian MOWR files for the mille and logiya Basin.Modeled sub basins were delineated mainly based on those designated by the MOWR that cover the major tributaries of the Mille and Logiya River.

Additional sub basins were created using AVSWAT in order to subdivide the mainstream of the basin into multiple sub basins to enable more accurate routing and climate inputs along the mainstream. Additionally, some sub basins were also re-defined to coincide with various monitoring locations for calibration purpose. A total of 12 and 8 sub basins were used to represent the Mille and Logiya Basin respectively.

Within each sub basin, HRUs are created by AVSWAT. HRU creation in AVSWAT requires land use and soil threshold inputs (DiLuzio et al. 2001) in order to define the level of spatial detail to include in the model. These thresholds are applied to each sub basin and function to control the size and number of HRUs created. For example, if a sub basin has an area of deciduous forest in the original land use data that covered less than the land use threshold, the AVSWAT processing would convert the deciduous forest to the other land uses in the basin, proportional to their relative sizes that were above the land use threshold. For a more detailed description of the AVSWAT land use and soils threshold application refer to the AVSWAT manual (DiLuzio et al. 2001). The land use and soils threshold values used in this application were 20% and 10%, respectively, and were selected in order to keep the number of HRUs to a reasonable number. Application of these thresholds eliminated a few of the land uses and soils that covered relatively small areas in the basin and created a total of 53 HRUs and 29HRUs for Mille and Logiya watershed respectively. HRUs are not necessarily contiguous parcels of land. The model calculated surface runoff is unique to each HRU (e.g. influenced by the land use, soil and sub basin).Model simulations covered the period from Jan. 1979 through Dec. 2030 in daily time steps were made up of separate model runs for each basin (Logiya and Mille).

4.6 Flood Frequency Estimation

An important problem in hydrogly is the estimation of flood magnitudes, especially because planning and design of water resource projects and flood plain management depend on the frequency and magnitude of peak discharges. A flood event can be described as a multivariate even whose main characteristics can be summarized by its peak, volume, and duration, which may be correlated. However, flood frequency analysis has often concentrated on the analysis of flood peaks. Several summaries, discussions and extensive reviews of the field of flood frequency analysis are given by different authors.

In the statistical analysis of floods extreme value probability distribution are fitted to measured peak flows. This method is data intensive and is applicable only to gauge watersheds. Selection of probability distribution is generally arbitrary, as no physical basis is available to rationalize the use of any particular distribution. Several distributions, Log-Normal , Pearson type III, Wiebull , log person Type III, Generalized Extreme Value, to name a few , have been used and these may seem appropriate for a given sample of data. To check the validity of accepting a distribution, goodness-of –fit test is used.

The objective of the research discussed in this section is to use the watershed (Mille and Logiya) generated Rainfall-Runoff model data for a Comparative analysis, and determine the best distribution for each watershed. These distributions include Pearson type III (LP III), Generalized Extreme Value (GEV), Person Type III, Log Normal Gamma, three-parameter Lognormal (LN(3)) distribution, two parameter Wiebull distribution, three parameter Wiebull distribution.

The method of moments, maximum Likelihood and Probability weighted moments are used for parameter estimation(using Easyfit Application Tool).Distributions fitted by using these methods are tested by using the Chi-Square ,Kolomogorov-Smirnov ,Anderson daring tests The results of these goodness –of –fit tests are used to select a distribution for a region.

4.6.1Parameter and Quantile Estimation

In flood frequency analysis, an assumed probability distribution is fitted to the available data to estimate the flood magnitude for a specified return period. The choice of an appropriate probability distribution is quite arbitrary, as no physical basis is available to rationalize the use of any particular distribution. The first of error which is associated with wrong assumption of a particular distribution for the given data can be checked to a certain extent by using goodness-of-fit tests. These are statistical tests which provide a probabilistic framework to evaluate the adequacy of a distribution.

Even if an acceptable distribution is selected, proper estimation of parameters is important. Some of the parameter estimation methods may not yield good estimates, or even converge. Therefore, some guidance is needed about the parameter estimation methods. In this study the parameters estimation is done using the EasyFit application with proper parameter estimation method suitable for each distribution within the interface.

4.6.1.2 Parameter Estimation

Several methods can be used for parameter estimation. In this study, the method of moments (MOM), the maximum likelihood method (MLM) and the probability weighed moment method (PWM) are used for parameter estimation with the application tool (EasyFit).

The maximum likelihood method (MLM) is considered to be the most accurate method, especially for large data sets since it leads to efficient parameter estimators with Gaussian asymptotic distributions. It provides the smallest variance of the estimated parameters, and hence of the estimated quantiles, compared to other methods. However, with small samples the results may not converge.

The method of moments (MOM) is relatively easy and is more commonly used. It can also be used to obtain starting values for numerical procedures involved in ML estimation. However, MOM estimates are generally not as efficient as the ML estimates, especially for distributions with large number of parameters, because higher order moments are more likely to be used to obtain starting values for numerical procedure involved in ML estimation. However, MOM estimates are generally not as efficient as the ML estimate especially for distribution with large number of parameters, because higher order moments are more likely to be highly biased for relatively small samples.

The PWM method gives parameter estimates comparable to the ML estimates. Yet, in some case the estimation procedures are not as complicated as in other methods and the computations are simpler. Parameter estimates from samples using PWM are sometimes more accurate than the ML estimates. Easy Fit uses the least computationally intensive methods. Thus, it employs the method of moments for those distributions whose moment estimates are available for all possible parameter values, and do not involve the use of iterative numerical methods.

For many distributions, EasyFit uses the MLM method involving the maximization of the log-likelihood function. For some distributions, such as the 2-parameter Exponential and the 2-parameter Weibull, a closed form solution of this problem exists. For other distributions, EasyFit implements the numerical method for multi-dimensional function minimization. Given the initial parameter estimates vector, this method tries to improve it on each subsequent iteration. The algorithm terminates when the stopping criteria is satisfied (the specified accuracy of the estimation is reached, or the number of iterations reaches the specified maximum). The advanced continuous distributions are fitted using the MLM, the modified LSM, and the L-moments methods.

4.6.1.3 Quantile Estimation

After the parameters of a distribution are estimated, quantile estimates (x_T) which correspond to different return periods T may be computed. The return period is related to the probability of non-exceedence (F) by the relation,

$$F = 1 - \frac{1}{T} \text{ ---------------------------------------Eqn.4.22}$$

Where F=(x_T) is the probability of having a flood of magnitude x_T or smaller. The problem then reduces to evaluating x_T for a given value of F. In practice, two types of distribution functions are encountered. The first type is that which can be expressed in the inverse form $X_{T=}$Ø (F). In this case, X_T is evaluated by replacing Ø(F) by its value from equation 4.22. In the second type the distribution cannot be expressed directly in the inverse form x_T corresponding to a given value of Ø (F).

4.6.2 Selection of Probability Distribution

There are many distributions which are used in flood frequency analysis. A few distribution which are commonly use in modeling flood data, are listed below and are used in the present study.

a. Three-parameter Lognormal (LN(3)) Distribution
b. Two-parameter Lognormal distribution
c. Two-parameter Gamma
d. Three-parameter Gamma(Pearson (3) distribution)
e. Generalized Extreme Value (GEV) Distribution

The choice of distribution to be used in flood frequency analysis has been a topic of interest for a long time. The best probability distribution to be used to fit the observed data can not be determined analytically. Often, the selection of the distribution is based on an understanding of the underlying physical process. For example, the extreme value distribution might be an appropriate choice for annual peak floods. General shape of the distribution and descriptors like skewness and kurtosis indicate whether a particular distribution is appropriate to a given situation. If the sample data are insufficient, the reliability in estimating more than two or three parameters may be quite low. So, a compromise has to be made between flexibility of the distribution and reliability of the parameters.

To assess the reasonability of the selected distribution, statistical tests like Chi-Square test, kolmogrov-Smirnov tests, Anderson-Darling are used. The Chi square test, Kolmogrov-smirnov tests, Anderson-Darling tests are discussed below.

4.6.2.1 Chi –Square Test

In the chi-square test, data are first divided in to K class interval. The statistic X^2 in equation 4.23 is distributed as chi-square with k-1 degrees of freedom.

$$X^2 = \sum_{j=1}^{k} \frac{(O_j - E_j)}{E_j} \text{-- Eqn.4.23}$$

In equation4.23, Oj is the observed number of events in the class interval j,Ej is the number of events that would be expected from the theoretical distribution, and K is the number of classes to which the observed data are sorted. If the class intervals are chosen such that each interval corresponds to an equal probability, then Ej=n/k where n is the sample size and k is the number of class intervals and, equation 4.23 reduces to equation 4.24.

$$X^2 = \frac{k}{n}\sum_{j=1}^{k} O_j^2 - n \text{ --------------------------------------- Eqn.4.24}$$

Class intervals can be computed by using the inverse of the distribution function corresponding to different values probability F, Similar to estimation quantiles.

4.6.2.2 Kolmogrov-Smirnov Test

A statistic based on the deviations of the sample distribution function FN ((X) is use in this test. The test statistic DN is defined in equation 4.25.

$$D_N = \max / F_N(x) - F_O(x) / \text{ --------------------- Eqn.4.24}$$

The values of F_N (x) are estimated as N_j/N where N_j is the cumulative number of sample events in class j. $F_0(x)$ is then 1/K, 2/k…..etc. Similar to the
chi-square test. The value of D_N must be less than a tabulated value of D_N at the specified confidence level for the distribution to be accepted.

4.6.3 Procedure to Select the Distribution

The selection of probability distributions by using data from the watersheds (simulated data using swat2005) is discussed in this section. More than fourty types of probability distributions included within EasyFit statistical Application software .The probability distributions included in this study are mentioned in section 4.7and the detail of the probability functions are presented .

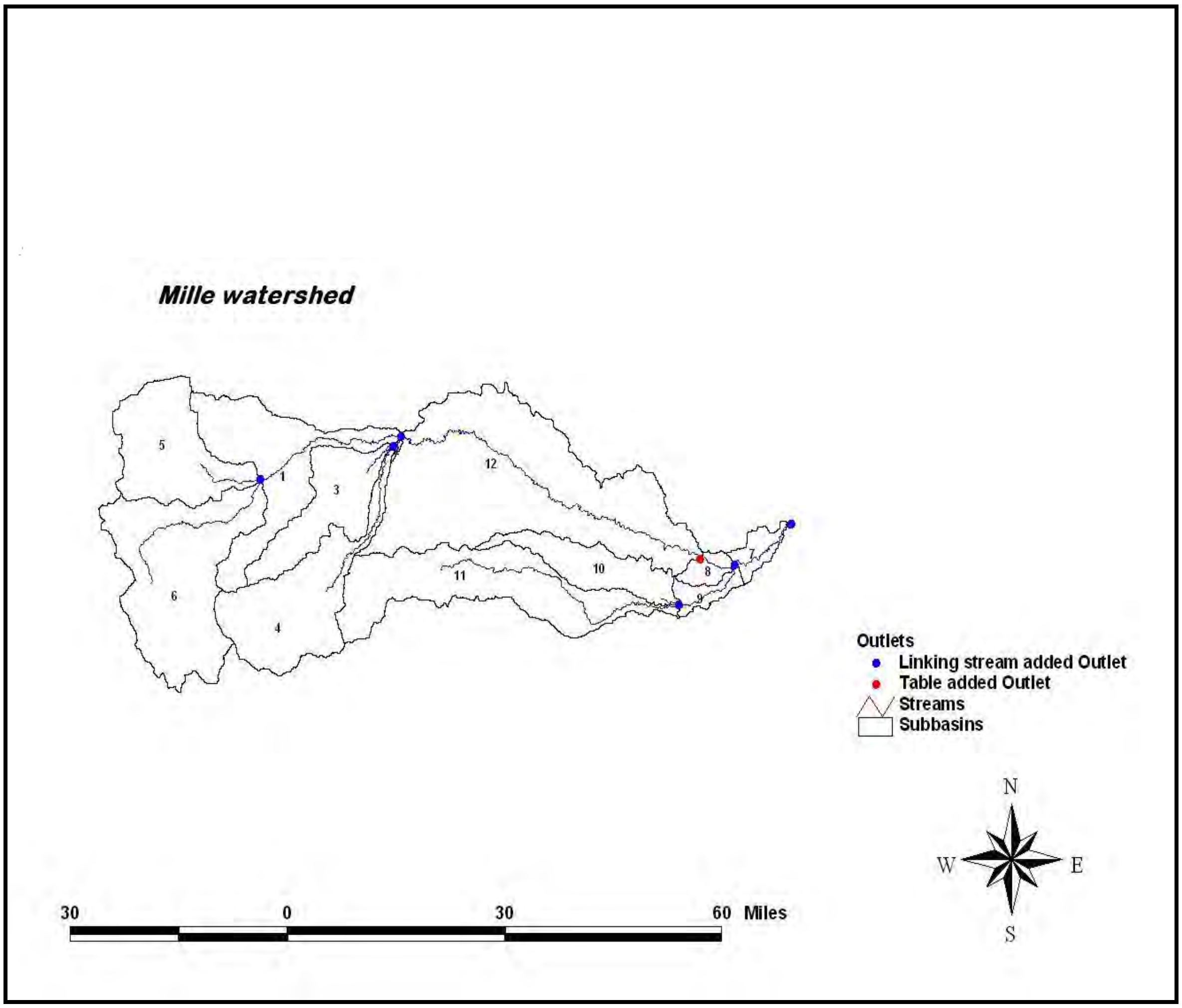
Method of moments, maximum likelihood and probability weighted moment were used to estimate the parameters for the data in the application software. These parameters are used to calculate the quintiles corresponding to return periods of , 10,20,25,50 and 100,500 years. Standard errors corresponding to the observed values are also obtained. Results of goodness of fit at 95% confidence limit are tabulated for each gage station in a region corresponding to each distribution is presented in section 5.2

5. RESULTS AND DISCUSSIONS

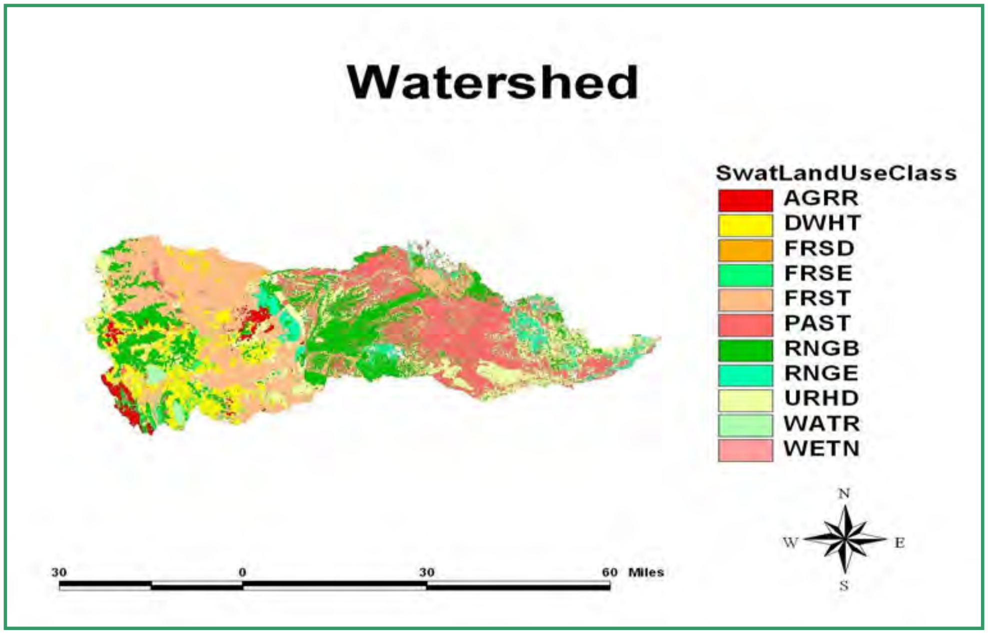
5.1 SWAT Hydrological Model Results

5.1.1 Flow Simulation for Mille Watershed

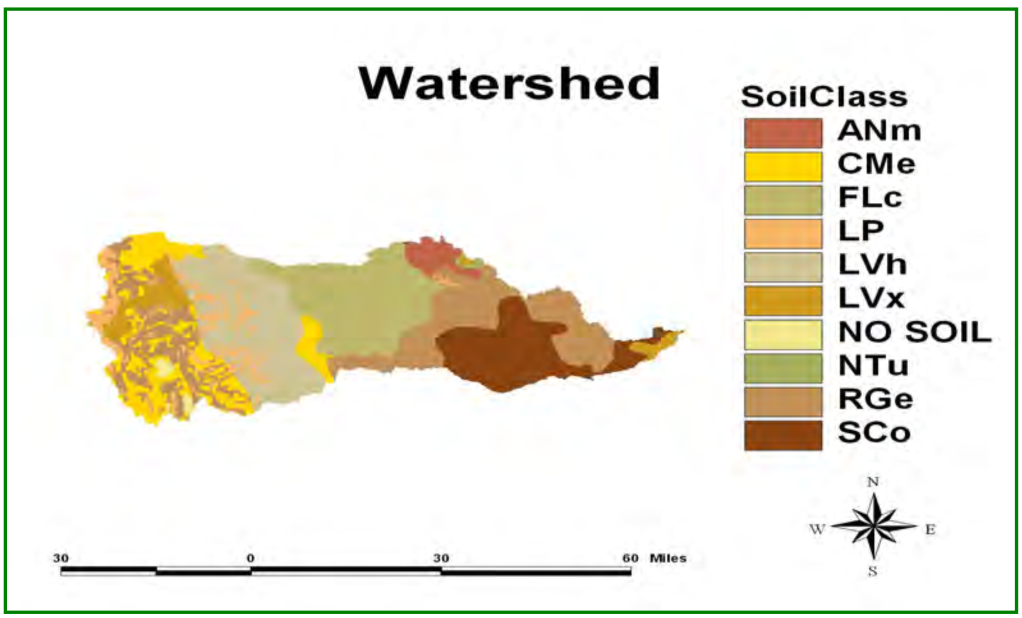
The Mille (Lower Awash) is one of the two main sub watersheds discharging flow to the Awash River. It is located in the western side of the Awash River and has elevations ranging from 409 to 3318 m.a.s.l. with a mean of 1863.5 m.a.s.l.



a) Delineated Sub basins



b) Land use Map



c) Soil Map

Figure 5.1: The delineated sub basins, land use, and soil map of the Mille Sub watershed

Totally, the sub watershed covers an area of 5570.154 km^2 and divided into 12 sub basins (based on a threshold area of 25,000 ha) and 52 HRUs. The area only up to the gauging stations at 033021 was considered for the calibration and validation purpose.

Table5.1: The land use types and their aerial coverage in Mille Subwatershed

Value	Land use	SWAT Land use Class	Area (Km^2)	% of Total Area
1	Agricultural land	AGRR	116.9732	2.1
2	Durum Wheat	DWHT	499.0857	8.96
3	Forest decidicious	FRSD	13.3684	0.24
4	Forest mixed	FRSE	65.7278	1.18
5		FRST	1467.1785	26.34
6	pasture	PAST	1184.7717	21.27
7	Range-Brush	RNGB	1057.7722	18.99
8	Range -Grasses	RNGE	208.3237	3.74
9	Urban	URHD	876.7422	15.74
10	Water body	WATER	15.03942	0.27
11	Wetland non forested	WETN	21.7236	0.39

As shown in figure 5.1 (b) and table 5.1, the sub watershed is composed of eleven land use types: (FRST) and water (WATR) covering the largest (26.34%) and smallest (0.27%) portion of it respectively. The land uses of the area were defined according to SWAT's system of nomenclature. The crop parameters corresponding to each of the above land uses are shown in *AppendixD*

Table5.2: The soil types and their aerial coverage in Mille Sub watershed

Value	*Soil Type*	*SWAT Soil Class*	*Area (Km^2)*	*% of Total Area*
2	*Mollic Andisol*	*ANm*	*140.9249*	*2.53*
4	*Eutric Cambisols*	*CMe*	*16.6291*	*11.80*
5	*Chromic Fluvisol*	*FLc*	*2.9799*	*17.92*
7	*Leptosol*	*Lp*	*0.1901*	*6.38*
8	*Humic Nitisols*	*NTu*	*15.5943*	*0.28*
9	*Chromic Luvisols*	*LVx*	*0.6894*	*4.42*
11	*EutricRegesol*	*RGe*	*1385.8543*	*24.88*
12	*OrticSolonachalk*	*SCo*	*755.3128*	*13.56*
10	*HaplicLuvisol*	*LVh*	*975.3339*	*17.51*
12	*Water Body*	*WBD*	*40.105*	*0.72*

Nine soil types are also identified in the sub watershed and the details are shown in table5.2and figure5.1 (c). The EutricRegesol , Chromic Fluvisol and HaplicLuvisol are the major soil types covering 24.88% ,17.92% and 17.51% of the overall sub watershed area, respectively. The smallest portion of the area is covered by Humic Nitisols.

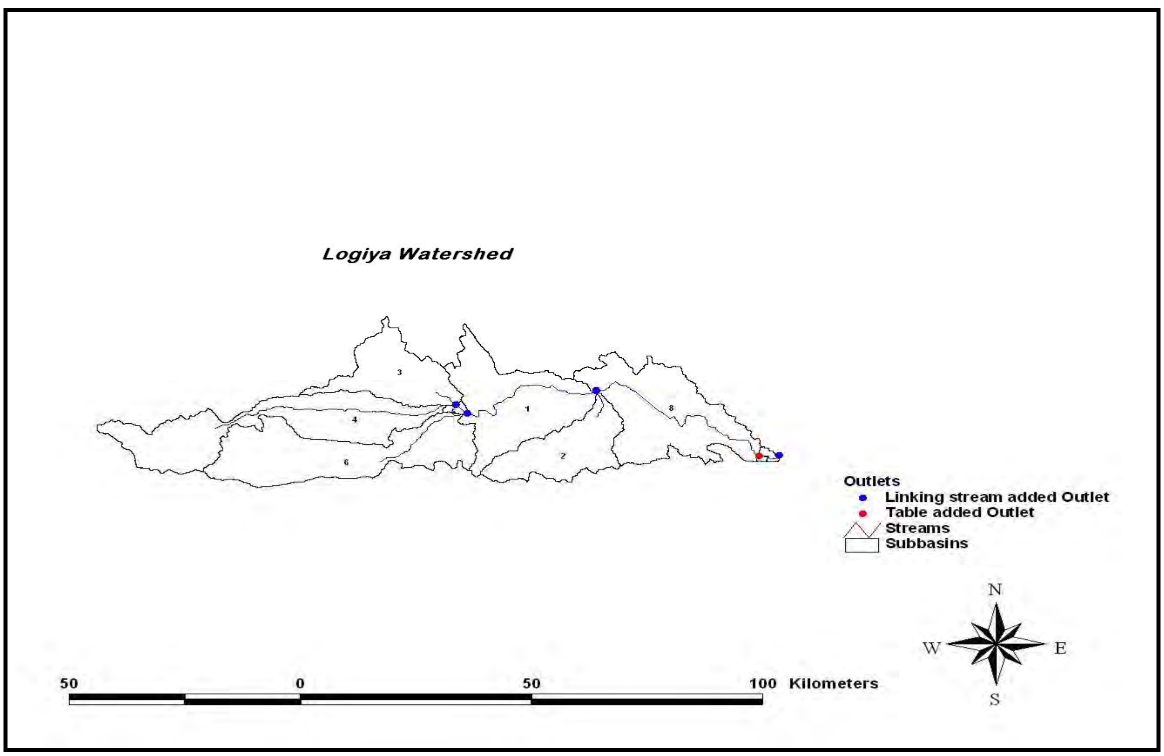
5.1.2 Flow Simulation for Logiya watershed

The Logiya (Lower Awash) is one of the two main sub watersheds discharging flow to the Awash River.

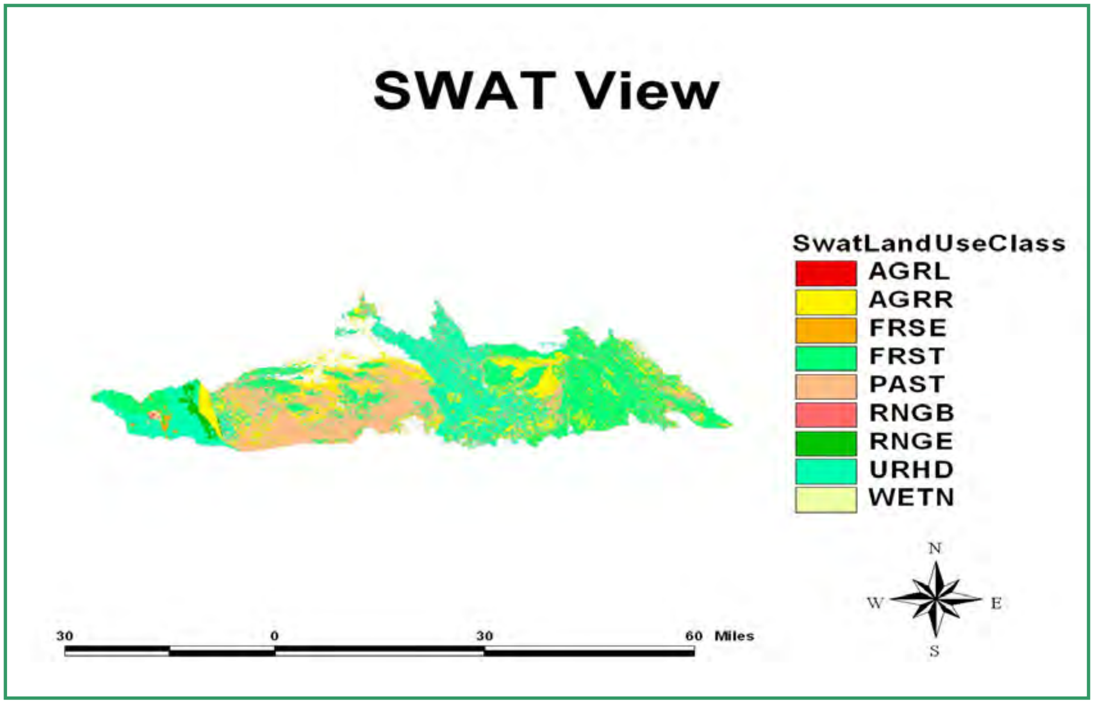
It is located in the western side of the Awash river and has elevations ranging from minimum elevation elevation to 384 to maximum elevation 2487 m.a.s.l. with a mean of 843.573 m.a.s.l and standard deviation 254.36m.a.s.l.

Totally, the sub watershed covers an area of 3197.968 km^2 and divided into eight sub basins (based on a threshold area of 25,000 ha) and 29 HRUs.

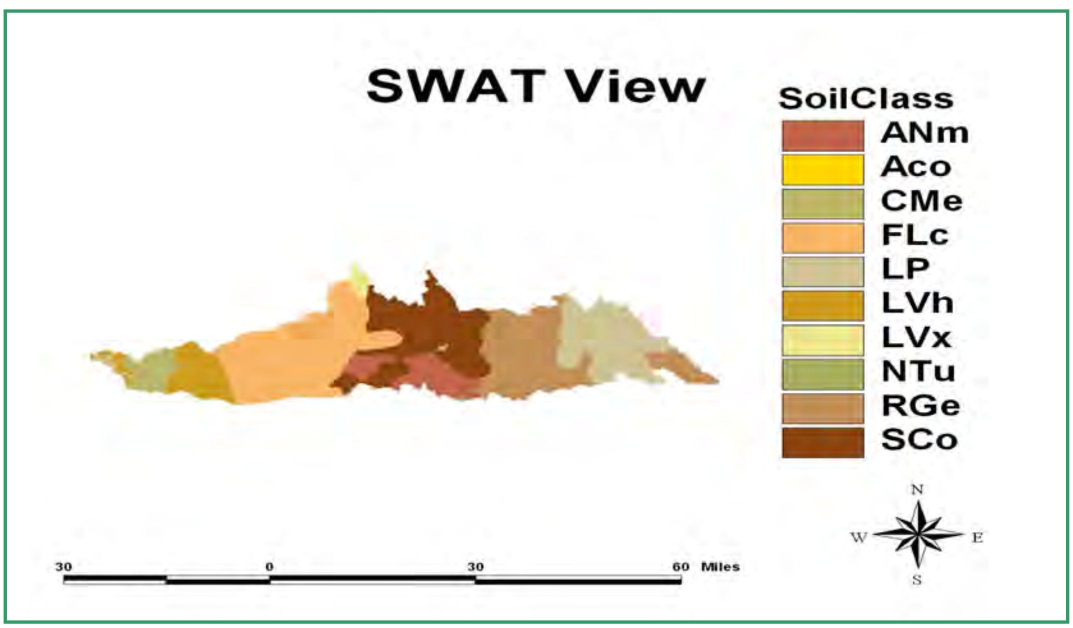
The area only up to the gauging station (one sub basin) was considered for the calibration and validation purpose Logiya at 033027(Ethiopian watershed code).



a)*Delineated Sub basins*



b) Land use Map



***c**) Soil Map*

Figure5.2: The delineated sub basins, land use, and soil map of the Logiya Sub watershed

Table5.3: The land use types and their aerial coverage in Logiya Sub watershed

Value	Land use	SWAT Land use Class	Area (Km^2)	% of Total Area
1	pasture	PAST	905.9843	28.33
2	Urban	URHD	753.4413	23.56
3		FRST	954.2736	29.84
4	Range-Brush	RNGB	2.8782	0.09
5	Range -Grasses	RNGE	34.5381	1.08
6	Forest mixed	FRSE	15.0304	0.47
7	Wetland non forested	WETN	6.0761	0.19
8	Agricultural land	AGRR	525.1063	16.42

As shown in figure5.2 b and table 5.3, the sub watershed is composed of eight land use types: (PAST), (URHD) andFRSTcovering 28.33%, 23.56% and29.84% the largest smallest portion of it respectively. The land uses of the area were defined according to SWAT's system of nomenclature. The crop parameters corresponding to each of the above land uses are shown in AppendixD.

Table5.4: The soil types and their aerial coverage in Logiya Sub watershed

No.	Soil Type	SWAT Soil Class	Area (Km^2)	% of Total Area
2	Mollic Andisol	ANm	226.7359	7.09
3	Eutric Cambisols	CMe	134.3146	4.2
4	Chromic Fluvisol	FLc	841.7052	26.32
5	Leptosol	LP	508.7967	15.91
6	Humic Nitisols	NTu	2.8782	0.09
7	Chromic Luvisols	LVx	31.9797	1.0
8	EutricRegesol	RGe	630.9591	19.73
9	OrticSolonachalk	SCo	604.0962	18.89
10	HaplicLuvisol	LVh	213.9440	6.69

Nine soil types are also identified in the Logiya sub watershed and the details are shown in table 5.4 and figure 5.2 (c). The Chromic Fluvisol and Eutric Vertisols (VRe) are the major soil types covering 26.32%and 19.73% of the overall sub watershed area, respectively. The smallest portion of the area is covered by Humic Nitisols..

5.1.3 Base Flow Separation for Mille and Logiya Sub watershed

The base flow separation using the base flow separator program based on the daily flow data measured at the outlet of the sub watershed at Mille and Logiya showed that 35.3%and37% of the flow is contributed by the base flow respectively and the rest by the surface runoff. This shows that the total stream flow is largely supplied by flow from the shallow aquifer. The base flow recession constant (alpha factor), which is the rate at which groundwater is returned to the stream, is found to be 0.0608and. **0.0528** respectively for Mille and Logiya watershed. The base flow days, which is the number of days for the base flow recession to decline through one log cycle, has a value of about 37.8068days and43.5927days respectively for Mille and Logiya watershed.

Table5.5 shows flow separation parameters for Mille watershed at033021

Base flow data file: this file summarizes the fraction of stream flow that is contributed by base flow for each of the 3 passes made by the program

Gage file	Base flow Fr1	Base flow Fr2	Base flow Fr3	Alpha Factor	Base flow Days
08095300.prn	0.48	0.32	0.26	0.0608	37.8068

Table5.6 shows flow separation parameters for Logiya watershed at033027

Base flow data file: this file summarizes the fraction of stream flow that is contributed by base flow for each of the 3 passes made by the program

Gage file	Base flow Fr1	Base flow Fr2	Base flow Fr3	Alpha Factor	Base flow Days
08095400.prn	0.49	0.34	0.27	0.0528	43.5927

5.1.4 Sensitivity Analysis for Mille and Logiya watershed

The sensitivity analysis was carried out for a period of five years, which included both the calibration period (from January 1st, 1990 to December 31st, 1995) were used for the sensitivity analysis.. As shown in table 5.6, the first eight parameters showed a relatively high sensitivity, being the curve number (CN2) the most sensitive of all. The three most sensitive parameters controlling the surface runoff in the sub watershed are the curve number (CN2), the soil

available water capacity (SOL_AWC), and the soil evaporation compensation factor (ESCO). With respect to the base flow, the threshold water depth in the shallow aquifer for flow (GWQMN), the saturated hydraulic conductivity (sol_k), the deep aquifer percolation fraction (rchrg_dp), and the groundwater revap coefficient (GW_REVAP) have the highest influence in controlling the flow. The relative sensitivity of all the twenty seven parameters are presented on the appendix.

Table5.7: Result of the sensitivity analysis of flow in Mille watershed

Rank	**Parameters**	**Description**	**Lower bound**	**Upper bound**	**Relative sensitivity**	**Catagory of sensitivity**
1	CN2	Initial SCS CN II value	-50%	50%	1.95	High
4	GWQMN	Threshold water depth in the shallow aquifer for flow [mm]	0.00	3000.00	0.204	High
3	SOL_AWC	Soil available water capacity [mm WATER/mm soil	-50%	50%	0.346	High
2	ESCO	Soil evaporation compensation factor	0.00	1.00	0.435	High
7	SLOPE	Average slope steepness [m/m]	0.00	0.60	0.09	High
10	sol_k	Saturated hydraulic conductivity [mm/hr]	-50%	50%	0.0532	High
5	rchrg_dp	Deep aquifer percolation fraction	0.00	1	0.26	High
6	sol_z	Soil depth [mm]	-50	+50%	0.145	High
8	GW_REVAP	Groundwater "revap" coefficient	0.02	0.20	0.0651	Medium
11	BIOMIX	Biological mixing efficiency	0.00	1.00	0.0245	Medium
13	CH_K2	Channel effective hydraulic conductivity [mm/hr]	0.00	150.00	0.0168	Small
9	canmx	Maximum canopy storage [mm]	0.00	10.00	0.0570	Small
15	surlag	Surface runoff lag time [days]	0.00	10.00	0.00745	Small
12	epco	Plant uptake compensation factor	-50%	+50%	0.0185	Small
14	ALPHA_BF	Alpha factor	0	1	0.00908	small

5.1.5 Flow Calibration for the Mille and Logiya watersheds

Flow calibration was performed a period of five years from January 1st, 1990 to December 31st, 1994 for daily peak surface runoff using the sensitive parameters identified. However, flow was simulated for five years from January 1st, 1989 to December 31st, 1994, within which the first year was considered as a *warm up* period. As discussed previously in section 4, the flow was calibrated manually using the observed flow gauged at the outlet of the sub watershed at Mille(Gauge033021) and Logiya(Gauge033027).

First of all, both the surface runoff and base flow components of the gauged flow were balanced with that of the simulated flow. Here the model was adjusted to calculate the potential evapotranspiration of this sub watershed by using the Hargreaves Method. Afterwards the adjusted flow was further calibrated temporally by making delicate adjustments to ensure best fitting of the simulated flow curves with the gauged flow curves. Manipulation of the parameter values were carried out within the allowable ranges recommended by SWAT developers. The initial/default and finally adjusted parameter values are shown in table 5.8.

The final values of the performance optimization parameters in this work were fine –tuned by a trial and error approach as opposed to any automatic calibration procedure. As a result ,the number of performance optimization parameters modified during the calibration was kept to a minimum relative to the total number of SWAT parameters available for calibration .The performance optimization parameters were modified iteratively ,within SWAT 2005 ranges ,and generally one at a time ,until no further significant improvement in model predictive performance was evident.

Table5.8 Initial/default and finally adjusted parameter values for the water shed

Parameter (SWAT variable name)	Change	Final Value(Defaul value)
Threshold water depth in the shallow aquifer for return flow to occure flow [mm](GWQMN)	Increase to create groundwater storage capacity]	8000mm(0mm)
SCSCurveNumber(CN 2)Multiplicative adjustment factor)	Reduce base CN2 by 25%(relative to their base value)	Varied by HRU outlined in appendix()
Manning's n for overland flow (OV_N)	Constant value for all land use due to extermily short model simulated time of concentrations for the majority of HRUs	0.25(varied by land use)
Surface runoff lag coefficient(SURLAG)	Reduce so that some portion of surface runoff is lagged 1.5 day before reaching the channel	1(4.0)
Lateral flow travel time(LAT_TIME)	Fixed for all HRUs so that lateral flowlag time was greater than surface runoff lag time	4days(calculated by the model and varied by HRU)
Available water capacity for all soils(AWC)	Increase base values by 78% for layer1inputs and 30%for all other layers so soil could hold more water; change related to decrease in rock fragment volume	Varied by HRU soil type
Soil evaporation compensation factor(ESCO)	Reduce to allow more evaporation from lower soil layer	0.7(0.95)
Base flow alpha factor(BF_ALPHA)	Increase to simulate steeper hydrograph recession	0.0528 for Logiya 0.0608forMille (0.048)
Ground water delay time(GW_DELAY)	Decreased so that ground water return flow occurs more quickly (increases the time between water exits the soil profile and enters the shallow aquifer)	20 (31days)
rchrg_dp	Deep aquifer percolation fraction	(0.275)0.05

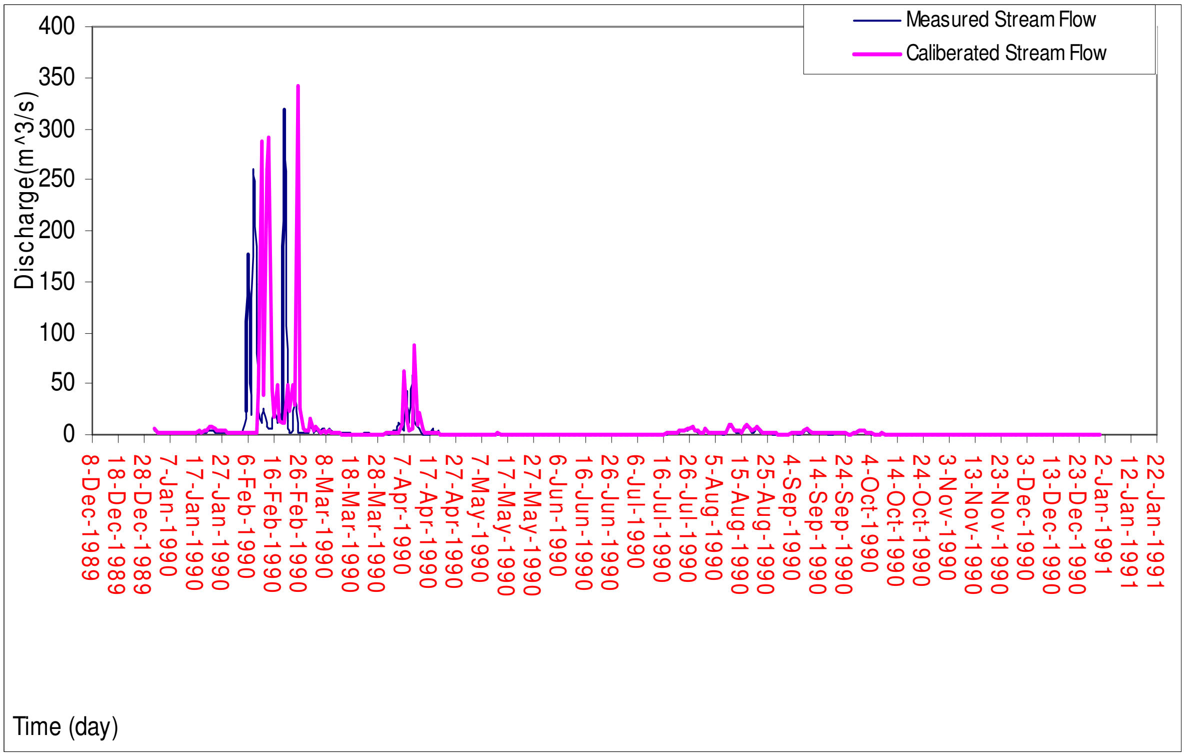
Table 5.9 Calibration statistics of simulated and gauged daily peak flow
Flows at the outlet of Mlle Watershed at 033021

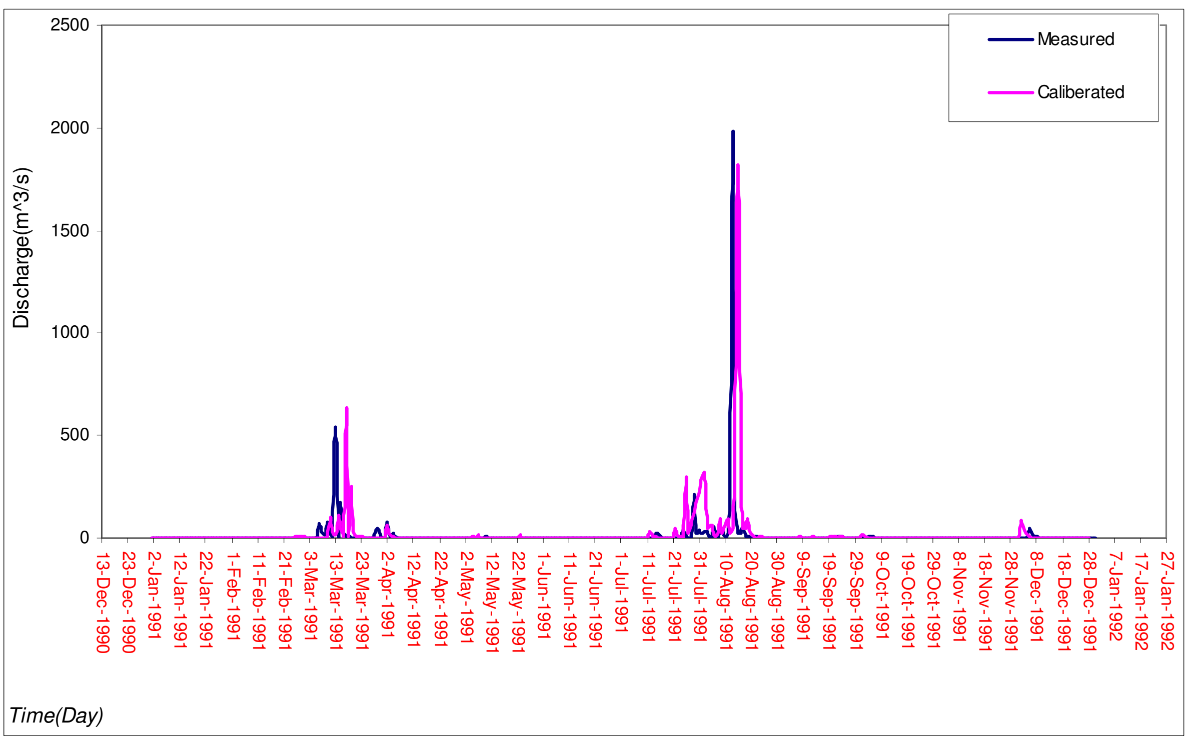
Period Daily	Total Flow (m^3/s)		% Error	R^2	E_{NS}
	Observed	Simulated			
(1990-1994)	14800.4	17795	20.2	0.78	0.71

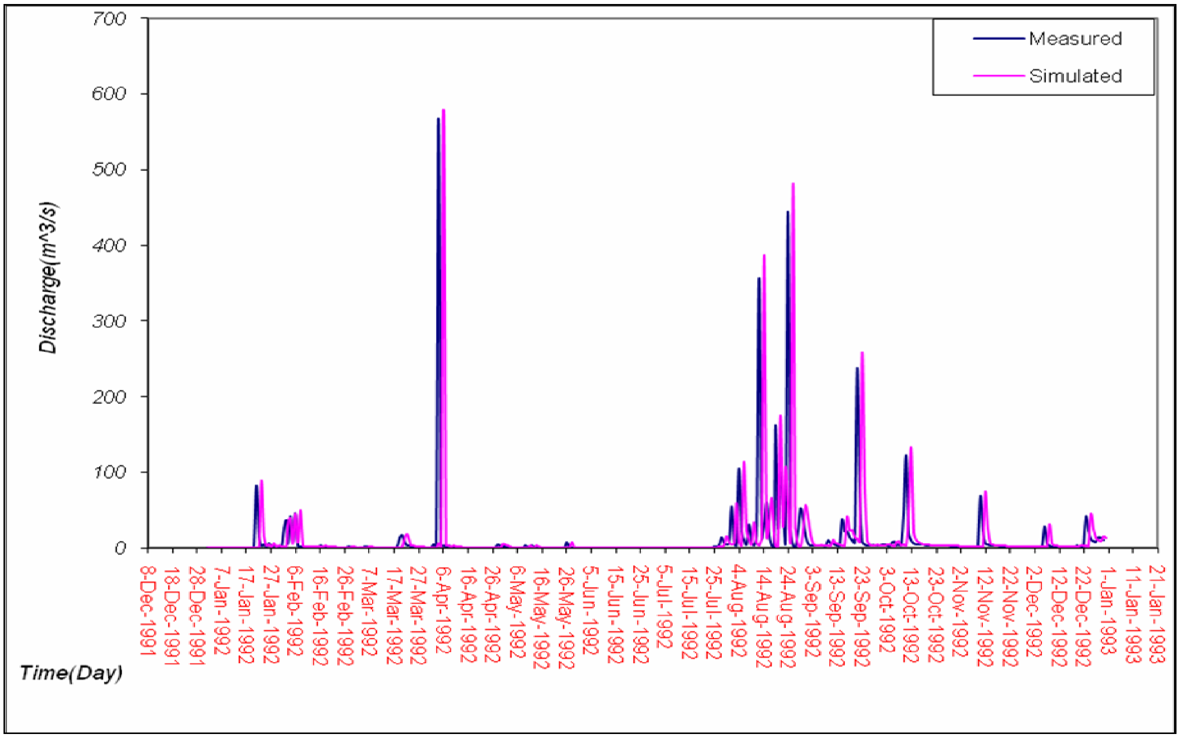
Table 5.10Calibration statistics of simulated and gauged daily peak flows at the outlet of logiya watershed at 033027

Period Daily	Total Flow (m^3/s)		% Error	R^2	E_{NS}
	Observed	Simulated			
(1990-1994)	3905.88	4980.6	27.5	0.71	0.69

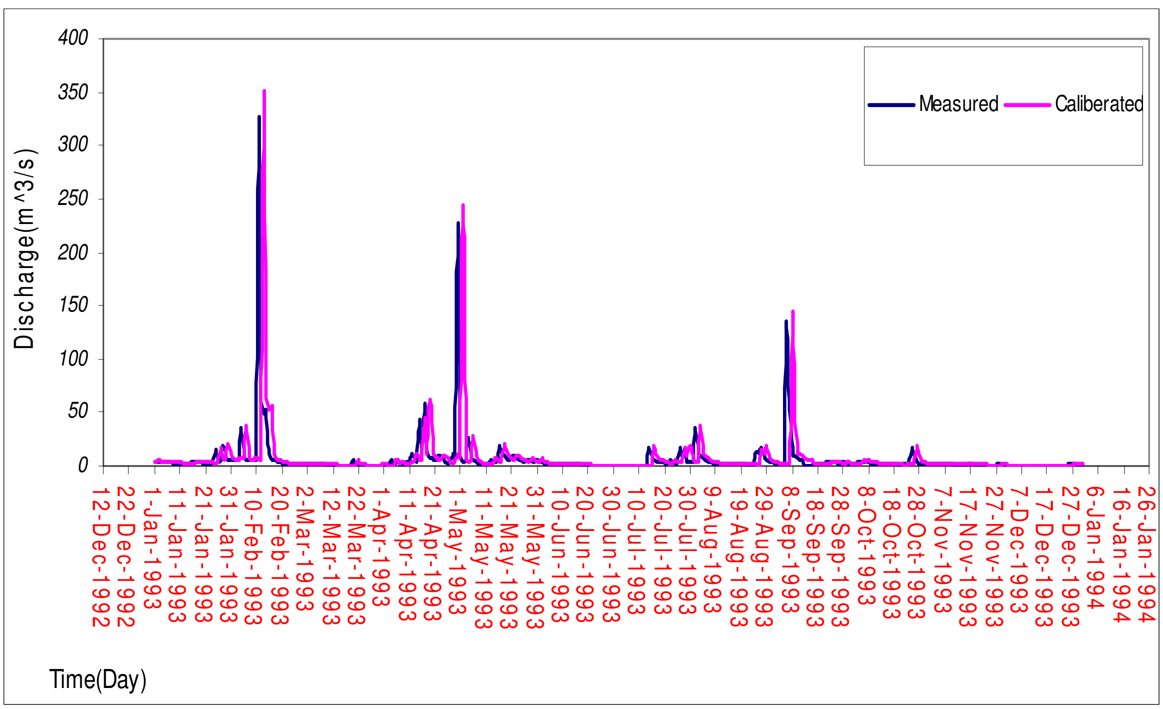
The calibration results in table 5.8 and 5.9 show that there is a good agreement between the simulated and gauged monthly flows. This is demonstrated by the correlation coefficient (R^2=0.78) and the Nash-Suttcliffe (1970) simulation efficiency (E_{NS}=0.71) values for Mille watershed and(R^2=0.71 and the Nash-Suttcliffe (1970) simulation efficiency (E_{NS}=0.69)Values for logiya watershed . The results fulfilled the requirements suggested by Santhi *et al.* (2001) for R^2 >0.6 and E_{NS} > 0.5


Measured Stream Flow
Caliberated Stream Flow
Discharge(m^3/s)
Time (day)


Measured
Caliberated
Discharge(m^3/s)
Time(Day)



700
600
500
400
300
200
100
0
Discharge(m^3/s)
Measured
Simulated
8-Dec-1991
18-Dec-1991
28-Dec-1991
7-Jan-1992
17-Jan-1992
27-Jan-1992
6-Feb-1992
16-Feb-1992
26-Feb-1992
7-Mar-1992
17-Mar-1992
27-Mar-1992
6-Apr-1992
16-Apr-1992
26-Apr-1992
6-May-1992
16-May-1992
26-May-1992
5-Jun-1992
15-Jun-1992
25-Jun-1992
5-Jul-1992
15-Jul-1992
25-Jul-1992
4-Aug-1992
14-Aug-1992
24-Aug-1992
3-Sep-1992
13-Sep-1992
23-Sep-1992
3-Oct-1992
13-Oct-1992
23-Oct-1992
2-Nov-1992
12-Nov-1992
22-Nov-1992
2-Dec-1992
12-Dec-1992
22-Dec-1992
1-Jan-1993
11-Jan-1993
21-Jan-1993
Time(Day)



400
350
300
250
200
150
100
50
0
Discharge(m^3/s)
Measured
Caliberated
12-Dec-1992
22-Dec-1992
1-Jan-1993
11-Jan-1993
21-Jan-1993
31-Jan-1993
10-Feb-1993
20-Feb-1993
2-Mar-1993
12-Mar-1993
22-Mar-1993
1-Apr-1993
11-Apr-1993
21-Apr-1993
1-May-1993
11-May-1993
21-May-1993
31-May-1993
10-Jun-1993
20-Jun-1993
30-Jun-1993
10-Jul-1993
20-Jul-1993
30-Jul-1993
9-Aug-1993
19-Aug-1993
29-Aug-1993
8-Sep-1993
18-Sep-1993
28-Sep-1993
8-Oct-1993
18-Oct-1993
28-Oct-1993
7-Nov-1993
17-Nov-1993
27-Nov-1993
7-Dec-1993
17-Dec-1993
27-Dec-1993
6-Jan-1994
16-Jan-1994
26-Jan-1994
Time(Day)

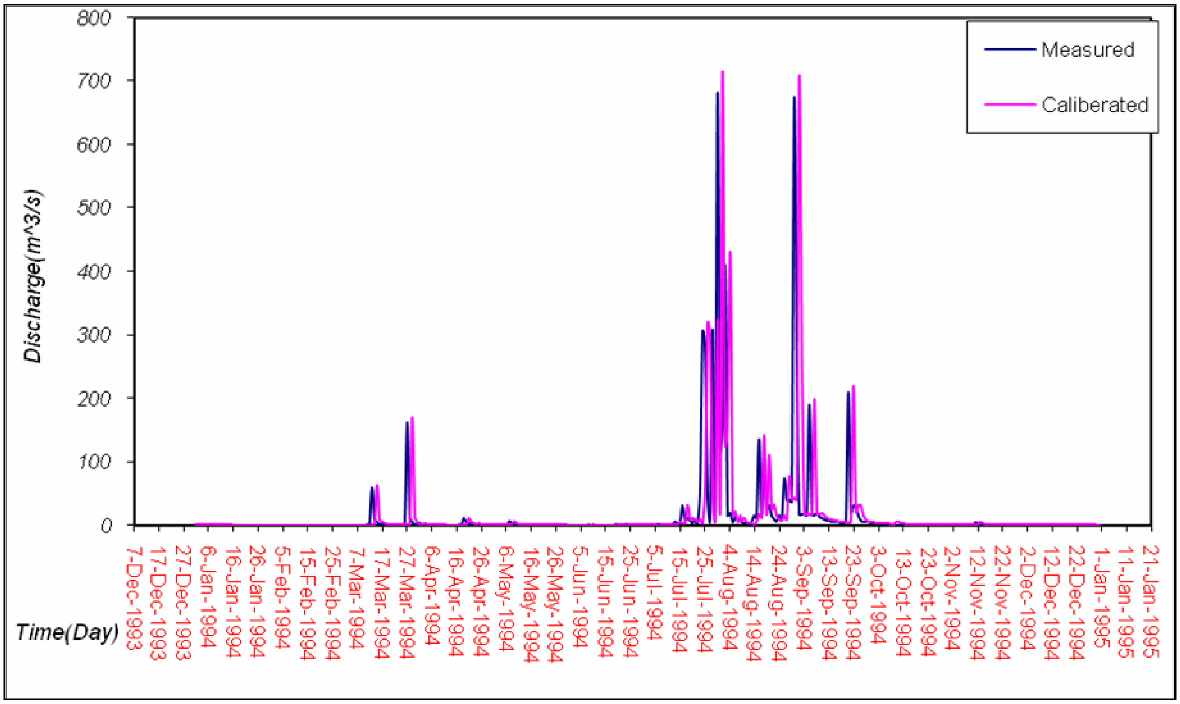
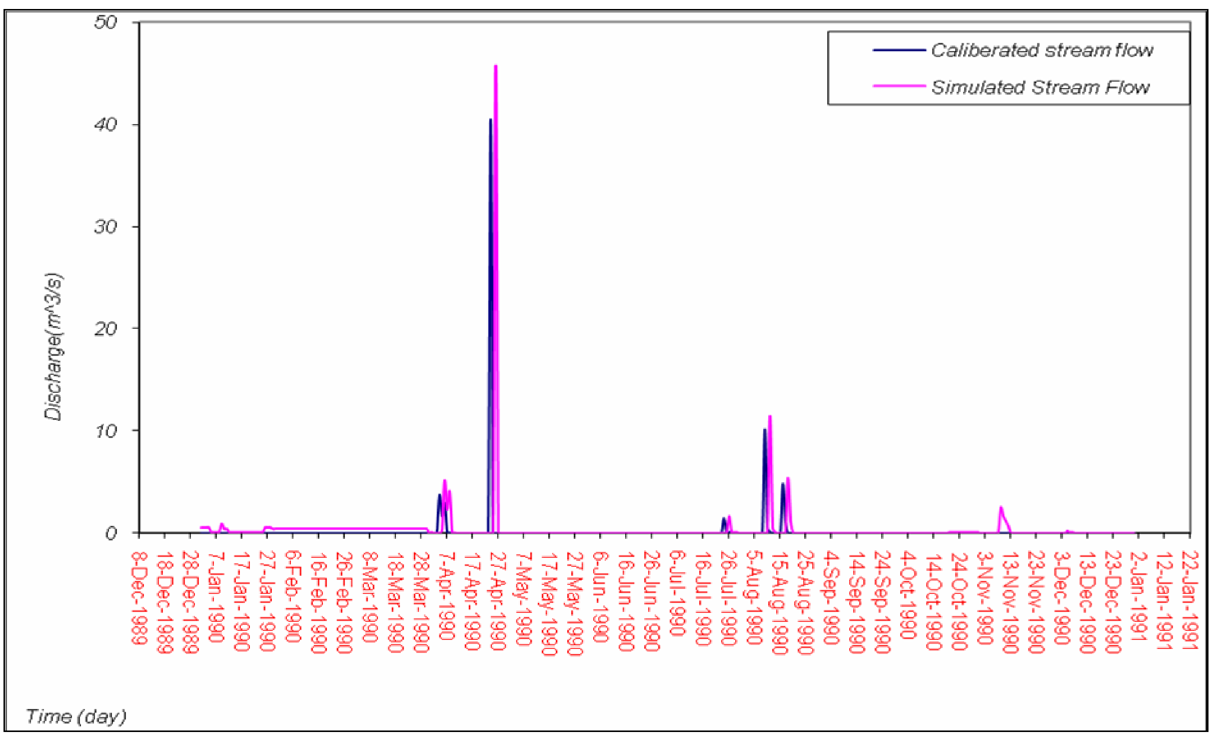
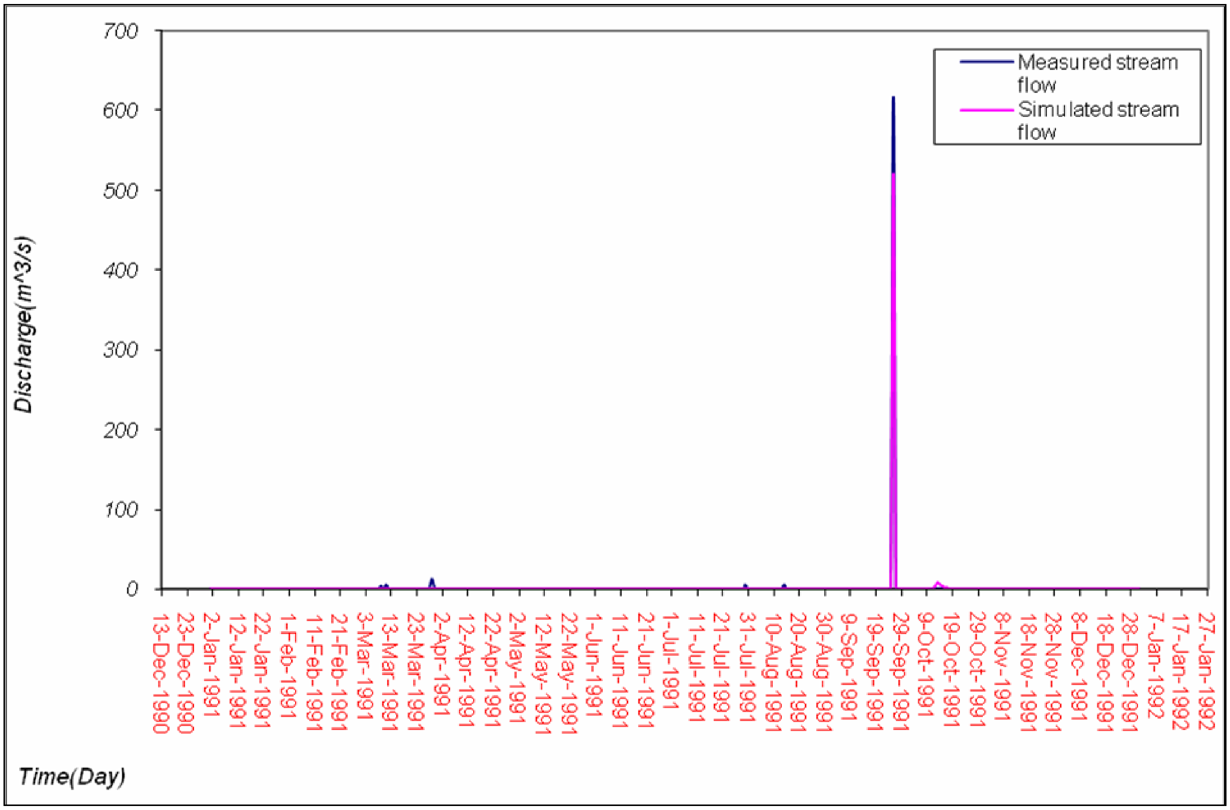
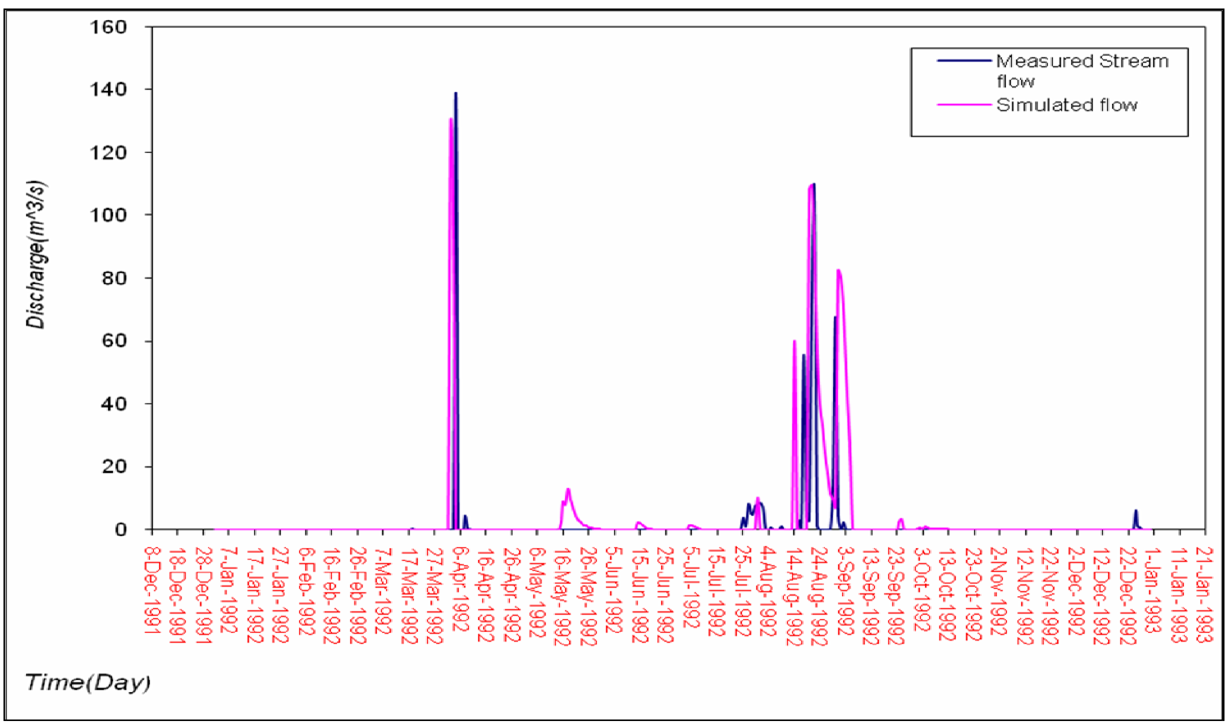


Figure5.3: Calibration result of Daily simulated and gauged flows at the outlet of Mille watershed at 033021




Discharge(m^3/s)
Time(Day)
Measured stream flow
Simulated stream flow
0
100
200
300
400
500
600
700
13-Dec-1990
23-Dec-1990
2-Jan-1991
12-Jan-1991
22-Jan-1991
1-Feb-1991
11-Feb-1991
21-Feb-1991
3-Mar-1991
13-Mar-1991
23-Mar-1991
2-Apr-1991
12-Apr-1991
22-Apr-1991
2-May-1991
12-May-1991
22-May-1991
1-Jun-1991
11-Jun-1991
21-Jun-1991
1-Jul-1991
11-Jul-1991
21-Jul-1991
31-Jul-1991
10-Aug-1991
20-Aug-1991
30-Aug-1991
9-Sep-1991
19-Sep-1991
29-Sep-1991
9-Oct-1991
19-Oct-1991
29-Oct-1991
8-Nov-1991
18-Nov-1991
28-Nov-1991
8-Dec-1991
18-Dec-1991
28-Dec-1991
7-Jan-1992
17-Jan-1992
27-Jan-1992


Discharge(m^3/s)
Time(Day)
Measured Stream flow
Simulated flow
0
20
40
60
80
100
120
140
160
8-Dec-1991
18-Dec-1991
28-Dec-1991
7-Jan-1992
17-Jan-1992
27-Jan-1992
6-Feb-1992
16-Feb-1992
26-Feb-1992
7-Mar-1992
17-Mar-1992
27-Mar-1992
6-Apr-1992
16-Apr-1992
26-Apr-1992
6-May-1992
16-May-1992
26-May-1992
5-Jun-1992
15-Jun-1992
25-Jun-1992
5-Jul-1992
15-Jul-1992
25-Jul-1992
4-Aug-1992
14-Aug-1992
24-Aug-1992
3-Sep-1992
13-Sep-1992
23-Sep-1992
3-Oct-1992
13-Oct-1992
23-Oct-1992
2-Nov-1992
12-Nov-1992
22-Nov-1992
2-Dec-1992
12-Dec-1992
22-Dec-1992
1-Jan-1993
11-Jan-1993
21-Jan-1993

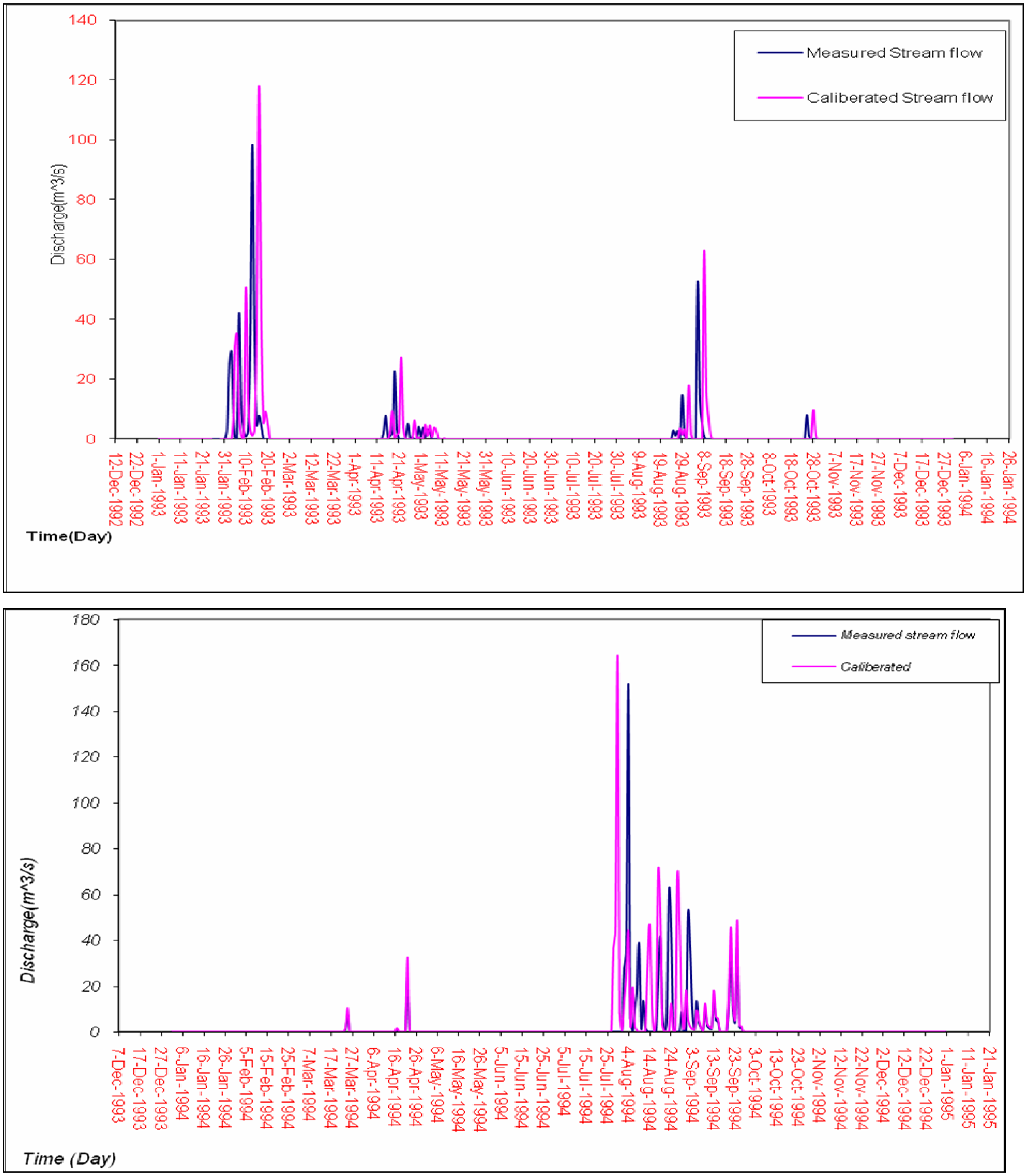


Figure5.4: Calibration result of daily simulated peak flow rate and gauged flows at the outlet of Logiya watershed at 033021

5.1.6 Flow Validation of the Watersheds

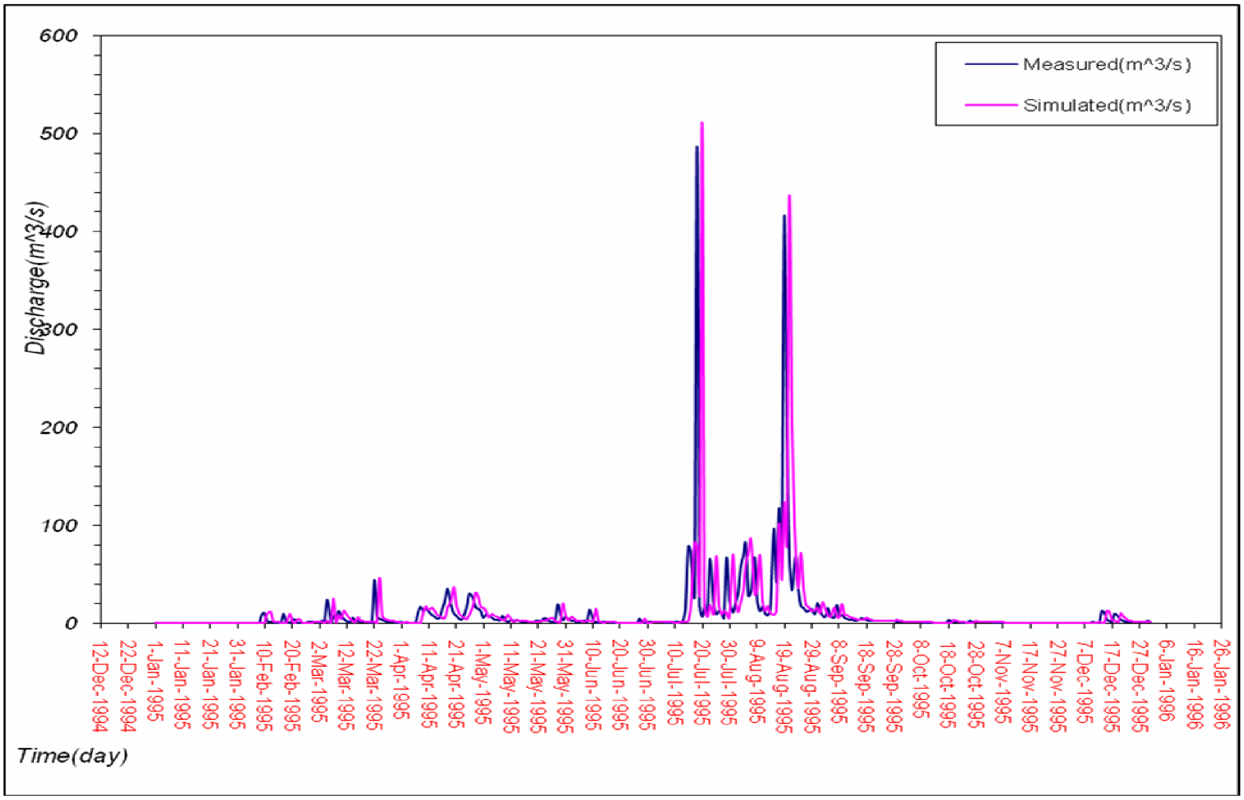
Validation, as discussed previously, proves the performance of the model for simulated flows in periods different than the calibration periods, but without any further adjustment in the calibrated parameters. Consequently, validation was performed for four years period from January 1st, 1995to December 31st, 1998 for Mille and Logiya watershed.

Table5.11: Validation statistics of the daily peak simulated and gauged flows at the outlet of Mille watershed @ 033021

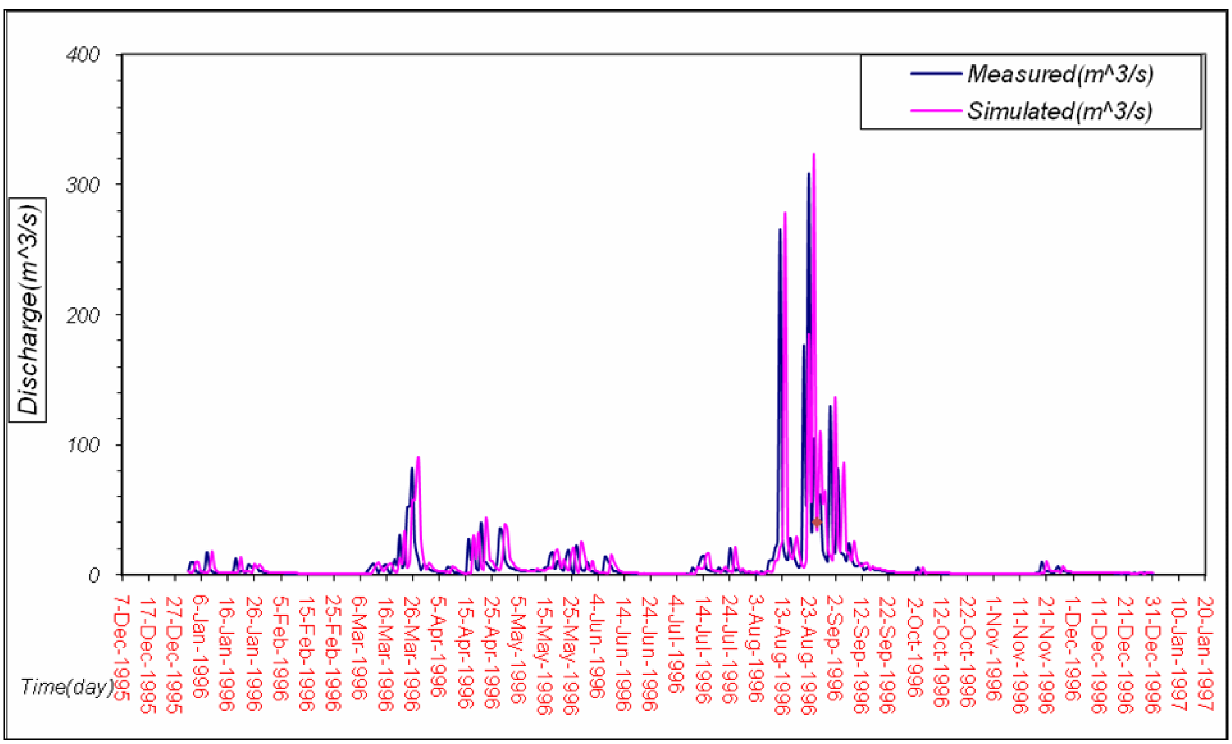
Period daily	Total Flow (m^3/s)		% Error	R^2	E_{NS}
	Observed	Simulated			
(1995-1998)	17046	20279.3	18.9	0.75	0.70

Table5.12: Validation statistics of the daily peak simulated and gauged flows at the outlet of Logiya watershed *at Logiya@033027*

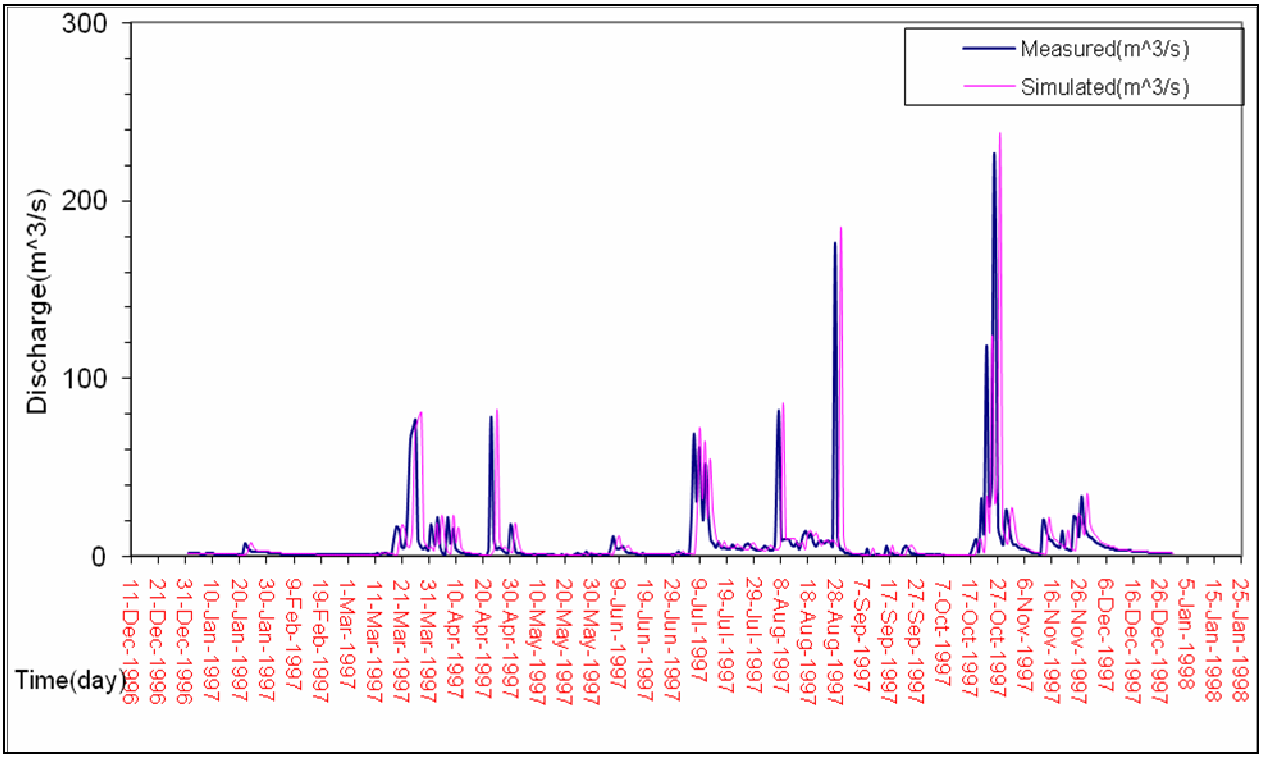
Period daily	Total Flow (m^3/s)		% Error	R^2	E_{NS}
	Observed	Simulated			
(1995-1998)	5436.4	6295.5	15.8	0.81	0.79



Measured(m^3/s)
Simulated(m^3/s)
Discharge(m^3/s)
Time(day)



Measured(m^3/s)
Simulated(m^3/s)
Discharge(m^3/s)
Time(day)



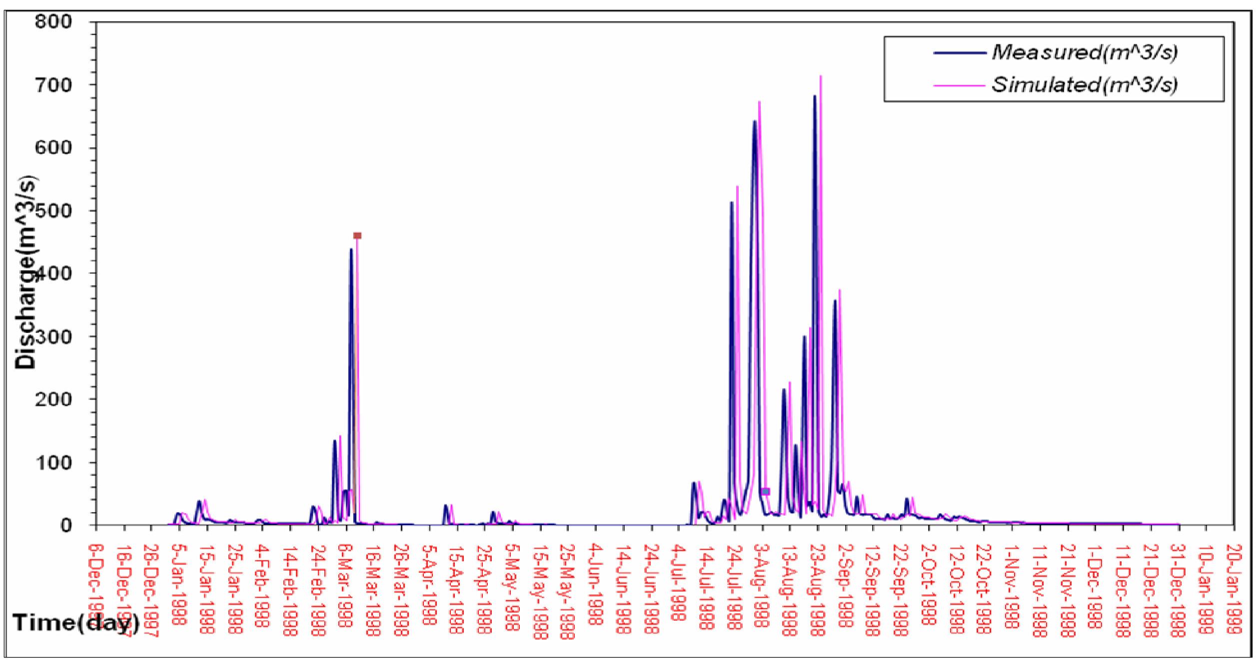
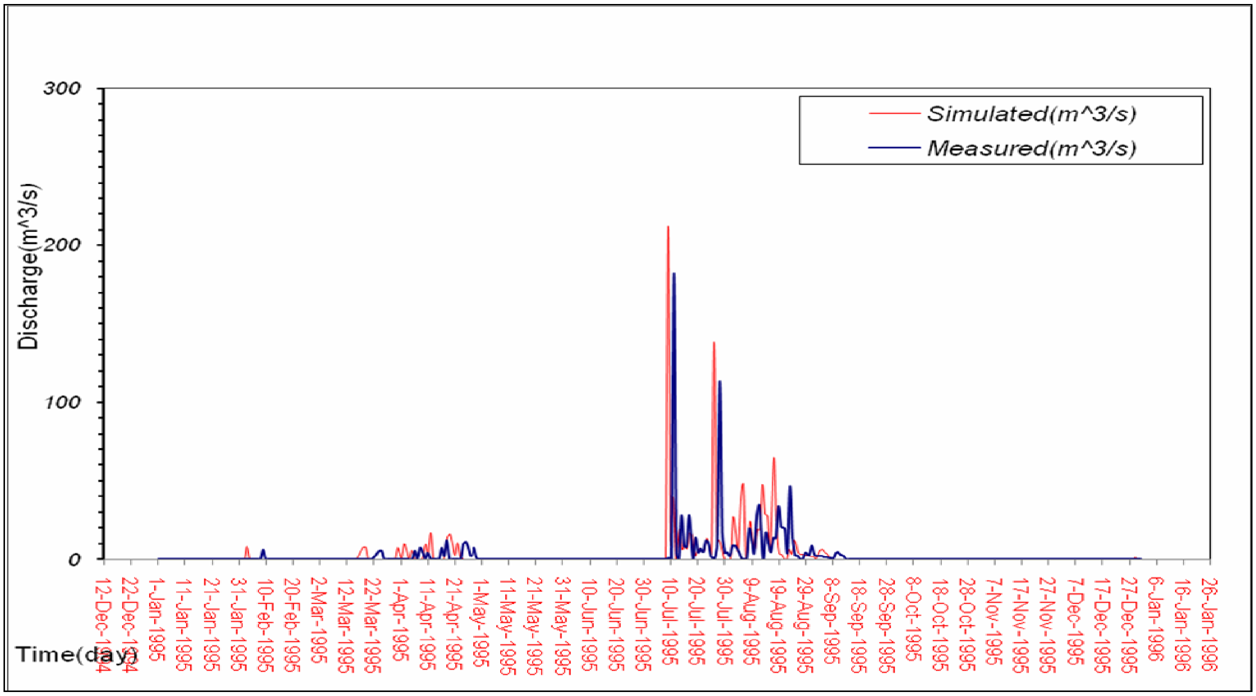
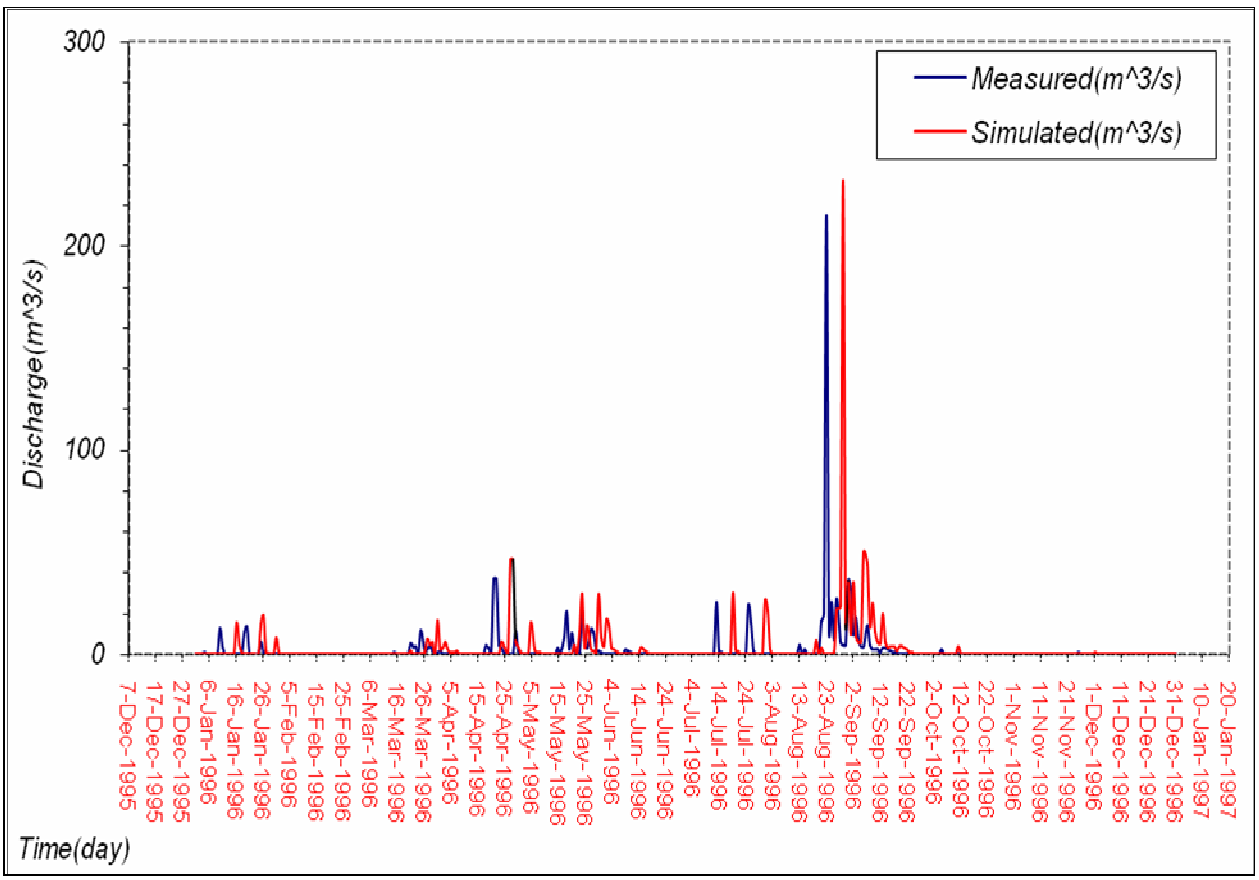


Figure5.5: Validation result of daily peak simulated and gauged flows at the outlet of Mille Sub watershed at Mille@033027.



Simulated(m^3/s)
Measured(m^3/s)
Discharge(m^3/s)
Time(day)



Measured(m^3/s)
Simulated(m^3/s)
Discharge(m^3/s)
Time(day)

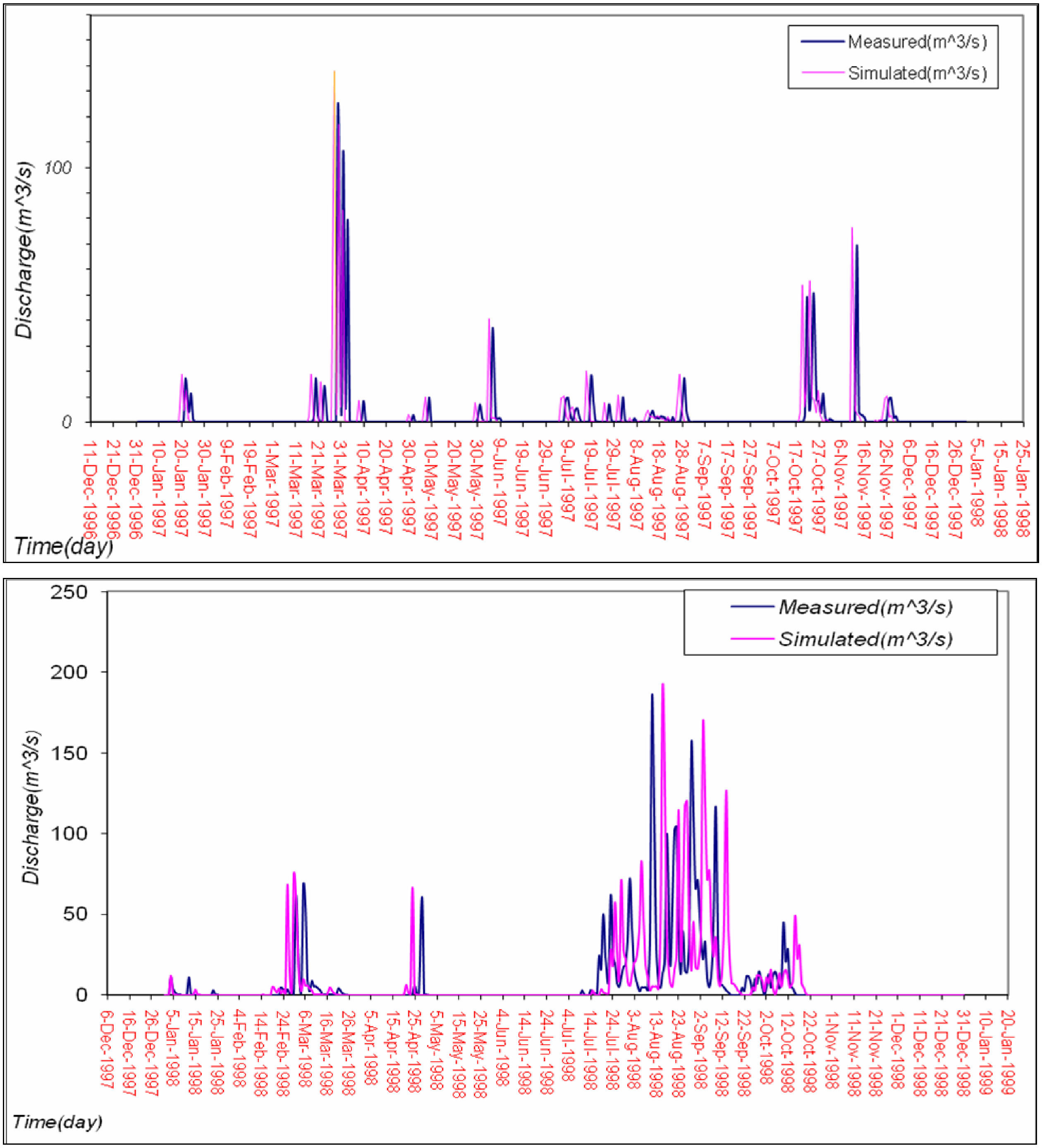


Figure5.6: Validation result of daily peak simulated and gauged flows at the outlet of Logiy Sub watershed at Logiya@033027

These results show that the model has again simulated the flow well resulting in best fit curves to the gauged flow within this time period.The Model performed well in simulating flows for periods outside of the calibration based on parameters adjusted during the calibration period. Therefore, these adjusted parameters can be considered to be accurately explaining the hydrologic characteristic of the mille and Logiya Sub watershed. As a result, further simulations can be carried out by using these parameters for any extra period of time.

The SWAT model was simulated for fifty years from Jan 1^{st},1979 to Dec 31,2029 for the two watersheds Mille and Logiya using the above calibrated parameters . The generated flow data is too much as it generates in a daily time base and the peak discharges is filtered from this simulated data set and used for the further flood frequency analysis.

5.2 Flood Frequency Analysis Result and Discussion

5.2.1 Selection of Distribution

In this paper Easy Fit application is used for selection of best fit distribution to the stream flow data generated using SWAT MODEL for Mille and Logiya watershed at 033021 and Logiya watershed at 033027(Ethiopian Code for gauging station).

EasyFit is a data analysis and simulation application allowing tofit probability distributions to sample data, select the best model, and apply the analysis results to make decisions. EasyFit can be used as a stand-alone Windows application; EasyFit combines classical statistical analysis methods and innovative data analysis techniques, making it a tool of choice for anyone dealing with probability data. Product features include: support for more than 40 continuous and discrete distribution; powerful automated fitting mode combined with flexible manual fitting capability interactive graphs, goodness of fit tests**,** random number generation. In this paper With EasyFit, analyze large data sets of 50 years generated peak flow data using SWAT MODEL_2005 for both watersheds (Mille and Logiya). To improve the validity of the statistical models and to select the best fit distribution for the watersheds, apply the following procedure within the application software:- select the advance distributions, enter and manipulate data using an Excel-Like spreadsheet, , organize the data and analysis Files(analysis descriptive statistics and fitting distribution parameters), view goodness of fit tests and distribution graphs .The latest version of EasyFit can be downloaded from http://www.mathwave. com/products/easyfit.html.

5.2.2 Descriptive Statistics Result

Easy Fit calculates and display the following basic statistics: sample size; minimum value; maximum value; range; mean; median; variance; standard deviation; coefficient of variation; standard error; skewness; (excess) kurtosis; 5%, 10%, 25%, 75%, 90%, and 95% percentiles for the Mille and Logiya watersheds.

Table 5.13: Descriptive statistics result for Mille watershed @033021

Statistic	**Value**	**Percentile**	**Value**
Sample Size	54	5%	93.37
Range	721.27	10%	117.845
Mean	389.063796	25% (Q1)	134.685
Variance	44634.7197	50% (Median)	223.8375
Std. Deviation	211.269306	75% (Q3)	309.5
Coef. of Variation	0.543019701	90%	557.3655
Std. Error	28.750111	95%	741
Skewness	0.56303818	Max	768
Kurtosis	-0.931158862	Max	814.64

Table5.14Descriptive statistics result for Logiya watershed @033027

Statistic	**Value**	**Percentile**	**Value**
Sample Size	54	Min	41.5178571
Range	325.070143	5%	52.8883929
Mean	172.085596	10%	60.3761071
Variance	8719.76577	25% (Q1)	100.726875
Std. Deviation	93.3796861	50% (Median)	138.112857
Coef. of Variation	0.54263511	75% (Q3)	244.832625
Std. Error	12.7073657	90%	333.00225
Skewness	0.619231087	95%	345.6672
Kurtosis	0.789345977	Max	366.588

5.2.3 Goodness of Fit Tests

The goodness of fit (GOF) tests measures the compatibility of a random sample with a theoretical probability distribution function. In other words, these tests show how well the selected distribution fits to the data. The results are presented in the form of interactive table that help to decide which model describes the data in the best way. The following GOF tests are supported in the application Kolmogrov-Smirnov, Anderson-Darling, Chi-Squared

Table 5.15 shows Goodness of fit tests result summary for Mille watershed

	Distribution	**Kolmogorov Smirnov**		**Anderson Darling**		**Chi-Squared**	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gamma	0.1205	5	0.7332	5	2.2219	1
2	Gamma (3P)	0.0800	1	0.5319	1	2.9208	3
3	Gen. Extreme Value	0.1231	6	0.7625	6	6.2033	6
4	Lognormal	0.0867	2	0.6173	3	3.3556	5
5	Lognormal (3P)	0.0874	3	0.6251	4	2.9872	4
6	Weibull	0.1313	7	0.9330	7	6.5898	7
7	Weibull (3P)	0.0966	4	0.53971	2	2.70166	2

Table 5.16 shows Goodness of fit tests result summary for Logiya watershed

	Distribution	**Kolmogorov Smirnov**		**Anderson Darling**		**Chi-Squared**	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Gamma	0.10902	6	0.67612	5	6.75555	5
2	Gamma (3P)	0.08450	1	0.50680	1	3.02762	2
3	Gen. Extreme Value	0.10800	5	0.70270	6	6.85343	6
4	Lognormal	0.09262	4	0.58368	3	2.72623	1
5	Lognormal (3P)	0.09004	3	0.58936	4	3.30194	3
6	Weibull	0.12168	7	0.93117	7	11.8070	7
7	Weibull (3P)	0.08715	2	0.51057	2	3.46130	4

5.2.4 Parameter Estimation

There are a number of well-known methods which can be used to estimate distribution parameters based on available sample data. For every supported distribution, EasyFit implements one of the following parameter estimation methods: method of moments (MOM); maximum likelihood estimates (MLE); least squares estimates (LSE); method of L-moments.

EasyFit uses the least computationally intensive methods. Thus, it employs the method of moments for those distributions whose moment estimates are available for all possible parameter values, and do not involve the use of iterative numerical methods.

For many distributions, EasyFit uses the MLE method involving the maximization of the log-likelihood function. For some distributions, such as the 2-parameter Exponential and the 2-parameter Weibull, a closed form solution of this problem exists. For other distributions, EasyFit implements the numerical method for multi-dimensional function minimization. Given the initial parameter estimates vector, this method tries to improve it on each subsequent iteration. The algorithm terminates when the stopping criteria is satisfied (the specified accuracy of the estimation is reached, or the number of iterations reaches the specified maximum). The advanced continuous distributions are fitted using the MLE, the modified LSE, and the L-moments methods.

Table5.17 Parameter estimation result for Mille watershed at 033021

	Distribution	**Parameters**
1	Gamma	$\alpha=3.39132044$ $\beta=114.723395$
2	Gamma (3P)	$\alpha=1.73245606$ $\beta=177.131506$ $\gamma=82.1912453$
3	Gen. Extreme Value	$k=-0.002769047$ $s=173.375396$ $m=289.462429$
4	Lognormal	$\sigma=0.577298389$ $\mu=5.80741572$
5	Lognormal (3P)	$=0.551560375$ $\mu=5.85277766$ $\gamma=-13.1454212$
6	Weibull	$\alpha=2.00387618$ $\beta=430.458256$
7	Weibull (3P)	$\alpha=1.39566982$ $\beta=329.850437$ $\gamma=87.3784685$

Table5.18 Parameter estimation result for Logiya watershed at 033027

	Distribution	***Parameters***
1	*Gamma*	$\alpha=3.39612933$ $\beta=50.6710962$
2	*Gamma (3P)*	$\alpha=1.77679004$ $\beta=76.4846881$ $\gamma=36.1883627$
3	*Gen. Extreme Value*	$k=0.01563979$ $\sigma=75.0267347$ $\mu=127.601488$
4	*Lognormal*	$\sigma=0.57154551$ $\mu=4.9940309$
5	*Lognormal (3P)*	$\sigma=0.54893636$ $\mu=5.03419016$ $\gamma=-5.15898611$
6	*Weibull*	$\alpha=2.02660223$ $\beta=190.206164$
7	*Weibull (3P)*	$\alpha=1.40327976$ $\beta=145.857047$ $\gamma=38.8412387$

5.2.5 Graphical Selection of Distribution

5.2.5.1 Q-Q Plot

The quantile-quantile (Q-Q) plot is a graph of the input (observed) data values plotted against the theoretical (fitted) distribution quantiles. Both axes of this graph are in units of the input data set. The quantile-quantile graphs are produced by plotting the observed data values x_i (i = 1, ..., n) against the X-axis, and the following values against the Y-axis:

$$F^{-1}(F_n(x_i)) - \frac{0.5}{n}$$

where:

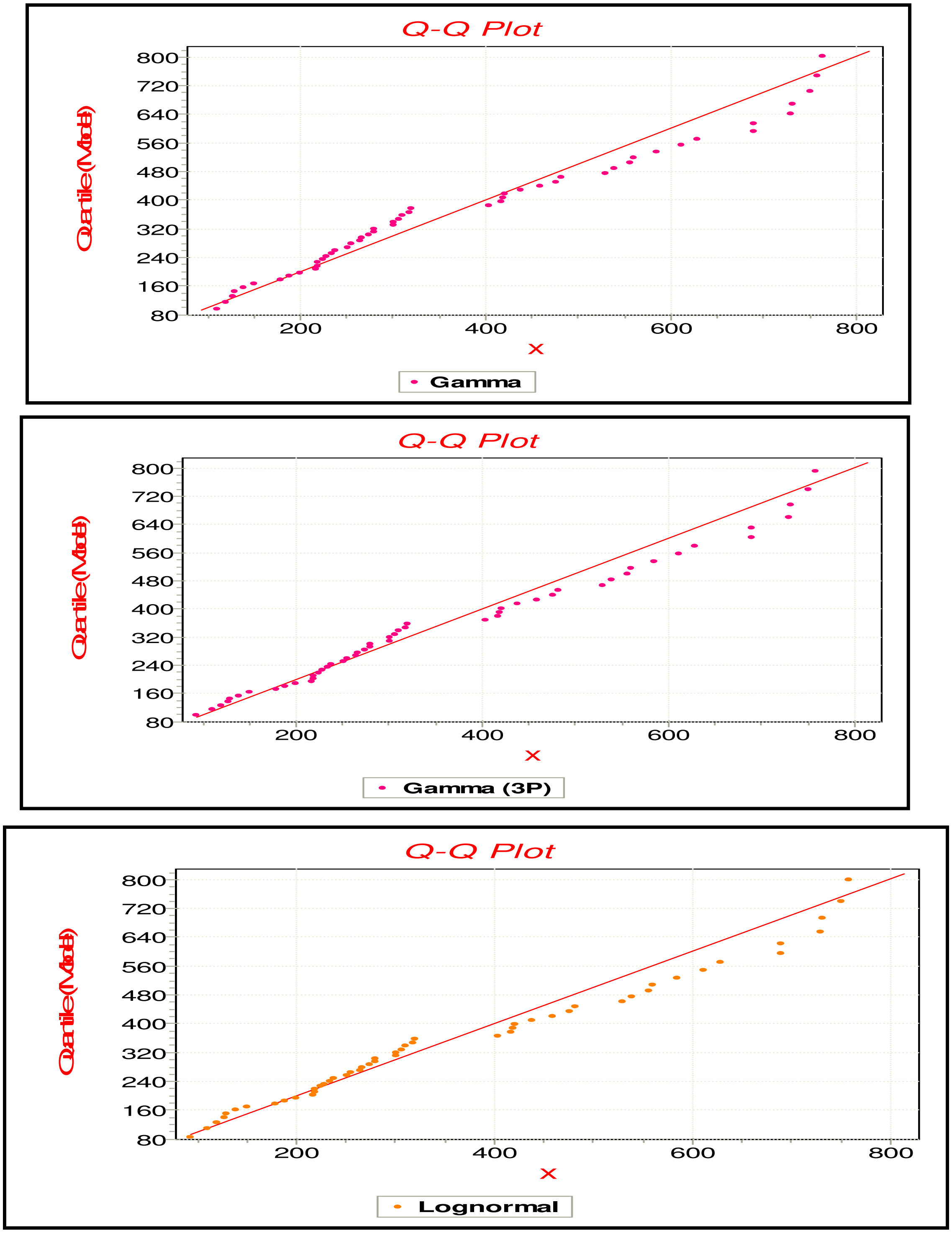
$F^{-1}(x_i)$ - Inverse cumulative distribution function (ICDF)

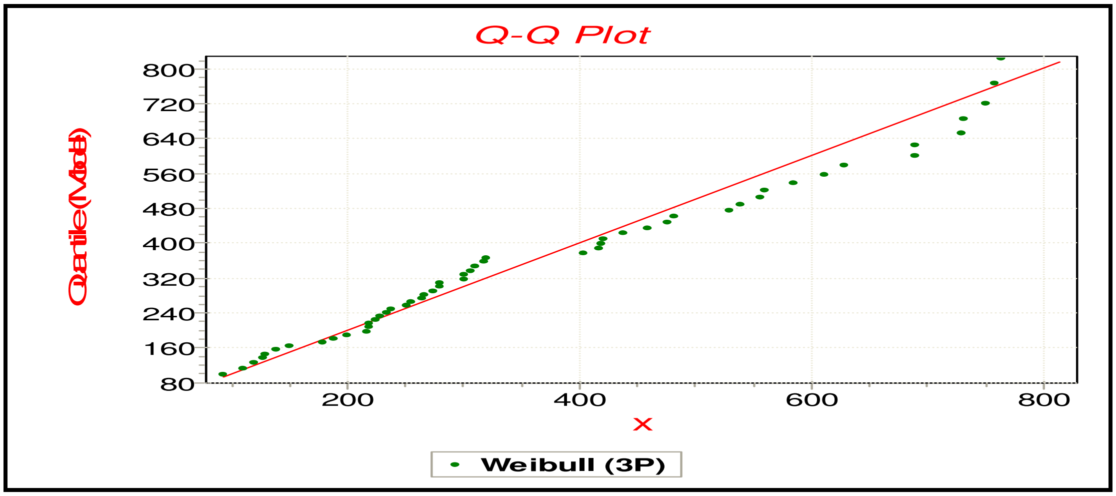
$F_n(x)$-empirical CDF

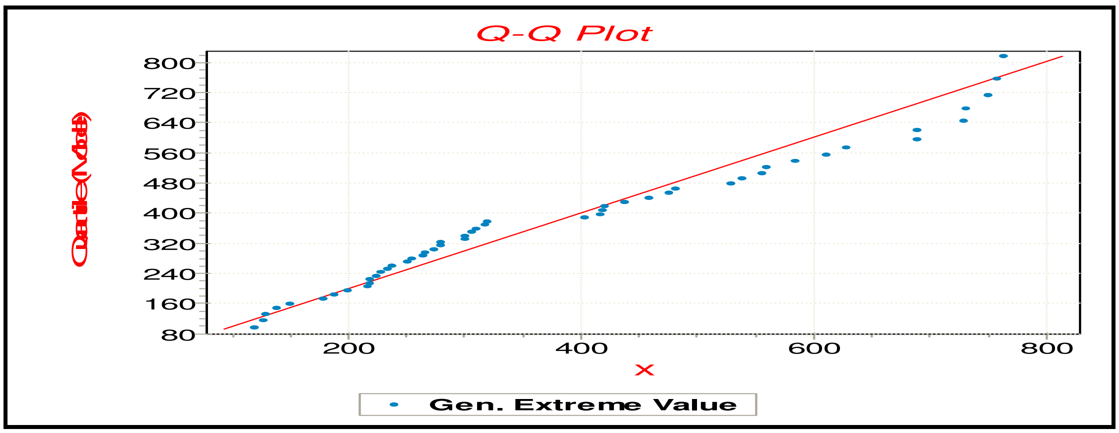
n - sample size.

The Q-Q plot will be approximately linear if the specified theoretical distribution is the correct model. EasyFit displays the reference diagonal line along which the graph points should fall.

Fig5.7 Below shows Graph of Q-Q Plot Mille watershed at 033021




Q-Q Plot
800
720
640
560
480
400
320
240
160
80
200
400
600
800
X
Weibull (3P)


Q-Q Plot
800
720
640
560
480
400
320
240
160
80
200
400
600
800
X
Gen. Extreme Value

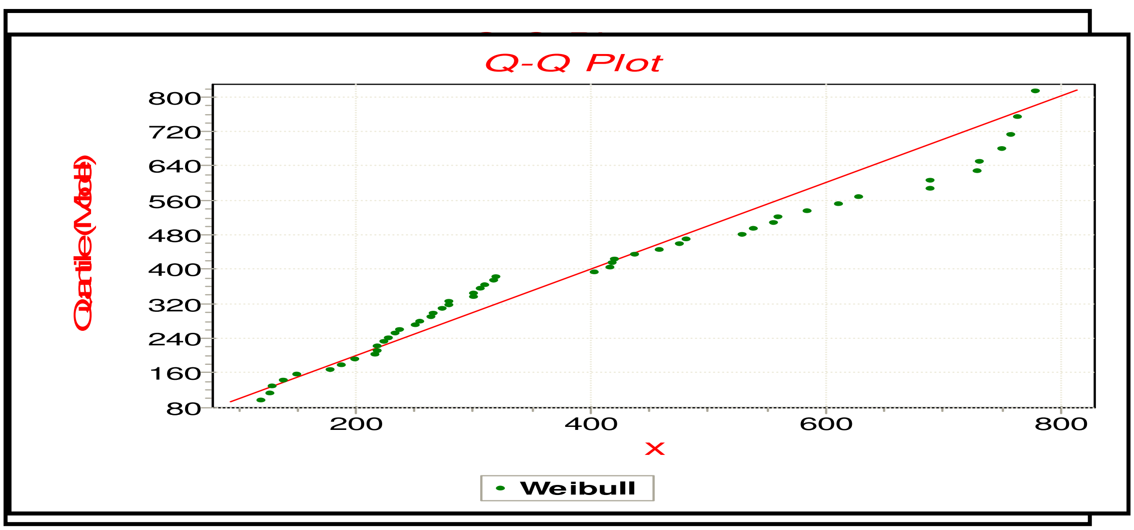
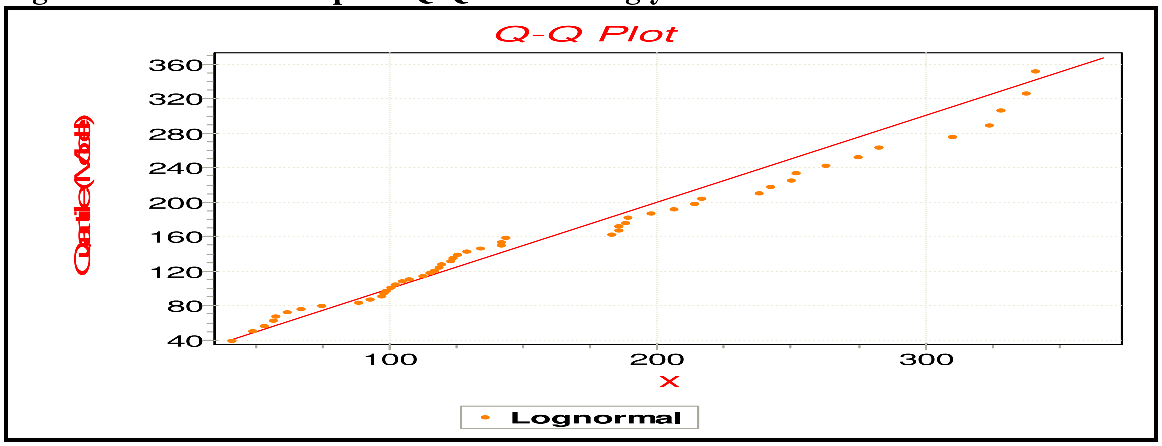
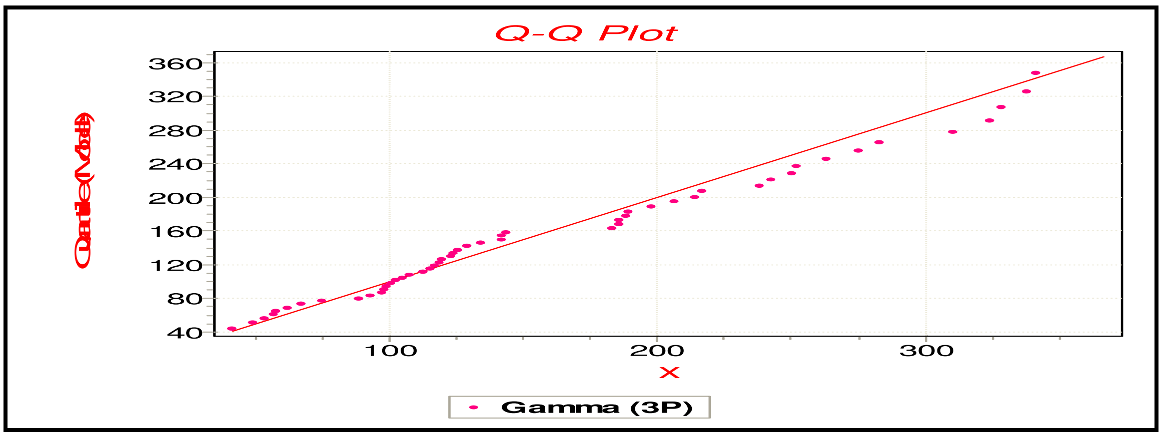
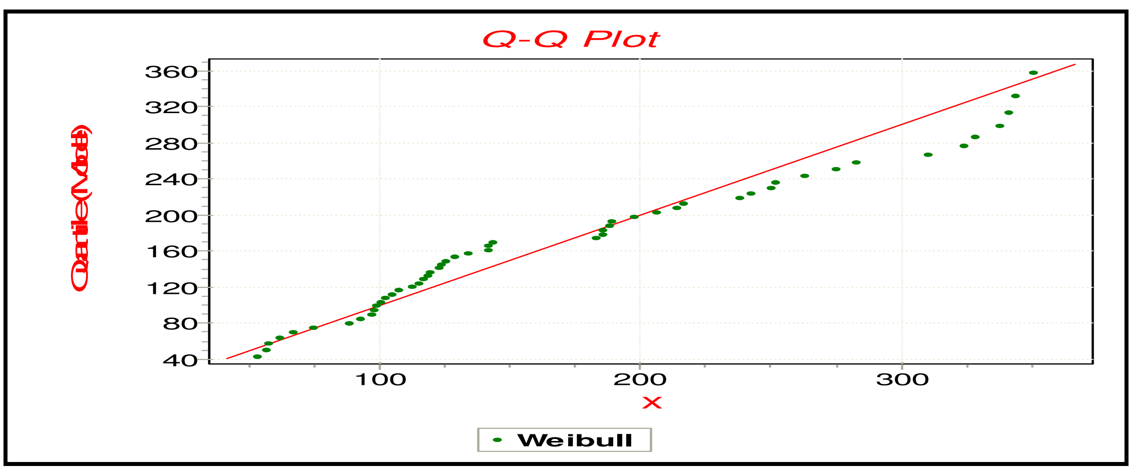
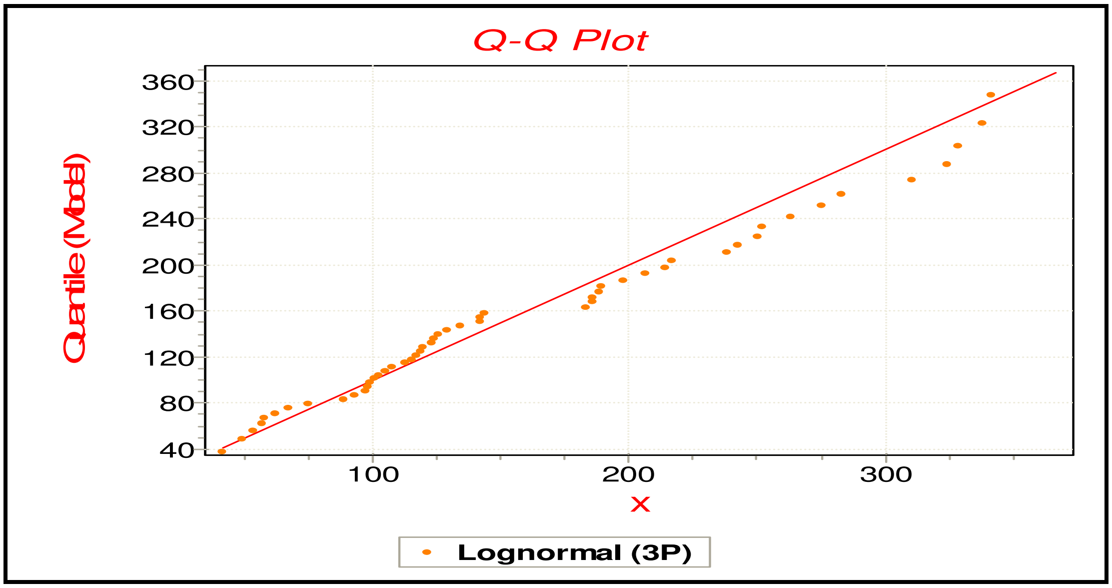

Q-Q Plot
800
720
640
560
480
400
320
240
160
80
200
400
600
800
X
Weibull

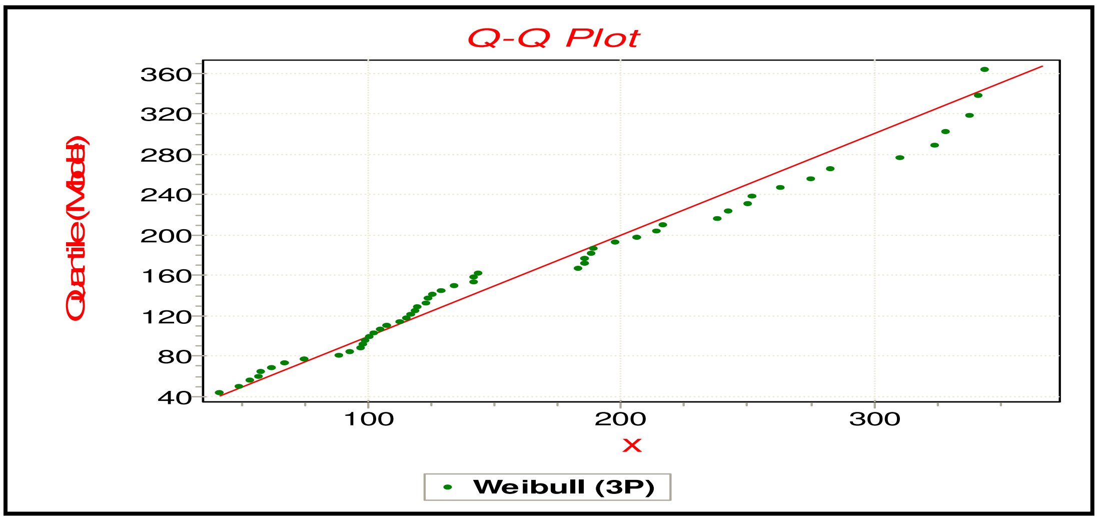
Fig5.8 Below shows Graph of Q-Q Plot for Logiya watershed at 033027

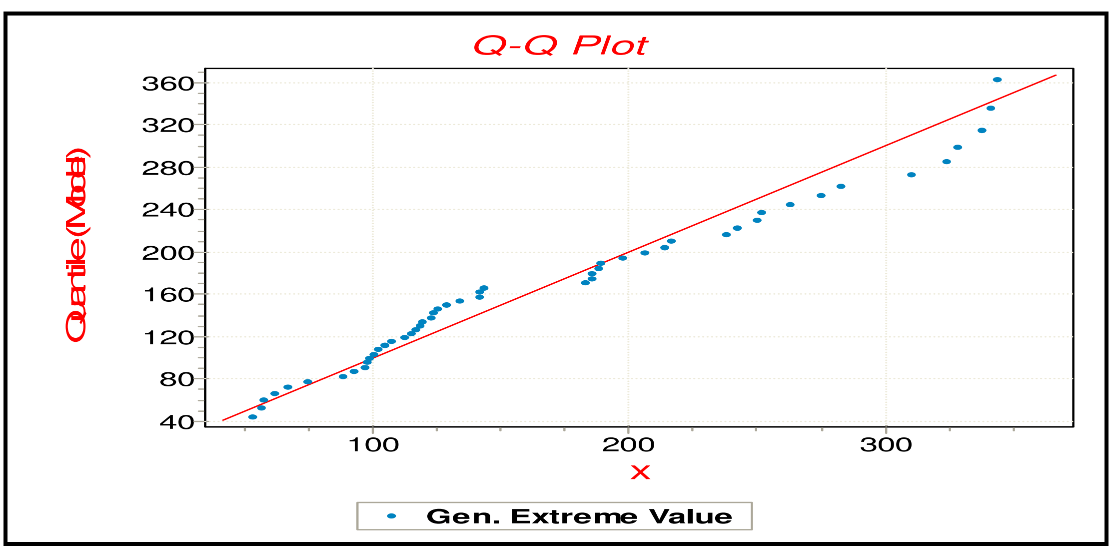







Q-Q Plot
Quantile (Model)
x
Lognormal (3P)


Q-Q Plot
Quantile (Model)
x
Weibull (3P)


Q-Q Plot
Quantile (Model)
x
Gen. Extreme Value

5.2.5.2 Probability Difference

The probability difference graph is a plot of the difference between the empirical CDF and the theoretical CDF. This graph can be used to determine how well the theoretical distribution fits to the observed data and compare the goodness of fit of several fitted distributions. It is displayed as a continuous curve or a scatter plot for continuous distributions and a collection of vertical lines (at each integer x) for discrete distributions:

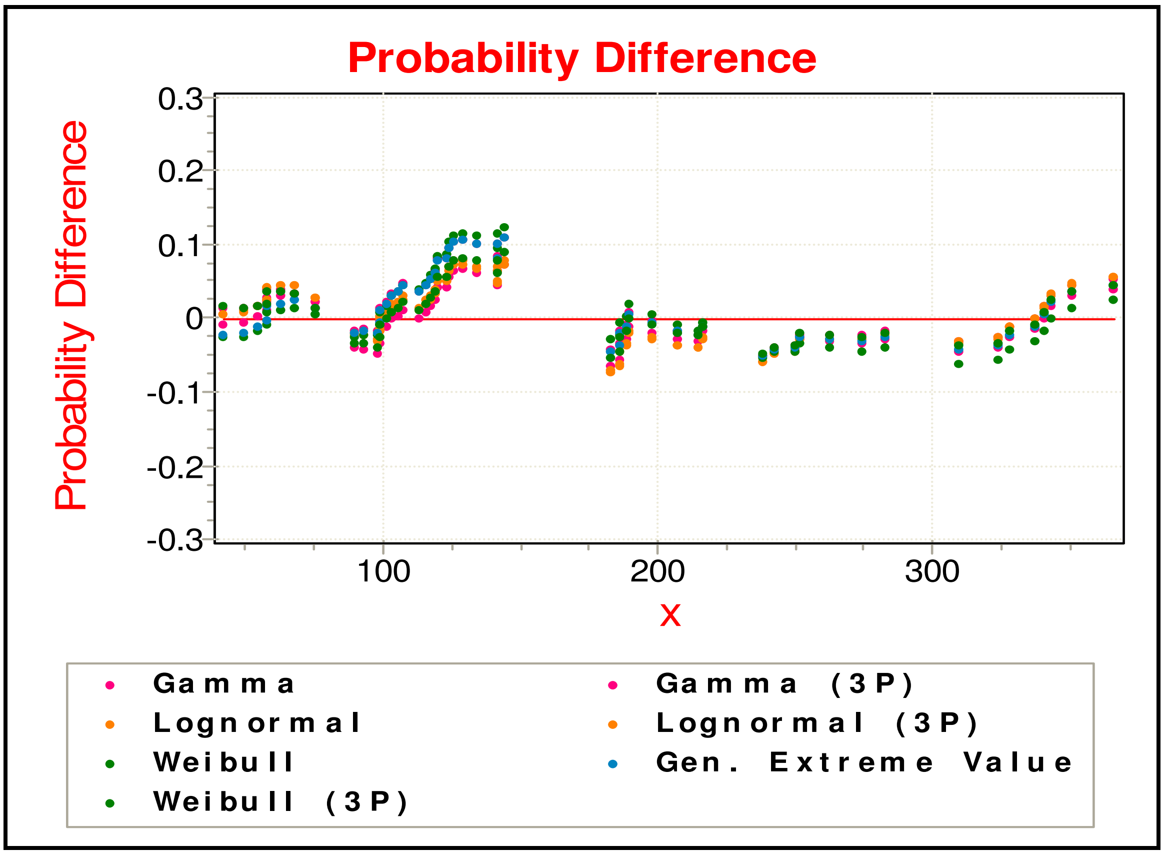


Fig.5.9 shows Graph of Probability Difference Plot for Mille watershed

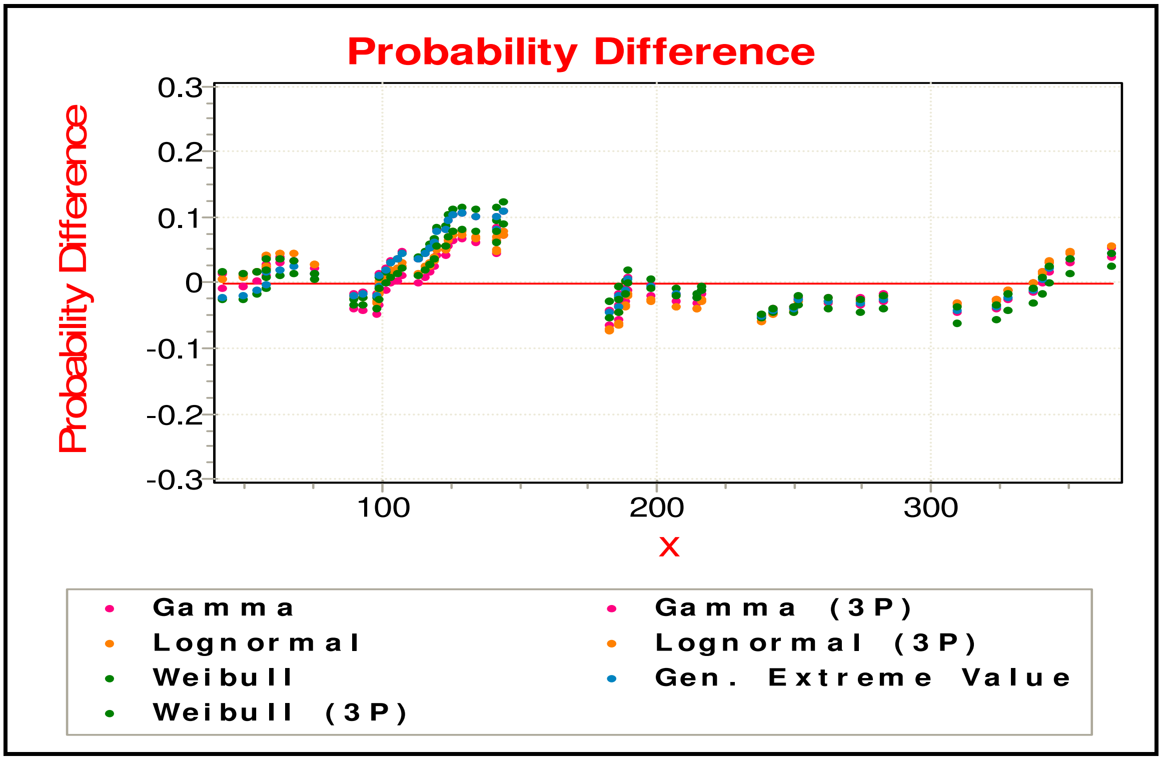


Fig.5.10shows Graph of Probability Difference Plot for Logiya watershed

From the above graphical representation and GOF analysis the Gamma (3P) distribution is selected as the best fit distribution for Mille watershed at033021 and Logiya watershed at033027.

5.2.6 Frequency Analysis Result of Stream Flows

In Order to study the occurrence of floods for Mille and logiya,Flood frequency analysis undertaken on the annual maximum flood of the generated fifty one years and the observed record of stream flow. The annual maximum generated series (fifty one years of data) are fitted to the above selected probability distributions and Gamma three parameter distribution is the best fit distribution for the two watersheds at 033021at mille and 033027 Logiya:

Stream flow predictions for the different return periods can be calculated on the basis of the selected distributions and Statistical analysis were performed for the peak yearly discharges for both stations, Mille and Logiya, to the best fit distribution according to Gamma (3p) parameter distribution. Table 5.18 shows the peak yearly discharge predictions for the two stations at different return period.

Table: 5.19 Peak yearly Discharge Prediction (m^3/s) for the Mille and Logiya watershed

Return period, year	Mille	Logiya
2	369	163
5	558	246
10	669	295
20	766	339
25	796	352
50	884	390
100	966	427
200	1045	462
500	1144	505
1000	1216	537

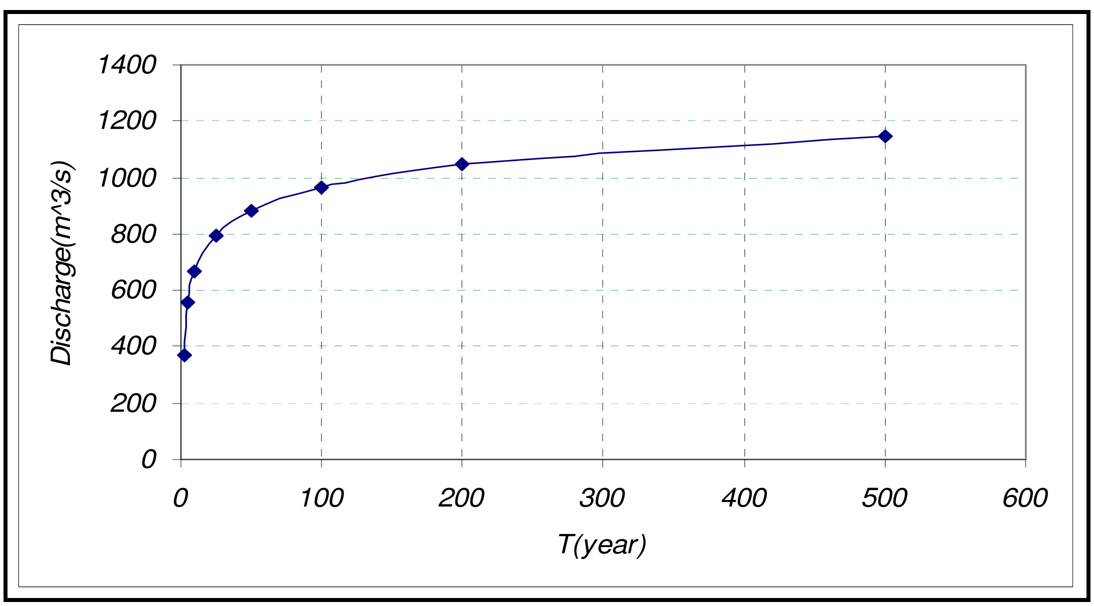


Fig.5.11 shows Graph of Flood Frequency Curve for Mille watershed (Gamma (3p) distribution)

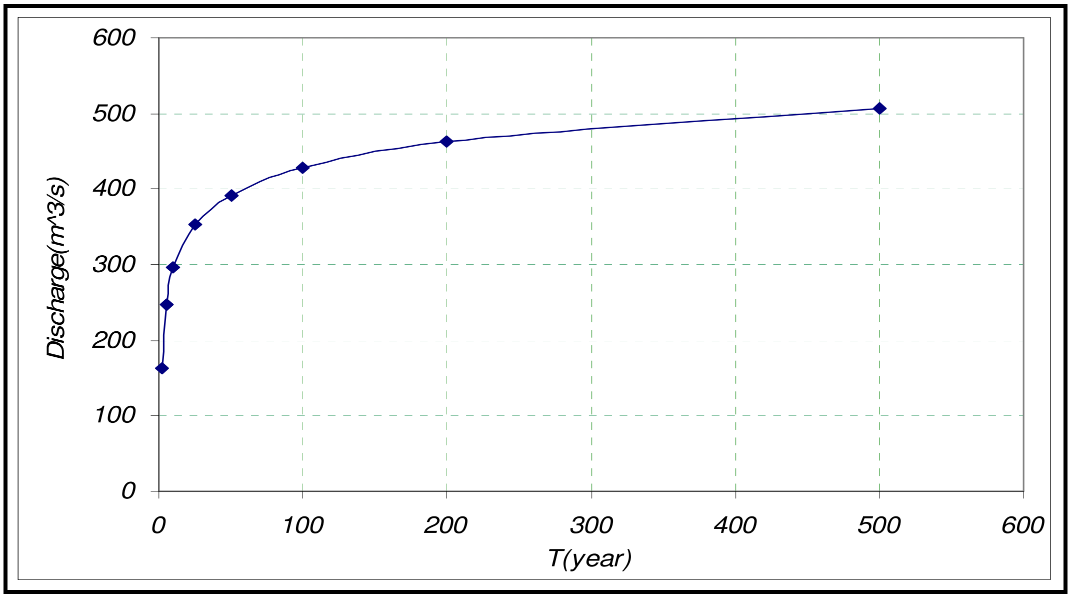


Fig.5.12 shows Graph of Flood Frequency Curve for Logiya watershed (Gamma (3p) distribution)

5.2.7 Comparison of Frequency Analysis Result with Past Study

Many empirical formulas developed for the estimation of flood peaks are essentially regional formulas based on statistical correlation of the observed peak and catchments properties. Dr.Admassu developed an empirical formula for areas ranging from 200-9980km$^{2.}$.

.

$$\overline{Q} = 0.87A^{0.7}$$

Where

A;Catchementsarea

Q;Average discharge

$$Q_T = \overline{Q}(1 + K_T C_V)$$

Where C_V =0.4;Average regional Coefficient

Estimated flood for different return periods for the study area using regional flood frequency analysis (Dr.Admassu) are given in table5.20 and figure5.13 and 5.14 shows plot of frequency estimates based on SWAT generated 51years data and the regional analysis .It is noted from figure 5.13 and figure 5.14 the regional estimates shows under estimate for Mille watershed and higher estimates for logiya watershed in contrast with the model estimate.

Table: 5.20 Peak yearly Discharge Prediction (m^3/s) for the two watershed (Dr.Admassu Gebeyehu Regional analysis)

Return period, year	Mille at(033021)	Logiya at(033027)
2	350.8437	229.2759
5	481.198	314.4624
10	557.5654	364.3684
20	625.0448	408.4661
25	645.4714	421.8148
50	*705.9261*	*461.3219*
100	*762.8338*	*498.511*
200	*817.0625*	*533.9494*
500	*885.5896*	*578.7318*
1000	*935.5321*	*611.3692*

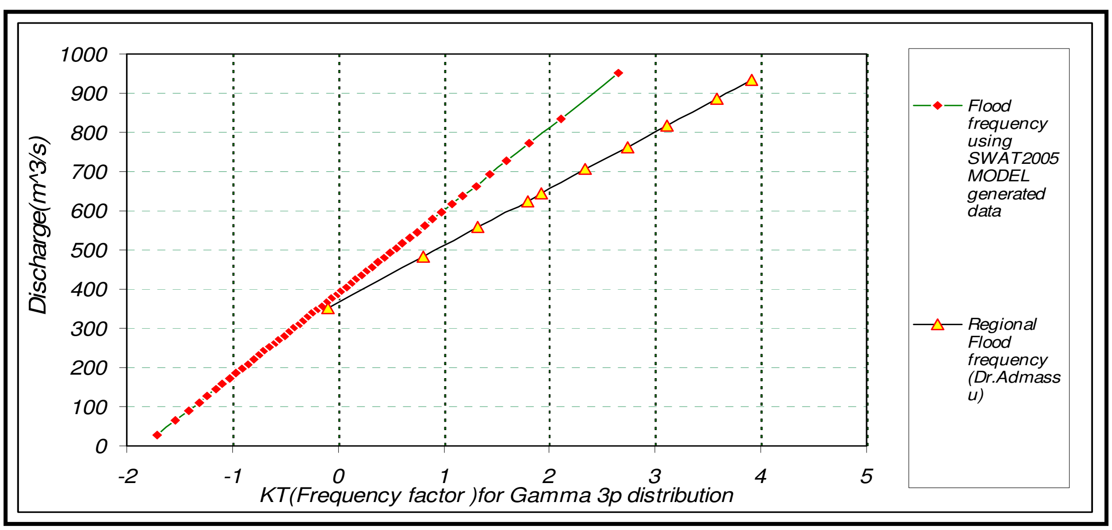


Fig.5.13shows comparison of Flood Frequency result of Mille watershed at 033021 with regional flood frequency analysis(Dr. Admassu).

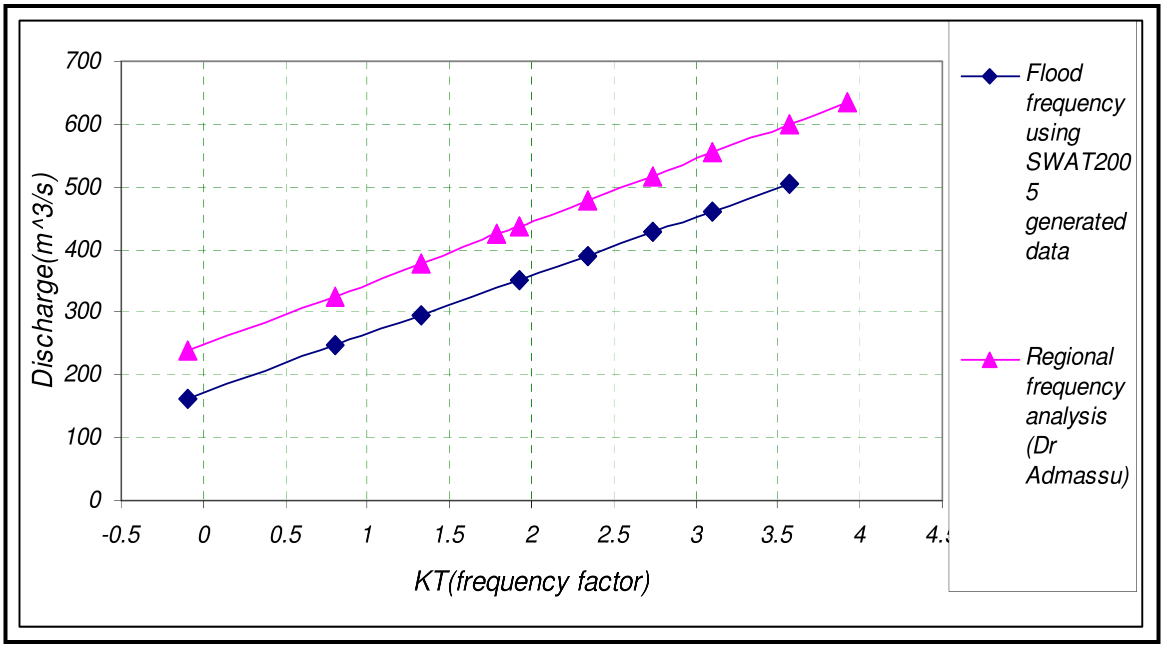


Fig.5.14 shows comparison of Flood Frequency result of Logiya watershed at 033027 with regional flood frequency analysis(Dr. Admassu).(

Halcrow(1989)established a mean annual regional flood regression equation based on 26 stations in the basin maximum daily discharge data they obtained from hydrology Department. The Halcrow (1989) regional flood equation has been used for estimating the flood frequency of the study are for comparison of the flood frequency analysis using generated data even though the use of the above equation is restricted only for preliminary

The Halcrow (1989) regional flood equation is

$$Q_{BAR} = 0.35404 AREA^{0.70727} (RAIN - 580)^{0.14101}$$

Where; Q_{BAR} =The mean annual flood (m^3/s)

Area=Watershed area (Km^3)

RAIN=Mean annual areal rainfall over the watershed area(mm)

With R^2 of 0.89

The flood of a given return period is then estimated by multiplying with a growth factor they derived.

Table 5.21 Growth factor

Location	Return Period in years		
	20	50	100
Upper valley	2.1	2.53	2.85
Middle and Lower Valley	2.48	3.13	3.52

Estimated flood for different return periods using regional flood frequency analysis (Halcrow 1989) are given in table5.24 and figure 5.15, 5.16 shows plot of flood frequency for SWAT generated 51years data of the model and the Halcrow regional flood frequency result.

It is noted from figure 5.15 and figure 5.16 the regional estimates gives higher result for Mille watershed and Logiya watershed in contrast with the model estimate.

Table: 5.22 Data used for determine aerial rainfall for mille watershed

sub basin	Subbasin area (km^2)	Precipitation (mm)	subbasin elevation(m)
1	575.6870	1089.037	1188.00
2	5.0067	917.489	844.00
3	362.8483	917.489	1136.00
4	580.5573	917.489	1521.00
5	498.4843	1089.037	1438.00
6	860.0915	1089.037	1907.00
7	72.7873	61.934	456.00
8	59.2260	61.934	481.00
9	67.6832	61.934	482.00
10	266.1093	917.490	639.00
11	721.1025	917.489	765.00
12	1522.0558	917.489	696.00

Table: 5.23 Data used for determine aerial rainfall for logiya watershed

sub basin	Subbasin area (km^2)	Precipitation (mm)	subbasin elevation(m)
1	556.0404	62.607	843.00
2	337.7758	62.607	726.00
3	336.2130	1076.895	747.00
4	663.5335	1076.895	815.00
5	11.4397	912.304	843.00
6	658.0134	1076.895	754.00
7	13.2267	62.607	845.00
8	621.7254	62.607	394.00
9	3197.9679	62.607	607.00

Table: 5.24 peak yearly Discharge Prediction (m^3/s) for the two stations in the watershed (Halcrow1989) Regional analysis

Location	**Return Period in years**		
	20	50	100
Mille at(033021)	855	1079	1214
Logiya at(033027)	373	471	529

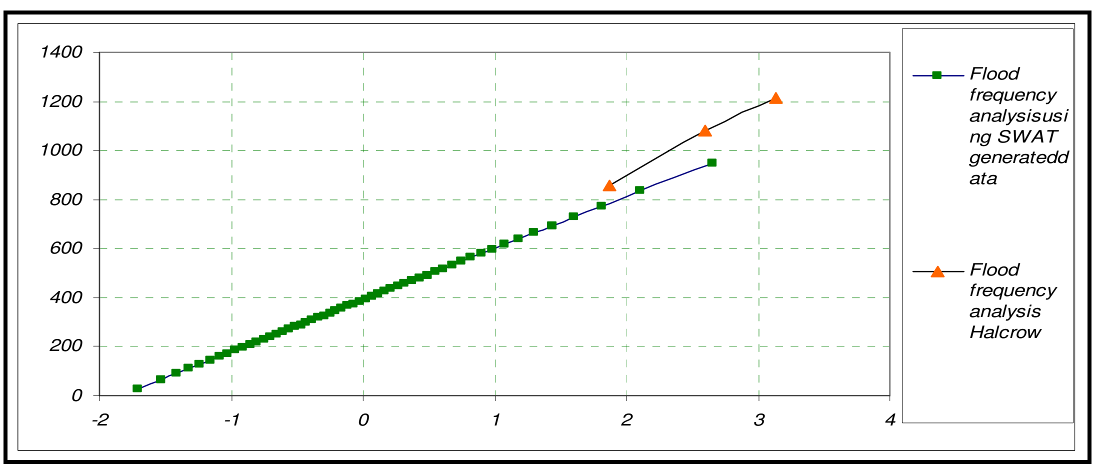


Fig.5.15 shows comparison Flood Frequency result of Mille watershed at 033027 with regional flood frequency analysis (Hal crow).

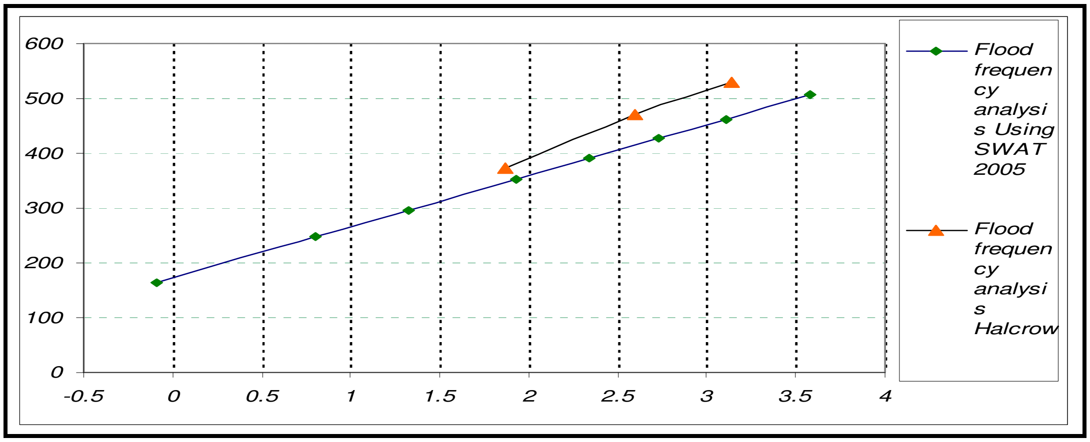


Fig.5.16 shows comparison of Flood Frequency result of Logiya watershed at 033027 with regional flood frequency analysis (Halcrow).

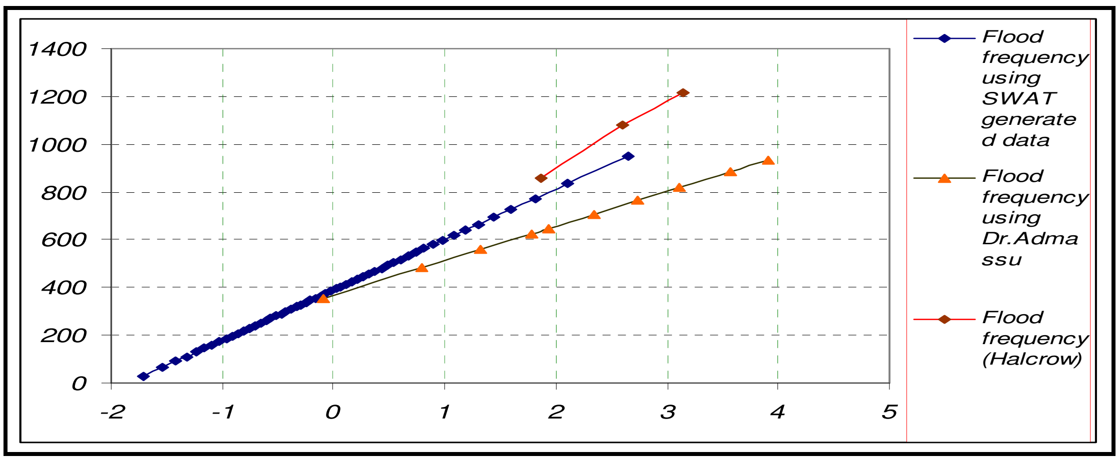


Fig.5.17shows comparison of Flood Frequency result of Mille watershed at 033027 with regional flood frequency analysis(Halcrow) and (Dr.Admassu).

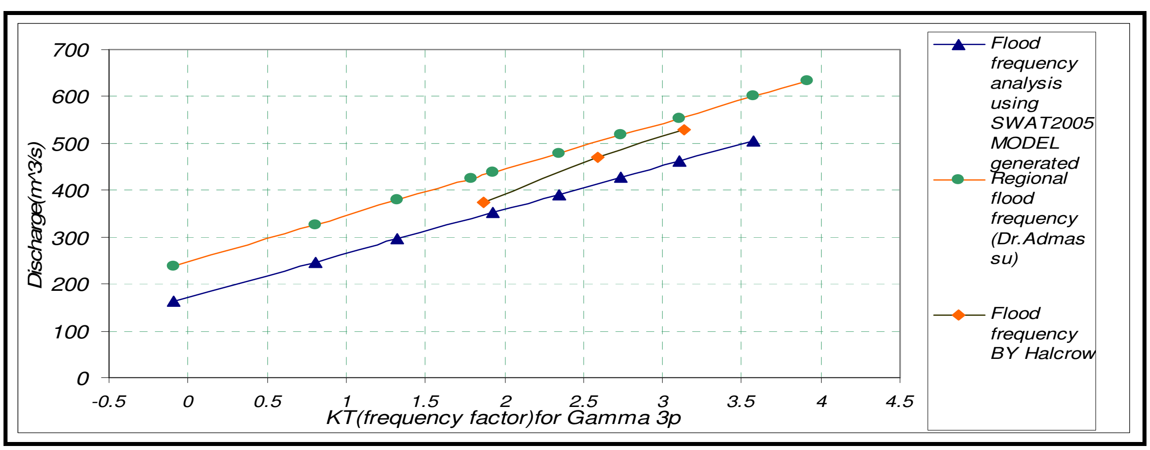


Fig.5.18 shows comparison of Flood Frequency result of Logiya watershed at 033027 with regional flood frequency analysis (Halcrow) and (Dr.Admassu).

The quintiles estimates using the Halcrow method compared to the model estimates shows over exaggerated estimates of quintiles .The estimates of quintiles for 25,50,100 years return period using the Halcrow method shows 11.62%,22.1%,25.67%and 10%,20.77%,23.89% over estimates for Mille and Logiya watershed respectively compared to the model estimates .The quintile estimates using Dr.Admassu empirical formula compared to the model estimates shows underestimate for Mille watershed and over estimate for logiya water sheds .Table 5.25 below shows percentage underestimate and overestimates values of of quintiles estimates for different return period.

Table: 5.25 Shows percentage underestimate and overestimate flood frequency analysis values of Dr.Admassu regional formula as compared to the model results for different return period.

Return period, year	Mille at(033021) %age underestimates	Logiya at(033027) %age overestimates
2	4.92	40.7
5	13.8	27.8
10	16.65	23.5
20	18.4	20.5
25	23.32	19.8
50	20.14	18.2
100	21	16.74
200	21.8	15.57
500	22.5	14.6
1000	23.1	13.8

6 Conclusions and Recommendations

Conclusions

On the basis of the research presented in this report, the following conclusions are offered.

The modeling approach was conducted to assess the procedure for predicting flood frequency analysis for the Mille and Logiya watersheds .With the associated changes in parameter values for the Mille and Logiya watershed as described in table 5.8 at the calibration period, the SWAT model has been calibrated and validated successfully.

At Mille station (Gauge Mille at033021) which drains 91% of the entire watersheds ,the R^2 ,ENs and percentage difference performance measure values for daily peak surface runoff values in the calibration period (simulation years 1991 to 1994) are 0.78,0.71, 20.2% and R^2, ENs and percentage difference performance measure values for daily peak surface runoff values in the validation period (simulation year 1995 to 1998) are 0.75,0.70,18.9%, .Similarly for Logiya gauging station(Gauge Logiya at 033021) which drains 99% of the entire watershed the R^2 , ENs and percentage difference performance measures values for daily peak surface runoff in the calibration period (Simulation year 1995 to 1998) are 0.71,0.69,27.5%and R^2,ENs and percentage difference performance measures values for daily peak surface runoff in the validation period (simulation year 1995 to 1998) are 0.81,0.79,15.8%,. These model performance measure results indicate the model is effectively simulating daily peak stream flows of both watersheds. The model has been shown to be reasonably representing the temporal and spatial nature of the measured flow of the watershed.

Although, the model performance is generally good, there are some significant limitations evident from the model calibration. Limitations for the model calibration existed in the availability of data and model formulation .The greatest limitations are perhaps the availability of climatic data to distribute over a large area. For the watersheds, there exist only five gauging stations for an area of 11,000Km^2 basin area.

Parameter value were changed in the calibration process from default set from the SWAT data base as shown at table 5.8.These changes attempted to reflect the Mille and Logiya watershed conditions .Parameters modified during calibration included reductions in curve number ,increase evaporation compensation factor, available moisture content were primarily related to the representation of land surface and soils of the watershed. The default curve number set by the SWAT users interface (i.e. the values recommended by the SCS Handbook-(Service (1972) were reduced by 25%, indicaing that the Mille and Logiya watershed has better soil/drainage than the assumed condition in the default database.

The lack of a more robust R^2, ENs and percent difference values indicate limitations in predictive capability of calibrated model. There are possible source of limitations, including; error in input data (climatic data, soil type, and land cover), values of calibrated parameters which are not the more optimal and errors in the observed output data (daily peak flow).

One of the objectives of the study is selecting the probability distribution which best fits the annual maximum data in each of the two watersheds outlet in the study area for flood frequency analysis. Based on the results presented in chapter 5, distribution in each region are ranked .In general, Gamma three parameter distribution is the best distribution for Mille and Logiya with Parameter: $\alpha = 1.732$, $\gamma = 82.19$, $\beta = 177.13$ and $\alpha = 1.776$, $\gamma = 36.19$, $\beta = 76.48$ for Mille and Logiya watersheds respectively.

Dr.Admassu regional formula flood frequency results give underestimate values for Mille watershed and overestimate values for Logiya watershed in contrast with the model results. Similarly, comparing model flood frequency result of the watersheds with Halcrows , Halcrow's estimates shows over exaggerated results. Applying the design flood of high magnitude in the final design and planning of water resource project in the basin have resulted in conservative and unnecessary costly structure while adoption of a low design flood can, if a higher flood results in the loss of the structure itself causing thereby untold miserly to the people residing downstream ,besides damaging valuable immovable properties. Therefore these regional methods are strictly used only for preliminary purpose where flood hydrology is not a dominant factor.

In the lower plains, the Dubit area plantation and most of Dubit town have been inundated with floods mainly coming from Logiya river such flows have cause damage to the Afar pastoralist in the area between Dubit and Assaita isolating them and their livestock. Therefore, flood frequency analysis result provided in this paper uses as an input data for flood plain management in the lower plain of Dubti and Assaita town and flow regulation of Tendaho dam.

Recommendations

The model analysis series is used as informative input to both modelers/scientists and decision makers. There are a number of other useful modeling analysis that can be conducted based on this modeling approach Such as: Critical examination of model uncertainties may be important to take in to account when evaluating model predictions for management option, Calibration and validation of the model sediment transport simulation result for sediment transport study for Tendaho dam due to Mille watershed, Lower plain downstream of tendaho dam due to Logiya watershed, contribution of sediment load from the sub watershed to identify which sub watershed has more contribution and to take land conservation/management measure.

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The parameters had to adjusted on a basin wide basis during calibration .While these parameters adjusted seemed to be accurate for the system as whole ,these may not have been representative for small sub watersheds with the system .Because of the size ,the response of the sub watersheds to precipitation event is more sensitive and timing of the events is crucial for model performance measures .Consequently, errors that may be ’averaged out’ on larger basins would be quite apparent on small basins because input data and parameters have been set on large scale. In this case it is recommended more accurately calibrate the small sub basin within the system separately and account for timing shifts in precipitation data or changes on land surface in order to accurately capture the processes on a small scale.

However, based on current information, the model demonstrates its utility as a useful tool to understand surface flow hydrology processes in the watershed and as basis for effective management in Mille and Logiya watershed

Generally the SWAT basin model approach provides the scientific frame work for further hydrological study in the watershed; improving the flow simulation model performance measure, and the basis for some input data information is outlined in sufficient detail for future modeler in the basin to repeat the input development when new input data become available or if a future model of the basin (with or without SWAT) is developed.

APPENDICES

Appendix A: Climatic Data Summary of average monthly climatic data values of all the stations in the study area

Location of the Meteorological stations in the study area

No.	Station Name	Latitude	Longitude
1	Assaita	11.567	41.45
2	Dubti	11.75	41.1
3	Kombolcha	11.11	39.73
4	Sirinka	11.55	39.61
5	Bati	11.22	40.22
6	Wurgessa	11.55	39.61

Assaita

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shine Hrs	wind speed (m/s)
Jan	4.6	20.5	33	79.54	8.8	1.58
Feb	13.5	20.80	34	76.42	9.6	1.61
Mar	20.9	23	35.8	71.35	9.2	1.63
Apr	24.3	24.9	38.1	70.06	9.5	1.73
May	11.8	26.9	40.3	66.88	10.1	1.46
Jun	4.2	27.9	41.7	63.62	8.2	1.55
Jul	34.6	28.1	41	67.77	7.9	1.56
Aug	38.3	26.2	39	72	8.3	1.51
Sep	14.2	27	39.5	69.28	8.3	1.29
Oct	7.9	24	37.5	70.95	9.5	1.5
Nov	5.4	22.1	35.2	73.14	10.6	1.69
Dec	2.3	20.9	33.1	77	9.4	1.61

Bati

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shine Hrs	wind speed (m/s)
Jan	39.87	11.2	24.7	71.38	7.3	0.89
Feb	47.13	11.8	25.6	65.12	6.6	0.97
Mar	63.45	13.6	27.1	66.902	7.4	1.02
Apr	84.66	14.7	29.0	61.91	7.9	1.03
May	57.90	15.2	31.1	53.09	9.0	1.00
Jun	20.14	17.0	32.8	43.70	8.5	1.21
Jul	189.94	16.1	30.8	58.25	7.0	1.34
Aug	206.57	15.4	28.9	66.52	7.4	1.15
Sep	81.588	14.2	29.1	63.65	7.4	0.81
Oct	29.59	11.5	28.2	59.35	8.4	0.71
Nov	28.35	10.4	26.8	58.51	9.4	0.81
Dec	36.49	10.4	25.2	63.35	8.5	0.85

]

Dubti

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shine Hrs	wind speed (m/s)
Jan	15.50	18	32.3	60.83	8.8	2
Feb	26.75	19.5	33.3	60.5	7.9	2.1
Mar	46.32	21.7	36.1	57.44	8.2	2.3

Kombolcha

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shine Hrs	wind speed (m/s)
Jan	29.173	10	24.2	62.26	7.6	1.28
Feb	38.71	10.9	25.3	6026.	7.5	1.41
Mar	76.21	12.4	26.3	59.95	7.0	1.34

Apr	74.77	22.7	37.8	54.73	9.4	2.6
May	79.01	24.7	41	46.89	9.8	1.4
Jun		25.9	43.4	40.59	8.7	1.5
Jul		25.8	40.7	48.48	7.0	1.6
Aug		25.3	39.0	51.79	7.9	1.6
Sep		24.8	39.6	51.21	8.0	1.1
Oct		20.9	37.1	54.92	8.8	1.2
Nov		18	34.3	55.61	10	1.6
Dec		17.1	32.7	60.65	9.7	1.7

Apr	94.36	13.2	27.0	59.47	7.2	1.32
May	57.25	13.6	28.3	48.57	8.1	1.32
Jun	32.55	14.6	30.1	39.75	6.5	1.32
Jul	263.62	14.1	27.9	58.08	5.3	1.48
Aug	258.87	13.8	26.5	64.19	5.9	1.49
Sep	120.36	13	25.9	64.12	6.0	1.32
Oct	36.1	10.4	25.1	59.55	7.9	1.10
Nov	19.89	8.4	24.6	57.35	8.6	0.85
Dec	18.98	8.4	24.1	59.81	8.1	0.93

Sirinka

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shin Hrs	wind speed (m/s)
Jan	47.68	10.6	23.2	71.19	6.7	1.32
Feb	61.98	11.55	24.2	69.22	6.7	1.35
Mar	96.44	13.2	25.3	67.10	7.3	1.35
Apr	102.19	14	26.5	66.14	7.5	1.17
May	67.67	14.7	28.3	57.27	8.7	1.26
Jun	29.69	15.9	30.8	43.86	7.7	1.5
Jul	207.49	15.3	28.3	57.15	5.8	1.37
Aug	248.38	14.7	27.1	66.62	5.8	1.25
Sep	89.21	14	26.8	68.16	7.1	1.04
Oct	56.87	12.3	25.8	65.72	7.8	1.03
Nov	26.77	10.7	24.8	61.4	8.3	1.19
Dec	35.14	10.3	25.8	66.37	5.8	1.41

Wurgessa

Month	RF (mm)	Tmin (°C)	Tmax (°C)	RH (%)	Sun-shine Hrs	wind peed n/s)
Jan	6.07					
Feb	30.99					
Mar	55.35					
Apr	61.77					
May	61.72					
Jun	61.84					
Jul	163.45					
Aug	158.23					
Sep	91.96					
Oct	44.00					
Nov	6.82					
Dec	4.71					

Appendices:B

Appendix 1 Soil Properties in Lower Awash River Basin, which are stored in the file Usersoil.dbf and values of each parameters.

Most of the soil parameters adapted from Delinesaw (2006) and derived from the sources which are mentioned in section 4, but the following parameters were estimated using the indicated methods:

A) Available water capacity of the soil layer (SOL_AWC(mm/mm)),
B) Organic Carbon content (SOL_CBN (%soil weight) and
C) Saturated hydraulic conductivity (SOL_K(mm/hr)),
D) Moist soil albedo (SOL_ALB (fraction))
E) Soil Erodibility (USLE_K)

A) Available water capacity of the soil layer (SOL_AWC(mm/mm)),

Soil Texture classes	Available water in mm/m of depth
Coarse sands	20-65
Fine sands	60-85
Loamy sands	65-110
Sandy loams	90-130
Fine sandy loams	100-170
Silt loams	150-230
Silty clay loams	130-160
Silty clay	125-170
Clay	110-150
Peats and Mucks	160-240

Typical available water holding capacities based on soil texture (Sources Hargreaves. et al, 2004)

B) Soil Organic Carbon content (SOL_CBN (%soil weight))

Textural Classes	Symbol	Average Organic carbon content
Sand	S	0.9
Loamy sand	lS	1.0
Loamy silt	lU	1.6
Sandy loam	sL	1.3
Loam	L	1.7
Silty loam	UL	1.7
Clay	T	1.9

Average C_{org} contents for various soil textures (Sources Lieberoth, 1982)

C) Saturated hydraulic conductivity of each texture class was estimated from the following two tables:.

Texture class	Saturated hydraulic conductivity (mm/hr)	Texture class	Saturated hydraulic conductivity (mm/hr)
Sand	210.0	Clay loam	2.3
Loamy sand	61.1	Silty clay loam	1.5
Sandy loam	25.9	Sandy clay	1.2
Loam	13.2	Silty clay	0.9
Silt loam	6.8	Clay	0.6
Sandy clay loam	4.3		

Saturated Soil Hydraulic Conductivity (Sources Rawls et al (1982))

SOIL TEXTURAL CLASSES & RELATED SATURATED HYDRAULIC CONDUCTIVITY CLASSES					HYDROTREND VALUES
Texture	Textural Class	General	Ksat Class	Ksat Rate (µm/sec.)	Ksat Rate (mm/day)
Coarse sand	Coarse	Sandy	Very rapid	>141.14	>1219.45
SandsLoamy sands			Rapid	42.34-141.14	364.95-1219.45
Sandy loam Fine sandy loam	Moderat coarse	Loamy	Moderatly Rapid	14.11-42.34	121.91-364.95
Very fine loam Loam Silt loam Silt	Medium		Moderate	4.23-14.11	36.55-121.91
Clay loam Sandy clay loam Silty clay loam	Moderatly fine		Moderate Slow	1.41-4.23	12.18-36.55
Sandy clay Silty Clay Clay	Fine and very fine	Clayey	Slow	0.42-1.41	3.63-12.18
Cd horizon Natric horizon, Fragipan, Ortstein			Very slow or impermeable	0.00-0.42	0.00-3.63

Saturated Soil Hydraulic Conductivity (Sources INSTAAR, Univ. of Colorado, 2002)

D) Moist soil albedo (SOL_ALB) is based on Taylor and Ashcroft[1]

Soil Color	Albedo[1]
Brown	0.13
Red	0.14
Black	0.09
Gray	0.13
Yellow	0.17

[1]Natural Resources Conservation Service Soil Survey Staff. 1996. National soil survey handbook. Title 430-VI. US Government Printing Office, Washington, D.C.

E) Soil Erodibility (USLE_K) were estimated from two sources Hurni (1985) and Stewart et al. (1975)

Soil Colour	Soil Erodibility (K)
Black	0.15
Brown	0.20
Red	0.25
Yellow	0.30

Source: Hurni (1985

	P_{om}(%) Organic Matter Content		
Textural Class	<0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16

Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	-	0.13-0.20	-

Soil Erodibility Factor K_{fact} (Source: Stewart et al. 1975)[a]

(a) The values shown are estimated averages of broad ranges of specific soil values. When a texture is near the border line of two texture classes, use the average of the two K_{fact} values. In addition, the values shown are commensurate with the English units used in the cited reference (and as used in the source-term module input files). To obtain analagous values in the metric units used in this report, the above values should be multiplied by 1.292.

Soil Type : Eutric Vertisols (RGe)

Soil Name:	RGe		
Soil Hydrologic Group:	C		
Maximum rooting depth(mm) :	2422		
Texture 1 :	C		
Layers	Layer-1	Layer-2	Layer-3
Depth [mm]:	181.68	363.37	847.85
Bulk Density Moist [g/cc]:	1.1	1.27	1.28
Ave. AW Incl. Rock Frag :	0.11	0.11	0.1
Ksat. (est.) [mm/hr]:	4.34	4.54	5.16
Organic Carbon [weight %]:	1.47	1.37	1.41
Clay [weight %]:	60.6	60.6	62.6
Silt [weight %]:	23.3	18.6	17
Sand [weight %]:	16.1	20.8	20.4
Rock Fragments [vol. %](Optional)	No Data	No Data	No Data
Soil Albedo (Moist) :	0.09	0.09	0.09
Erosion K :	0.20	0.20	0.20
Salinity (EC, Form 5 : (Optional)	No Data	No Data	No Data
Crack volume potential of soil(	0.03	-	-
Porosity fraction from which anions are excluded	0.01	-	-

Soil type: Chromic Luvisols (LVx)

Soil Name:	LVx		
Soil Hydrologic Group:	B		
Maximum rooting depth(mm) :	1800		
Texture 1 :	SiL		
Layers	Layer-1	Layer-2	Layer-3
Depth [mm]:	210	260	460
Bulk Density Moist [g/cc]:	1.45	1.46	1.45
Ave. AW Incl. Rock Frag :	0.22	0.21	0.2
Ksat. (est.) [mm/hr]:	38.4	37.2	34.8
Organic Carbon [weight %]:	1.2	0.3	0.21
Clay [weight %]:	11	14	19
Silt [weight %]:	67	66	59
Sand [weight %]:	22	20	22
Rock Fragments [vol. %](Optional)	No Data	No Data	No Data
Soil Albedo (Moist) :	0.13	0.13	0.13
Erosion K :	0.30	0.30	0.30
Salinity (EC, Form 5 : (Optional)	No Data	No Data	No Data
Crack volume potential of soil:	0.01	-	-
Porosity fraction from which anions are excluded	0.01	-	-

Soil Type: Haplic Luvisol (LVh)

Soil Name:	LVh		
Soil Hydrologic Group:	B		
Maximum rooting depth(mm) :	900		
Texture 1 :	L-CL		
Layers	Layer-1	Layer-2	Layer-3
Dept[mm]:	200	600	900
Bulk Density Moist [g/cc]:	1.45	1.37	1.42
Ave. AW Incl. Rock Frag :	0.19	0.09	0.15
Ksat. (est.) [mm/hr]:	30	5.52	10.56
Organic Carbon [weight %]:	0.5	0.22	0.21
Clay [weight %]:	25	44	35
Silt [weight %]:	31	23	35
Sand [weight %]:	44	33	30
Rock Fragments [vol. %](Optional)	No Data	No Data	No Data
Soil Albedo (Moist) :	0.13	0.13	0.13
Erosion K :	0.30	0.11	0.28
Salinity (EC, Form 5 : (Optional)	No Data	No Data	No Data
Crack volume potential of soil	0.01	0	0
Porosity fraction from which anions are excluded	0.01	-	-

Soil type: Lithic Leptosols (LP)

Soil Name:	LPq
Soil Hydrologic Group:	A
Maximum rooting depth(mm) :	500
Texture 1 :	SCL
Layers	Layer-1
Dept[mm]:	500
Bulk Density Moist [g/cc]:	1.44
Ave. AW Incl. Rock Frag :	0.19
Ksat. (est.) [mm/hr]:	287.3
Organic Carbon [weight %]:	1.8
Clay [weight %]:	35
Silt [weight %]:	38
Sand [weight %]:	27
Rock Fragments [vol. %](Optional)	No Data
Soil Albedo (Moist) :	0.13
Erosion K :	0.21
Salinity (EC, Form 5 : (Optional)	No Data
Crack volume potential of soil	0.00
Porosity fraction from which anions are excluded	0.01

Soil type: Humic Nitisols (NTu)

Soil Name:	NTu
Soil Hydrologic Group:	B
Maximum rooting depth(mm) :	1816
Texture 1 :	C-CL
Layers	Layer-1
Dept[mm]:	1816
Bulk Density Moist [g/cc]:	1.35
Ave. AW Incl. Rock Frag :	0.1
Ksat. (est.) [mm/hr]:	65.68
Organic Carbon [weight %]:	1.9
Clay [weight %]:	50
Silt [weight %]:	23
Sand [weight %]:	27
Rock Fragments [vol. %](Optional)	No Data
Soil Albedo (Moist) :	0.14
Erosion K :	0.25
Salinity (EC, Form 5 : (Optional)	No Data
Crack volume potential of soil	0.002
Porosity fraction from which anions are excluded	0.01

Soil type: Eutric Cambisols (CMe)

Soil Name:	Cme	
Soil Hydrologic Group:	B	
Maximum rooting depth(mm) :	900	
Texture 1 :	L	
Layers	Layer-1	Layer-2
Dept[mm]:	600.00	900.00
Bulk Density Moist [g/cc]:	1.50	1.46
Ave. AW Incl. Rock Frag :	0.20	0.18
Ksat. (est.) [mm/hr]:	33.63	39.86
Organic Carbon [weight %]:	1.63	1.10
Clay [weight %]:	21.00	13.00
Silt [weight %]:	33.00	46.00
Sand [weight %]:	46.00	41.00
Rock Fragments [vol. %](Optional)	No Data	No Data
Soil Albedo (Moist) :	0.00	0.00
Erosion K :	0.31	0.34
Salinity (EC, Form 5 : (Optional)	No Data	No Data
Crack volume potential of soil	0	-
Porosity fraction from which anions are excluded	0.01	-

Soil type: Ortic solanachalk(Sco)

Soil Name:	Sco
Soil Hydrologic Group:	B
Maximum rooting depth(mm) :	1500
Texture 1 :	SICL-CL
Layers	Layer-1
Dept[mm]:	1500.00
Bulk Density Moist [g/cc]:	1.43
Ave. AW Incl. Rock Frag :	0.20
Ksat. (est.) [mm/hr]:	307.15
Organic Carbon [weight %]:	1.80
Clay [weight %]:	33.00
Silt [weight %]:	55.00
Sand [weight %]:	12.00
Rock Fragments [vol. %](Optional)	No Data
Soil Albedo (Moist) :	0.13
Erosion K :	0.21
Salinity (EC, Form 5 : (Optional)	No Data
Crack volume potential of soil	0.00
Porosity fraction from which anions are excluded	0.01

Soil type: Mollic Andisol (ANM)

Soil Name:	ANM		
Soil Hydrologic Group:	B		
Maximum rooting depth(mm) :	1250		
Texture 1 :	C-SCL		
Layers	Layer-1	Layer-2	Layer-3
Dept[mm]:	120.00	450.00	700.00
Bulk Density Moist [g/cc]:	1.10	1.19	1.14
Ave. AW Incl. Rock Frag :	0.12	0.09	0.20
Ksat. (est.) [mm/hr]:	6.23	4.98	9.34
Organic Carbon [weight %]:	1.90	1.60	1.70
Clay [weight %]:	55.00	67.80	30.00
Silt [weight %]:	30.00	27.00	60.00
Sand [weight %]:	15.00	5.20	10.00
Rock Fragments [vol. %](Optional)	No Data	No Data	No Data
Soil Albedo (Moist) :	0.17	0.17	0.17
Erosion K :	0.20	0.20	0.30
Salinity (EC, Form 5 : (Optional)	No Data	No Data	No Data
Crack volume potential of soil	0.01	-	-
Porosity fraction from which anions	0.01	-	-
are excluded			

Appendix C:Weather Generator Statistic and Probability Value

The weather generator input file contains the statistical data needed to generate representative daily climate data for the subbasins. Climatic data will be generated in two instances: when the user specifies that simulated weather will be used or when measured data is missing.
Following values were calculated for weather stations.

TMPMX(mon)	Average or mean daily maximum air temperature for month (ºC).
TMPMN(mon)	Average or mean daily minimum air temperature for month (ºC).
TMPSTDMX(mon)	Standard deviation for daily maximum air temperature in month (ºC).
TMPSTDMN(mon)	Standard deviation for daily minimum air temperature in month (ºC).
PCPMM(mon)	Average or mean total monthly precipitation (mm H2O).
PCPSTD(mon)	Standard deviation for daily precipitation in month (mm H2O/day).
PCPSKW(mon)	Skew coefficient for daily precipitation in month.
PR_W(1,mon)	Probability of a wet day following a dry day in the month.
PR_W(2,mon)	Probability of a wet day following a wet day in the month.
PCPD(mon)	Average number of days of precipitation in month.
RAINHHMX(mon)	Maximum 0.5 hour rainfall in entire period of record for month (mm H2O).
SOLARAV(mon)	Average daily solar radiation for month (MJ/m2/day).
DEWPT(mon)	Average daily dew point temperature in month (ºC).
WNDAV(mon)	Average daily wind speed in month (m/s).

TMPMX(mon): Average or mean daily maximum air temperature for month (ºC).
Calculated based on following formula:

$$\mu mx_{mon} = \frac{\sum_{d=1}^{N} T_{mx,mon}}{N}$$

Where μmax_{mon} is the mean daily maximum temperature for the month (°C), *Tmx,mon* is the daily maximum temperature on record *d* in month *mon* (°C), and *N* is the total number of daily maximum temperature records for month *mon*.

TMPMN(mon): Average or mean daily minimum air temperature for month (ºC).
Calculated based on following formula:

$$\mu mn_{mon} = \frac{\sum_{d=1}^{N} T_{mn,mon}}{N}$$

where μmn_{mon} is the mean daily minimum temperature for the month (°C), *Tmn,mon* is the daily minimum temperature on record *d* in month *mon* (°C), and *N* is the total number of daily minimum temperature records for month *mon*.

TMPSTDMX(mon): Standard deviation for daily maximum air temperature in month (ºC)

Calculated based on following formula:

$$\sigma mx_{mon} = \sqrt{\frac{\sum_{d=1}^{N} (T_{mx,mon} - \mu mx_{mon})^2}{N-1}}$$

Where σmx_{mon} is the standard deviation for daily maximum temperature in month *mon* (ºC), Tmx,mon is the daily maximum temperature on record d in month *mon* (°C), $\mu mxmon$ is the average daily maximum temperature for the month (°C), and N is the total number of daily maximum temperature records for month *mon*.

TMPSTDMN(mon): Standard deviation for daily minimum air temperature in month (ºC).

Calculated based on following formula:

$$\sigma mn_{mon} = \sqrt{\frac{\sum_{d=1}^{N} (T_{mn,mon} - \mu mn_{mon})^2}{N-1}}$$

Where σmn_{mon} is the standard deviation for daily minimum temperature in month *mon* (ºC), Tmn,mon is the daily minimum temperature on record d in month *mon* (°C), $\mu mnmon$ is the average daily minimum temperature for the month (°C), and N is the total number of daily minimum temperature records for month *mon*.

PCPMM(mon): Average or mean total monthly precipitation (mm H2O).

Calculated based on following formula:

$$\overline{R}_{mon} = \frac{\sum_{d=1}^{N} R_{day,mon}}{yrs}$$

where $\overline{R}_{mon}$ is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitation for record d in month *mon* (mm H2O), N is the total number of records in month *mon* used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSTD(mon): Standard deviation for daily precipitation in month (mm H2O/day).

Calculated based on following formula:

$$\sigma_{mon} = \sqrt{\frac{\sum_{d=1}^{N} (R_{day,mon} - \overline{R}_{mon})^2}{N-1}}$$

Where σ_{mon} is the standard deviation for daily precipitation in month *mon* (mm H2O), $\overline{R}_{mon}$ is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitation for record d in month *mon* (mm H2O), N is the total number of records in month *mon* used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation.

PCPSKW(mon): Skew coefficient for daily precipitation in month.

Calculated based on following formula:

$$g_{mon} = \frac{N \cdot \sum_{d=1}^{N} (R_{day,mon} - \overline{R}_{mon})^3}{(N-1) \cdot (N-2) \cdot (\sigma_{mon})^3}$$

Where g_{mon} is the skew coefficient for precipitation in the month, N is the total number of daily precipitation records for month *mon*, $R_{day,mon}$ is the amount of precipitation for record d in month *mon* (mm H2O), $\overline{R}_{mon}$ is the average precipitation for the month (mm H2O), and σ_{mon} is the standard deviation for daily precipitation in month *mon* (mm H2O). (Note: daily precipitation values of 0 mm are included in the skew coefficient calculation).

PR_W(1,mon) : Probability of a wet day following a dry day in the month.
Calculated based on following formula:

$$P_i(W/D) = \frac{days_{W/D,i}}{days_{dry,i}}$$

Where *Pi(W/D)* is the probability of a wet day following a dry day in month *i*, $days_{W/D,i}$ is the number of times a wet day followed a dry day in month *i* for the entire period of record, and $days_{dry,i}$ is the number of dry days in month *i* during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PR_W(2,mon) : Probability of a wet day following a wet day in the month.
Calculated based on following formula:

$$P_i(W/W) = \frac{days_{W/W,i}}{days_{wet,i}}$$

Where *Pi(W/W)* is the probability of a wet day following a wet day in month *i*, $days_{W/W,i}$ *i* is the number of times a wet day followed a wet day in month *i* for the entire period of record, and $days_{wet,i}$ is the number of wet days in month *i* during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.

PCPD(mon): Average number of days of precipitation in month.
Calculated based on following formula:

$$\overline{d}_{wet,i} = \frac{days_{wet,i}}{yrs}$$

Where $\overline{d}_{wet,i}$, is the average number of days of precipitation in month *i*, $days_{wet,i}$ is the number of wet days in month *i* during the entire period of record, and *yrs* is the number of years of record.

RAINHHMX(mon): Maximum 0.5 hour rainfall in entire period of record for month (mm H2O).
This value represents the most extreme 30-minute rainfall intensity recorded in the entire period of record.

SOLARAV(mon): Average daily solar radiation for month (MJ/m2/day).
Calculated based on following formula:

$$\mu rad_{mon} = \frac{\sum_{d=1}^{N} H_{day,mon}}{N}$$

Where μrad_{mon} is the mean daily solar radiation for the month (MJ/m^2/day), $H_{day,mon}$ is the total solar radiation reaching the earth's surface d in month *mon* (MJ/m^2/day), and N is the total number of daily solar radiation records for month
mon.

DEWPT(mon): Average daily dew point temperature in month (ºC).

Calculated based on following formula: $$\mu dew_{mon} = \frac{\sum_{d=1}^{N} T_{dew,mon}}{N}$$

Where μdew_{mon} is the mean daily dew point temperature for the month (ºC), *Tdew,mon* is the dew point temperature for day d in month *mon* (ºC), and N is the total number of daily dew point records for month *mon*.

WNDAV(mon): Average daily wind speed in month (m/s).

Calculated based on following formu

$$\mu wnd_{mon} = \frac{\sum_{d=1}^{N} \mu_{wnd,mon}}{N}$$

Where μwnd_{mon} is the mean daily wind speed for the month (m/s), $\mu_{wnd,mon}$ is the average wind speed for day d in month *mon* (m/s), and N is the total number of daily wind speed records for month *mon*.

SWAT input variables that pertain to generation of maximum half-hour rainfall

Variable name	Definition	File Name
ISED_DET	Code governing calculation of daily maximum half-hour rainfall: 1-use monthly maximum half-hour rainfall value	.bsn
RAINHHMX(mon)	$R_{0.5x}$: extreme half-hour rainfall for month (mm H_2O)	.wgn
ADJ_PKR	$adj_{0.5\alpha}$: peak rate adjustment factor	.bsn
PCPMM(mon)	average amount of precipitation falling in month (mm H_2O)	.wgn
PCPD(mon)	$days_{wet}$: average number of days of precipitation in month	.wgn
PCPD)	(μ_{mon} = PCPMM /	
RAIN_YRS	yrs: number of years of data used to obtain values for RAINHHMX	.wgn

SWAT input variables that pertain to peak rate calculations

Variable Name	Definition	Input File
SUB_KM	Area of the subbasin (km^2)	.sub
HRU_FR	Fraction of subbasin area contained in HRU	.hru
SLSUBBSN	L_{slp}: Average slope length (m)	.hru
HRU_SLP	slp: Average slope steepness (m/m)	.hru
OV_N	n: Manning's "n" value for overland flow	.hru
CH_L(1)	L: Longest tributary channel length in subbasin (km)	.sub
CH_S(1)	slp_{ch}: Average slope of tributary channels (m/m)	.sub
CH_N(1)	n: Manning's "n" value for tributary channels	.sub

Station
Assaita

	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec
TMPMX	32.95	34.1	35.84	38.1	40.3	41.7	40.99	39.56	39.5	37.5	35.2	33.1
TMPMN	20.45	20.8	23.03	24.9	26.9	27.9	28.06	26.20	26.9	24.6	22.1	20.9
TMPSTDMX	2.55	2.41	2.79	1.75	1.33	1.60	1.62	1.73	1.33	1.74	2.39	2.55
TMPSTDMN	2.82	2.99	2.78	3.14	3.49	3.83	3.40	2.74	3.06	3.14	2.67	3.08
PCPMM	0.30	2.30	7.00	7.70	0.50	1.90	6.90	23.60	5.00	2.30	1.50	3.00
PCPSTD	0.57	31.4	13.73	6.87	1.68	4.60	5.45	11.62	5.27	6.36	20.65	8.75
PCPSKW	1.07	1.07	1.07	1.80	1.68	2.71	1.82	2.81	2.04	2.23	0.00	0.71
PR_W1_	0.00	0.00	0.02	0.03	0.01	0.01	0.05	0.07	0.03	0.02	0.00	0.01
PR_W2_	0.00	0.00	0.18	0.33	0.00	0.13	0.10	0.29	0.29	0.18	0.50	
PRD	0.10	0.10	0.60	1.20	0.30	0.40	1.50	2.60	1.20	0.60	0.10	0.30
RAINHHMX	3.80	45.6	38.00	29.0	4.80	4.00	22.20	60.10	18.4	21.2	30.0	23.4
SOLARAV	19.85	21.4	22.23	22.4	21.57	20.8	19.54	19.59	20.5	21.2	21.2	19.0
DEWPT	11.10	11.9	11.36	14.2	13.8	14.9	15.97	16.27	15.6	11.6	10.3	10.51
WNDAV	1.58	1.61	1.63	1.73	1.46	1.55	1.56	1.51	1.29	1.50	1.69	1.61

Station
Bati

	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec
TMPMX	24.73	25.63	27.05	28.95	31.14	32.81	30.77	28.90	29.11	28.21	26.77	25.25
TMPMN	11.18	11.7	13.56	14.7	15.1	16.9	16.07	15.35	14.2	11.5	10.2	10.4
TMPSTDMX	2.63	2.24	1.63	1.90	1.24	1.33	1.49	1.21	1.25	1.10	1.16	1.75
TMPSTDMN	2.78	3.34	2.47	2.58	2.69	2.33	2.92	3.98	4.83	2.82	2.12	2.56
PCPMM	35.48	53.53	72.67	83.02	49.96	19.86	192.68	211.81	85.96	32.62	22.98	46.93
PCPSTD	33.01	50.00	50.00	50.00	50.00	22.67	50.00	50.00	29.84	39.26	50.00	50.00
PCPSKW	0.67	1.73	0.95	1.18	1.63	1.71	-0.16	0.52	0.39	1.49	2.79	1.37
PR_W1_	0.05	0.06	0.08	0.14	0.07	0.06	0.23	0.25	0.19	0.06	0.02	0.03
PR_W2_	0.66	0.65	0.47	0.45	0.44	0.45	0.65	0.66	0.57	0.37	0.31	0.63
PRD	0.10	0.10	0.60	1.20	0.30	0.40	1.50	2.60	1.20	0.60	0.10	0.30
RAINHHMX	3.70	4.30	3.80	6.10	3.30	2.80	12.40	13.10	9.10	2.60	0.60	2.50
SOLARAV	49.00	64.80	48.80	70.40	54.10	60.90	50.60	68.40	54.30	38.70	71.60	35.10
DEWPT	20.00	21.00	21.00	20.00	20.00	17.00	14.00	14.00	14.00	17.00	22.00	21.00
WNDAV	6.86	6.71	7.53	9.55	9.09	10.69	11.38	11.42	10.58	7.25	6.34	6.58

Station
Dubti

	Jan	Feb	Mar	Apr	May	June	July	Augst	Sep	Oct	Nov	Dec
TMPMX	32.35	33.26	36.06	37.81	40.98	43.43	40.72	38.99	39.58	37.13	34.27	32.73
TMPMN	17.99	19.46	21.96	22.73	24.72	25.88	25.83	25.32	24.78	20.94	18.01	17.07
TMPSTDMX	0.95	2.07	1.08	1.65	1.43	2.60	1.31	1.99	0.82	0.71	1.08	0.81
TMPSTDMNZ	2.64	1.74	1.71	2.14	2.17	2.90	2.29	2.36	1.54	2.50	2.23	2.53
PCPMM	3.84	13.34	24.73	35.71	9.39	2.68	43.14	55.61	14.76	6.70	1.95	6.62
PCPSTD	10.59	33.68	28.21	48.93	15.08	5.01	29.06	35.59	12.68	13.88	6.26	17.79
PCPSKW	3.84	13.34	24.73	45.71	9.39	2.68	43.14	55.61	14.76	6.70	1.95	6.62
PR_W1_	0.04	0.04	0.06	0.08	0.04	0.02	0.15	0.17	0.07	0.02	0.01	0.01
PR_W2_	0.36	0.36	0.35	0.22	0.00	0.08	0.31	0.29	0.16	0.00	0.00	0.17
PRD	0.60	1.60	2.60	2.90	1.20	0.60	5.60	6.10	2.20	0.70	0.20	0.30
RAINHHMX	35.30	16.00	90.80	46.20	13.90	39.40	38.70	48.30	21.10	20.50	43.20	15.20
SOLARAV	19.85	21.44	22.23	22.43	21.57	20.84	19.54	19.59	20.52	21.23	21.19	19.03
DEWPT	11.10	11.93	11.36	14.23	13.89	14.90	15.97	16.27	15.59	11.61	10.31	10.51
WNDAV	1.99	2.11	2.31	2.03	1.45	1.45	1.58	1.56	1.09	1.18	1.56	1.70

Station
Kombolcha

	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec
TMPMX	24.23	25.33	26.34	26.95	28.31	30.12	27.90	26.46	25.90	25.13	24.61	24.09
TMPMN	9.96	10.97	12.42	13.22	13.58	14.57	14.14	13.83	12.99	10.37	8.37	8.64
TMPSTDMX	1.61	1.57	1.44	1.40	1.36	0.98	1.34	1.09	0.93	0.92	1.07	1.06
TMPSTDMN	1.95	2.00	1.46	1.33	1.34	1.64	1.80	1.73	1.74	1.93	1.83	1.80
PCPMM	15.50	7.30	32.00	41.10	17.60	16.00	158.30	136.00	50.40	28.90	10.40	9.10
PCPSTD	8.74	6.55	8.44	7.57	5.62	6.17	14.91	10.94	7.58	10.05	12.13	8.23
PCPSKW	3.24	1.94	2.63	1.35	1.34	2.64	1.86	1.57	2.37	2.52	2.23	2.15
PR_W1_	0.04	0.03	0.08	0.08	0.06	0.06	0.12	0.12	0.15	0.04	0.02	0.03
PR_W2_	0.58	0.55	0.58	0.65	0.50	0.49	0.80	0.81	0.59	0.66	0.48	0.50
PRD	2.80	1.50	4.80	5.30	3.10	3.30	12.00	11.90	7.80	3.50	1.10	1.60
RAINHHMX	19.00	64.80	48.80	70.40	54.10	60.90	50.60	68.40	54.30	38.70	71.60	35.10
SOLARAV	20.00	21.00	21.00	20.00	20.00	17.00	14.00	14.00	17.00	21.00	22.00	21.00
DEWPT	6.86	6.71	7.53	9.55	9.09	10.69	11.38	11.42	10.58	7.25	6.34	6.58
WNDAV	1.28	1.41	1.34	1.32	1.31	1.48	1.49	1.32	1.10	0.85	0.93	1.06

Station
Sirinka

	Jan	Feb	Mar	Apr	May	June	July	August	Sep	Oct	Nov	Dec
TMPMX	23.20	24.23	25.50	26.49	28.33	30.79	28.33	27.06	26.83	25.76	24.80	23.68
TMPMN	10.62	11.81	13.43	14.67	15.29	16.60	15.90	15.14	14.54	12.70	11.08	10.32
TMPSTDMX	1.82	2.20	1.54	1.69	1.77	1.42	1.32	1.26	1.00	1.25	1.30	0.95
TMPSTDMN	2.60	2.62	2.73	2.91	3.05	3.40	3.32	3.00	2.92	2.90	2.40	2.42
PCPMM	40.00	52.50	88.40	98.60	43.70	26.60	236.40	278.70	93.60	67.90	27.80	42.00
PCPSTD	36.70	50.00	50.00	50.00	48.40	29.10	50.00	50.00	23.30	50.00	32.10	50.00
PCPSKW	0.68	1.25	0.97	1.17	2.57	1.30	0.22	0.07	0.43	2.24	1.00	1.72
PR_W1_	0.45	0.05	0.07	0.08	0.06	0.02	0.11	0.13	0.13	0.06	0.03	0.02
PR_W2_	0.60	0.58	0.49	0.58	0.41	0.59	0.63	0.60	0.47	0.42	0.41	0.46
PRD	2.90	3.00	3.80	4.80	2.80	1.60	7.30	7.40	6.00	2.80	1.50	1.30
RAINHHMX	49.00	64.80	48.80	70.40	54.10	60.90	50.60	68.40	54.30	38.70	71.60	35.10
SOLARAV	20.00	21.00	21.00	20.00	20.00	17.00	14.00	14.00	17.00	21.00	22.00	21.00
DEWPT	6.86	6.71	7.53	9.55	9.09	10.69	11.38	11.42	10.58	7.25	6.34	6.58
WNDAV	1.32	1.35	1.35	1.17	1.26	1.50	1.37	1.25	1.4	1.03	1.19	1.41

Appendix D Crop parameters.

The crop parameters used by the model are shown below. The descriptions of each variable are given in Neitsch (b) *et al.* (2002) pp. 138-154.

FRST (Forest-Mixed)
15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50 30.00 10.00 0.0015 0.0003 0.0060 0.0020
0.0015 0.0007 0.0004 0.0003 0.010 0.001 0.002 4.000 0.750 8.000 330.000 16.000 0.050 0.75
0.30
FRSE (Forest-Evergreen)
15.00 0.76 5.00 0.15 0.70 0.25 0.99 0.99 10.00 3.50 30.00 0.00 0.0015 0.0003 0.0060 0.0020
0.0015 0.0007 0.0004 0.0003 0.600 0.001 0.002 4.000 0.750 8.000 330.000 16.000 0.050 0.75
0.30
WETN (Wetlands-Non-Forested)
47.00 0.90 6.00 0.10 0.20 0.20 0.95 0.70 2.50 2.20 25.00 12.00 0.0160 0.0022 0.0350 0.0150
0.0038 0.0014 0.0010 0.0007 0.900 0.003 0.005 4.000 0.750 8.500 330.000 54.000 0.050 0.00
0.00
PAST (Summer Pasture)
35.00 0.90 4.00 0.05 0.05 0.49 0.95 0.99 0.50 2.00 25.00 12.00 0.0234 0.0033 0.0600 0.0231
0.0134 0.0084 0.0032 0.0019 0.900 0.003 0.005 4.000 0.750 10.000 330.000 36.000 0.050 0.00
0.00
RNGE (Range-Grasses)
34.00 0.90 2.50 0.05 0.10 0.25 0.70 0.35 1.00 2.00 25.00 12.00 0.0160 0.0022 0.0200 0.0120
0.0050 0.0014 0.0010 0.0007 0.900 0.003 0.005 4.000 0.750 10.000 330.000 39.000 0.050 0.00
0.00

RNGB (Range-Brush)
34.00 0.90 2.00 0.05 0.10 0.25 0.70 0.35 1.00 2.00 25.00 12.00 0.0160 0.0022 0.0200 0.0120
0.0050 0.0014 0.0010 0.0007 0.900 0.003 0.005 4.000 0.750 10.000 330.000 39.000 0.050 0.00
0.00

39.00 0.50 3.00 0.15 0.05 0.50 0.95 0.70 2.50 2.00 25.00 8.00 0.0140 0.0016 0.0470 0.0177
0.0138 0.0048 0.0018 0.0014 0.300 0.190 0.007 4.000 0.750 7.200 330.000 45.000 0.050 0.00
0.00
DWHT (Durum Wheat)
30.00 0.40 4.00 0.15 0.01 0.50 0.95 0.80 1.00 2.00 15.00 0.00 0.0263 0.0057 0.0600 0.0231
0.0130 0.0084 0.0032 0.0019 0.200 0.230 0.006 4.000 0.750 7.000 330.000 45.000 0.050 0.00
0.00
WATR (Water)

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.00

AGRR (Agriculture land)

34.00 0.87 3.50 0.05 0.10 0.49 0.99 0.35 1.00 1.00

25.00 12.00 0.0310 0.0029 0.0400 0.0310 0.0180 0.0084 0.0032 0.0019

0.090 0.380 0.005 4.000 0.750 10.000 660.000 39.000 0.050 0.00

0.0

Appendix E: Calibrated Parameters for Mille Watershed

SUBBASIN	HRU	LANDUSE	SOIL	HRU_FR	SLSUBBSN	HRU_SLP	OV_N	LAT_TTIME	CN2
1	1	FRST	LVh	1.0000000	24.390	0.126	0.200	4.000	58.40
2	1	RNGB	FLc	0.3698445	121.951	0.014	0.150	4.000	48.80
2	2	PAST	FLc	0.3786342	121.951	0.014	0.150	4.000	55.20
2	3	FRST	FLc	0.2515213	121.951	0.014	0.100	4.000	48.00
3	1	FRST	FLc	0.2943714	60.976	0.076	0.100	4.000	48.00
3	2	FRST	LP	0.1417500	60.976	0.076	0.100	4.000	60.00
3	3	FRST	LVh	0.5638787	24.390	0.126	0.200	4.000	58.40
4	1	DWHT	CMe	0.1212338	24.390	0.148	0.140	4.000	59.00
4	2	DWHT	RGe	0.0961075	24.390	0.148	0.140	4.000	59.00
4	3	DWHT	LVh	0.1179459	24.390	0.148	0.140	4.000	65.00
4	4	FRST	CMe	0.1040965	24.390	0.148	0.100	4.000	60.00
4	5	FRST	LP	0.1068723	24.390	0.148	0.200	4.000	60.00
4	6	FRST	LVh	0.4537440	24.390	0.126	0.200	4.000	58.40
5	1	FRST	CMe	0.3640178	18.293	0.184	0.200	4.000	60.00
5	2	FRST	LP	0.1002029	18.293	0.184	0.200	4.000	60.00
5	3	FRST	LVx	0.2920789	18.293	0.184	0.200	4.000	65.00
5	4	FRST	RGe	0.1411403	18.293	0.184	0.200	4.000	60.00
5	5	FRST	LVh	0.1025600	24.390	0.126	0.200	4.000	58.40
6	1	RNGB	CMe	0.1220446	15.244	0.206	0.250	4.000	61.00
6	2	RNGB	LP	0.0683367	15.244	0.206	0.250	4.000	61.00
6	3	RNGB	RGe	0.2941009	15.244	0.206	0.250	4.000	61.00
6	4	DWHT	CMe	0.1962586	15.244	0.206	0.250	4.000	59.00
6	5	DWHT	LP	0.0678257	15.244	0.206	0.250	4.000	65.00
6	6	DWHT	RGe	0.2514336	15.244	0.206	0.200	4.000	59.00
7	1	URHD	LVx	0.3771691	91.463	0.022	0.200	4.000	65.00
7	2	URHD	SCo	0.3006844	91.463	0.022	0.200	4.000	62.00
7	3	RNGE	LVx	0.2405690	91.463	0.022	0.200	4.000	65.00
7	4	RNGE	SCo	0.0815775	91.463	0.022	0.200	4.000	69.00
8	1	URHD	RGe	0.2442813	121.951	0.017	0.200	4.000	77.00
8	2	URHD	SCo	0.2151316	121.951	0.017	0.200	4.000	77.00
8	3	PAST	RGe	0.2299016	121.951	0.017	0.200	4.000	69.00
8	4	PAST	SCo	0.3106855	121.951	0.017	0.200	4.000	69.00
9	1	URHD	RGe	0.1156815	121.951	0.015	0.200	4.000	77.00
9	2	URHD	SCo	0.2291279	121.951	0.015	0.200	4.000	62.00
9	3	PAST	RGe	0.1769453	121.951	0.015	0.200	4.000	69.00
9	4	PAST	SCo	0.4782453	121.951	0.015	0.200	4.000	69.00
10	1	URHD	RGe	0.0672831	91.463	0.024	0.200	4.000	65.00
10	2	URHD	SCo	0.2033948	91.463	0.024	0.200	4.000	62.00
10	3	PAST	RGe	0.0831987	91.463	0.024	0.200	4.000	69.00
10	4	PAST	SCo	0.6461234	91.463	0.024	0.200	4.000	69.00
11	1	URHD	RGe	0.0743867	91.463	0.037	0.200	4.000	62.00
11	2	URHD	SCo	0.2723634	91.463	0.037	0.200	4.000	62.00

11	3	RNGB	CMe	0.0418253	91.463	0.037	0.200	4.000	61.00
11	4	RNGB	FLc	0.1087408	91.463	0.037	0.200	4.000	48.80
11	5	RNGB	RGe	0.1732673	91.463	0.037	0.200	4.000	61.00
11	6	PAST	RGe	0.0797042	91.463	0.037	0.200	4.000	69.00
11	7	PAST	SCo	0.2497124	91.463	0.037	0.200	4.000	69.00
12	1	RNGB	FLc	0.2798253	91.463	0.032	0.200	4.000	60.00
12	2	RNGB	RGe	0.1057533	91.463	0.032	0.200	4.000	61.00
12	3	PAST	FLc	0.2630762	91.463	0.032	0.200	4.000	55.20
12	4	PAST	RGe	0.2576142	91.463	0.032	0.200	4.000	69.00
12	5	PAST	SCo	0.0937311	91.463	0.032	0.200	4.000	69.00

Appendix F: Calibrated parameters FOR Logiya WATERSHED

SUB	HRU	LANDUSE	SOIL	HRU_FR	SLSUBBSN	HRU_SLP	OV_N	LAT_TTIME	CN2
1	1	URHD	ANm	0.1328910	91.463	0.032	0.200	4.000	72.00
1	2	URHD	SCo	0.8671090	91.463	0.032	0.200	4.000	74.00
2	1	URHD	ANm	0.1387732	91.463	0.021	0.200	4.000	72.00
2	2	URHD	RGe	0.4021345	91.463	0.021	0.200	4.000	72.00
2	3	FRST	LP	0.1264234	91.463	0.021	0.200	4.000	60.00
2	4	FRST	RGe	0.3326689	91.463	0.021	0.200	4.000	60.00
3	1	URHD	LVx	0.0430225	121.951	0.017	0.200	4.000	60.00
3	2	URHD	SCo	0.3530560	121.951	0.017	0.200	4.000	60.00
3	3	PAST	FLc	0.1000775	121.951	0.017	0.200	4.000	69.00
3	4	PAST	LVx	0.0559627	121.951	0.017	0.200	4.000	55.00
3	5	PAST	SCo	0.1331005	121.951	0.017	0.200	4.000	69.00
3	6	AGRR	FLc	0.1372422	121.951	0.017	0.200	4.000	65.00
3	7	AGRR	LVx	0.0439234	121.951	0.017	0.200	4.000	65.00
3	8	AGRR	SCo	0.1336151	121.951	0.017	0.200	4.000	72.00
4	1	URHD	CMe	0.1630474	60.976	0.057	0.200	4.000	72.00
4	2	URHD	LVh	0.1522306	60.976	0.057	0.200	4.000	72.00
4	3	PAST	FLc	0.3194701	60.976	0.057	0.200	4.000	65.00
4	4	FRST	CMe	0.1109308	60.976	0.057	0.200	4.000	60.00
4	5	FRST	FLc	0.2124084	60.976	0.057	0.200	4.000	60.00
4	6	FRST	LVh	0.0419126	60.976	0.057	0.200	4.000	63.00
5	1	URHD	SCo	0.3673344	91.463	0.030	0.200	4.000	63.00
5	2	PAST	SCo	0.3241911	91.463	0.030	0.200	4.000	69.00
5	3	AGRR	SCo	0.3084746	91.463	0.030	0.200	4.000	63.00
6	1	PAST	ANm	0.1555676	91.463	0.027	0.200	4.000	62.00
6	2	PAST	FLc	0.5997373	91.463	0.027	0.200	4.000	64.00
6	3	PAST	SCo	0.2446951	91.463	0.027	0.200	4.000	55.00
7	1	FRST	RGe	1.0000000	121.951	0.010	0.200	4.000	57.00
8	1	FRST	LP	0.7682567	91.463	0.033	0.200	4.000	50.00
8	2	FRST	RGe	0.2317433	91.463	0.033	0.200	4.000	52.00

Appendix G: SWAT HRU DISTRIBUTION REPORT FOR MILLEWATERSHED AFTER HRU THRESHOLD APPLICATION

SUBBASIN	ARSUB	LANDUSE	ARLU	SOIL	ARSO
1	57836.7488	FRST	57836.7488	LVh	57836.7488
2	627.3819	RNGB	232.0337	FLc	232.0337
2	627.3819	PAST	237.5483	FLc	237.5483
2	627.3819	FRST	157.7999	FLc	157.7999
3	36210.1056	FRST	36210.1056	FLc	10659.2189
3	36210.1056	FRST	36210.1056	LP	5132.7809
3	36210.1056	FRST	36210.1056	LVh	20418.1058
4	58071.6544	DWHT	19470.6842	CMe	7040.2474
4	58071.6544	DWHT	19470.6842	RGe	5581.1212
4	58071.6544	DWHT	19470.6842	LVh	6849.3156
4	58071.6544	FRST	38600.9702	CMe	6045.0567
4	58071.6544	FRST	38600.9702	LP	6206.2516
4	58071.6544	FRST	38600.9702	LVh	26349.6620
5	49826.9888	FRST	49826.9888	CMe	18137.9129
5	49826.9888	FRST	49826.9888	LP	4992.8109
5	49826.9888	FRST	49826.9888	LVx	14553.4118
5	49826.9888	FRST	49826.9888	RGe	7032.5954
5	49826.9888	FRST	49826.9888	LVh	5110.2578
6	85994.8544	RNGB	41662.9712	CMe	10495.2037
6	85994.8544	RNGB	41662.9712	LP	5876.6007
6	85994.8544	RNGB	41662.9712	RGe	25291.1669
6	85994.8544	DWHT	44331.8832	CMe	16877.2307
6	85994.8544	DWHT	44331.8832	LP	5832.6604
6	85994.8544	DWHT	44331.8832	RGe	21621.9921
7	6695.2144	URHD	4538.3748	LVx	2525.2280
7	6695.2144	URHD	4538.3748	SCo	2013.1468
7	6695.2144	RNGE	2156.8396	LVx	1610.6611
7	6695.2144	RNGE	2156.8396	SCo	546.1785
8	5653.5848	URHD	2597.3298	RGe	1381.0653
8	5653.5848	URHD	2597.3298	SCo	1216.2645
8	5653.5848	PAST	3056.2550	RGe	1299.7682
8	5653.5848	PAST	3056.2550	SCo	1756.4868
9	6426.5220	URHD	2215.9251	RGe	743.4296
9	6426.5220	URHD	2215.9251	SCo	1472.4955
9	6426.5220	PAST	4210.5969	RGe	1137.1428

9	6426.5220	PAST	4210.5969	SCo	3073.4541
10	25913.3744	URHD	7014.1763	RGe	1743.5310
10	25913.3744	URHD	7014.1763	SCo	5270.6453
10	25913.3744	PAST	18899.1981	RGe	2155.9598
10	25913.3744	PAST	18899.1981	SCo	16743.2383
11	72247.0400	URHD	25051.6680	RGe	5374.2210
11	72247.0400	URHD	25051.6680	SCo	19677.4470
11	72247.0400	RNGB	23396.0033	CMe	3021.7521
11	72247.0400	RNGB	23396.0033	FLc	7856.1995
11	72247.0400	RNGB	23396.0033	RGe	12518.0517
11	72247.0400	PAST	23799.3687	RGe	5758.3899
11	72247.0400	PAST	23799.3687	SCo	18040.9788
12	151511.9104	RNGB	58419.7438	FLc	42396.8648
12	151511.9104	RNGB	58419.7438	RGe	16022.8790
12	151511.9104	PAST	93092.1666	FLc	39859.1797
12	151511.9104	PAST	93092.1666	RGe	39031.6126
12	151511.9104	PAST	93092.1666	SCo	14201.3744

SWAT model simulation Tue Jan 08 09:45:24 2008
MDL

MULTIPLE HRUs LandUse/Soil OPTION THRESHOLDS : 20 / 10 [%]

Number of HRUs: 52

Number of Subbasins: 12

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

WATERSHED: 557015.3799 1376412.8545

LANDUSE:

Residential-High Density-->URHD 41417.4740 102344.6492 7.44

Range-Brush-->RNGB 123710.7520 305695.4537 22.21

Pasture-->PAST 143295.1336 354089.4398 25.73

Range-Grasses-->RNGE 2156.8396 5329.6585 0.39

Durum Wheat-->DWHT 63802.5674 157659.3341 11.45
Forest-Mixed-->FRST 182632.6133 451294.3192 32.79

SOIL:

LVx	18689.3009	46182.1969	3.36
FLc	101398.8448	250561.6154	18.20
CMe	61617.4034	152259.6846	11.06
SCo	84011.7099	207597.1358	15.08
RGe	146692.9265	362485.5560	26.34
LP	28041.1044	69290.9711	5.03
LVh	116564.0900	288035.6947	20.93

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

SUBBASIN # 1 57836.7488 142917.4981 10.38

LANDUSE:

Forest-Mixed-->FRST 57836.7488 142917.4981 10.38 100.00

SOIL:

LVh 57836.7488 142917.4981 10.38 100.00

HRUs:

1 Forest-Mixed-->FRST/LVh 57836.7488 142917.4981 10.38 100.00 1

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

SUBBASIN # 2 627.3819 1550.2920 0.11

LANDUSE:

Range-Brush-->RNGB	232.0337	573.3670	0.04	36.98
Pasture-->PAST	237.5483	586.9936	0.04	37.86
Forest-Mixed-->FRST	157.7999	389.9315	0.03	25.15

SOIL:

FLc 627.3819 1550.2920 0.11 100.00

HRUs:

2	Range-Brush-->RNGB/FLc	232.0337	573.3670	0.04	36.98	1
3	Pasture-->PAST/FLc	237.5483	586.9936	0.04	37.86	2
4	Forest-Mixed-->FRST/FLc	157.7999	389.9315	0.03	25.15	3

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

SUBBASIN # 3 36210.1056 89476.9814 6.50

LANDUSE:

Forest-Mixed-->FRST 36210.1056 89476.9814 6.50 100.00

SOIL:

FLc	10659.2189	26339.4628	1.91	29.44
LP	5132.7809	12683.3582	0.92	14.17
LVh	20418.1058	50454.1604	3.67	56.39

HRUs:

5	Forest-Mixed-->FRST/FLc	10659.2189	26339.4628	1.91	29.44	1
6	Forest-Mixed-->FRST/LP	5132.7809	12683.3582	0.92	14.17	2
7	Forest-Mixed-->FRST/LVh	20418.1058	50454.1604	3.67	56.39	3

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

SUBBASIN # 4 58071.6544 143497.9616 10.43

LANDUSE:

Durum Wheat-->DWHT	19470.6842	48113.0341	3.50	33.53
Forest-Mixed-->FRST	38600.9702	95384.9275	6.93	66.47

SOIL:

LP 6206.2516 15335.9579 1.11 10.69

LVh	33198.9776	82036.3335	5.96	57.17
CMe	13085.3041	32334.4406	2.35	22.53
RGe	5581.1212	13791.2296	1.00	9.61

HRUs:

8	Durum Wheat-->DWHT/CMe	7040.2474	17396.8033	1.26	12.12	1
9	Durum Wheat-->DWHT/RGe	5581.1212	13791.2296	1.00	9.61	2
10	Durum Wheat-->DWHT/LVh	6849.3156	16925.0012	1.23	11.79	3
11	Forest-Mixed-->FRST/CMe	6045.0567	14937.6373	1.09	10.41	4
12	Forest-Mixed-->FRST/LP	6206.2516	15335.9579	1.11	10.69	5
13	Forest-Mixed-->FRST/LVh	26349.6620	65111.3323	4.73	45.37	6

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN # 5	49826.9888	123124.9807	8.95	

LANDUSE:

Forest-Mixed-->FRST	49826.9888	123124.9807	8.95	100.00

SOIL:

LVx	14553.4118	35962.2082	2.61	29.21
LP	4992.8109	12337.4854	0.90	10.02
LVh	5110.2578	12627.7026	0.92	10.26
CMe	18137.9129	44819.6898	3.26	36.40
RGe	7032.5954	17377.8948	1.26	14.11

HRUs:

14	Forest-Mixed-->FRST/CMe	18137.9129	44819.6898	3.26	36.40	1
15	Forest-Mixed-->FRST/LP	4992.8109	12337.4854	0.90	10.02	2
16	Forest-Mixed-->FRST/LVx	14553.4118	35962.2082	2.61	29.21	3
17	Forest-Mixed-->FRST/RGe	7032.5954	17377.8948	1.26	14.11	4
18	Forest-Mixed-->FRST/LVh	5110.2578	12627.7026	0.92	10.26	5

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

SUBBASIN # 6 85994.8544 212497.5850 15.44

LANDUSE:

Range-Brush-->RNGB 41662.9712 102951.2850 7.48 48.45

Durum Wheat-->DWHT 44331.8832 109546.3000 7.96 51.55

SOIL:

LP 11709.2611 28934.1696 2.10 13.62

CMe 27372.4343 67638.6538 4.91 31.83

RGe 46913.1590 115924.7615 8.42 54.55

HRUs:

19 Range-Brush-->RNGB/CMe 10495.2037 25934.1730 1.88 12.20 1

20 Range-Brush-->RNGB/LP 5876.6007 14521.3741 1.06 6.83 2

21 Range-Brush-->RNGB/RGe 25291.1669 62495.7379 4.54 29.41 3

22 Durum Wheat-->DWHT/CMe 16877.2307 41704.4808 3.03 19.63 4

23 Durum Wheat-->DWHT/LP 5832.6604 14412.7956 1.05 6.78 5

24 Durum Wheat-->DWHT/RGe 21621.9921 53429.0236 3.88 25.14 6

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

SUBBASIN # 7 6695.2144 16544.2095 1.20

LANDUSE:

Residential-High Density-->URHD 4538.3748 11214.5511 0.81 67.79

Range-Grasses-->RNGE 2156.8396 5329.6585 0.39 32.21

SOIL:

LVx 4135.8891 10219.9887 0.74 61.77

SCo 2559.3253 6324.2208 0.46 38.23

HRUs:

25 Residential-High Density-->URHD/LVx 2525.2280 6239.9647 0.45 37.72 1

26 Residential-High Density-->URHD/SCo 2013.1468 4974.5864 0.36 30.07 2

27 Range-Grasses-->RNGE/LVx 1610.6611 3980.0240 0.29 24.06 3

28 Range-Grasses-->RNGE/SCo 546.1785 1349.6344 0.10 8.16 4

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

SUBBASIN # 8 5653.5848 13970.2907 1.01

LANDUSE:

Residential-High Density-->URHD 2597.3298 6418.1318 0.47 45.94

Pasture-->PAST 3056.2550 7552.1590 0.55 54.06

SOIL:

SCo 2972.7513 7345.8170 0.53 52.58

RGe 2680.8335 6624.4737 0.48 47.42

HRUs:

29 Residential-High Density-->URHD/RGe 1381.0653 3412.6814 0.25 24.43 1

30 Residential-High Density-->URHD/SCo 1216.2645 3005.4503 0.22 21.51 2

31 Pasture-->PAST/RGe 1299.7682 3211.7923 0.23 22.99 3

32 Pasture-->PAST/SCo 1756.4868 4340.3667 0.32 31.07 4

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

SUBBASIN # 9 6426.5220 15880.2572 1.15

LANDUSE:

Residential-High Density-->URHD 2215.9251 5475.6618 0.40 34.48

Pasture-->PAST 4210.5969 10404.5954 0.76 65.52

SOIL:

SCo 4545.9496 11233.2687 0.82 70.74

RGe 1880.5724 4646.9884 0.34 29.26

HRUs:

33 Residential-High Density-->URHD/RGe 743.4296 1837.0517 0.13 11.57 1

34 Residential-High Density-->URHD/SCo 1472.4955 3638.6101 0.26 22.91 2

35 Pasture-->PAST/RGe 1137.1428 2809.9367 0.20 17.69 3

36 Pasture-->PAST/SCo 3073.4541 7594.6587 0.55 47.82 4

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

SUBBASIN # 10 25913.3744 64033.2438 4.65

LANDUSE:

Residential-High Density-->URHD 7014.1763 17332.3803 1.26 27.07

Pasture-->PAST 18899.1981 46700.8635 3.39 72.93

SOIL:

SCo 22013.8835 54397.4069 3.95 84.95

RGe 3899.4909 9635.8369 0.70 15.05

HRUs:

37 Residential-High Density-->URHD/RGe 1743.5310 4308.3524 0.31 6.73 1

38 Residential-High Density-->URHD/SCo 5270.6453 13024.0280 0.95 20.34 2

39 Pasture-->PAST/RGe 2155.9598 5327.4846 0.39 8.32 3

40 Pasture-->PAST/SCo 16743.2383 41373.3789 3.01 64.61 4

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

SUBBASIN # 11 72247.0400 178526.0482 12.97

LANDUSE:

Residential-High Density-->URHD 25051.6680 61903.9243 4.50 34.68

Range-Brush-->RNGB 23396.0033 57812.6940 4.20 32.38

Pasture-->PAST 23799.3687 58809.4300 4.27 32.94

SOIL:

FLc 7856.1995 19413.0619 1.41 10.87

SCo 37718.4259 93204.1162 6.77 52.21

CMe 3021.7521 7466.9005 0.54 4.18

RGe 23650.6625 58441.9696 4.25 32.74

HRUs:

41	Residential-High Density-->URHD/RGe	5374.2210	13279.9687	0.96	7.44	1
42	Residential-High Density-->URHD/SCo	19677.4470	48623.9555	3.53	27.24	2
43	Range-Brush-->RNGB/CMe	3021.7521	7466.9005	0.54	4.18	3
44	Range-Brush-->RNGB/FLc	7856.1995	19413.0619	1.41	10.87	4
45	Range-Brush-->RNGB/RGe	12518.0517	30932.7316	2.25	17.33	5
46	Pasture-->PAST/RGe	5758.3899	14229.2693	1.03	7.97	6
47	Pasture-->PAST/SCo	18040.9788	44580.1607	3.24	24.97	7

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN #	12	151511.9104	374393.5062	27.20	

LANDUSE:

Range-Brush-->RNGB	58419.7438	144358.1078	10.49	38.56
Pasture-->PAST	93092.1666	230035.3984	16.71	61.44

SOIL:

FLc	82256.0445	203258.7987	14.77	54.29
SCo	14201.3744	35092.3062	2.55	9.37
RGe	55054.4915	136042.4013	9.88	36.34

HRUs:

48	Range-Brush-->RNGB/FLc	42396.8648	104764.7727	7.61	27.98	1
49	Range-Brush-->RNGB/RGe	16022.8790	39593.3351	2.88	10.58	2
50	Pasture-->PAST/FLc	39859.1797	98494.0260	7.16	26.31	3
51	Pasture-->PAST/RGe	39031.6126	96449.0662	7.01	25.76	4
52	Pasture-->PAST/SCo	14201.3744	35092.3062	2.55	9.37	5

Appendix H: SWAT HRU DISTRIBUTION REPORT FOR LOGIYA WATERSHED AFTER HRU THRESHOLD APPLICATION

SUBBASIN	ARSUB	LANDUSE	ARLU	SOIL	ARSO
1	55604.0384	URHD	55604.0384	ANm	7389.2741
1	55604.0384	URHD	55604.0384	SCo	48214.7643
2	33777.5776	URHD	18270.5517	ANm	4687.4232
2	33777.5776	URHD	18270.5517	RGe	13583.1286
2	33777.5776	FRST	15507.0259	LP	4270.2770
2	33777.5776	FRST	15507.0259	RGe	11236.7488
3	33621.3024	URHD	13316.6782	LVx	1446.4741
3	33621.3024	URHD	13316.6782	SCo	11870.2041
3	33621.3024	PAST	9721.2878	FLc	3364.7352
3	33621.3024	PAST	9721.2878	LVx	1881.5396
3	33621.3024	PAST	9721.2878	SCo	4475.0130
3	33621.3024	AGRR	10583.3364	FLc	4614.2613
3	33621.3024	AGRR	10583.3364	LVx	1476.7610
3	33621.3024	AGRR	10583.3364	SCo	4492.3140
4	66353.3504	URHD	20919.7500	CMe	10818.7395
4	66353.3504	URHD	20919.7500	LVh	10101.0105
4	66353.3504	PAST	21197.9130	FLc	21197.9130
4	66353.3504	FRST	24235.6874	CMe	7360.6334
4	66353.3504	FRST	24235.6874	FLc	14094.0093
4	66353.3504	FRST	24235.6874	LVh	2781.0446
5	1143.9729	URHD	420.2206	SCo	420.2206
5	1143.9729	PAST	370.8658	SCo	370.8658
5	1143.9729	AGRR	352.8866	SCo	352.8866
6	65801.3440	PAST	65801.3440	ANm	10236.5590
6	65801.3440	PAST	65801.3440	FLc	39463.5196
6	65801.3440	PAST	65801.3440	SCo	16101.2654
7	1322.6679	FRST	1322.6679	RGe	1322.6679
8	62172.5376	FRST	62172.5376	LP	47764.4700
8	62172.5376	FRST	62172.5376	RGe	14408.0676

SWAT model simulation Tue Dec 08 14:03:37 2008

MDL

MULTIPLE HRUs LandUse/Soil OPTION THRESHOLDS : 20 / 10 [%]

Number of HRUs: 29

Number of Subbasins: 8

		Area [ha]	Area [acres]	%Wat.Area
WATERSHED:		319796.7912	790233.8609	
LANDUSE:				
	Residential-High Density-->URHD	108531.2389	268186.1179	33.94
	Pasture-->PAST	97091.4106	239917.7302	30.36
	Forest-Mixed-->FRST	103237.9188	255106.0592	32.28
	Agricultural Land-Row Crops-->AGRR	10936.2229	27023.9536	3.42
SOIL:				
	FLc	82734.4385	204440.9343	25.87
	LVx	4804.7747	11872.8386	1.50
	CMe	18179.3729	44922.1394	5.68
	RGe	40550.6129	100202.5920	12.68
	SCo	86297.5337	213245.5207	26.99
	LP	52034.7470	128580.4616	16.27
	ANm	22313.2563	55137.1720	6.98
	LVh	12882.0551	31832.2023	4.03

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	1	55604.0384	137400.3591	17.39		
LANDUSE:						
	Residential-High Density-->URHD	55604.0384	137400.3591	17.39	100.00	
SOIL:						
	ANm	7389.2741	18259.2658	2.31	13.29	
	SCo	48214.7643	119141.0933	15.08	86.71	
HRUs:						
1	Residential-High Density-->URHD/ANm	7389.2741	18259.2658	2.31	13.29	1

2 Residential-High Density-->URHD/SCo 48214.7643 119141.0933 15.08 86.71 2

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

SUBBASIN # 2 33777.5776 83466.0831 10.56

LANDUSE:

Residential-High Density-->URHD 18270.5517 45147.4468 5.71 54.09

Forest-Mixed-->FRST 15507.0259 38318.6363 4.85 45.91

SOIL:

LP 4270.2770 10552.0681 1.34 12.64

ANm 4687.4232 11582.8570 1.47 13.88

RGe 24819.8774 61331.1581 7.76 73.48

HRUs:

3 Residential-High Density-->URHD/ANm 4687.4232 11582.8570 1.47 13.88 1

4 Residential-High Density-->URHD/RGe 13583.1286 33564.5898 4.25 40.21 2

5 Forest-Mixed-->FRST/LP 4270.2770 10552.0681 1.34 12.64 3

6 Forest-Mixed-->FRST/RGe 11236.7488 27766.5682 3.51 33.27 4

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

SUBBASIN # 3 33621.3024 83079.9193 10.51

LANDUSE:

Residential-High Density-->URHD 13316.6782 32906.1778 4.16 39.61

Pasture-->PAST 9721.2878 24021.7882 3.04 28.91

Agricultural Land-Row Crops-->AGRR 10583.3364 26151.9533 3.31 31.48

SOIL:

LVx 4804.7747 11872.8386 1.50 14.29

FLc 7978.9965 19716.4994 2.50 23.73

SCo 20837.5312 51490.5814 6.52 61.98

HRUs:

7	Residential-High Density-->URHD/LVx	1446.4741	3574.3099	0.45	4.30	1
8	Residential-High Density-->URHD/SCo	11870.2041	29331.8678	3.71	35.31	2
9	Pasture-->PAST/FLc	3364.7352	8314.4289	1.05	10.01	3
10	Pasture-->PAST/LVx	1881.5396	4649.3784	0.59	5.60	4
11	Pasture-->PAST/SCo	4475.0130	11057.9810	1.40	13.31	5
12	Agricultural Land-Row Crops-->AGRR/FLc	4614.2613	11402.0705	1.44	13.72	6
13	Agricultural Land-Row Crops-->AGRR/LVx	1476.7610	3649.1503	0.46	4.39	7
14	Agricultural Land-Row Crops-->AGRR/SCo	4492.3140	11100.7325	1.40	13.36	8

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN #	4	66353.3504	163962.4465	20.75	

LANDUSE:

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
Residential-High Density-->URHD	20919.7500	51693.7482	6.54	31.53
Pasture-->PAST	21197.9130	52381.1030	6.63	31.95
Forest-Mixed-->FRST	24235.6874	59887.5953	7.58	36.53

SOIL:

	Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
FLc	35291.9224	87208.1048	11.04	53.19
LVh	12882.0551	31832.2023	4.03	19.41
CMe	18179.3729	44922.1394	5.68	27.40

HRUs:

15	Residential-High Density-->URHD/CMe	10818.7395	26733.6462	3.38	16.30	1
16	Residential-High Density-->URHD/LVh	10101.0105	24960.1019	3.16	15.22	2
17	Pasture-->PAST/FLc	21197.9130	52381.1030	6.63	31.95	3
18	Forest-Mixed-->FRST/CMe	7360.6334	18188.4932	2.30	11.09	4
19	Forest-Mixed-->FRST/FLc	14094.0093	34827.0018	4.41	21.24	5
20	Forest-Mixed-->FRST/LVh	2781.0446	6872.1003	0.87	4.19	6

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

SUBBASIN # 5 1143.9729 2826.8142 0.36

LANDUSE:

Residential-High Density-->URHD 420.2206 1038.3860 0.13 36.73

Pasture-->PAST 370.8658 916.4279 0.12 32.42

Agricultural Land-Row Crops-->AGRR 352.8866 872.0003 0.11 30.85

SOIL:

SCo 1143.9729 2826.8142 0.36 100.00

HRUs:

21 Residential-High Density-->URHD/SCo 420.2206 1038.3860 0.13 36.73 1

22 Pasture-->PAST/SCo 370.8658 916.4279 0.12 32.42 2

23 Agricultural Land-Row Crops-->AGRR/SCo 352.8866 872.0003 0.11 30.85 3

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

SUBBASIN # 6 65801.3440 162598.4111 20.58

LANDUSE:

Pasture-->PAST 65801.3440 162598.4111 20.58 100.00

SOIL:

FLc 39463.5196 97516.3301 12.34 59.97

ANm 10236.5590 25295.0491 3.20 15.56

SCo 16101.2654 39787.0318 5.03 24.47

HRUs:

24 Pasture-->PAST/ANm 10236.5590 25295.0491 3.20 15.56 1

25 Pasture-->PAST/FLc 39463.5196 97516.3301 12.34 59.97 2

26 Pasture-->PAST/SCo 16101.2654 39787.0318 5.03 24.47 3

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

SUBBASIN # 7 1322.6679 3268.3785 0.41

LANDUSE:

Forest-Mixed-->FRST 1322.6679 3268.3785 0.41 100.00

SOIL:

RGe 1322.6679 3268.3785 0.41 100.00

HRUs:

27 Forest-Mixed-->FRST/RGe 1322.6679 3268.3785 0.41 100.00 1

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area
SUBBASIN #	8	62172.5376	153631.4490	19.44	

LANDUSE:

Forest-Mixed-->FRST 62172.5376 153631.4490 19.44 100.00

SOIL:

LP 47764.4700 118028.3936 14.94 76.83

RGe 14408.0676 35603.0555 4.51 23.17

HRUs:

28 Forest-Mixed-->FRST/LP 47764.4700 118028.3936 14.94 76.83 1

29 Forest-Mixed-->FRST/RGe 14408.0676 35603.0555 4.51 23.17 2

Appendix I: SWAT SENSITIVITY ANALYSIS FLOW RESULT FOR WATERSHED

```
=====================================================
        sensitivity analysis inputs and results
 =====================================================
 =====================================================
 Control parameter are :
 number of intervals in Latin Hypercube =          10
  parameter change for OAT  =   5.000000000000000E-002
  random seed number =        2003
 =====================================================
 Objective functions are (objmet.dat):
OBJECTIVE FUNCTION  1 =
SSQ   for flow            (m^3/s) at location  1
 Response functions are (responsmet.dat):
OUTPUT   1 =
aver. for flow           (m^3/s) at location  1
 =====================================================
        Parameter list of changepar.dat
 =====================================================


      INITIAL PARAMETER VALUES AND PARAMETER BOUNDS
      ================================================

  PARAMETER     INITIAL VALUE     LOWER BOUND     UPPER BOUND
  ---------     -------------     -----------     -----------
   1   0.00000  10.00000   34    1    0 SMFMX
   2   0.00000  10.00000   35    1    0 SMFMN
   3   0.00000   1.00000    1    1 2001 ALPHA_BF
   4   0.000005000.00000    6    1 2001 GWQMN
   5   0.02000   0.20000    3    1 2001 GW_REVAP
   6   0.00000 500.00000    5    1 2001 REVAPMN
   7   0.00000   1.00000   27    1 2001 ESCO
   8 -50.00000  50.00000   23    3 2001 SLOPE
   9 -50.00000  50.00000   24    3 2001 SLSUBBSN
  10 -50.00000  50.00000   52    3 2001 TLAPS
```

```
 11   0.00000 150.00000   54    1 2001 CH_K2
 12 -50.00000  50.00000   10    3 2001 CN2
 13 -50.00000  50.00000   17    3 2001 SOL_AWC
 14   0.00000  10.00000   33    1    0  surlag
 15   0.00000   5.00000   36    1    0  SFTMP
 16   0.00000   5.00000   37    1    0  SMTMP
 17   0.01000   1.00000   38    1    0  TIMP
 18   0.00000 100.00000    2    1 2001 GW_DELAY
 19   0.00000   1.00000    4    1 2001  rchrg_dp
 20   0.00000  10.00000    7    1 2001  canmx
 21 -50.00000  50.00000   15    3 2001  sol_k
 22 -50.00000  50.00000   16    3 2001  sol_z
 23   0.00000   1.00000   22    1 2001  sol_alb
 24 -50.00000  50.00000   28    3 2001  epco
 25 -20.00000  20.00000   51    3 2001  ch_n
 26 -50.00000  50.00000   61    3 2001  blai
 27   0.00000   1.00000   25    1 2001 BIOMIX
AOT sensitivity analyses on objective functions
OBJECTIVE FUNCTION           1
results per loop
  1 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00 0.00000E+00 0.00000E+00
  2 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00 0.00000E+00 0.00000E+00
  3 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00 0.00000E+00 0.00000E+00
  4 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
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maximum

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variance

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mean

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ranking

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28 28 28 28 28 28 28 28 28 28 28 28 28 28

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parname	rank	mean
SMFMX	28	0.000E+00
SMFMN	28	0.000E+00
ALPHA_BF	28	0.000E+00
GWQMN	28	0.000E+00
GW_REVAP	28	0.000E+00
REVAPMN	28	0.000E+00
ESCO	28	0.000E+00
SLOPE	28	0.000E+00
SLSUBBSN	28	0.000E+00
TLAPS	28	0.000E+00
CH_K2	28	0.000E+00
CN2	28	0.000E+00
SOL_AWC	28	0.000E+00
surlag	28	0.000E+00
SFTMP	28	0.000E+00
SMTMP	28	0.000E+00
TIMP	28	0.000E+00
GW_DELAY	28	0.000E+00
rchrg_dp	28	0.000E+00
canmx	28	0.000E+00
sol_k	28	0.000E+00
sol_z	28	0.000E+00
sol_alb	28	0.000E+00
epco	28	0.000E+00
ch_n	28	0.000E+00
blai	28	0.000E+00
BIOMIX	28	0.000E+00

AOT sensitivity analyses on objective functions

OUTPUT VALUE 1

results per loop

1 0.00000E+00 0.00000E+00 0.92660E-03 0.00000E+00 0.00000E+00 0.00000E+00 0.14623E+00 0.10167E-01 0.27842E-02 0.00000E+00 0.55420E-02 0.22013E+01 0.31904E+00 0.83067E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.43587E-01 0.12003E-01 0.17170E+00 0.18563E-02 0.43589E-01 0.00000E+00 0.00000E+00 0.92394E-02

2 0.00000E+00 0.00000E+00 0.23283E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.23828E+00 0.10804E+00 0.17580E-02 0.00000E+00 0.86311E-02 0.24459E+01 0.58067E+00 0.23440E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.62840E-01 0.75190E-01 0.16821E+00 0.37400E-02 0.00000E+00 0.58426E-03 0.00000E+00 0.20962E-01

3 0.00000E+00 0.00000E+00 0.32270E-03 0.00000E+00 0.00000E+00 0.00000E+00 0.20673E+00 0.21486E+00 0.16688E-02 0.00000E+00 0.29712E-01 0.11179E+01 0.15474E+00 0.31928E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.40718E-01 0.17413E+00 0.80688E-01 0.66200E-03 0.19859E-02 0.63859E-03 0.00000E+00 0.73439E-02

4 0.00000E+00 0.00000E+00 0.27071E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.90880E+00 0.51331E-01 0.13524E-02 0.00000E+00 0.96282E-01 0.21093E+01 0.24600E+00 0.40728E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.69783E-01 0.17134E-01 0.18940E-01 0.40605E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.25964E-01

5 0.00000E+00 0.00000E+00 0.24188E-01 0.15033E+01 0.65136E+00 0.44202E-01 0.10535E+01 0.36163E-01 0.00000E+00 0.00000E+00 0.42579E-02 0.14316E+01 0.71145E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.18092E-01 0.14492E+01 0.67434E-01 0.32172E-01 0.30865E+00 0.41873E-02 0.24157E-01 0.00000E+00 0.00000E+00 0.60348E-01

6 0.00000E+00 0.00000E+00 0.31256E-03 0.00000E+00 0.00000E+00 0.00000E+00 0.13589E+00 0.25280E+00 0.30680E-03 0.00000E+00 0.49083E-02 0.17375E+01 0.27605E+00 0.25004E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.53193E-01 0.11839E+00 0.17972E+00 0.31969E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00

7 0.00000E+00 0.00000E+00 0.54054E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.83363E+00 0.10231E+00 0.44992E-02 0.00000E+00 0.00000E+00 0.24428E+01 0.15104E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.85030E-01 0.39284E-01 0.64455E-01 0.21841E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.47930E-01

8 0.00000E+00 0.00000E+00 0.32201E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.26703E+00 0.22552E-01 0.00000E+00 0.00000E+00 0.10883E-01 0.14552E+01 0.31679E+00 0.68503E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.46168E-01 0.22549E-01 0.15697E+00 0.53707E-02 0.68832E-01 0.00000E+00 0.00000E+00 0.68521E-02

9 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.40042E+00 0.90798E-01 0.13587E-02 0.00000E+00 0.13527E-02 0.34303E+01 0.36786E+00 0.54351E-02 0.00000E+00 0.00000E+00

0.00000E+00 0.00000E+00 0.00000E+00 0.56877E-01 0.32630E-01 0.35311E-01 0.27180E-02 0.00000E+00 0.13605E-02 0.00000E+00 0.95018E-02

10 0.00000E+00 0.00000E+00 0.27524E-02 0.53913E+00 0.00000E+00 0.00000E+00 0.16368E+00 0.11246E-01 0.00000E+00 0.00000E+00 0.61252E-02 0.10852E+01 0.34048E+00 0.51912E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.66583E-01 0.44701E-01 0.87431E-02 0.26789E+00 0.36520E-02 0.46425E-01 0.86513E-03 0.00000E+00 0.56952E-01

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maximum

0.00000E+00 0.00000E+00 0.54054E-01 0.15033E+01 0.65136E+00 0.44202E-01 0.10535E+01 0.25280E+00 0.44992E-02 0.00000E+00 0.96282E-01 0.34303E+01 0.71145E+00 0.40728E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.18092E-01 0.14492E+01 0.85030E-01 0.17413E+00 0.30865E+00 0.53707E-02 0.68832E-01 0.13605E-02 0.00000E+00 0.60348E-01

variance

0.00000E+00 0.00000E+00 0.30155E-03 0.23705E+00 0.42428E-01 0.19538E-03 0.12585E+00 0.71213E-02 0.20882E-05 0.00000E+00 0.84956E-03 0.52971E+00 0.31133E-01 0.14415E-03 0.00000E+00 0.00000E+00 0.00000E+00 0.32732E-04 0.20833E+00 0.20224E-03 0.29257E-02 0.92257E-02 0.18245E-05 0.66206E-03 0.23993E-06 0.00000E+00 0.50730E-03

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mean

0.00000E+00 0.00000E+00 0.90812E-02 0.20424E+00 0.65136E-01 0.44202E-02 0.43542E+00 0.90027E-01 0.13728E-02 0.00000E+00 0.16769E-01 0.19457E+01 0.34641E+00 0.74548E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.18092E-02 0.15158E+00 0.57033E-01 0.53223E-01 0.14525E+00 0.31628E-02 0.18499E-01 0.34485E-03 0.00000E+00 0.24509E-01

ranking

28 28 14 4 8 16 2 7 19 28 13 1 3 15 28 28 28 18 5 9 10 6 17 12 20 28 11

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	par #	mean
SMFMX	28	0.000E+00
SMFMN	28	0.000E+00
ALPHA_BF	14	0.908E-02
GWQMN	4	0.204E+00
GW_REVAP	8	0.651E-01
REVAPMN	16	0.442E-02
ESCO	2	0.435E+00
SLOPE	7	0.900E-01

SLSUBBSN	19	0.137E-02
TLAPS	28	0.000E+00
CH_K2	13	0.168E-01
CN2	1	0.195E+01
SOL_AWC	3	0.346E+00
surlag	15	0.745E-02
SFTMP	28	0.000E+00
SMTMP	28	0.000E+00
TIMP	28	0.000E+00
GW_DELAY	18	0.181E-02
rchrg_dp	5	0.152E+00
canmx	9	0.570E-01
sol_k	10	0.532E-01
sol_z	6	0.145E+00
sol_alb	17	0.316E-02
epco	12	0.185E-01
ch_n	20	0.345E-03
blai	28	0.000E+00
BIOMIX	11	0.245E-01

Appendix J MODEL GENERATED ANNUAL PEAK STREAM FLOW DATA

Generated annual peak stream flow for Logiya watershed at 033027

1979	186.3393	2000	141.94	2021	337.644
1980	141.9643	2001	283.365	2022	105.75
1981	102.7156	2002	123.2	2023	98.6238
1982	58.03571	2003	188.91	2024	310.5
1983	134.2857	2004	341.19	2025	115.362
1984	89.28571	2005	126	2026	243
1985	49.55357	2006	207	2027	275.1246
1986	41.51786	2007	324.3	2028	351
1987	328.3605	2008	366.588	2029	119.4012
1988	250.3305	2009	144	2030	101.25
1989	62.7165	2010	97.8282	2031	252.2664
1990	99.1575	2011	67.671	2032	214.6896
1991	57.582	2012	113.526		
1992	189.3375	2013	54		
1993	117.484	2014	263.3742		
1994	119.6734	2015	217.062		
1995	129.36	2016	124.0524		
1996	93.1	2017	343.8896		
1997	75.6	2018	238.7385		
1998	186.3	2019	107.55		
1999	183.36	2020	197.766		

Generated annual peak stream flow for Mille watershed at 033021

1979	417.4	2000	302	2021	750.32
1980	318	2001	629.7	2022	235
1981	230.083	2002	280	2023	219.164
1982	130	2003	419.8	2024	690
1983	300.8	2004	758.2	2025	256.36
1984	200.36	2005	280	2026	540
1985	111.38	2006	460	2027	611.388
1986	93.37	2007	690	2028	780
1987	729.69	2008	814.64	2029	265.336
1988	556.29	2009	320	2030	225
1989	139.37	2010	217.396	2031	560.592
1990	220.35	2011	150.38	2032	477.088
1991	127.96	2012	252.28		
1992	420.75	2013	120		
1993	267	2014	585.276		
1994	311	2015	482.36		
1995	308	2016	275.672		
1996	190	2017	731.68		
1997	180	2018	530.53		
1998	405	2019	239		
1999	764	2020	439.48		