EVALUATING THE PERFORMANCE OF SWAT AND HEC- HMS MODELS ON RAINFALL-RUNOFF ESTIMATION AT THE GREAT AKAKI RIVERWATERSHED, ETHIOPIA.

M. Sc. THESIS

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A THESIS SUBMITTED TO THE DEPARTMENT OF HYDRAULIC ENGINEERING, COLLEGE OF BIO SYSTEMS AND ENVIRONMENTAL ENGINEERING, SCHOOL OF GRADUATE STUDIES HAWASSA UNIVERSITY, ETHIOPIA

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ADVISOR APPROVAL SHEET

This is to certify that the proposal entitled **“Evaluating the Performance of SWAT and HEC-HMS Modals on Rainfall – Runoff Estimation at the Great Akaki River Watershed, Ethiopia.”** as MSc. thesis in Hydraulic Engineering submitted to the Faculty of Civil Engineering and Built Environment, and has been carried out by **HENOK GEZAHEGN ID NO GpHydrw/0007/12** under my supervision. Therefore I recommend that the student has filled the requirements and hence hereby can submit the proposal to the department.

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EXAMANIER APPROVAL SHEET

We, the undersigned, members of the board of examiners of MSc thesis proposal defense by **HENOK GEZAHEGN MULUNEH** have read and evaluated his MSc thesis entitled **" Evaluating the Performance of SWAT and HEC-HMS Modals on Rainfall-Runoff Estimation at the Great Akaki River watershed, Ethiopia."** and examined the candidate .This is, therefore, to certify that the MSc thesis proposal has been accepted.

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DECLARATION

I hereby declare that this MSc Specialty or equivalent thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis/dissertation have been duly acknowledged.

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This MSc Specialty or equivalent thesis has been submitted for examination with my approval as thesis advisor.

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ABBREVATIONS AND ACRONYMS

m.a.s.	lmater above sea level
CN	Curve Number
DEM	Digital Elevation Modal
EMSA	Ethiopian Meteorological Service Agency
CRR	Conceptual rainfall runoff
HEC- HMS	Hydrologic engineering center for Hydrological Modeling System
LPM	Linear Perturbation Model
MoWIE	Ministry of Water Irrigation and Electricity
NSE	Nash and Sutcliffe Efficiency Criteria
LULC	Land Use Land Cover
PDE	Partial Differential Equation
PET	Potential Evapotranspiration
RSR	Root mean square error observation standard deviation ratio
PCP_MM	Average Monthly Precipitation [mm]
PCPSTD	Standard Deviation of Precipitation
PCPSKW	Skew Coefficient of Precipitation
PR_W1	Probability of a wet day following a dry day
PR_W2	Probability of a wet day following a wet day

PCPD	average number of days of precipitation in month
SCS	Soil Conservation Service
SLM	Simple Linear Model
TF	Transfer Function Models
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
SMAR	Soil Moisture Accounting and Routing
SVGFM	Seasonally Varying Gain Factor Models
SWAT	Soil and Water Assessment Tool

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ABSTRACT

The present study was conducted to examine the accuracy and applicability of the hydrological models Soil and Water Assessment Tool (SWAT) and Hydrologic Engineering Center (HEC)-

Hydrologic Modeling System (HMS) to simulate stream flow. Models combined with the ArcGIS interface have been used for hydrological study in the Great Akaki River watershed. The critical focus of the stream flow analysis was to determine the efficiency of the models when the models were calibrated and optimized using observed flows in the simulation of stream flow. Daily weather gauge stations data were used as inputs for the models from the 1995-2017 periods. Other data inputs required to run the models included land use/land cover (LU/LC) classes resulting from Map agency and related offices, soil map and digital elevation model (DEM). For evaluating the model performance and calibration, daily stream discharge from the catchment outlet data was used. For the SWAT model calibration, ALPHA_BF (Base flow alpha factor (days), curve number (CN) and GW_DELAY(Groundwater delay(day)) are identified as the sensitive parameters. SCS.lag (MI), Curve number(AMC_II) and Initial abstraction (Ia) are the significant parameters identified for the HEC-HMS model calibration. The models were subsequently adjusted by auto calibration for 1995-2010 to minimize the variations in simulated and observed stream flow values at the catchment outlet (Aba Samuel). The hydrological models were validated for the 2011-2017 period by using the calibrated models. For evaluating the simulating daily stream flow during calibration and validation phases, performances of the models were conducted by using the Nash-Sutcliffe model efficiency (NSE) and coefficient of determination (R2). The SWAT model yielded high R2 and NSE values of 0.85 and 0.82 for daily stream flow comparisons for the catchment outlet at the calibration and validation time, suggesting that the SWAT model showed relatively good results compared to the HEC-HMS model. Also, under modified LU/LC and ungaugedstream flow conditions, the calibrated models can be later used to simulate stream flow for future predictions. Overall, the SWAT model seems to have done well in stream flow analysis for hydrological studies.

Key words: calibration, hydrological models, sensitivity, simulation, stream flow, validation

1. INTRODUCTION

1.1 Background

Establishing a rainfall-runoff relationship is the central focus of hydrologic modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flux equations. As the computing capabilities are increasing, the use of these models to simulate a catchment response has become a standard. Models are generally used as utility in various areas of water resources development, in assessing the available resources, in studying the impacts of human interference in an area such as land use change, deforestation and other hydraulics structures such as dams and reservoirs (Moreda, 1999).

The fact that the world faces a water crisis has become increasingly clear in recent years. Challenges remain widespread and reflect severe problems in the management of water resources in many parts of the world. These problems will intensify unless effective and concerted actions are taken (WWAP, 2003). However, from a water resource assessment point of view, the primary objective of modeling is often to generate a long representative time series of stream flow volumes for the purpose of planning and management of water resources.

Rainfall-runoff models have been under a continuous state of development. Models used in the earlier days did not integrate the different phases of the hydrological cycle. Instead, they implemented simplified mathematical relationships between precipitation and certain attributes of the final catchment’s response. However, estimation of runoff is essential in various kinds of water resources studies. Runoff estimation is normally based on rainfall runoff process. In order to model rainfall-runoff process, a variety of hydrological models have been applied (Hundecha, 2005). Appropriate assessment of runoff amount is essential for design, planning, and management of river basin projects that deals with conservation and utilization of water for the various purposes. To determine accurately the quantity of surface runoff that takes place in a river basin, understanding of the complex relationships between rainfall and runoff process, which depend upon many geomorphologic and climate factors, is necessary.

1.2 Statement of the Problem

The magnitude of water-related challenges becomes large, and it will expect to increase in the future. The current and future water-related challenges are location and time specific and cause an impact on economic growth, floods or extended and more prolonged droughts. In addition to these problems, most of the rivers in Ethiopia are ungauged.

Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. Human health and welfare, food security, industrial development and the ecosystems on which they depend, are all at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past(ICWE, 1992).

Development of hydrological model plays a great role to analyze, understand, and explore solutions for water resource problems. Different studies revealed that several types of hydrological models used to simulate rainfall-runoff relationship in different parts of a river basin (Kebede, 2009; Ymti, 2007 and Ytayal,2011). However, selecting the suitable hydrological model to simulated stream flow is always challenging.

To investigate the efficient model most researcher’s used model performance comparison criteria, but the criteria depend only on the output of the model, on the other hand, less emphasis given for relative strength of hydrological model to simulate stream flow hydrograph components.

Generally, the application of the study evaluates the performance, and relative strength of SWAT and HEC- HMS models to simulate stream flow, and compare representative time series stream flow data of each model to the selected catchment in the Great Akaki river watershed.

1.3 Objectives

1.3.1 General objective

The genera objective of this study was to conduct catchment modeling for better understanding of stream flow of Great Akaki River and to compare and select the best conceptual rainfall-runoff model that can be used in the design, planning, and management of water resources in Great Akaki River Catchment.

1.3.2. Specific objectives

The Specific objectives of the study were:

1. To simulate the Great Akaki River Catchment using HEC-HMS and SWAT hydrological models.
2. To compare the performance of the HEC-HMS and SWAT models in the Great Akaki River watershed.

1.4 Research Question

1. Which hydrological model represents hydrological system on Great Akaki watershed?
2. Which hydrological modal highly perform according to existing criteria and in terms of simulating result?

1.5 Significance of the Study

The application and development of hydrological models are key activities of future water resource management and planning. These increase our knowledge about hydrological processes, and provide sustainable solutions for integrated water resources management. This research emphasized on comparing, and analyzing of the selected hydrological models in the selected catchment, to show the comparative advantage of each model for planning and development of water resource. The selection of hydrological model helps to understand hydrological characteristics of the different watershed in the river basin and sub-basin in order to know the stream flow at the outlet of ungagged catchments. It also helps to identify better hydrological models that improve water resources development and effective management of the water resources system in the sub basin.

1.6 Scope of the Study

This study primarily observed the performance of HEC- HMS and SWAT modelsto better simulate Great Akakistream flow and inter comparison of the candidate model only.

2. LITERATURE REVIEW

2.1 General

The knowledge and understanding that the scientist has about the world is often represented in the form of models. The goal of the scientific method is to simplify and explain the complexity and confusion of the world. A model is a representation containing the essential structure of some event in the real world. It can be classified as quantitative and qualitative model. In science and engineering, the most essential attribute of model is that of quantitative which yields numerical value. A quantitative model is essential to determine physical variables that cost much to measure in the field. To understand the hydrological process in the system which is essential in decision making, models have been used long in water resources management.

A model used in water resources management should be sufficiently accurate to be used for the intended purpose. The existence of observations determines the validity of the model. Model prediction is compared with field measurement to evaluate its performance without any adjustment to the model parameters (Ward et al., 1999). This process is termed as model validation or verification.

Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrological prediction and for understanding hydrological processes. Whenever data is not available, hydrological models are important to establish baseline characteristics and determine long term impacts which are difficult to calculate (Lenhart et al. 2002). A modeler should understand the hydrological process and then simulate this process at a desired spatial and temporal resolution (de vos et al., 2006, cited in Musefa, 2007). Two major types of hydrological models can be distinguished: (1) Models based on data; these models are black box systems, using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output (for instance runoff). The simplest of these models may be linear models, but it is common to deploy non-linear components to represent some general aspects of a catchment's response. Without going deeply into the real physical processes involved. (2) Models based on process descriptions; these models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. These models are known as deterministic hydrology models.

It is essential to determine the amount of water available in the system in order to state the available water potential within the river basin system. Hence, it requires understanding and properly describing water inflow and outflow from the system. In order to describe the movement of water, it would be necessary to have rainfall data and information on runoff, evaporation, infiltration, percolation etc.

2.1Hydrological cycle and rainfall-runoff processes in a catchment

An important question in hydrology is how much stream flow occurs in a river in response to a given amount of rainfall. To answer this question we need to know where water goes when it rains, how long does water reside in a watershed, and what pathway does water take to the stream channel. These are the questions addressed in the study of rainfall – runoff processes, or more generally surface water input – runoff processes. The term, "surface water input" is used in preference to rainfall or precipitation to be inclusive of snowmelt as a driver for runoff.

Answering the question of how much runoff is generated from surface water inputs requires partitioning water inputs at the earth surface into components that infiltrate and components that flow overland and directly enter streams. The pathways followed by infiltrated water need to be understood. Infiltrated water can follow subsurface pathways that take it to the stream relatively quickly, in which case it is called interflow or subsurface storm flow. Infiltrated water can also percolate to deep groundwater, which may sustain the steady flow in streams over much longer time scales that is called base flow. Infiltrated water can also remain in the soil to later evaporate or be transpired back to the atmosphere. The paths taken by water determine many of the characteristics of a landscape, the occurrence and size of floods, the uses to which land may be put and the strategies required for wise land management. Understanding and modeling the rainfall – runoff process is therefore important in many flood and water resources problems.

Precipitation (P) is a climatic variable that provides critical information on the hydrological and energy cycles and is the key input to hydrological, agricultural and water resource models. Hence, it is essential to derive high-quality estimates of the occurrence, intensity and distribution of precipitation (Houet al.2014).

Knowledge of the spatial and temporal distribution of rainfall in hydrological modeling is very important. Rainfall partly intercepted by the vegetation canopy before it reaches the ground surface. The quantity of rain captured by trees, plants, depends not only on their sort, stage of development, and density of vegetation canopy, but also on the intensity and duration of precipitation(Ymeti, 2007). For rainfall – runoff, interception is considered as a loss.

The remaining rain that reaches the ground either evaporates, infiltrates, or remains at the land surface as overland flow. Infiltrated rainfall may percolate to recharge the saturated domain, but also may flow to a channel through interflow. Due to evaporation and transpiration at the land surface the water availability in the subsurface reduces

2.2 Hydrological modeling

According to Sorooshian et al. (2008), a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behavior and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

2.3. Types of models

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on the other criteria. Deterministic model will give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs. According to Moradkhani and Sorooshian (2008) in lumped models, the entire river basin is taken as a single unit where spatial variability is disregarded and hence the outputs are generated without considering the spatial processes where as a distributed model can make predictions that are distributed in space by dividing the entire catchment in to small units, usually square cells or triangulated irregular network, so that the parameters, inputs and outputs can vary spatially. Another classification is static and dynamic models based on time factor. Static model exclude time while dynamic model include time. Sorooshian et al. (2008) had classified the models as event based and continuous models. The former one produce output only for specific time periods while the latter produces a continuous output. One of the most important classifications is empirical model, conceptual models and physically based models.

2.3.1Empirical models (Metric model)

These are observation oriented models which take only the information from the existing data without considering the features and processes of hydrological system and hence these models are also called data driven models. It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment. These models are valid only within the boundaries. Unit hydrograph is an example of this method. Statistically based methods use regression and correlation models and are used to find the functional relationship between inputs and outputs. Artificial neural network and fuzzy regression are some of the machine learning techniques used in hydro informatics methods.

2.3.2Conceptual methods (Parametric models)

This model describes all of the component hydrological processes. It consists of a number of interconnected reservoirs which represents the physical elements in a catchment in which they are recharged by rainfall, infiltration and percolation and are emptied by evaporation, runoff, drainage etc. Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. Large number of meteorological and hydrological records is required for calibration. The calibration involves curve fitting which makes the interpretation difficult and hence the effect of land use change cannot be predicted with much confidence. Many conceptual models have been developed with varying degree of complexity. Stanford Watershed Model IV (SWM) is the first major conceptual model developed by Crawford and Linsley in 1966 with 16 to 20 parameters.

2.3.3 Physically based model

This is a mathematically idealized representation of the real phenomenon. These are also called mechanistic models that include the principles of physical processes. It uses state variables which are measurable and are functions of both time and space. The hydrological processes of water movement are represented by finite difference equations. It does not require extensive hydrological and meteorological data for their calibration but the evaluation of large number of parameters describing the physical characteristics of the catchment are required (Abbott et al. 1986 a). In this method huge amount of data such as soil moisture content, initial water depth, topography, topology, dimensions of river network etc. are required. Physical model can overcome many defects of the other two models because of the use of parameters having physical interpretation. It can provide large amount of information even outside the boundary and can applied for a wide range of situations. SHE/ MIKE SHE model is an example. (Abbott et al.1986a,b).

Table2.1. Characteristics of three model

Empirical model	Conceptual model	Physically based model
Data based or metric or black box model	Parametric or grey box model	Mechanistic or white box model
Involve mathematical equations , derive value from available time series	Based on modeling of reservoirs and Include semi empirical equations with a physical basis	Based on spatial distribution, Evaluation of parameters describing physical characteristics
Little consideration of features and processes of system	Parameters are derived from field data and calibration.	Require data about initial state of model and morphology of catchment
High predictive power, low explanatory depth	Simple and can be easily implemented in computer code	Complex model. Require human expertise and computation capability
Cannot be generated to other catchments	Require large hydrological and meteorological data	Suffer from scale related problems
ANN, unit hydrograph	HBV model, TOPMODEL	SHE or MIKESHE model, SWAT
Valid within the boundary of given Domain	Calibration involves curve fitting make difficult physical interpretation	Valid for wide range of situations

2.4 Hydrologic Model Selection

There are a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. Beven, K.J (2002) suggested four criterions for selecting model structures as below.

1. Consider models which are readily available and whose investment of time and money appeared worthwhile.

2. Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.

3. Prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes.

4. Make a list of the inputs required by the model and decide whether all the information required by the model can be provided within the time and cost constraints of the project.

2.5 Selected Conceptual Rainfall Runoff models

2.5.1 SWAT Model

The Soil and Water Assessment Tool (SWAT) is a physical based model used to estimate the runoff, sediment and chemical yields in gauged and un-gauged basins . The hydrologic cycle of a basin simulated by SWAT is based on the following water balance equation:

$$SW_{t=}SW_{to} \sum_{i=1}^{i}(R_{day} + Q_{surf} - E_a - W_{seep} - Q_{gw})\ldots\ldots\ldots\ldots\ldots\ldots..(2.1)$$

Where:-

SW_t is final soil water content (mm),

SW_{to} is initial soil water content (mm), t is time (days),

R_{day} is amount of precipitation (mm),

Q_{Surf} is amount of surface runoff (mm),

E_a is amount of evapotranspiration (mm),

W_{seep} is amount of water entering the vodose zone from the soil profile (mm) and

Q_{gw} is amount of return flow (mm). In SWAT, the surface runoff from daily rainfall is estimated using a modified

SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture conditions . The surface runoff component of the water balance is determined from the SCS method as:

$$Q_{surf} = \frac{\left(R_{day} - Ia\right)^2}{(R_{day} - I_a + S)} \qquad (1)$$

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

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

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

S is a retention parameter (mm water) which varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. *S* can be expressed as:

$$S = 25.4\,(\frac{1000}{CN} - 10) \qquad (2)$$

Where, CN is the curve number for the day.

CN is a function of land use practice, soil permeability, and 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, I_a, is commonly approximated as 0.2S and the equation becomes:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{(R_{day} + 0.8S)} \qquad (3)$$

Runoff will only occur when Rday>Ia

The CNs for different land use and land cover, soil groups and antecedent moisture conditions are provided with SWAT2012 manual that takes in account of soil infiltration rate when thoroughly wetted, and slope adjustments.

2.5.1 HEC-HMS model

The HEC-1 hydrologic model was originally developed in 1967 by Leo R. Beard and other staff members of the Hydrologic Engineering Center, with the U. S. Army Corps of Engineers, to simulate flood hydrographs in complex river basins (Singh, 1982). Since then, the program has undergone a revision: different versions of the model with greatly expanded capabilities have been released. The current version of HEC-HMS and this study used the 4.2.1 HEC-HMS Version. The HEC-HMS model is designed to simulate the surface runoff response of a catchment to precipitation by representing the catchment with interconnected hydrologic and hydraulic components. It is primarily applicable to flood simulations (Oleyiblo& Li, 2010).

Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. Computations are performed with SI (System 10 International units) units. However you can enter input and view output with units in the U.S. Customary system, and can readily convert input results from one unit system to the other.

HEC-HMS includes four main components: basin, meteorological, control specifications component, and time series data component. The basin model stores the physical datasets describing the catchment properties and the meteorological model includes precipitation, evapotranspiration, and snowmelt data. Six different historical and synthetic precipitation methods, two evapotranspiration methods, and one snowmelt method are included. The time span of a simulation is controlled by control specifications including a starting date and time, ending date and time, and computation time step. The last component used for controlling time series data such as rainfall, discharge and evapotranspiration data.

HEC-HMS provides a variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1, HEC

HMS capabilities currently available include: a linear-distributed runoff transformation that can be applied with girded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option. The latest version also has capabilities for continuous soil moisture accounting and reservoir routing operations. HEC-HMS also includes an automatic calibration package that can estimate certain model parameters and initial conditions, for the given observations of hydro meteorological conditions. It also links to a database management system that permits data storage, retrieval and connectivity with other analysis tools available from HEC and other sources.

2.6 Model Performance Evaluation

The accuracy, consistence and adaptability performance of the model must be evaluated (Go swami et al., 2005). Subjective and/or objective estimate of the closeness of simulated behavior of the model to observation is required to assess the performance of the model (P.Krause et al., 2005). The performance of the model has been evaluated using efficiency criteria, determination coefficient (R2), Nash- Sutcliff Efficiency (NSE) and The Root Mean Square Error (RMSE) to measure how well trend in the measure data are reproduced by simulated results over a specified period. Determination coefficient for n time step is calculated .

Decisions on the goodness of the estimated model parameters was to a great extent based on measurement of the model performance, collective use of the three efficiency criteria will considered. The selected performance criteria with their short description and limitation of each efficiency criteria is summarized from Krause, Boyle, &Ba¨se, (2005) as follows

The Nash-Sutcliffe efficiency coefficient (NSE) (Nash and Sutcliffe, 1970) normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance and indicates how well the plot of the observed data versus the simulated data fits the 1:1 line (Wang et al., 2009). The NSE equation can be seen below in Equation11.

2.6.1 The Coefficient of Determination (R^2)

$R^2$is used to describe the percentage of the variance in calculated data experienced by the model.Thevalue ofR^2ranges from (0–1). Where,a value close to 1.0 a value indicates good performance (good correlation) of the model and a value close to 0.0 indicates poor performance (poor correlation) of the model (Krauseet al., 2005; Shin et al., 2013; Saraswat and Pai, 2011).

Advantages: $R^2$and Rare widely used in hydrological modalingstudies,thus seving asbenchmark for performance evaluation.

Disadvantages: $R^2$and R are oversensitive to additive and proportional difference between model prediction and measured data (legates and McCabee,1999)

2.6.2 Nash-Sutcliffe Efficiency Coefficient (NSE)

It is used to assess the predictive power of the hydrological models. The value of NSE varies from one to zero. The general performance of NSE in SWAT according to (Masih et al., 2011) is NSE > 0.65 is very good, NSE between 0.5 and 0.65 is adequate, NSE > 0.5 is satisfactory and NSE < 0.5 is unsatisfactory both for calibration and validation.

Advantages: NSE is: (1) a quantitative measure conducive to development of PEC; (2) good for use with continuous long-term simulations and can be used to determine how well the model simulates trends for the output response of concern; (3) robust and can be used to evaluate model performance for several output responses (e.g.,stream flow, sediments, nutrients, pesticides) and temporal scales;and (4) commonly used, which means that there is extensive information on reported values, which can be used for comparison purposes. Further, it can incorporate measurement uncertainty (Harmel,R. and Smith,P.K. 2007)

Disadvantages: NSE can not help identify model bias and cannot be used to identify differences in timing and magnitude of peak flows and shape of recession curves; in other words, it cannot be used for single-event simulations.

$$\text{NSE}=1-\frac{\sum_{(Qobs\ -Qsim\ )}2}{\sum_{(Qobs\ -\overline{Qobs}\ )}2}12$$

where: Qobs and Qsim refer to the observed and simulated data respectively. and refer to the mean of the observed and simulated data respectively.

2.6.3 Root mean square error (RMSE)

The Root Mean Square Error (RMSE) (also called the root mean square deviation, RMSD) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power. The value for perfect fit is approach to zero.

Advantages: RMSE are: (1) computed and reported in the same units as the model output of concern and are hence easy for readers to interpret; (2) work well for continuous long-term simulations; and (3) commonly used in model performance evaluation.

Disadvantages: Error indices are measured in the same unit as the model output being investigated, so they cannot be used by themselves to gauge model performance for values other than zero

$$\text{RMSE} = \sqrt{\frac{\sum(\text{Qobs}\ -\text{Qsim}\ )\ 2}{\text{No .of days}}}\ 13$$

2.7 Review of previous comparative of HEC_HMS and SWATModels.

In Case Of Katar River basin. The results of calibration and validation indicated that, for river basin Katar, both models could simulate fairly well the stream flow. SWAT gave the model performance with the R2 > 0.78 and NSE > 0.67; and the HEC-HMS model provided the model performance with the R2 > 0.87 and NSE > 0.73. Hence, the simulated stream flow given by the HEC-HMS model is more satisfactory thanthat provided by the SWAT model (M.A.Aliye et al,2020).

In Case Of Robigumero Catchment**.** The performance of the models based on NSE during daily calibration period were, 60%, 66% and 67% of PED-W, HEC-HMS and SMAR model respectively. Similarly, for validation period, the model performs a NSE values; 51%, 53%, 56%of NSE of PED-W, HECHMS and SMAR respectively. The study result shown on the performance of the model to simulate major hydrograph components were, PED-W model shows higher performance to simulate Low flow, SMAR and HEC-HMS model better simulates a direct runoff, and HEC-HMS model higher capacity to simulate maximum flows than PED-W and SMAR model.The study concludes that the comparative analysis of models can be a promising approach in the case of the best hydrological model selection mechanism.(Wasihun.D. 2019).

In case of the sub-humid tropical Hemavathicatchmen India. For evaluating the simulating daily stream flows during calibration and validation phases, performances of the models were conducted by using the Nash-Sutcliffe model efficiency (NSE) and coefficient of determination (R2). The SWAT model yielded high R2 and NSE values of 0.85 and 0.82 for daily stream flow comparisons for the catchment outlet at the validation time, suggesting that the SWAT model showed relatively good results compared to the HEC-HMS model. Also, under modified LU/LC and ungauged stream flow conditions, the calibrated models can be later used to simulate stream flows for future predictions. Overall, the SWAT model seems to have done well in stream flow analysis for hydrological studies(N. C. Sanjay Shekara,* and D. C. Vinayb,2021).

Comparison of Two Hydrological Models, HEC-HMS and SWAT in Runoff Estimation: Application to Huai Bang Sai Tropical Watershed, Thailand. The study results demonstrated that the spatial discretization of the HBS watershed through the SWAT and HEC-HMS models did not have a significant impact on response to stream flow simulations. The differences in equations used to compute hydrologic processes did not demonstrate large deviations in reproducing stream flow. Hence, both the SWAT and HEC-HMS are recommended to be used in the tropical humid conditions in Thailand and elsewhere in the world.: (I.M.Chathuranikaet al. 2022)

According Garland (2013) studies in two New York catchments (Little Tonawanda Creek and Black Creek), stated that the PED-W model was easier to set up and calibrate and yields comparable results to SWAT. The time, forcing variables and parameters required for SWAT are large and in terms of efficiency, the simple, and during validation period PED-W model efficiency was higher than SWAT model

In Japan Ishigaki Island watershed, SWAT and GSSHA models were evaluated by Sith, R. and Nadaoka, K. (2017).forhigh time resolution prediction of stream flow and sediment concentration. As the result, they have reported that, for long-term simulations, both models yielded the comparable results. In similar manner, the applicability of MIKESHE, APEX, SWAT models were tested by (Golmohammadi, G.et.al.2014) in Canagagigue Watershed, Canada. And, as the result, they reported as the mean daily/monthly flow at the outlet of the Canagagigue Watershed simulated by MIKESHE was more accurate than that simulated by SWAT and APEX model, for both calibration and validation periods. In Virginia, Polecat Creek watershed, SWAT and HSPF were evaluated /and reported as both models are able to simulate effectively the stream flow(Im,s. et al 2003).

From these studies we can conclude that the models performances are very site specific, and no one model is superior under all hydrologic conditions. Therefore, a complete understanding of comparative model performance requires applications under different hydrologic conditions and watershed scales. As reported by Melese, et al (2018),SWAT has been successfully applied to simulate stream flow in different basins of the country Ethiopia and HEC-HEM has been also successfully applied for hydrological studies in different Ethiopian basins (Demlie, G.Z. and Melese, A.M. 2018). Therefore, the objective of the present study is to compare and assess the suitability of those two widely-used watershed simulation models, namely HEC-HMS and SWAT, for simulating the hydrology of great akaki watershed, Ethiopia.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Akaki River is one of the tributaries of the Awash River. It rises on the high plateau near Ginch town West of Addis Ababa and Entoto Mountain Addis Ababa in Ethiopia. The city Addis Ababa is located at the center of Akaki River catchment and this catchment geographically bounded 8^{0}46’ -9^{0}14N and 38^{0}34’ -39^{0}04’E with in an area of about 1500km^{2}. Akaki River has two main branches; the Great Akaki River and Little Akaki River. The Great Akaki River is gauged since 1981 at Addis Ababa-Bishoftu road and the station is equipped with an automatic water level recorder and a cable for discharge measurements Feyera (2007).area delineation of this study the size of catchment up to the bridge is 884.63km2 and geographically bounded 8^{0}52’34’’– 9^{0}14’N and 38^{0}43’18’’ – 93^{0}04’07’’E.

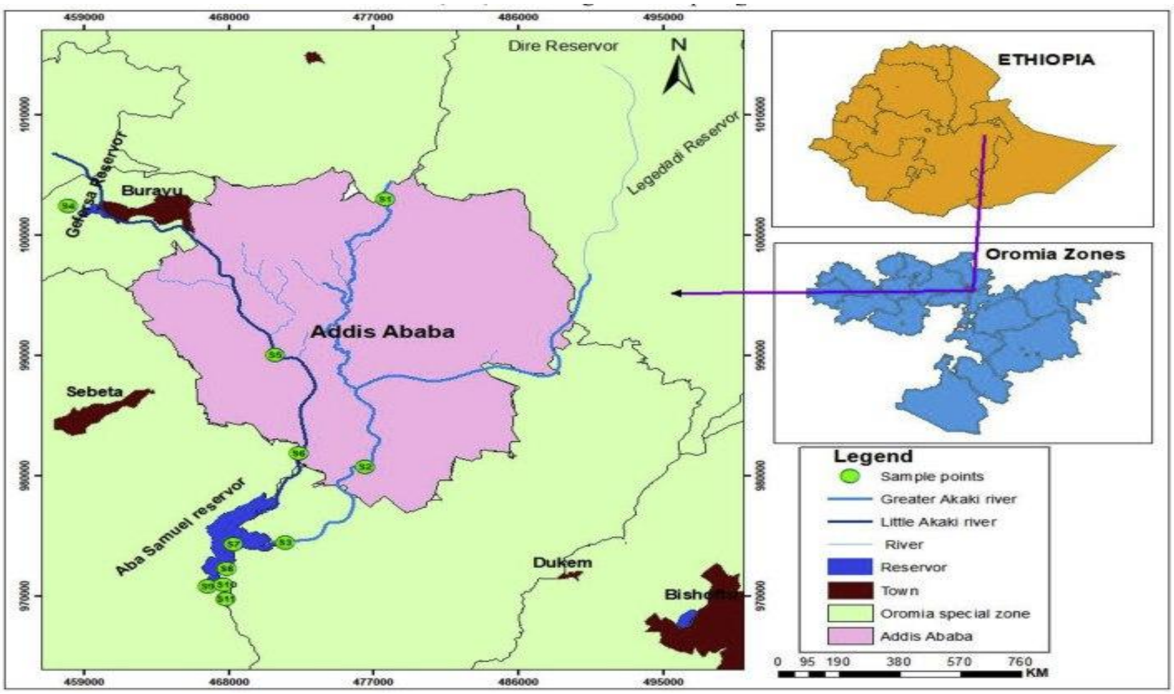


Figure3. 1Location of study area

3.1.2 Topography

The topography of Great Akaki River basin is rugged and steep mostly between Entoto and Filwoha but it is gentle and flat lying in south and southwest parts of the basin. According to the extracted elevation of the project area from DEM, the watershed is located along elevation range from 2060 m.a.s.l around Addis Ababa Bishoftu Road Bridge to 3227 m.a.s.l on Entoto Mountain. Almost all of surrounding area is dominated by residential setting.

3.1.3 Climate and Hydrology

The Great Akaki River watershed has a subtropical highland climate. Geographical, the study area found near to the equator due to this temperature is very constant from month to month. Based on monthly averages for the 26-year period 1991-2017 as shown from table the mean monthly minimum and maximum temperatures varies from 7-11 $°C$ and 21-25°C respectively.The lowest temperature of the project area is 70C which is registered in November and December, and the maximum temperature is 25 °C registered in March and May. The climate of Great Akaki River catchment is characterized by two distinct seasonal weather patterns. The main wet season, locally known as kiremt extends from June to September, contributing about 70% of the total annual rainfall. A minor rainy season, locally kwown as Belgi, contributes moisture to the region from mid-February to mid-April. The remaining five months are dry season.

Table3.1Climate of Addis Ababa based on monthly averages for the 26-year period 1991-2017

Month	**Mean Daily Minimum Temperature (°C)**	**Mean Daily Maximum Temperature (°C)**	**Mean Total Rainfall (mm)**	**Mean Number of Rain Days**
Jan	8	24	13	3
Feb	9	24	30	5
Mar	10	25	58	7
Apr	11	24	82	10
May	11	25	84	10
Jun	10	23	138	20
Jul	10	21	280	27
Aug	10	21	290	26
Sep	10	22	149	18
Oct	9	23	27	4
Nov	7	23	7	1
Dec	7	23	7	1
Total mean rain fall or rain days per year			1165	132

Source: World Weather Information Service

3.1.4 Land Use of the study area

Based on Landsat image and aerial photography, a land use map was generated for Great Akaki River catchment. The land use and Land cover date file describe the vegetation, water, natural surface and cultural features on the land surface.

The land use in for Great Akaki River catchment is dominated by Agriculture and settlement. Forest land is also observed in some parts of the sub basin. The agro ecological zones are characterized by tepid to cool moist highlands. The north western part of the lowlands is hot to warm moist lowlands.

Table3. 2 LULC of Great Akaki Watershed

SWAT LULC	SWAT Code	Coverage(%)	Area(km2)
Agricultural land	AGRL	63.551	557.3
Settlement	WETN	24.543	216.7
Forest	FRST	8.281	72.5
Eucalyptus	FRSD	1.213	10.6
Acacica	CORN	1.007	8.8
Dispersed shrub	RNGB	0.845	7.4
Water body	WATER	0.555	4.4
Grass land	RNGE	0.005	0.4

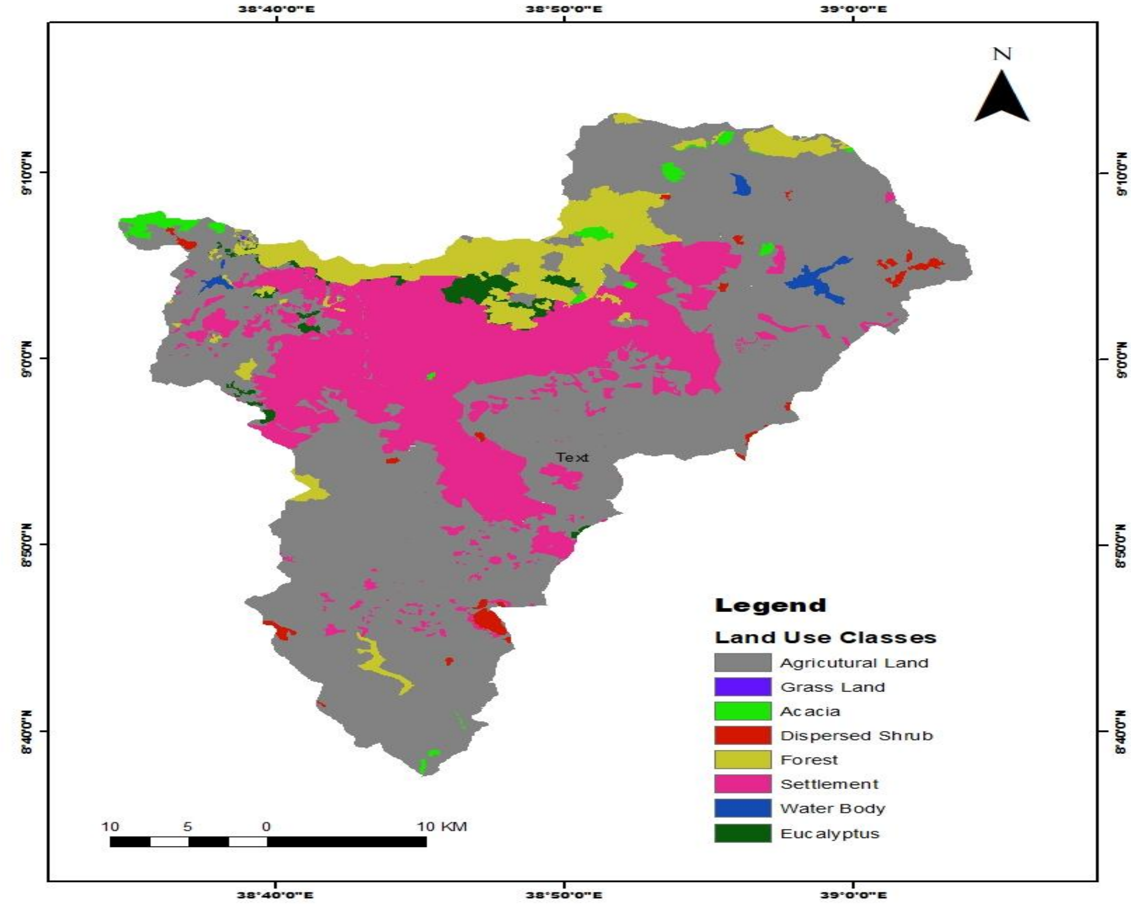


Figure3. 2LULC map of the Great akaki River Basin for the years 2013.

3.1.5 Soil Types of the Project Area

The soil development in the study area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the areas of Addis Ababa (Tsegaye, 2006). The soil data used for this research is obtained from ministry of agriculture and developed by Ministry of water resource in vector form. Based on this data the study area has a total of nine soil classes namely, Calcic Xerosols, Chromic Cambisols, Chromic Luvisols, Chromic Vertisols, EutricNitisols, Leptosols, Orthic Solonchaks, Pellic Vertisols, and Vertic Cambisols. As shown from table 3.2 and figure 3.3 soil class type PellicVertisols is the dominant type with 65.74% and

OrthicSolonchaks, Calcic Xerosols, EutricNitisols and Chromic Luvisols are second, third, fourth and fifth with 11.14%, 7.96%, 5.68% and 5.26% respectively. According to the world reference base for soil resources FAO which is updated on 2015 the major soil types of the study area defined as follows:

Chromic and VerticCambisols: medium and fine textured materials derived from a wide range of rocks have a property of increasing clay percentage which is the parent material of the soil is still young.

Chromic Luvisols: soils with a pedogenetic clay differentiation (especially clay migration) between topsoil with a lower and subsoil with higher clay content, high-activity clays and a high base saturation at some depth. In subtropical and tropical regions, Luvisols occur mainly on young land surfaces. Luvisols (many with the Chromic, Calcic or Vertic qualifier) are common in colluvial deposits of limestone weathering, the lower slopes are widely sown with wheat and/or sugar beet while the often eroded upper slopes are used for extensive grazing or planted with tree crops.

EutricNitisols: Deep, well-drained, red tropical soils with a clayey nitic horizon that has typical angular blocky structure breaking into polyhedral or flat-edged or nut-shaped elements with, in moist state, shiny aggregate faces.

Leptosols: comprise very thin soils over continuous rock and soils that are extremely rich in coarse fragments and particularly common in mountainous regions. Continuous rock at less than 10 cm depth in mountain regions are the most extensive Leptosols Such kind of soils has a resource potential for wet-season grazing and as forest land. The excessive internal drainage and the shallow depth of many Leptosols can cause drought even in a humid environment.

Orthic Solonchaks: such kind of soils have a high concentration of soluble salts and found in arid and semi-arid regions, notably in areas where ascending groundwater reaches the upper soil or where some surface water is present, with vegetation of grasses and/or halophytic herbs, and in inadequately managed irrigation areas.

Pellic and chromic Vertisols: heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out are medium.

Calcic Xerosols: These Soils occurring under an aridic moisture regime soils with accumulation of calcium carbonate (FAO – Unesco, 1974).

Major and dominant soil types identified in the sub basin are pellicvertisols, Eutric Fluviosols, Leptosols, Chromic Luvisols, Eutric Nitisols, OrthicSolonchakes, Calcic Xerosols, Chromic Vertisols and VerticCambisols. The most dominant soil type is pellicvertisols. The second dominant soil isEutricFluviosols. Small patches ofLeptosols, Vertic Cambisols and Eutric Nitisolsare also in some parts of the basin.

Table 3.3 Soil classes of the project area.

Soil class type	Surface Area Coverage	
	Km2	%
Calcic Xerosols	70.45	7.96
Chromic Cambisols	4.76	0.54
Chromic Luvisols	46.56	5.26
Chromic Vertisols	19.13	2.16
Eutric Nitisols	50.21	5.68
Leptosols	12.16	1.37
OrthicSolonchaks	98.59	11.14
PellicVertisols	581.57	65.74
Vertic Cambisols	1.21	0.14
Total	884.63	100

Source: Ministry of Agriculture

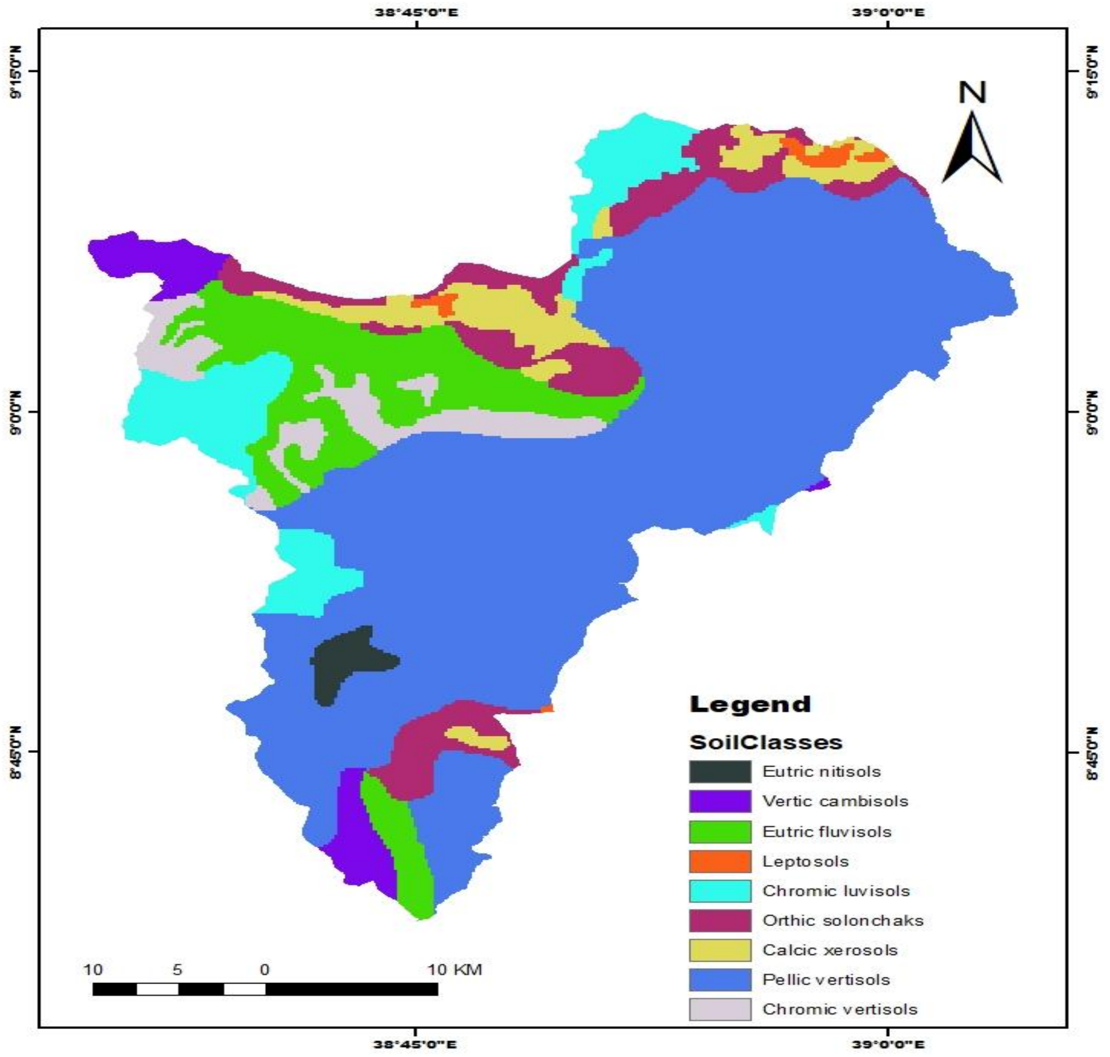


Figure3. 3 Soil type of the project area

3.1.6 Wind Speed, Sunshine and Relative Humidity

The wind flow pattern is influenced by the seasonal variation of the ITCZ. The predominant wind direction during June to September is southerly to southwesterly. The wind speed pattern is distinctly bimodal in Addis Ababa region with peaks occurring in March to September and minimum speeds being recorded in July and August. The mean annual wind speed at Addis

Ababa is0.9m/s in (2008-2009). The mean annual relative humidity of the basin is 60.2% measured at Addis Ababa. The monthly variation in relative humidity at Addis Ababa ranges from 50.9% in March to 78.5% in August in (2008-2009).

3.2 Date Collection

3.2.1 Rainfall-Runoff modeling of the Great akaki watershed.

This study compared the performance of HEC-HMS and SWAT hydrological models to simulate stream flow at the aba Samuel hydrological station from 1995 to 2017. Both the HEC-HMS and SWAT models are capable of continuous simulation(Bekele, et al. 2022).These models simplify water resource systems for ease of understanding of the model behavior. Understanding the components of the hydrological cycle including surface run off, infiltration, evaporation, transpiration, and precipitation is of prime importance in hydrologic modeling studies.

In the case of the HEC-HMS model, the HEC-GeoHMS and Archydro tools were used to delineate and calculate the physical and drainage characteristics of the watershed. They were used in the HEC-HMS model as inputs for the initial simulation.The whole water shed was delineated into 4 sub-watersheds considering nearly equal surface areas for each sub-watershed. HEC-HMS model development process includes four main components namely, basin model, input data (time series, paired and gridded data), meteorological model, and control specifications (Bhuiyan, et al 2017). The basin model connects sub-water sheds, reaches, junctions, diversions, reservoirs, etc., to create a drainage system (Hamdan, et al.2021).The time interval for a simulation is controlled by control specifications (Tassew, et al. 2019). In this study climate data were added to meteorological modal to distributed them spatially and temporary over the watershed. Time series data of the precipitation, temperature and stream flow data in adaily step were include in the model. The HEC-HMS model was calibrated from 1 January 1995 to 31 December 2017 and validated 1 January 2012 to 31 December 2017.A sensitivity analysis was conducted by considering the changes in the percentage error in runoff volume (PEV). The Nash Sutcliffe Efficiency (NSE) and the Coefficient of Determination (R2) were used to determine the statistical performance of the HEC-HMS model on a daily and monthly basis. If the simulated values exactly match with the observed values NSE and R2 would be zero and one, respectively.

In the case of the SWAT model for the Great akakiwatershed using the SWAT 2020 version. In this previous study, firstly, the entire watershed was delineated into 4 sub-watersheds in the model setup process. Then, these sub-basins were subdivided into43 HRUs. Afterward, the model was calibrated from 1 January 1995 to 31 December 2017(23years) and validated from 1 January 2012 to 31 December 2017 (6years). A warm-upperiod of 3 years (1 January 1992 to 31 December 1994) was considered to equilibrate between various water storages in the model. Stream flows observed at the Aba samual hydrological station were used for hydrologic model development. A sensitivity analysis was conducted through the manual calibration process. SWAT Calibration and Uncertainty Procedures(SWAT-CUP) were initially used to identify the most sensitive parameters to stream flow. In the SWAT model developed through the previous study, surface runoff was predicted bythe Soil Conservation Service Curve Number (SCS-CN) method. Initially, the Digital Elevation Model (DEM) of the Great akaki watershed was delineated into sub watersheds by the watershed delineation tool available in SWAT. Thereafter, the reclassified land use and soil maps were used as input in the SWAT model. Then, the weather data were inserted to run the model. Finally, the observed stream flow data Aba Samual gauging station was used to calibrate the model.

3.2.2.Comparison of hydrological models performance in terms of existing criteria.

Having known discharge gauge and simulation data allows a direct comparison to be made to evaluate the performance of the model. This comparison will be completed using two different statistical measures; the Nash-Sutcliffe efficiency coefficient, and the coefficient of determination (R2) Test. These statistics were used to quantitatively compare the hydrologic simulation results to determine which precipitation input method yielded the most accurate results for the various simulations events .The coefficient of correlation (R2) measures the strength and direction of the linear relationship between variables of the measured gauge data and simulation data. The calculated r value will be between -1 and 1, with 0 representing no correlation. The linear correlation becomes stronger as the r value approaches -1 or 1. The coefficient of determination (R2) gives the variance of the data and assesses a goodness of fit at each calibration point for the model. It can help explain the variability of the model and how well the model may produce results for future predictions. The coefficient of determination is between 0 and 1, with 1 indicating a perfect fit with all variation explained.

The ranges for NSE can vary between $-\infty$ to 1, where: NSE=1 corresponds to a perfect match between discharge data and observed data; NSE=0 shows that the model predictions are as accurate as the mean of the observed data; and $-\infty<\text{NSE}<0$ occurs when the observed mean is a better predictor than the model, which indicates unacceptable performance (Wang et al., 2009). The St. Johns River Water Supply Impact Study (2012) completed by the SJRWMD used the Nash-Sutcliffe statistic to explain the calibration performance for their hydraulic model. Following similar methodology, the Nash-Sutcliffe coefficient values will be divided into intervals which explain performance rating. The intervals are as follows: $0.75 < \text{NSE} < 1$ is a “very good” performance rating, $0.65 < \text{NSE} < 0.75$ is a “good” performance rating, $0.50 < \text{NSE} < 0.65$ is a “satisfactory” performance rating, and $\text{NSE} < 0.50$ is an “unsatisfactory” performance rating.

3.2.1.1 Meteorological Data

Daily rainfall records from 1st January 1992 to 31st December 2017of four rainfall gauging stations lying in and around Akaki basin were taken from the Ethiopian Meteorology Agency is used for this study. The meteorological data used for study four stations (A.A Obs station, Akaki station, A.A bole station, Intoto station)

3.2.1.2 Hydrological Data

Hydrological data are very much important in the simulation and setup run process of the model. Daily discharge recorded data of fourteen years of Akaki River at Aba Samuale station for model analysis was collected from Ministry of Water Resource for the study.

3.3 Data analysis

Hydrological modeling to a large extent depends on hydro meteorological (precipitation, temperature and potential evapotranspiration) and hydrological (river discharge and lake water level) data. Reliability of the collected raw hydro meteorological and hydrological data significantly affects quality of the model input data and, consequently, the model simulation. This sub chapter sequentially presents, rough data screening of raw hydro meteorological and hydrological data, completion of identified missing data, estimation of a real rainfall and temperature for the study area (catchment and sub catchments), and analysis done to check consistency and homogeneity of the estimated a real data sets.

3.3.1 Filling missed precipitation data

Missed data existed due to lack of appropriate records, shifting of station location, and processing, are a serious problem because they lead inconsistency and ambiguous results that may contradict to the actual situation.

The missing values of precipitation data were filled using the normal ratio method because the annual precipitation of each gauging stations varying above 10%. The Normal ratio method expressed by the following relationship. The missed rainfall data filled using the nearby station.

$$p_x = \frac{N_x}{N}\left(\frac{P_1}{N_1}+\frac{P_2}{N_2}+\text{---}+\frac{P_n}{N_n}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

Where, Px =Missing value of precipitation to be computed; Nx = Average value of rainfall for the station in question for recording period; N1, N2………Nn= Average value of rainfall for the neighboring station; and P1, P2....Pn = Rainfall of neighboring station during missing period; and N= Number of stations used in the computation.

3.4.2 Conceptual frame of the study

After detail data analysis of meteorological and hydrological data's, based on the required data format of each model, time series data was arranged. The next step was splitting data for two thirds of them for calibration and one third for validation, Sensitivity analysis, Calibration, and Validation has been achieved. Figure 3.4 stated that the overall flow chart of this study from the beginning of input data preparation up to model comparison.

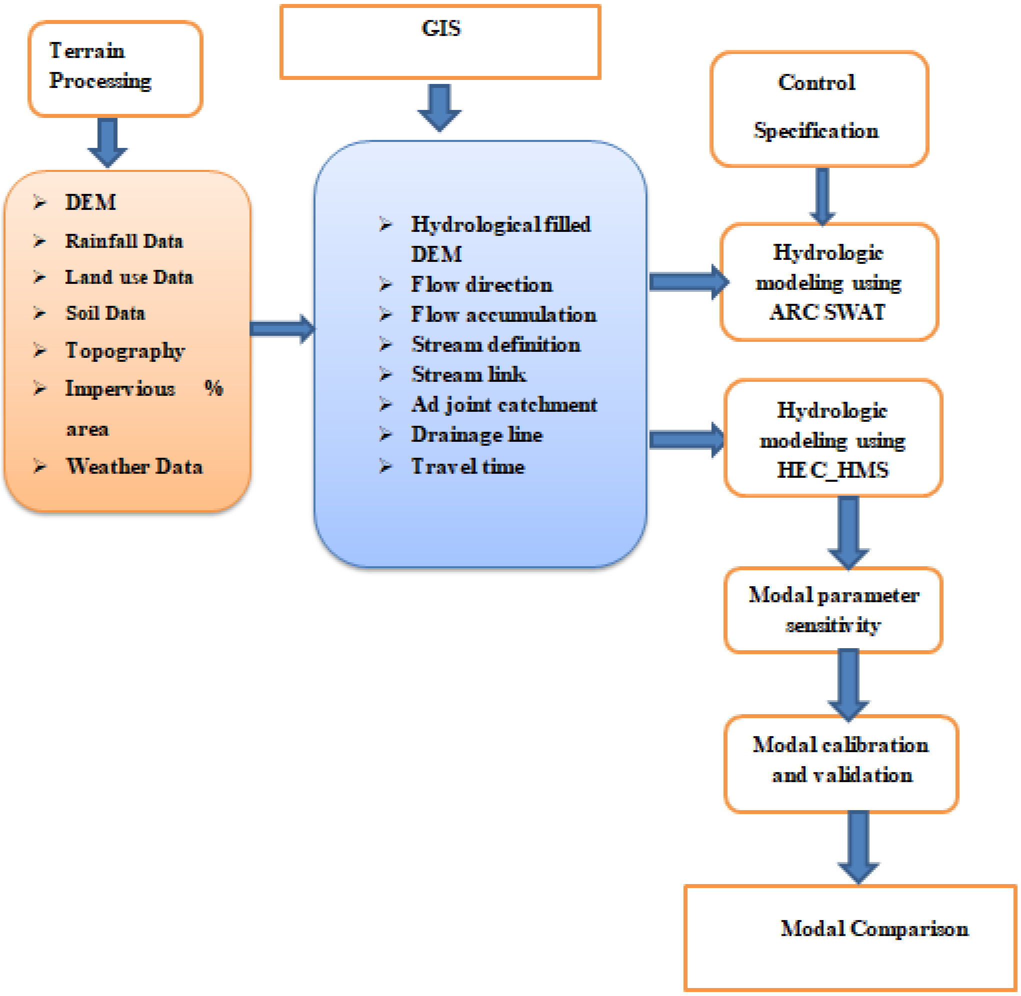


Figure3. 4 General Flow Chart of the study

3.4.3 Digital Elevation Model Data Processing

Delineation of a basin area using traditional method like processing topographic maps consumes much time and its accuracy is very low. But, now a time this traditional method has been replaced by automatic extraction from a Digital Elevation Model (DEM) due to the release of different type of high resolution satellites to space at different time and the production of high quality data. This high quality data is freely available on different websites. DEM data is used to describe topographic characteristics such as contour, slope, elevation difference, aspect, hill shade and others. For this research, DEM is the main dataset used for development of the basin model components and geometrical data in the HEC-HMS and ARC SWAT models respectively as well as for stimation of Rainfall Runoff at Great AkakiRiver watershed. The Digital Elevation Model data used in this study is downloaded from the official website of United States Geological Survey (USGS) and it is accessible by using the following link **http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=3accg**. The data is available in the form of GCS_WGS_1984 raster form with 30X30m resolution and it is already conditioned. To make it available for hydrologic modeling purpose the following tasks are done.

1. The DEM in the form of GCS_WGS_1984 raster format is changed in to the Universal Transverse Mercator (UTM) projection raster form by considering zone of the study area which WGS-1984, UTM Zone 37N by using Arc GIS 10.7.1software package.

2. The projected DEM clipped by using shape file of the study area as shown from picture 1

3. Fill sinks: If cells are available with higher elevation surrounding a cell, the water is trapped in that cell and cannot flow. Therefore this functions used for this study to modify the elevation value to eliminate these problems by creating a depression less or hydrologic ally corrected DEM based on the input row DEM.

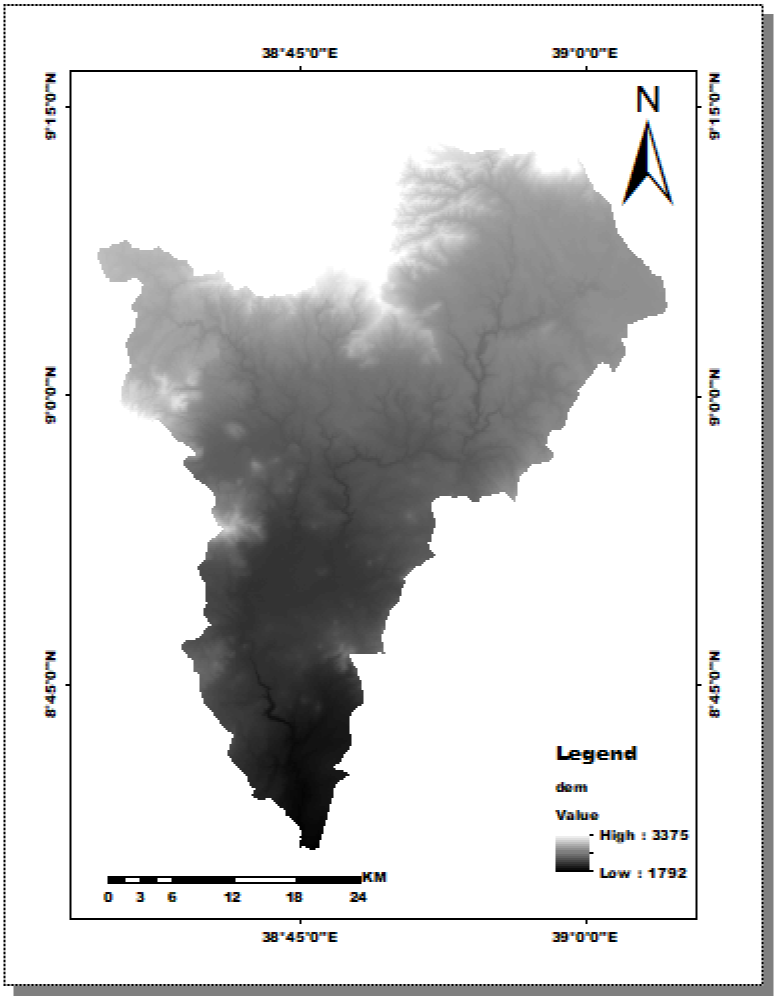


Figure3. 5Clipped hydro filled DEM.

3. Flow direction: It is generated from the fill sinks grid and indicates the direction of the steepest descent to a neighbor cell and defined for each grid cell. As shown from figure 4.2the number in the legend represents directions; 1 = east, 2 = southeast, 4 = south, 8 =south west, 16 = west, 32 = northwest, 64 = north, 128 = northeast.

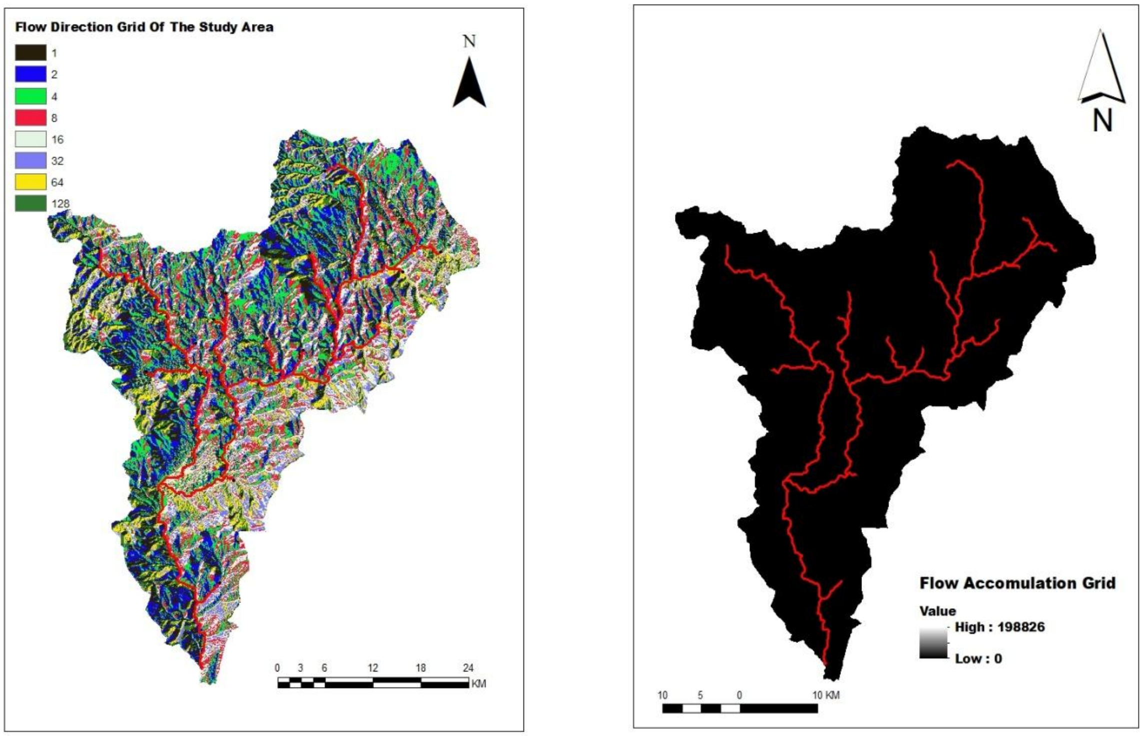


Figure3. 6 Generated flow direction (left) and flow accumulation (right)

5. Flow accumulation: generated from the flow direction grid and defines the number of upstream cells draining into any given cell in the grid.

6. Stream definition: the cells that form the stream network are defined based on a threshold number of cells that drain into a given cell.

7. Stream segmentation: created by splitting the streams as defined in the stream definition grid at any junction.

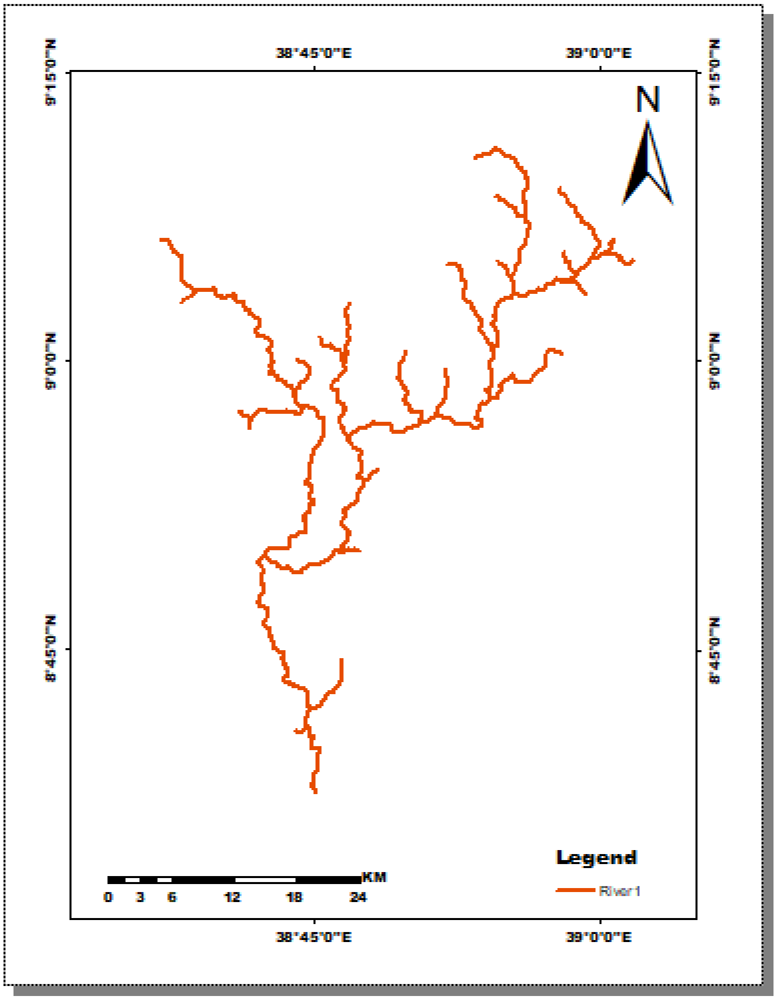


Figure3. 7: Stream definition.

8. Catchment grid delineation: For every stream segment defined by the stream segmentation Grid, the corresponding watershed is delineated and stored in a grid file. As shown from Picture.

9. Catchment polygon processing: This polygon generated from the catchment grid to delineate the boundaries of each sub basin.

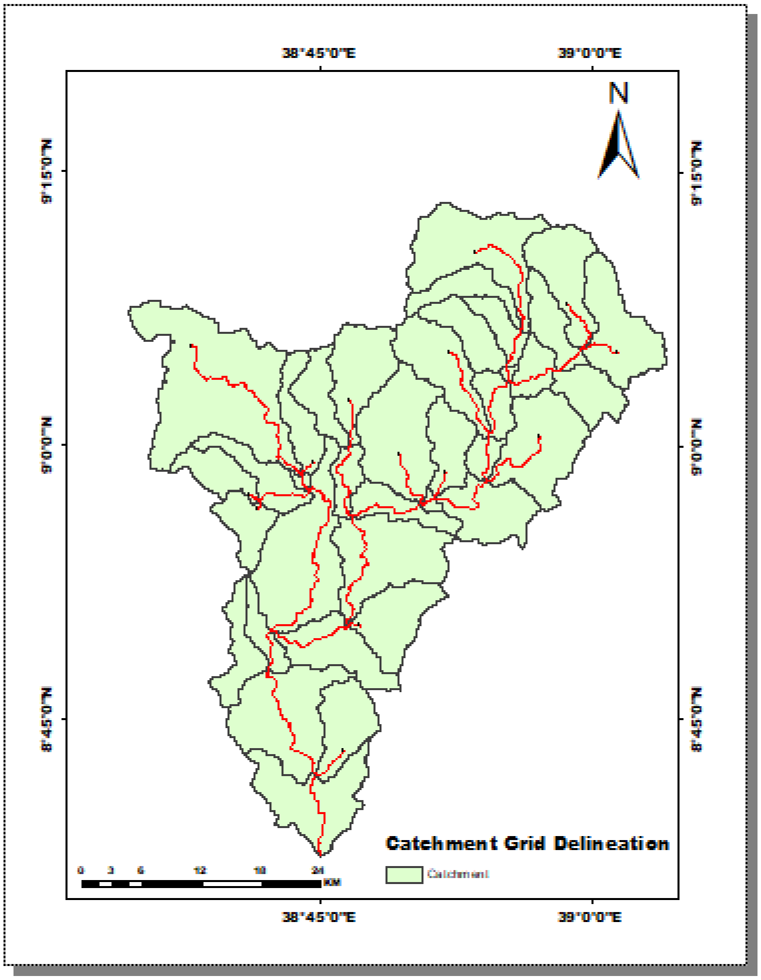


Figure3.8 Catchment grid.

10. Drainage line processing: generated from stream segmentation grid are transformed into a vector stream layer by this function.

11. adjoint catchment processing: the upstream sub basins are aggregated at any stream Confluence

12. Watershed slope According to FAO (2006) slope classification, the study area is characterized on a range of flat (below 0.2 % slope) to very step which is > 60% around Intoto as shown from table 3.4.

Table3. 4Slope gradient classes (FAO, 2006)

Class	Description	Slop %
1	Flat	0-0.2
2	Level	0.2-0.5
3	Nearly level	0.5-1.0
4	Very gently level	1.0-2
5	Gently slop	2-5
6	Sloping	5-10
7	Strongly sloping	10-15
8	Moderately steep	15-30
9	Steep	30-60
10	Very steep	>60

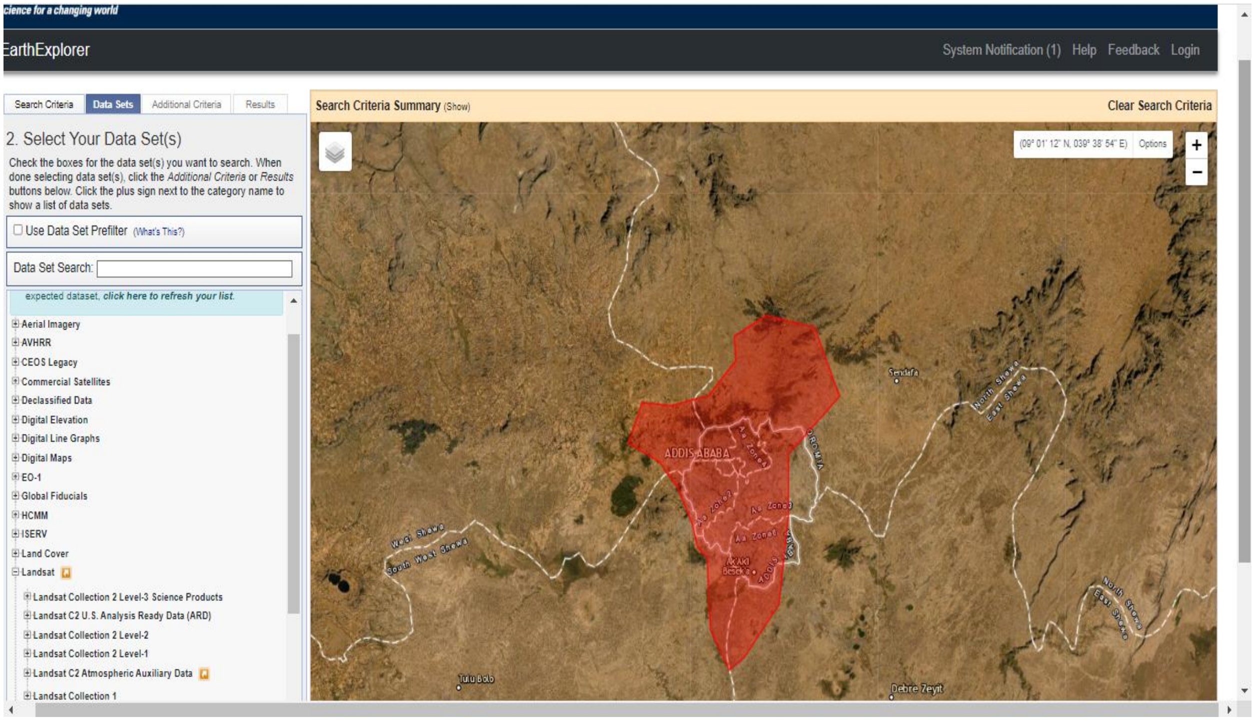
3.5 Curve Number (CN) Grid Input Preparation

3.5.1 General

The U.S. Natural Resource Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)) Curve Number method used in this study estimates the effective rainfall as a function of the cumulative rainfall, the land use, the soil type and the antecedent moisture condition of the soil The runoff curve number is an empirical parameter uses for estimating direct runoff or infiltration from rainfall excess. The runoff curve number is generated from the study area’s land use and hydrologic soil groups. Watershed land cover has a great importance in estimating the basin’s curve number with the identification of soil textures and its permeability. Thus, according to the classification of Soil Conservation Service (SCS) method soil types of the catchment are grouped for each of the Great Akaki River sub-basins already created on previous. This method has been widely applied to estimate storm runoff depth for every patch within a watershed based on runoff curve numbers (CN) (QihaoWeng, 2001). The first step for curve number generation is Landsat data processing and analysis by using Arc GIS 10.7.1 software package.

3.5.2 Landsat Data Processing

As previously described, determination of Runoff Curve Number (CN) requires land use classification and the potential of deriving land use maps from satellite images is one of the main aims of this study. Land use from large areas can be detected easily in a short time with low cost compared to the traditional methods. The Landsat data used is downloaded from the official website of United States Geological Survey (USGS) and it is freely accessible by using the following link:http://earthexplorer.usgs.gov/.For this study the Landsat data of the catchment 2010 with a resolution of 30mX30m is selected and used. The selection is based on the available hourly rainfall, quality of image and resolution available for the above years.



Check the boxes for the data set(s) you want to search. When done selecting data set(s), click the *Additional Criteria* or *Results* buttons below. Click the plus sign next to the category name to show a list of data sets.

Figure3. 9: Landsat data downloaded from official website

As shown from Figure, to downloading the Landsat data first KML file with a maximum of 30 points of the watershed is prepared and uploaded to the above site. The Landsat data downloaded from the Landsat archive in the form of Geotiff with different bands. Before utilizing the data the following activities are done using Arc GIS 10.7.1 software package.

1. All the available bands of satellite image are combined by using composite bands function

2. The combined Landsat data in the form of GCS_WGS_1984 raster format is changed in to the Universal Transverse Mercator (UTM) projection raster form by considering zone of the study area which WGS-1984, UTM Zone 37N by using Arc GIS 10.7.1 software package.

3. The projected Landsat data is clipped by using the shape file of the study area which is previously prepared.

4. Individual bands composited in a Red, Green and Blue (RGB) combination in order to visualize the data in color. There are many different combinations that can be made but in this case 3, 2, 1 RGB combination is selected. This color composite is as close to true color. As shown from the picture the numbers 3, 2, 1 are representing Red, Green and Blue respectively. At this stage the Landsat data is ready for land use classification.

3.6 Watershed model structure and model set up

3.6.1 HEC-HMS model structure and model set up

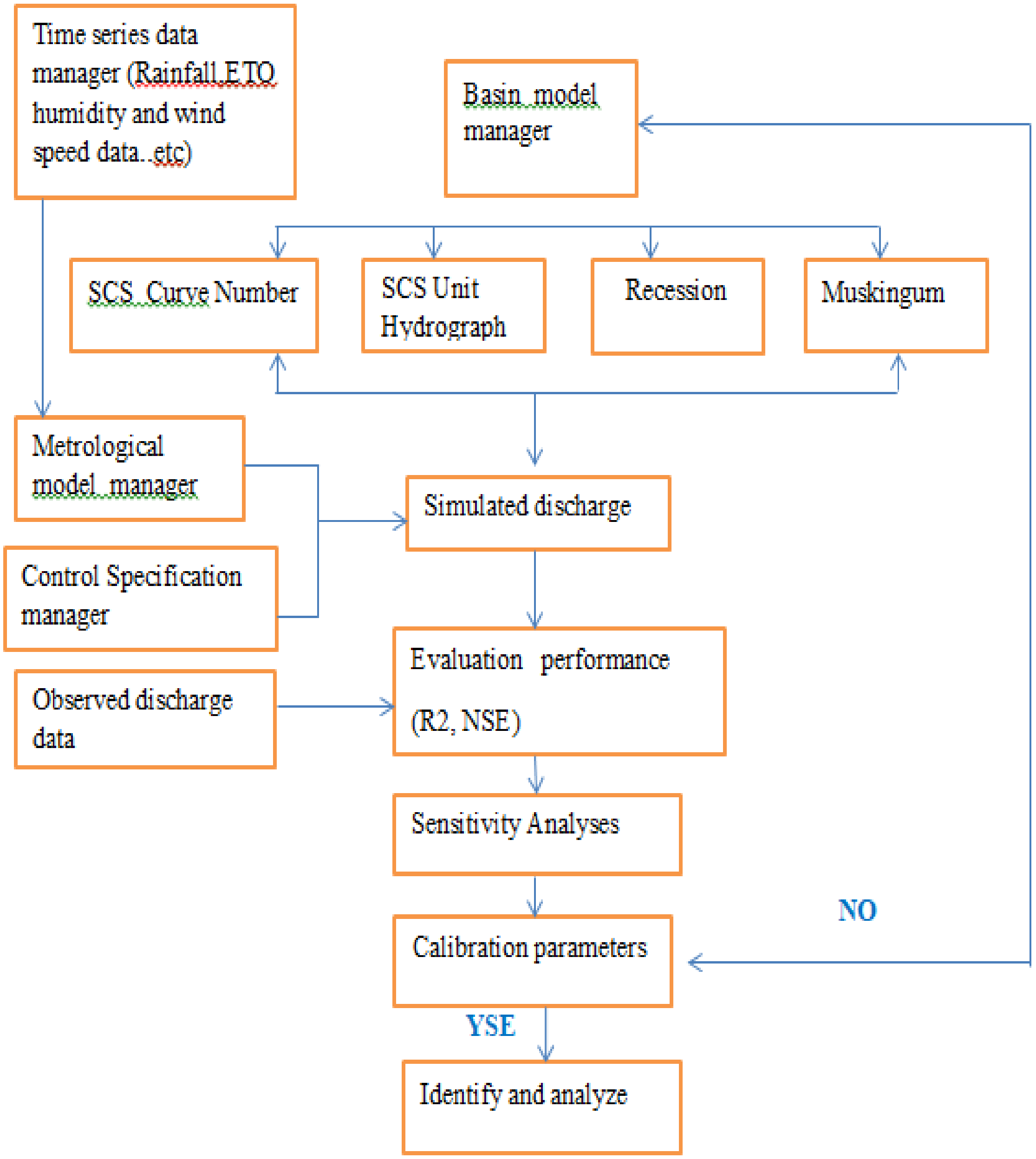


Figure3. 10: HEC-HMS work flow chart.

3.6.1 Catchment Area

The catchment area of study area which extends to Akaki Abasamuelartificial reservoir with 30mx30m resolution topographical maps was by Global Mapper and transformed to Digital elevation Model (Akaki). Akaki river catchment has different land use and hydro geological settings. These land use and geological settings of the area has direct effect on rainfall runoff coefficient.

3.6.2. Hydrologic Process

3.6.2.1Watershed and Stream Network Delineation using Arc Hydro Tools

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, stream network density, etc. The processing of DEM to delineate watersheds is referred to as terrain preprocessing. There are several tools for terrain pre-processing. However for this study Arc Hydro tools were used to process a DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. Arc Hydro Terrain Preprocessing should be performed in sequential order as follow.

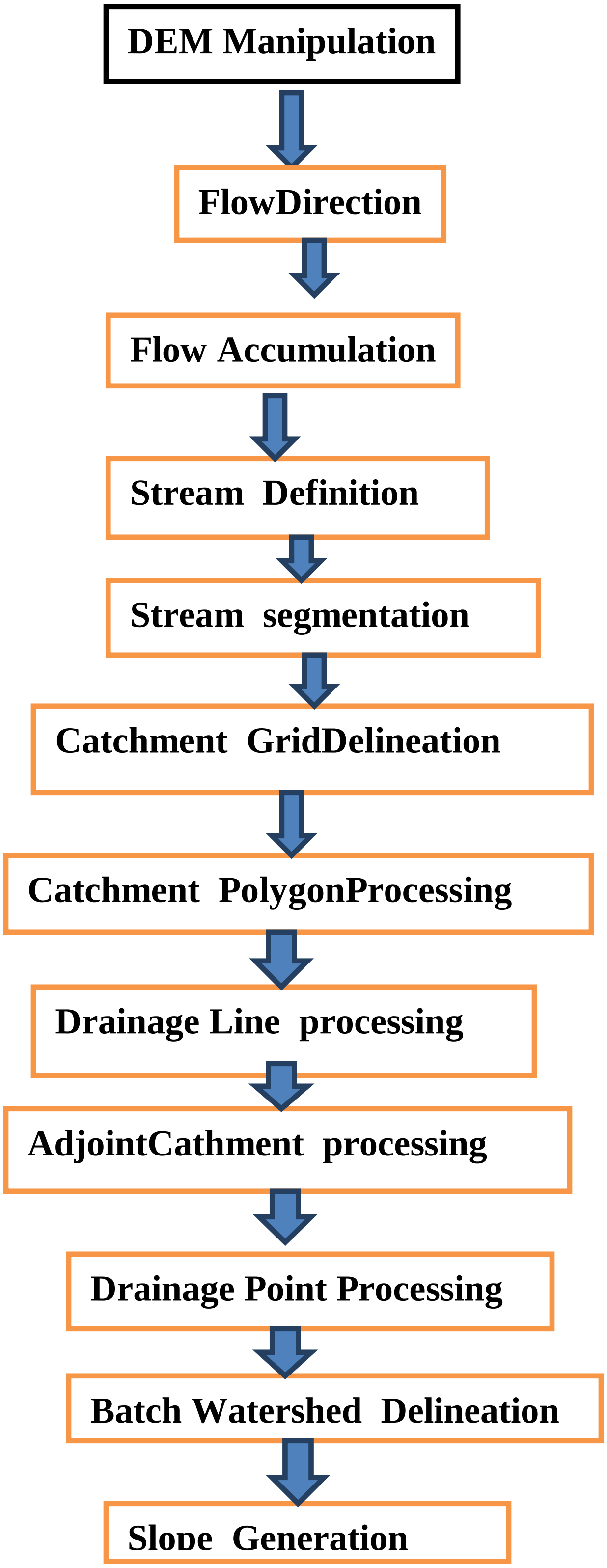

DEM Manipulation
FlowDirection
Flow Accumulation
Stream Definition
Stream segmentation
Catchment GridDelineation
Catchment PolygonProcessing
Drainage Line processing
AdjointCathment processing
Drainage Point Processing
Batch Watershed Delineation
Slope Generation

Figure3. 11: Flowchart of terrain preprocessing.

3.6.3 HMS-Model Development using Geo HEC-GeoHMS

HMS Modal is a program that works with Arc GIS (for this case use version 10.7.1) used to create input files for hydrologic modeling HEC- HMS.It transforms spatial information tomodel files for HEC-HMS.Arc GIS has a capability of data processing and coordinate transformation which results DEM.HEC-GeoHMSoperates on the DEM to delineates sub basins and hydrologic inputs like longest flowcentroids, river and basin slopes, etc.To accomplish this, HEC-GeoHMS has different components in which each steps should followed sequentially. Terrain processing involves using the DEM to create a stream network and catchments. This processing of HEC-Geo HMS is done by Arc Hydro tools using the previous procedure for this case.

3.6.3.1 HEC-GeoHMS Project Setup

The HEC-Geo HMS project setup menu has tools for defining the outlet for the watershed (Project Point) and delineating the watershed (Project Area) feature classes for the HEC-HMS project.

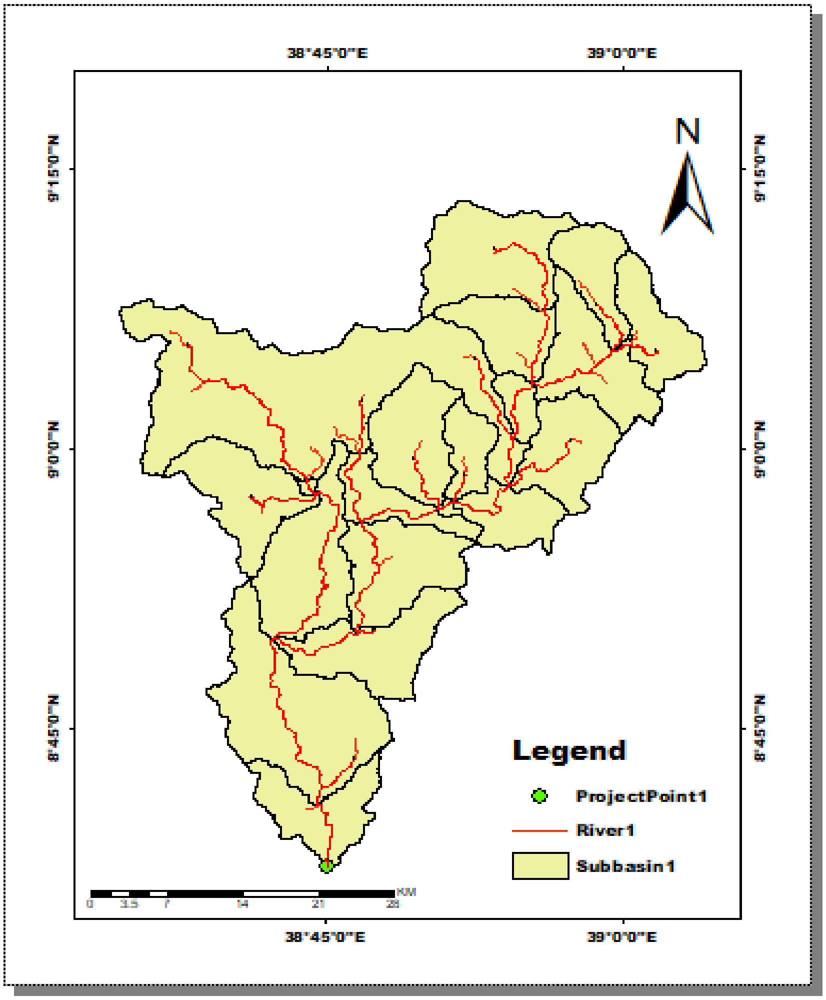
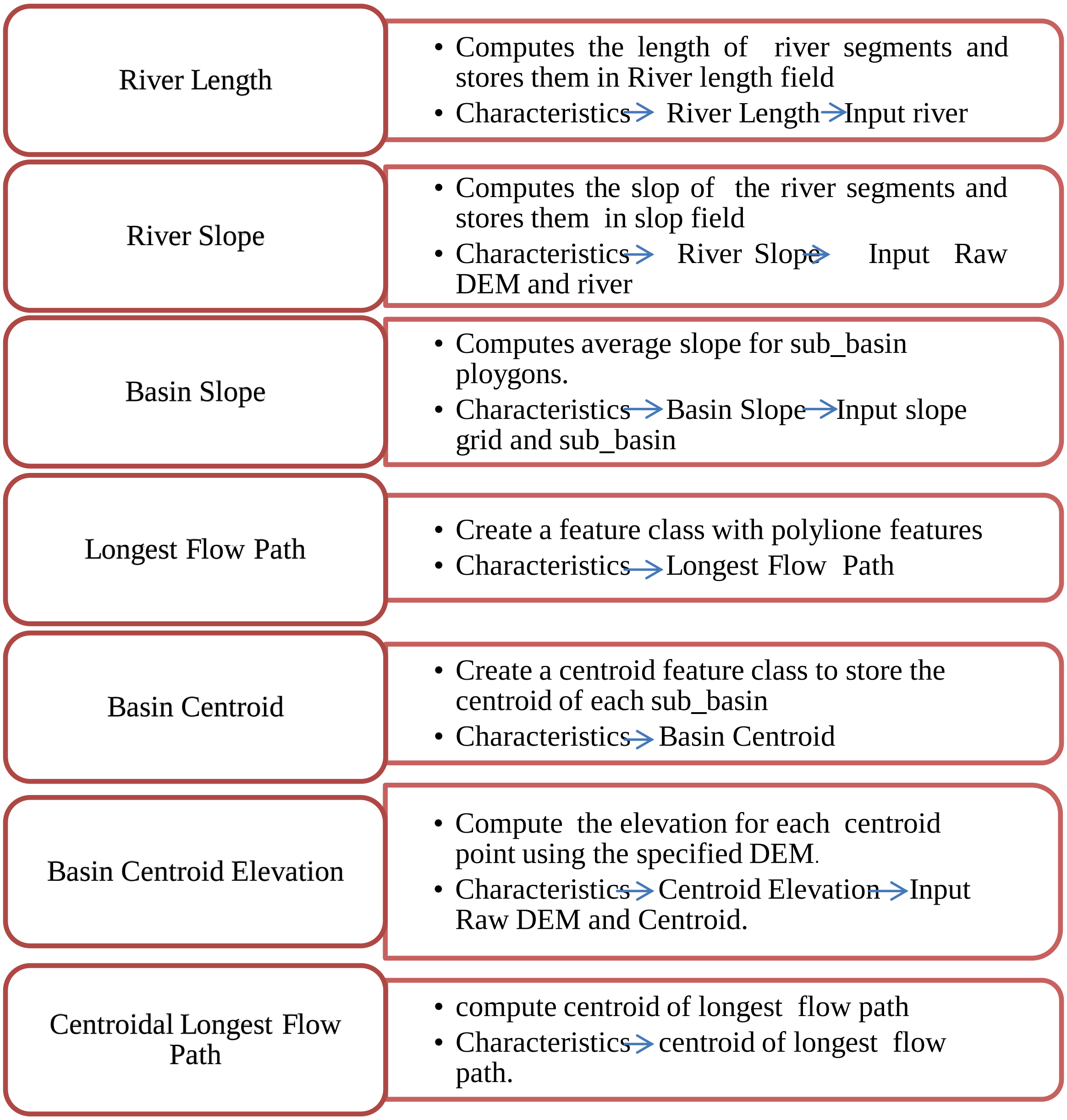


Figure3. 12: Project Point and project area with sub-basins.

Project point of this study was selected at existing Bridge of Road from Addis Ababa to Adama where river gauging device exists. The purpose of choosing this location is that at this location there is a gage station with flow gage data, to calibrate hydrologic parameters for observed flow data with determined flow by hydrologic modeling. Peak flows was determined at new railway crossing by adding additional flow from downstream area of project point to railway crossing and finally enter to **Aba Samuel reservoir**.

3.6.4 Extracting Basin Characteristics

In the basin characteristics, the HEC-GeoHMS provides tools for extracting physical characteristics of streams and sub-basins into attribute tables.These topographic characteristics extracted from HEC- Geo HMS are listed below.



River Length	• Computes the length of river segments and stores them in River length field • Characteristics → River Length → Input river
River Slope	• Computes the slop of the river segments and stores them in slop field • Characteristics → River Slope → Input Raw DEM and river
Basin Slope	• Computes average slope for sub_basin ploygons. • Characteristics → Basin Slope → Input slope grid and sub_basin
Longest Flow Path	• Create a feature class with polylione features • Characteristics → Longest Flow Path
Basin Centroid	• Create a centroid feature class to store the centroid of each sub_basin • Characteristics → Basin Centroid
Basin Centroid Elevation	• Compute the elevation for each centroid point using the specified DEM. • Characteristics → Centroid Elevation → Input Raw DEM and Centroid.
Centroidal Longest Flow Path	• compute centroid of longest flow path • Characteristics → centroid of longest flow path.

Figure3. 13: Process of extracting physical characteristics of sub basin and rivers.

3.6.5. HMS Inputs/Parameters Estimation

The HEC-Geo HMS provides tools to estimate hydrologic parameters and methods used in HMS. These parameters include SCS curve number, time of concentration, channel routing coefficients, etc. In HEC-Geo HMS transform (rainfall to runoff) method, channel routing, Loss method and base flow methods can be specified, even though in HEC can also be assigned.

A. Transform method

Transform method is the process of converting excess rainfall to direct runoff and determine peak flow. There are many methods developed for calculation of the design flood like; rational Formula and U.S. Soil Conservation Services (SCS) Unit hydrograph rainfall. But their applicability depends mainly on the availability of hydrological data and the size of catchments area. Depending on size of catchment area and availability of hydrological data. thisstudy was used SCS Unit hydrograph rainfall.

1. Loss method

The loss rate module in a subbasin is responsible for simulating how much precipitation infiltrates into the ground and how much remains on the ground surface method, Gridded deficit constant, green ampt method, Initial constant, SCS curve number etc are some method to determine quantity of precipitation in filtered to the ground. All methods require different hydrologic parameters. Depending on available data and easily accessibility of parameters, SCS curve number was used for this study to determine amount of loss.

C. Routing method

The routing method handles movement of the water in the reach popular and relatively simple to use is used for this case. The muskingumcunge method issimilar to the plain muskingum method; however it uses a measured cross section and channel properties to determine the routing coefficients. The lag method includes no attenuation and simply delays the water travelling through the reach by a certain amount of time.

D. Base flow methods

Base flow is the sustained runoff prior to rainfall that was temporally stored in the watershed. There are different method to determine base flow quantities and parameters. Constant monthly, bounded recession, linear recession are the methods. Recession method was selected for this study depending on available information.

3.6.6 Creating HEC- HMS project

HEC-Geo HMS provides hydrologic input for HEC_HMS like background shape file, basin model file and metrological model file. The process is as follo

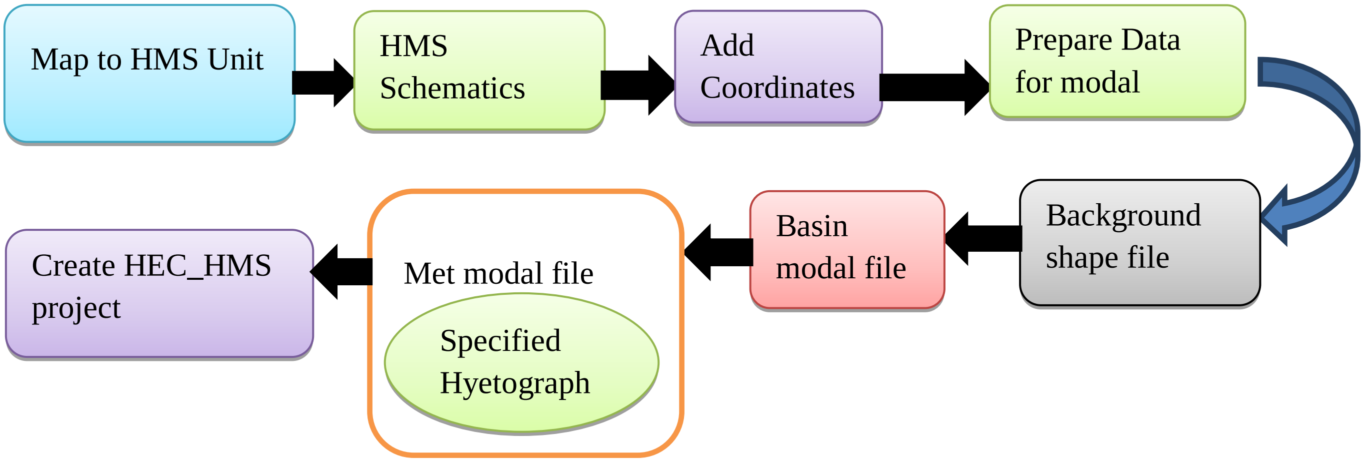


Figure3. 14: Process of creating HEC HMS project using HEC-GeoHMS.

HEC-HMS has different components like basin model, metrological model, control specification etc., to determine hydrologic parameters that determined later in hydrologic analysis. In hydrologic analysis the following methodology was followed.

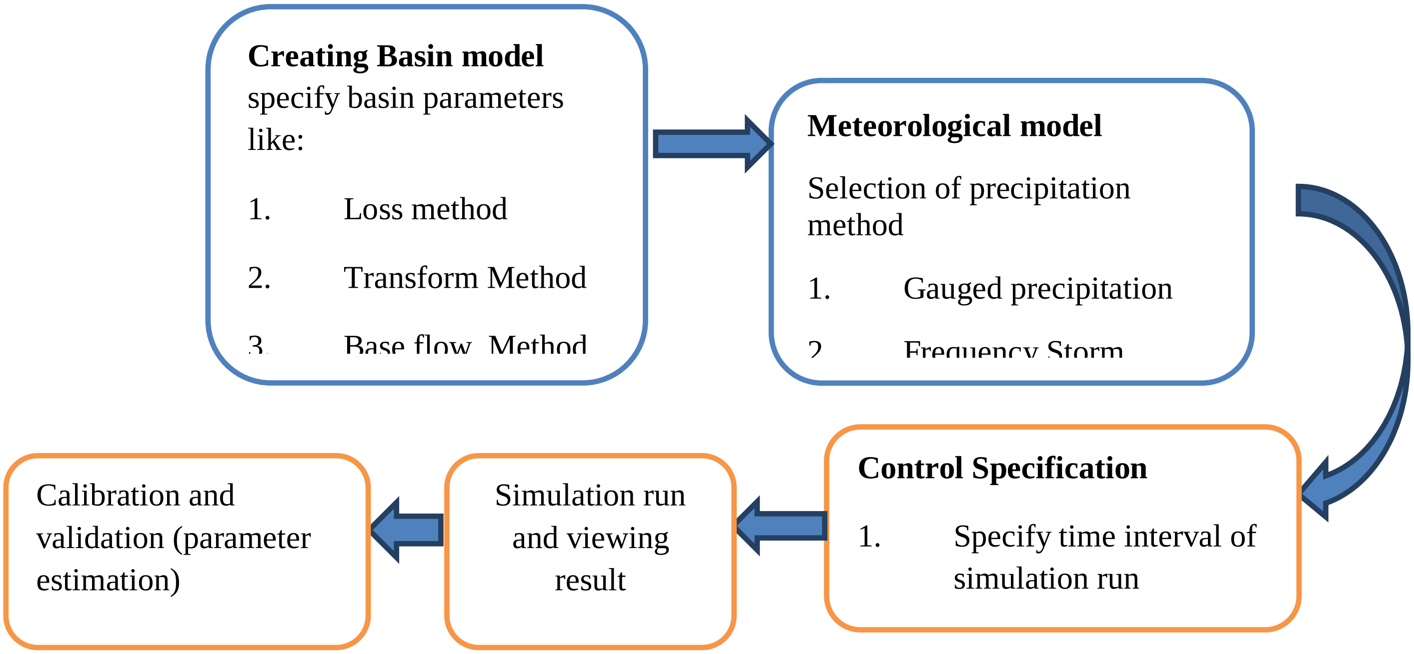


Figure3. 15: HEC- HMS process.

3.6.7 Rain fall (Precipitation) methods

Rainfall is the most common factor used to predict design discharge. Precipitation gauge were collected from the Ethiopian Meteorological Services Agency (EMSA) of A.A Obs station, Akaki station, A.A bole station, Intoto station. Monthly total and daily maximum rainfall data is available at this station. The data from these gauging stations have been used to develop meteorological model. Meteorological model calculates precipitation inputs for subbasins. It uses both Historical methods: like Gage weights, Inverse distance, User-specified hyetograph, Gridded precipitation and Hypothetical methods like Frequency storm, SCS storm, Standard project storm calculation. The gage weights method uses multiple gages and any weights specified. Normal sources of weights are Thiessen polygons or arithmetic mean methods. The inverse distance method also uses multiple gages but the weights are always inverse distance squared. This was originally designed for real-time forecasting use. The user specified method, selects a time-series gage for each subbasin and optionally a total storm depth override. The gridded method uses radar rainfall or other sources of gridded data. Thus for this study gage weight method and frequency storm was used from both historical method and hypothetical method respectively. It is based on the assumption that the precipitation depth at any point within the watershed is the same as the precipitation depth at the nearest gage in or near the watershed. The method of constructing the polygons implies the following steps. Adjacent stations are connected with lines. Perpendicular bisectors of each line are constructed (perpendicular line at the midpoint of each line connecting two stations). The bisectors are extended and used to form the polygon around each gauge station. Rainfall value for each gauge station is multiplied by the area of each polygon.

3.6.8 HEC-HMS Model Calibration

The model evaluation procedure includes sensitivity analysis, calibration and validation. The sensitivity analysis of the model was performed to determine the important parameters which needed to be precisely estimated to make accurate prediction of basin yield. HEC-HMS has many parameters associated with stream flow calibration. These are sub-basin parameters used in loss method, transform method, base flow method and river routing method as shown in table below. The values of each parameter were initially specified from various watershed and channel characteristics to estimate runoff and routing hydrograph. Their actual values were obtained by trial–and-error method and automatic optimization algorithm built in HEC-HMS with observed flow data.

Table3. 5Sub-basin parameters

Model	Method Used	Parameters
Losses	SCS Curve Number	Initial Abstraction Curve Number % impervious
Transform	SCS Unit Hydrograph	Lag time
Base flow	Recession	Initial Discharge Recession constant Threshold Ratio
Channel Routing	Muskingum	Muskingum k
		Muskingum X

The above listed parameters were used for this study in addition to other parameters like time of concentration (tc), potential maximum retention of the soil, roughness coefficient, hydraulic length of the channel, average slope of the channel, etc. Most of the parameters, as specified earlier, were estimated from physical characteristics of watershed where as other parameters have no direct physical meaning. These parameters were determined by using available empirical formula and feasible ranges had been taken from existing literatures. The question is how can the appropriate parameters value be selected? And what types of data berequired to get relatively consistence value? Calibration (optimization) techniques can answer the first question, how can the appropriate parameter value be selected? And stream flow data was required. Calibration of a model refers to the process that involves adjustment and refinement of parameter values to provide the best match between observed flow data and simulated values of hydrographs for each hydrologic element. For this case observed stream flow data of Akaki River was collected from Ministry of Water, Irrigation and Energy (MoWIE) for a period of 1/01/1992-31/12/2017 GC. Daily rainfall records of Bole, AA Observatory, Intotoand Akaki stations are available for the same. The observations inthe time period (1995 to 2010) were used for calibrating the model and the data from the time-period (2011 to 2017) were used to validate the model. The automated calibration procedure in HEC-HMS was used an iterative method to minimize an objective function. HEC-HMS program is equipped with the feature that optimizes the parameters following the following process.

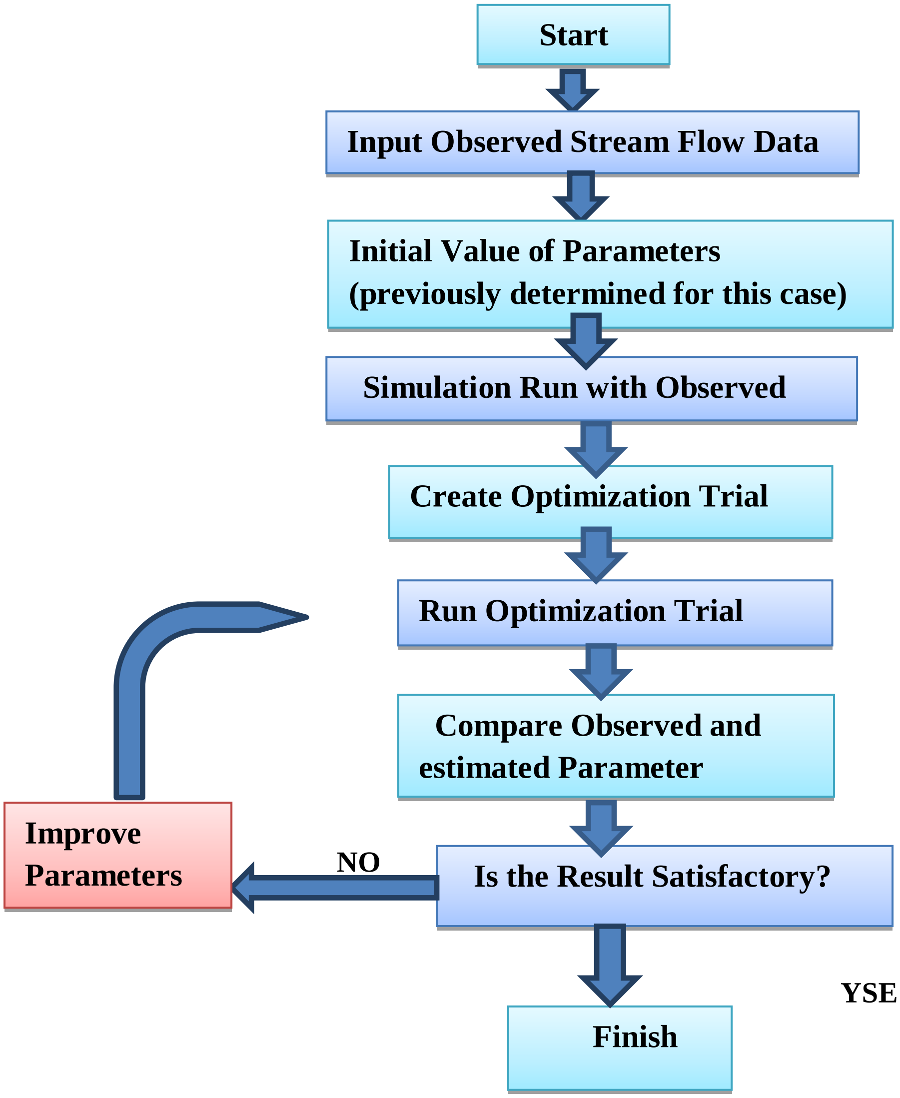


Figure3. 16: General Calibration Procedure (Arlen D.Feldman, 2000).

3.6.8 SWAT model structure and model set up

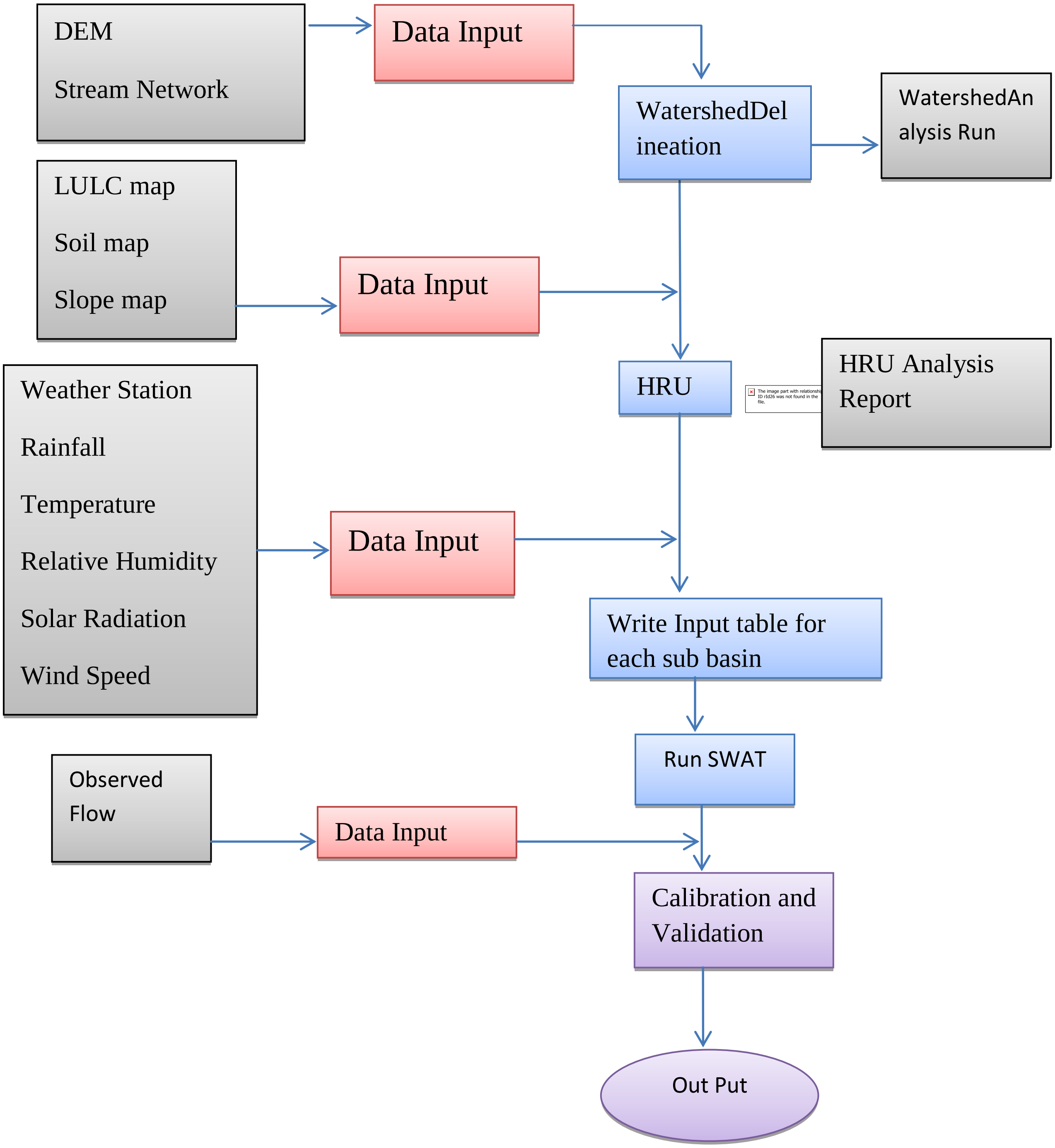
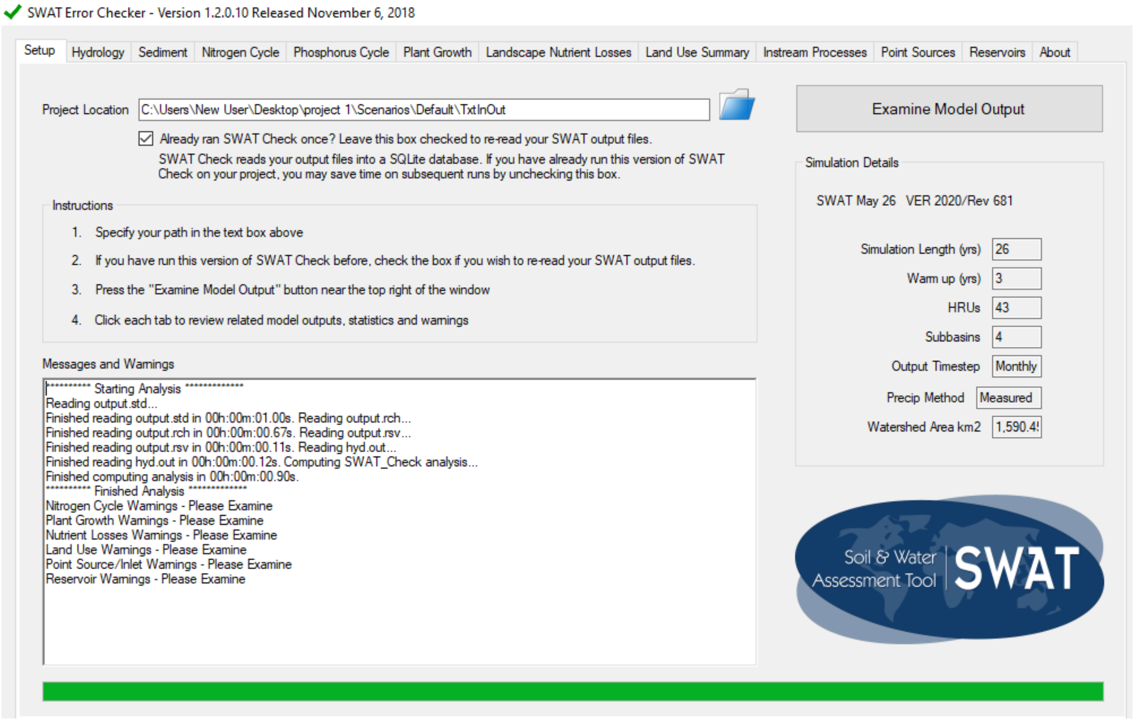


Figure3. 17: Work flow chart of SWAT Model.

3.6.9 SWAT Modal Analysis

SWAT stands for Soil and Water Assessment Tool, it is a river basin scale developed to predict the impact of land management practices on water, sediment and agricultural chemical yields. Data Organization were done in a sub-basins or hydrologic response units (HRU's), HRU's are portions of a sub-basin that possess unique land use/management/soil attributes in time scale and a continuous time model yields a long term model based on a daily scale not for a single event. It is a public domain model actively supported by the USDA/Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. The SWAT system (ARCSWAT), embedded within geographic information system (GIS)can integrate various spatial environmental data, including soil, land cover, climate, and topographic features. It is computationally efficient (Simulation of very large basins). SWAT enables to study long-term impacts.



Project Location: C:\Users\New User\Desktop\project 1\Scenarios\Default\TxtInOut

☑ Already ran SWAT Check once? Leave this box checked to re-read your SWAT output files.
SWAT Check reads your output files into a SQLite database. If you have already run this version of SWAT Check on your project, you may save time on subsequent runs by unchecking this box.

Instructions

1. Specify your path in the text box above
2. If you have run this version of SWAT Check before, check the box if you wish to re-read your SWAT output files.
3. Press the "Examine Model Output" button near the top right of the window
4. Click each tab to review related model outputs, statistics and warnings

Messages and Warnings

```
********** Starting Analysis **************
Reading output.std...
Finished reading output.std in 00h:00m:01.00s. Reading output.rch...
Finished reading output.rch in 00h:00m:00.67s. Reading output.rsv...
Finished reading output.rsv in 00h:00m:00.11s. Reading hyd.out...
Finished reading hyd.out in 00h:00m:00.12s. Computing SWAT_Check analysis...
Finished computing analysis in 00h:00m:00.90s.
********** Finished Analysis **************
Nitrogen Cycle Warnings - Please Examine
Plant Growth Warnings - Please Examine
Nutrient Losses Warnings - Please Examine
Land Use Warnings - Please Examine
Point Source/Inlet Warnings - Please Examine
Reservoir Warnings - Please Examine
```

Simulation Details

SWAT May 26 VER 2020/Rev 681

Simulation Length (yrs): 26
Warm up (yrs): 3
HRUs: 43
Subbasins: 4
Output Timestep: Monthly
Precip Method: Measured
Watershed Area km2: 1,590.4

Figure3. 18: SWAT model output interface.

3.6.10 Input data requirement

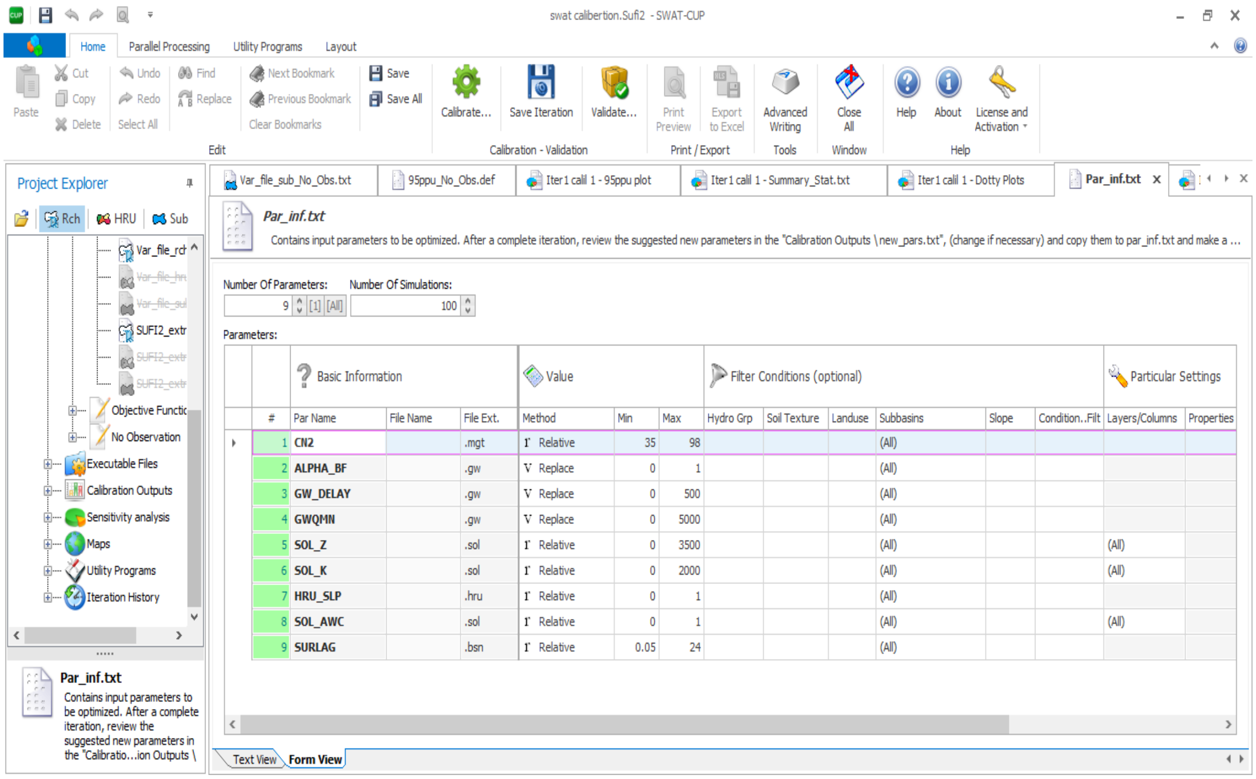
SWAT uses solar radiation values rather than daily sunshine hour's data, and thus, it has been converted using appropriate methods. Statistical analysis of the daily data had been summarized as mean daily maximum air temperature for month (ºC), mean daily minimum air temperature for month (ºC), standard deviation for daily maximum air temperature in month (ºC), standard deviation for daily minimum air temperature in month (ºC), average or mean total monthly precipitation (mm H_2O), standard deviation for daily precipitation in month (mm H_2O/day), skewness coefficient for daily precipitation in month, probability of a wet day following a dry day in the month, probability of a wet day following a wet day in the month, average number of days of precipitation in monthhad be estimated using pcpSTAT, average daily solar radiation for month (MJ/m^2/day), average daily temperature in month (ºC) estimated using dew point, average daily wind speed in month (m/s), which is used as an input for the weather generator. Finally, all the data had been prepared in .DBF format as an input into the SWAT model. Continuity test checked and the missing data had been filled with a missing data identifier of -999. To detect possible errors checking the station for data quality using appropriate method is essential. Therefore, inspection of consistency of individual stations, the data qualities withregard to possible temporal variations or errors had been carried out by Double- Mass Curve.

3.6.11 Weather generator data preparation

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. Up on checking the climatic data collected from all meteorological stations considered for the study, the data may have missing data. As SWAT has a built in weather generator called WGEN that is used to fill the gaps, all the missing values had been filled with a missing data identifier -999, and the weather generator first independently generates precipitation data for each day.

3.6.12 Model Calibration, Validation and Simulation

Stream flow sensitivity analysis was carried out to get the best sensitive parameters for Great-Akaki River watershed in SWAT-CUP. Manual calibration for 22 years' period from 1995–2017was performed at monthly time step using SUFI-2. The aim of calibration process is to create agreement between the simulated and observed value by adjusting the sensitive flow parameters in the recommended range and finally, after calibrating and getting acceptable results.the model was validated for the simulated stream flow for 5 years' period from 2012–2017was performed. For this study, model simulation was evaluated using efficiency criteria such as Nash and Sutcliffe simulation efficiency (NSE), coefficient of determination (R2). In general, NSE and R2 are used to evaluate the model ability to reproduce the pattern of the observed hydrograph.



Par_inf.txt

Contains input parameters to be optimized. After a complete iteration, review the suggested new parameters in the "Calibration Outputs \ new_pars.txt", (change if necessary) and copy them to par_inf.txt and make a ...

Number Of Parameters: 9 [1] [All]

Number Of Simulations: 100

Parameters:

	Basic Information			Value			Filter Conditions (optional)						Particular Settings	
#	Par Name	File Name	File Ext.	Method	Min	Max	Hydro Grp	Soil Texture	Landuse	Subbasins	Slope	Condition..Filt	Layers/Columns	Properties
1	CN2		.mgt	r Relative	35	98				(All)				
2	ALPHA_BF		.gw	V Replace	0	1				(All)				
3	GW_DELAY		.gw	V Replace	0	500				(All)				
4	GWQMN		.gw	V Replace	0	5000				(All)				
5	SOL_Z		.sol	r Relative	0	3500				(All)			(All)	
6	SOL_K		.sol	r Relative	0	2000				(All)			(All)	
7	HRU_SLP		.hru	r Relative	0	1				(All)				
8	SOL_AWC		.sol	r Relative	0	1				(All)			(All)	
9	SURLAG		.bsn	r Relative	0.05	24				(All)				

Par_inf.txt

Contains input parameters to be optimized. After a complete iteration, review the suggested new parameters in the "Calibratio...ion Outputs \

Figure3. 19: SWAT CUPinterface and parameter used.

4. Results and Discussion

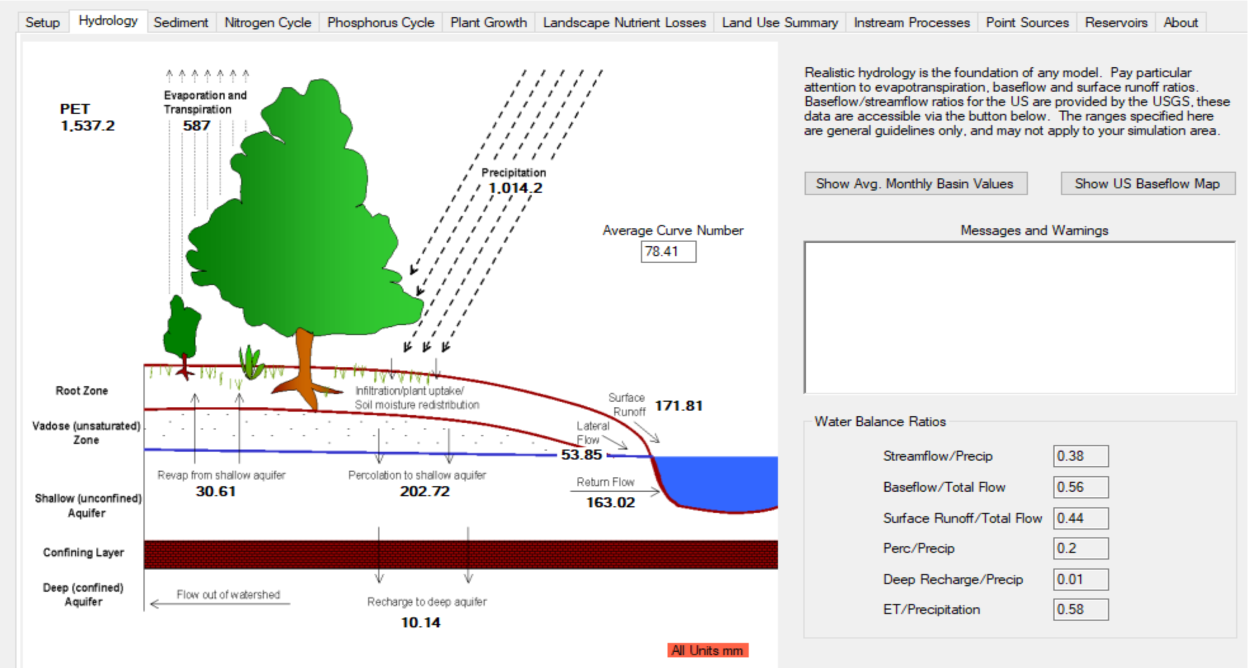
4.1 SWAT model results

4.1.1 SWAT simulation

Simulation was done for the initial and final day of simulation are set to the first and last days of measured weather data. The simulation time is 1995-2017 done for 26 years period in all the four weather station data.

4.1.2 Hydrologic Water Balance

Water balance is the driving force behind everything that happens in the watershed. In SWAT simulation of hydrology of the watershed can be separated in to two major divisions. The first division is the land phase of hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings in to the main channel in each sub basin. The second division is the routing phase of hydrological cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet. As far as this thesis work is concerned the hydrologic cycle mainly focused on only on the movement of water, which is the runoff generation. Figure 4.1, shows the total hydrological cycle used in SWAT Model.



Realistic hydrology is the foundation of any model. Pay particular attention to evapotranspiration, baseflow and surface runoff ratios. Baseflow/streamflow ratios for the US are provided by the USGS, these data are accessible via the button below. The ranges specified here are general guidelines only, and may not apply to your simulation area.

Water Balance Ratios

Streamflow/Precip	0.38
Baseflow/Total Flow	0.56
Surface Runoff/Total Flow	0.44
Perc/Precip	0.2
Deep Recharge/Precip	0.01
ET/Precipitation	0.58

Figure4. 1: Schematic representation of hydrologic cycle components flow simulation.

4.1.3 Demand and water balance

The overall simulation showed that the total sub basin load of Great akakiriver watershed are20.02 m3/s which is simulated for 26 years period weather data. The water balance of Great akaki river watershed are obtained from the Arc SWAT simulation result as shown below.

Table 4.1Average Monthly Basin Value.

Month	Rain(mm)	Snow fall(mm)	SURF Q(mm)	LAT Q(mm)	Water Yield(mm)	ET(mm)	PET(mm)
1	13.03	0.00	1.62	0.44	3.66	12.32	125.31
2	21.90	0.00	4.04	0.68	5.72	14.59	126.52
3	55.57	0.00	10.58	1.81	13.72	41.79	148..02
4	79.87	0.00	14.06	2.74	19.33	79.04	141.37
5	84.04	0.00	11.19	3.07	18.00	87.92	143.88
6	132.30	0.00	11.16	5.83	21.56	80.30	128.08
7	232.89	0.24	38.46	13.36	61.61	84.29	116.47
8	235.93	0.30	50.74	16.05	95.99	77.52	117.03
9	114.40	0.00	20.78	7.98	77.72	56.22	119.65
10	25.68	0.00	5.67	1.20	49.49	27.37	129.84
11	6.82	0.00	1.10	0.32	23.23	13.61	120.35
12	11.60	0.00	2.39	0.35	8.74	11.94	119.51

4.1.4SWAT model Sensitivity Analysis

In this study, 16 parameters were considered during the sensitivity analyses, which was carried out to determine the degree of effect that a parameter has on the output and, thus reducing the number of parameters to advance to the model calibration phase. Accordingly, among the 16 hydrological parameters selected for sensitivity analysis considering the sub-basin created by taking aba samuel gauging Station as an outlet, 9 parameters were selected as relatively sensitive based on t-stat and p-value (Table 4.2).

Table4. 2List of Parameters and their ranking based on t-stat and p-values.

Parameter	Description	Range	t-stat	p-value	Rank	Significance
CN2	Runoff curve number (%)	±25	-0.77	0.45	1	Very high
ALPHR_BF	Base flow alpha factor (days)	0-1	1.24	0.24	2	High
GW_DELAY	Groundwater delay (days)	0-5000	0.87	0.40	3	High
GWQMN	Threshold depth of water(mm)	0-5000	0.57	0.58	4	High
SOL_Z	Total Soil depth (mm)	0-1	0.00	1.00	5	Medium
SOL_K	Saturated Hydraulic Conductivity	0-2000	0.40	0.69	6	Medium
HRU_SLP	Average Steep Sloppiness	0-1	-0.15	0.88	7	Low
SOL_AWC	Available water capacity of the soil layer	0-1	1.30	0.22	8	Low
SURLAG	Surface runoff lag time	0.05-24	0.65	0.52	9	Low

Global Sensitivity

Global sensitivity analysis can be performed after an iteration.

Sort by: t-Stat

1:R__CN2.mgt : -0.7711221077456

Figure4. 2 :Global sensitivity analyses can be performed after iteration.

4.1.5 Model calibration and validation

SWAT model calibration is done by adjusting model parameters to match observed and simulated flow data as much as possible, with a limited range of acceptable deviation. A typical approach is to first select an initial estimate for the parameters, somewhere inside ranges previously specified. The values of the parameters are then adjusted to more closely fit the model behavior to that of the watershed. The calibrated flow parameters, their rank and fitted values are presented in Table 4.3.

Table4. 3 Calibrated flow parameters, their rank and fitted value.

Parameters	Description	Range	Calibrated value	Ranke
CN2	Runoff curve number (%)	±25	24.52	1
ALPHA_BF	Base flow alpha factor (days)	0-1	0.12	2
GW_DELAY	Groundwater delay (days)	0-500	387.50	3
GWQMN	Threshold depth of water(mm)	0-5000	3625.0	4
SOL_Z	Total Soil depth (mm)	0-1	0.437	5

SOL_K	Saturated Hydraulic Conductivity	0-2000	950.0	6
HRU_SLP	Average Steep Sloppiness	0-1	0.67	7
SOL_AWC	Available water capacity of the soil layer	0-1	0.17	8
SURLAG	Surface runoff lag time	0.05-24	17.41	9

After calibrating automatically and getting acceptable values of NSE and R2. Validation of simulated stream flow for 7 years' period from 2011–2017was performed without changing the calibrated parameter values.

Table4. 4 Performance evaluation of calibrated and validated Stream flow.

Performance criteria	Calibration	Validation
R2	0.85	0.83
NSE	0.82	0.80

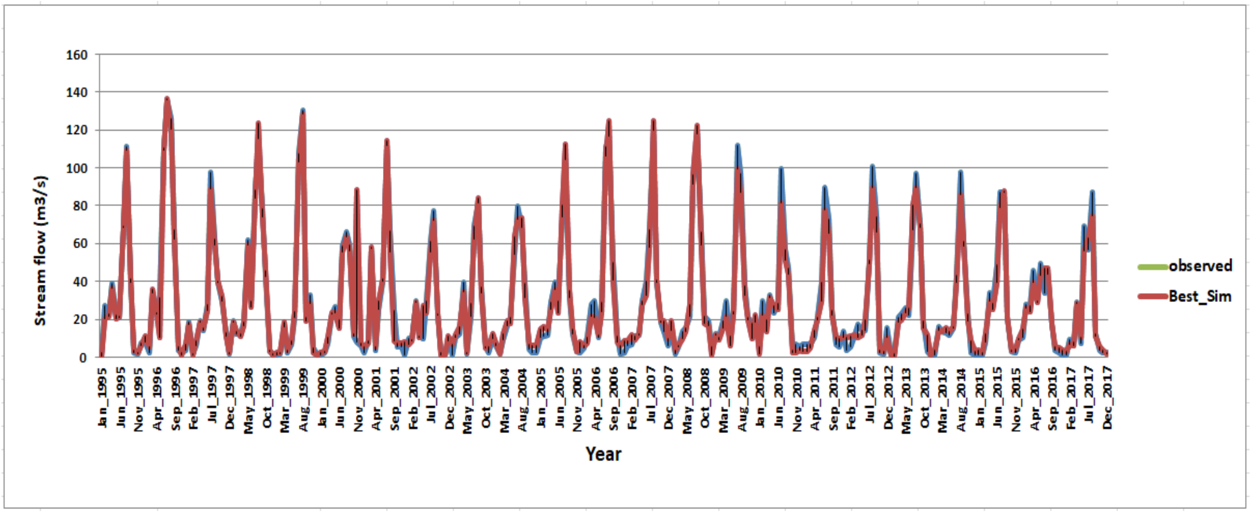


Figure4. 3: Simulated and observed stream flow for full period (1995-2017).

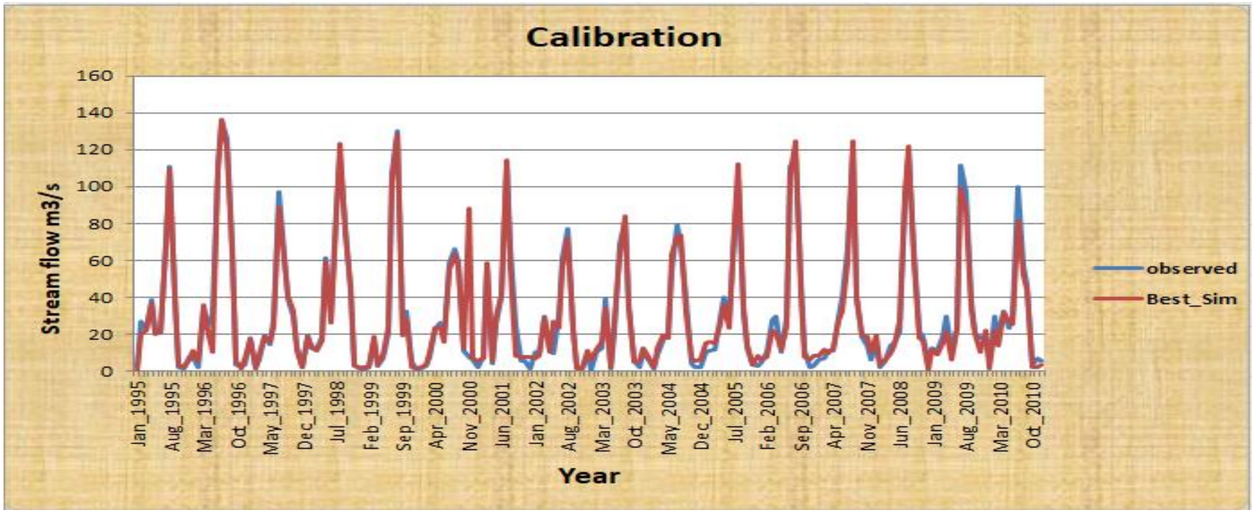


Figure4. 4: Simulated and observed stream flow after Calibration.

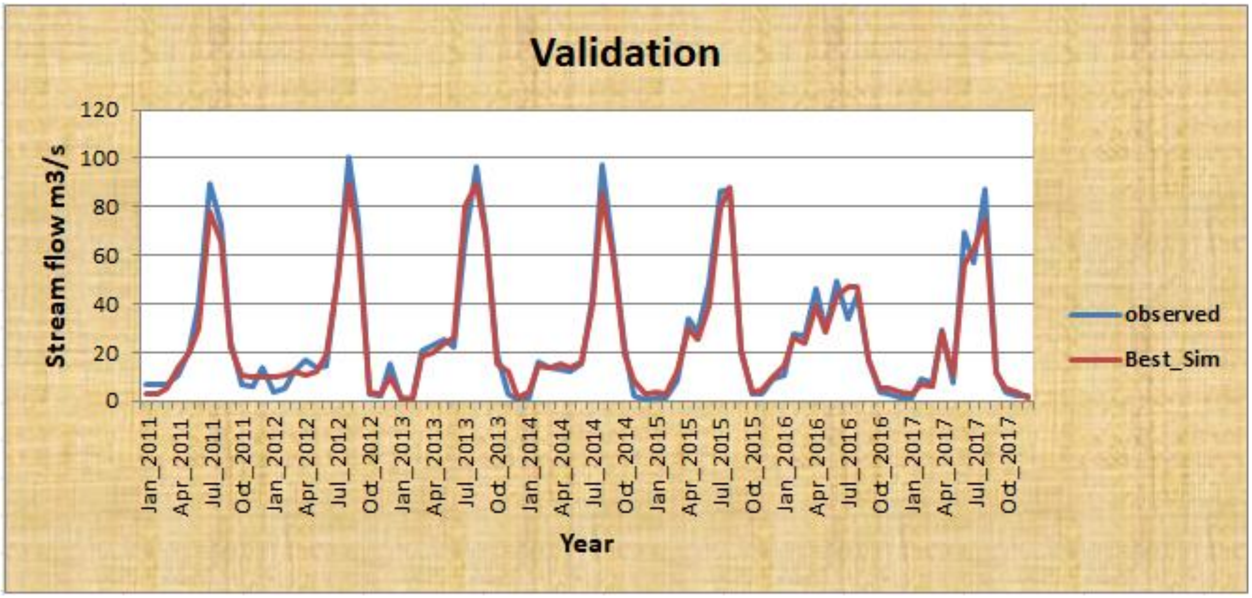


Figure4. 5: Simulated and observed stream flow after validation.

4.2 HEC_HMS model results

By considering the total area of the watershed, this study divides the watershed into three Subbasins and three reaches. Arc GIS along with HEC Geo-HMS extension is used to prepare a schematic drawing of sub-basins, reach. It also used to determine an initial parameter of CN, lag time and time of concentration. Under meteorological component time series, dataset such as rainfall, evaporation and stream flow gauges also arranged according to the available data and number of sub-basins

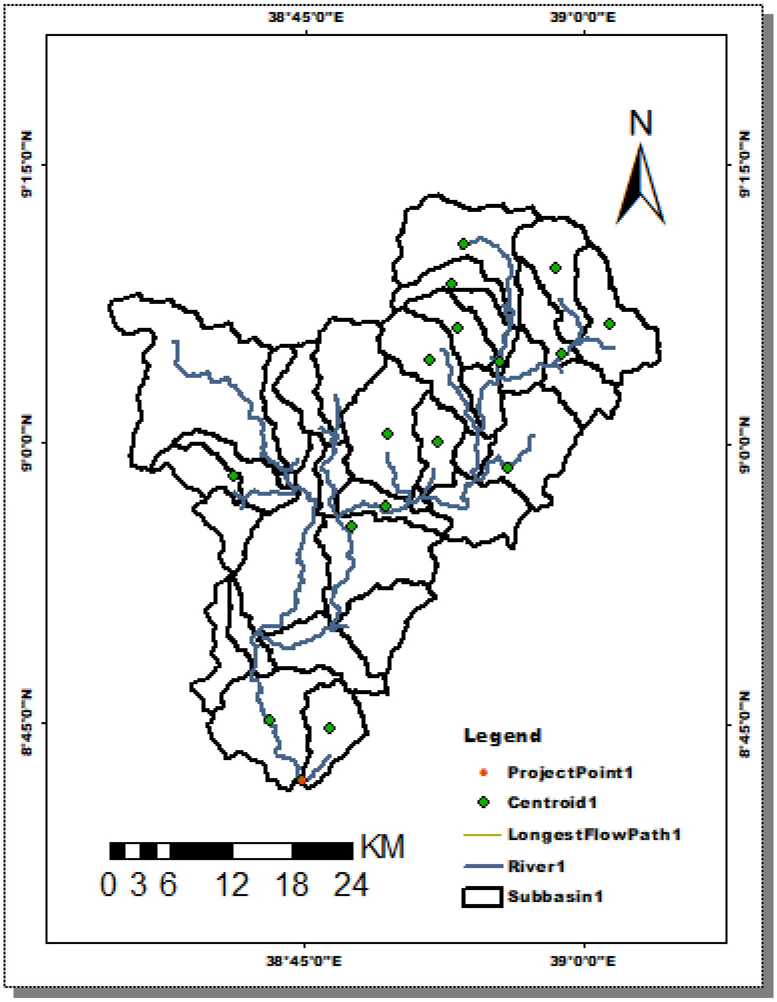


Figure4. 5:HEC-HMS Basin model of Great akaki watershed.

HEC-HMS model has different model packages to get the best result this study used four types of model combinations. But the selected model combinations had chosen based on the required input data and previous studies into consideration. After selected model combination as shown in table 4.5 simulation for each model combination has done

Table4. 5The Selected HEC-HMS model combination and Result.

No.	Loss model	Transform model	Base flow model	Routing Model	NSE
1	SCS curve number	SCS Unit hydrograph	Recessions	Muskingum	0.68
2	Deficit and constant	Snyder unit hydrograph	Recessions	Muskingum	0.63
3	Initial and constant	Clark	Muskingum	Muskingum	0.621
4	Soil moisture accounting	SCS unit hydrograph	Linear Reservoir	Muskingum	0.614

4.2.1 HEC-HMS model sensitivity analysis

HEC-HMS model was capacity to determine the sensitive parameter during automatic optimization methods or manual optimization method, For HEC-HMS model, SCS (unit hydrograph lag time, curve number, initial abstraction), Muskingum (k and x) and sub reaches as a major critical parameter with different sensitivity ranksbased on Objective function.This also seems true of SCS. lag time values with a higher level of sensitivity.

Table4. 6Parameters sensitivity rank based on objective function.

Parameter	Description	Min	Max	Rank
SCS. Lag(MI)	SCS unity Hydrograph Lag time	0.1	30000	1
Curve number(AMC_II)	SCS curve number	35	99	2
Initial abstraction (MI)	SCS Curve number initial abstraction	0.001	500	3
Muskingum-k (hr)	Flood wave travelling time	0.001	150	4
Muskingum-x	Weighted coefficient of discharge	0.001	0.5	5
Muskingum reaches	Muskingum sub reaches	1	100	6

4.2.2 Calibration Results

The effectiveness of calibration was evaluated by comparing simulated peak flow and totalvolume with measured stream flows .After many trials the following Calibration parameters andcalibration results were obtained.

Table4. 7 Sample ofCalibrated Parameters

Parameter	Description	Range	Calibration value	Rank
SCS. Lag(MI)	SCS unity Hydrograph Lag time	0.1-30000	0.96	1
Curve number(AMC_II)	SCS curve number	35-99	37.32	2
Initial abstraction (MI)	SCS Curve number initial abstraction	0.001-500	0.047	3
Muskingum-k (hr)	Flood wave travelling time	0.001-150	98.21	4
Muskingum-x	Weighted coefficient of discharge	0.001-0.5	0.32	5
Muskingum reaches	Muskingum sub reaches	1-100	56.30	6

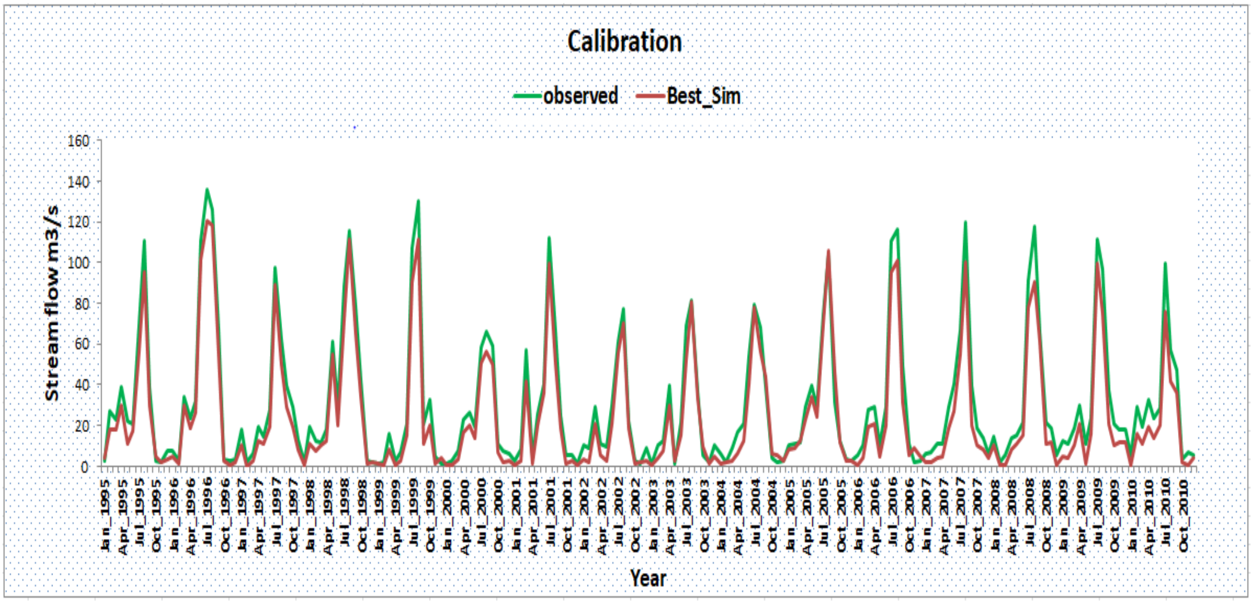


Figure4.6: Simulated and observed stream flow after model calibration.

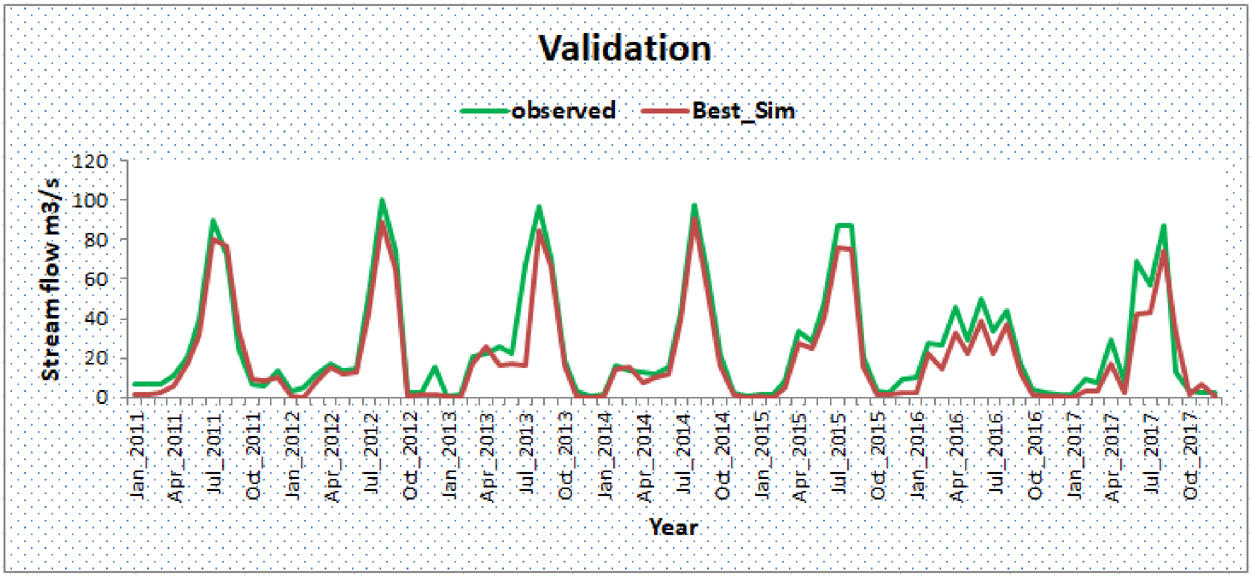


Figure4. 7: Simulated and observed stream flow after validation.

After calibrating (1995-2010)and getting acceptable values of NSE and R2. Validation of simulated stream flow for 7 years' period from 2011–2017 was performed without changing the calibrated parameter values.

Table4. 8 Performance evaluation of calibrated and validated Stream flow.

Performance criteria	Calibration	Validation
R^2	0.71	0.70
NSE	0.68	0.64

4.3 Model comparison

The peak daily discharge was simulated by SWAT during model calibration time high value than the HEC-HMS and observed value. ThePeak dischargesimulated by the SWATmodel during streamflow validation was lower than the observed values. The averagevalue of SWAT simulated was close to the observed than the HEC-HMS models simulated values. Thecomparison of HEC-HMS and SWAT models simulated and observed values of streamflow were shown inTable 4.9.

Years	Models	Analysis	Peak discharge (m3/s)
1995-2010	SWAT Calibration	Observed	130
		Simulation	138
2011-2017	SWAT Validation	Observed	100
		Simulation	90
1995-2010	HEC-HMS Calibration	Observed	130
		Simulation	120
2011-2017	HEC-HMS Validation	Observed	100
		Simulation	80

Table 4.9 Comparison of HEC-HMS and SWAT models simulated and observed values of stream flow.

4.3.1 Model Comparison based on the objective function

Based on the result shown in table 4.4 and 4.8 all model used in this study perform within the same range spatially monthly time steps all models simulated discharge have a good agreement to the observed discharge, but during Calibration period in all objective function, both model outputs minimized in their performance. Even if the performance of the models within the same range SWATS performance has higher than HEC_HMS model, this implies that the lumping of the model has not guaranteed to less performance than semi-distributed model Basher (2012). As recommended by(Moriasi et al. 215).the high R2 and NSE values indicate the good correlation and agreement between the observed and simulated values. Based with Reference Moriasi et al. 2015) vales, the model performance statistics determined for The model SWATE (Table) is good and hence the model SWAT is a suitable model for hydrological related studies for the Great Akaki river watershed.

Period of Simulation	Parameters	SWAT	HEC_HMS
Calibration	R^2	0.85	0.71
	NSE	0.82	0.68
Validation	R^2	0.83	0.70
	NSE	0.80	0.64

Table 4.10 Objective function result

Despite the statistical comparison, Fig. 4.3, 4.4, 4.5, 4.6 describe that during Average monthly calibration time HEC-HMS model could underestimate Peak flow. Comparatively SWAT model could simulate the highest flows than HEC-HMS model, the highest flow (138 m3/s) simulated by the HEC-HMS model during calibration and 130 m3/s simulated by during validation time.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

The genera objective of this study was to conduct catchment modeling for better understanding of Horizontal overland flow of Great Akaki River and to compare and select the best conceptual rainfall-runoff model that can be used in the design, planning, and management of water resources in Great Akaki River Catchmentcan be used in the design, planning, and management of water resources in Great Akaki River Catchment. The major activities accomplished are digital elevation model data processing, and Curve Number (CN) grid input preparation(land use classification, hydrological soil group preparation, and merging of soil and land use shape files) using GIS and GIS extension tools.For this research, DEM is the main dataset used for development of the basin model components and geometrical data in the HEC-HMS and ARC SWAT models respectively as well as for estimation of Rainfall Runoff at Great Akaki River watershed.The data used inform of GCS_WGS_1984 raster form with 30X30m resolution.

A twenty six years (1992-2017) hydro-meteorological data were used for comparisons of these models.The meteorological data used for study four stations (A.AObsstation, Akaki station, A.A bole station, Intoto station).The soil data used for this research is obtained from ministry of agriculture and developed by Ministry of water resource in vector form. Based on this data the study area has a total of nine soil classes namely, Calcic Xerosols, Chromic Cambisols, Chromic Luvisols, Chromic Vertisols, EutricNitisols, Leptosols, OrthicSolonchaks, PellicVertisols, and VerticCambisols. Based on Landsat image and aerial photography, a land use map was generated for Great Akaki River catchment. The land use and Land cover date file describe the vegetation, water, natural surface and cultural features on the land surface. The land cover type of Great Akaki catchment classified in to six major classes these are water body, residential, commercial/industry/transport, open space, mixed forest and agriculture Hydrological data used for Aba Samualgauging station.Up on checking the climatic data collected from all meteorological stations considered for the study, the data may have missing data. For SWAT hydrological model has a built in weather generator called WGEN that is used to fill the gaps, all the missing values had been filled with a missing data identifier -999, and the weather generator first independently generates precipitation data for each day.

Analysis of hydro-meteorological data, sensitivity analysis, calibration, and validation were carried out under this study for comparison of those hydrological models.The calibration was done using (1995-2010) hydro-meteorological data and from (2011-2017) hydro-meteorological data used for validation.The aim of calibration process is to create agreement between the simulated and observed value by adjusting the sensitive flow parameters in the recommended range and finally, after calibrating and getting acceptable results.Peak flow was determined at new railway crossing by adding additional flow from downstream area of project point to railway crossing and finally enters to **Aba Samuel reservoir**.For SWAThydrological model Calibration and Uncertainty Procedures (SWAT-CUP) were initially used to identify the most sensitive parameters to stream flow.

The coefficient of determination (R2) and the Nash-Sutcliffe efficiency coefficient (NSE) is used to determine the model performance. The parameters selected for SWAT is nine and six for HEC-HMS modal. The result of this study indicates that the most sensitive parameter in SWAT modal is CN2 and for HEC-HMS is SCS. Lag(MI).For HEC-HMS model, SCS (unit hydrograph, lag time, curve number, initial abstraction), Muskingum (k and x) and sub reaches as a major critical parameter with different sensitivity ranks based on Objective function. For SWAT modelAccordingly, among the 16 hydrological parameters selected for sensitivity analysis considering the sub-basin created by taking aba samuel gauging Station as an outlet, 9 parameters were selected as relatively sensitive based on t-stat and p-value.The performance of the models based on R^2 and NSE during the calibration period were (0.71 and 68%), (0.85 and 0.82) of HEC-HMS and SWAT model respectively. Similarly, for validation period, R^2 values of (70% and 83%) were found under HEC-HMS and SWAT respectively and NSE value of (0.64 and 0.80) were found under HEC-HMS and SWAT modal respectively..The study result shown on the performance of the model to simulate major hydrograph components were, SWAT model better simulates a direct runoff, and HEC-HMS model higher capacity to simulate maximum flow.

5.2 Conclusion

Comparative analysis Rainfall-runoff modeling were carried out in Great Akaki River watershed by applying HEC-HMS and SWAT models. The Specific objectives of the study were to compare the validity of the candidate model structures and its relative strength to simulate a runoff also to model the Great Akaki River Catchment using HEC_HMS and SWAT hydrological models. In this research work twenty six years (1992-2017) hydro-metrological data were used. Both models were calibrated using the observed daily stream flow at Aba Samuel gauging station. The performance of the models was evaluated by NSE and R2 objective function. The results of calibration and validation indicated that, for Great akaki river watershed, both models could simulate fairly well the stream flow based on objective function criteria. HEC-HMS gave the model performance with the R2 > 0.71 and NSE > 0.70and the SWAT model provided the model performance with the R2 > 0.85 and NSE > 0.83 for the calibration and validation periods. The average value of SWAT simulated was close to the observed than the HEC-HMS models simulated values. In general, the simulated stream flow given by the SWAT model is more satisfactory than that provided by the HEC-HMS model.

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APPENDICES

Appendix A: Total Monthly Precipitation of Akaka station.

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1992	23.52	33.7	20.2	41	52	109.1	248.5	294.7	209.4	69.7	0	2.9	1104.72
1993	10.8	67.2	16.1	157.9	97.2	208.3	274	426.5	243.3	62.1	0	4.5	1567.9
1994	0	0	82.4	82.3	63.3	123.4	308.9	225	142	0.5	14.7	0	1042.5
1995	0	69	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	48.4	1145.6
1996	28.1	5.2	106.8	128.2	122	258.5	266.4	338.7	294.2	0.2	0.2	0	1548.5
1997	39.2	0	24.5	51.3	38.5	104	272.6	194.3	113.8	62.4	50.3	1.5	952.4
1998	55.2	20.5	49	48.5	154.2	124.4	285.4	260	213.6	126.9	0	0	1337.7
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	75.4	0	0	929.4
2000	0	0	17.6	49.9	110	144.5	244.8	306.2	250.6	46.4	21.1	0	1191.1
2001	0	12.2	210.8	25	168	216.2	428	246.4	131.7	13.7	0	0	1452
2002	14.7	21	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0	16.5	1016.1
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9	1173.3
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164	76.9	0	0	1158.5
2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5	12.7	4.4	0	1395.9
2006	0.7	11.2	124.4	78.9	74.6	150.1	356.3	243.6	239.1	54	0.3	8	1341.2
2007	51.3	19.1	59.8	73.8	120.1	169.1	261.8	376.5	149.3	21.4	0	0	1302.2
2008	0	13	2.1	48.1	107.1	96.4	255.9	370.8	246.8	89.7	77.9	22.9	1330.7
2009	21.3	2.7	28.4	80.6	58.9	83.2	355	387.4	107.9	45.8	4.9	64.8	1240.9
2010	2.3	79.8	55.5	97.8	74.4	272	313	220.2	223.4	1.8	25.7	15	1380.9
2011	14.1	13.1	44.3	30.4	58.5	182	201.7	329.8	136.2	1	41.3	0	1052.4
2012	0	0	15.8	71.4	50.2	77.9	316.5	297.9	214.8	2.3	0	9.8	1056.6
2013	4.4	0	46.9	92.3	88.9	169.7	221	339.4	211.5	43.2	22.3	0	1239.6
2014	1.7	47.4	66.1	22.2	93	68.1	221.4	260.5	283.5	15.2	1.7	0	1080.8
2015	0	0	27.2	15	109.9	225.9	204.4	312.8	146	0	7.7	0.1	1049
2016	59.8	12.1	51.7	145.3	120.4	194.4	176.9	300.7	142.8	12.5	3.6	1.9	1222.1
2017	0	20.7	36.6	33.7	64.9	305.6	319.6	380.2	0	0	0	9.4	1170.7

Appendix B: Statistical Analysis of Daily Precipitation Data (1992 - 2017) on AAobs station by use

PcPSTAT Application.

Month	**PCP_MM**	**PCPSTD**	**PCPSKW**	**PR_W1**	**PR_W2**	**PCPD**
Jan.	15.82	2.6486	7.2154	0.0516	0.4348	2.65
Feb.	22.05	3.403	6.0353	0.0637	0.4725	3.5
Mar.	55.46	6.1363	7.9153	0.1486	0.5507	7.96
Apr.	77.72	6.4221	4.4089	0.2296	0.6113	11.58
May.	83.28	6.3545	3.5969	0.2267	0.6122	12
Jun.	159.67	7.3388	2.2787	0.493	0.7929	21.73
Jul.	270.16	9.2015	1.6247	0.8395	0.8772	27.88
Aug.	298.8	10.3266	1.878	0.8228	0.8762	27.96
Sep.	175.12	9.558	2.5596	0.3737	0.7455	19.19
Oct.	32.11	5.2157	8.9682	0.0919	0.4656	5.04
Nov.	10.68	2.478	9.0342	0.0396	0.375	1.85
Dec.	10.02	2.8908	13.6899	0.0286	0.3684	1.46

Appendix C: Landuse/Soil/slope Report.

Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 2/9/2022 12:00:00 AM Time: 10:01:05.6226817

	Area [ha]	Area[acres]
Watershed	159045.1200	393008.4438

Number of Subbasins: 4

	Area [ha]	Area[acres]	%Wat. Area
LANDUSE:			
Agricultural Land--> AGRL	101416.9210	250606.2826	63.77
Grass Land --> RNGE	8.1548	20.1509	0.01

Acacica --> CORN	1612.2000	3983.8268	1.01
Dispersed Shrub --> RNGB	1352.8780	3343.0292	0.85
Forest --> FRST	12529.0039	30959.7952	7.88
Settlement --> WETN	39294.6227	97098.9775	24.71
Water --> WATR	888.8710	2196.4447	0.56
Eucalyptus --> FRSD	1942.4686	4799.9370	1.22

SOILS:

Calcic xerosols	7377.6294	18230.4912	4.64
Chromic luvisols	12860.0880	31777.9204	8.09
Chromic vertisols	6813.3187	16836.0511	4.28
Eutricfluvisols	17555.6103	43380.7908	11.04
Eutricnitisols	1679.8847	4151.0790	1.06
Leptosols	1040.5499	2571.2509	0.65
Orthicsolonchaks	12593.4267	31118.9870	7.92
Pellicvertisols	94175.4764	232712.3109	59.21
Verticcambisols	4949.1360	12229.5624	3.11

SLOPE:

0-5	78248.3756	193355.6486	49.20
10-20	26155.6412	64631.8973	16.45
20-30	9493.7948	23459.6417	5.97
30-9999	4326.1108	10690.0360	2.72
5-10	40821.1975	100871.2201	25.67

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

SUBBASIN #                                   1         28291.6800         69910.1559     17.79

LANDUSE:
    Agricultural Land --> AGRL         11811.3833          29186.5187      7.43     41.75
Grass Land --> RNGE            8.1548            20.1509      0.01      0.03
Acacica--> CORN           724.9599           1791.4123      0.46      2.56
                         Dispersed Shurb --> RNGB          110.9050           274.0518      0.07      0.39
                         Forest-Mixed --> FRST          2186.2965           5402.4480      1.37      7.73
Settlement --> WETN          12639.0935          31231.8319      7.95     44.67
                              Water --> WATR          153.3099           378.8363      0.10      0.54
Eucalyptus --> FRSD           538.2155           1329.9574      0.34      1.90
SOILS:
                              Calcic xerosols           852.9900           2107.7809      0.54      3.01
                              Chromic luvisols          6446.3536          15929.2620      4.05     22.79
                             Chromic vertisols          4642.5162          11471.8897      2.92     16.41
Eutricfluvisols          10080.9390          24910.5043      6.34     35.63
Orthicsolonchaks           1186.5205           2931.9514      0.75      4.19
Pellicvertisols          2352.6540           5813.5257      1.48      8.32
Verticcambisols          2610.3451           6450.2932      1.64      9.23
SLOPE:
                                    0-5          9935.7839          24551.8188      6.25     35.12
                                   10-20          5984.7930          14788.7228      3.76     21.15
```

```
                    20-30        1944.0995        4803.9672     1.22     6.87
                   30-9999        1038.1035        2565.2056     0.65     3.67
                    5-10        9269.5384        22905.4928     5.83    32.76

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

SUBBASIN #                        2        79469.1000        196372.1196    49.97

LANDUSE:
   Agricultural Land --> AGRL        47645.9329        117735.4824    29.96    59.96
                         Corn --> CORN        760.8410        1880.0761     0.48     0.96
Dispersed Shurb --> RNGB        566.7572        1400.4854     0.36     0.71
               Forest --> FRST        9723.7596        24027.8962     6.11    12.24
                Wetlands-Non-Forested --> WETN        18459.9754        45615.5222    11.61    23.23
                         Water --> WATR        735.5612        1817.6084     0.46     0.93
Eucalyptus --> FRSD        1353.6935        3345.0443     0.85     1.70

SOILS:
                        Calcic xerosols        6115.2695        15111.1367     3.84     7.70
                        Chromic luvisols        4437.8313        10966.1029     2.79     5.58
                       Chromic vertisols        1917.1888        4737.4693     1.21     2.41
Eutricfluvisols        5001.3265        12358.5280     3.14     6.29
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Leptosols          1000.5915          2472.5116      0.63      1.26

Orthicsolonchaks          8198.8158          20259.6837      5.16      10.32

Pellicvertisols         52499.6579         129729.2797     33.01      66.06

Verticcambisols            75.8395            187.4031      0.05      0.10


SLOPE:

                                   0-5         35965.0261          88871.3776     22.61     45.26

                                  10-20          15061.8786          37218.6551      9.47     18.95

                                  20-30           6077.7575          15018.4427      3.82      7.65

                                 30-9999          2541.8449           6281.0259      1.60      3.20

                                   5-10         19600.0136          48432.6137     12.32     24.66

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


SUBBASIN #                              3          28331.3700          70008.2318     17.81

LANDUSE:

   Agricultural Land--> AGRL          20607.1290          50921.2460     12.96     72.74

                  Acacia --> CORN            29.3572              72.5431      0.02      0.10

Dispersed shrub--> RNGB             99.4883             245.8406      0.06      0.35

                      Forest --> FRST           153.3099             378.8363      0.10      0.54

Settlement --> WETN           7578.2370           18726.2026      4.76     26.75

Eucalyptus --> FRSD             50.5596             124.9354      0.03      0.18
```

SOILS:

Calcic xerosols 0.8155 2.0151 0.00 0.00

Chromic luvisols 1586.9202 3921.3591 1.00 5.60

Chromic vertisols 253.6137 626.6920 0.16 0.90

Eutricfluvisols 102.7502 253.9009 0.06 0.36

Eutricnitisols 863.5912 2133.9770 0.54 3.05

Leptosols 39.9584 98.7393 0.03 0.14

Orthicsolonchaks 142.7086 352.6402 0.09 0.50

Pellicvertisols 25527.7232 63080.2804 16.05 90.10

SLOPE:

0-5 18306.6655 45236.6859 11.51 64.62

10-20 2849.2801 7040.7136 1.79 10.06

20-30 863.5912 2133.9770 0.54 3.05

30-9999 384.0901 949.1059 0.24 1.36

5-10 6114.4540 15109.1216 3.84 21.58

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

SUBBASIN # 4 22952.9700 56717.9365 14.43

LANDUSE:

Agricultural Land --> AGRL 21352.4758 52763.0354 13.43 93.03

Acacica --> CORN 97.0419 239.7953 0.06 0.42

Dispersed Shrub --> RNGB 575.7275 1422.6514 0.36 2.51

Forest --> FRST	465.6379	1150.6146	0.29	2.03
Settlement --> WETN	617.3168	1525.4208	0.39	2.69

SOILS:

Calcic xerosols	408.5545	1009.5585	0.26	1.78
Chromic luvisols	388.9830	961.1965	0.24	1.69
Eutricfluvisols	2370.5945	5857.8576	1.49	10.33
Eutricnitisols	816.2935	2017.1020	0.51	3.56
Orthicsolonchaks	3065.3818	7574.7117	1.93	13.36
Pellicvertisols	13795.4413	34089.2251	8.67	60.10
Verticcambisols	2262.9514	5591.8662	1.42	9.86

SLOPE:

0-5	14040.9001	34695.7663	8.83	61.17
10-20	2259.6895	5583.8058	1.42	9.84
20-30	608.3466	1503.2548	0.38	2.65
30-9999	362.0722	894.6986	0.23	1.58
5-10	5837.1915	14423.9920	3.67	25.43

Appendix D: HRUS LandUse/Soil/Slope Report.

SWAT model simulation Date: 2/9/2022 12:00:00 AM Time: 00:00:00

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

Number of HRUs: 43

Number of Subbasins: 4

	Area [ha]	Area[acres]
Watershed	159045.1200	393008.4438

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

LANDUSE:

          Agricultural Land--> AGRL       114684.9427        283392.2277    72.11

Settlement --> WETN         44360.1773        109616.2161    27.89

SOILS:

                     Chromic luvisols         5413.3995         13376.7807     3.40

                     Chromic vertisols         6265.0385         15481.2234     3.94

Eutricfluvisols         19759.8450         48827.5650     12.42

Pellicvertisols        116759.7218         288519.1106     73.41

Verticcambisols          4800.7419          11862.8733      3.02

Orthicsolonchaks          6046.3733          14940.8907      3.80

SLOPE:

                          30-9999          830.3401          2051.8118      0.52

                           20-30          1146.8093          2833.8231      0.72

                           10-20         10439.4957          25796.5158      6.56

                            5-10         47398.5506         117124.1884     29.80

                             0-5        99229.9244         245202.1047     62.39

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                                    Area [ha]       Area[acres] %Wat.Area %Sub.Area
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SUBBASIN # 1 28291.6800 69910.1559 17.79

LANDUSE:

Agricultural Land --> AGRL 13609.3072 33629.2786 8.56 48.10

Settlement --> WETN 14563.0111 35985.9286 9.16 51.47

SOILS:

Chromic luvisols 5413.3995 13376.7807 3.40 19.13

Chromic vertisols 6265.0385 15481.2234 3.94 22.14

Eutricfluvisols 13164.0246 32528.9631 8.28 46.53

Pellicvertisols 1389.3470 3433.1459 0.87 4.91

Verticcambisols 1940.5087 4795.0940 1.22 6.86

SLOPE:

30-9999 830.3401 2051.8118 0.52 2.93

20-30 1146.8093 2833.8231 0.72 4.05

10-20 5452.2193 13472.7065 3.43 19.27

5-10 10368.3995 25620.8335 6.52 36.65

0-5 10374.5502 25636.0322 6.52 36.67

HRUs

1 Agricultural Land-Generic --> AGRL/Chromic luvisols/ 30-9999 830.3401 2051.8118 0.52 2.93 1

2 Agricultural Land-Generic --> AGRL/Chromic luvisols/20-30 1146.8093 2833.8231 0.72 4.05 2

3 Agricultural Land-Generic --> AGRL/Chromic luvisols/10-20 2074.2835 5125.6582 1.30 7.33 3

4 Agricultural Land-Generic --> AGRL/Chromic luvisols/5-10 1361.9666 3365.4876 0.86 4.81 4

5 Agricultural Land-Generic --> AGRL/Chromic vertisols/0-5 1166.6520 2882.8554 0.73 4.12 5

```
6 Agricultural Land-Generic --> AGRL/Chromic vertisols/5-10        739.5283         1827.4114     0.46      2.61    6
7 Agricultural Land-Generic --> AGRL/Eutricfluvisols/0-5          1042.7274         2576.6315     0.66      3.69    7
8 Agricultural Land-Generic --> AGRL/Eutricfluvisols/10-20         751.9190         1858.0294     0.47      2.66    8
9 Agricultural Land-Generic --> AGRL/Eutricfluvisols/5-10         1165.2254         2879.3303     0.73      4.12    9
10 Agricultural Land-Generic --> AGRL/Pellicvertisols/10-20        308.3780          762.0174     0.19      1.09   10
11 Agricultural Land-Generic --> AGRL/Pellicvertisols/0-5          645.2891         1594.5417     0.41      2.28   11
12 Agricultural Land-Generic --> AGRL/Pellicvertisols/5-10         435.6799         1076.5868     0.27      1.54   12
13 Agricultural Land-Generic --> AGRL/Verticcambisols/0-5         1346.8148         3328.0466     0.85      4.76   13
14 Agricultural Land-Generic --> AGRL/Verticcambisols/5-10         593.6939         1467.0474     0.37      2.10   14
15 Wetlands-Non-Forested --> WETN/Chromic vertisols/5-10          1741.8392         4304.1717     1.10      6.16   15
16 Wetlands-Non-Forested --> WETN/Chromic vertisols/10-20          579.3958         1431.7161     0.36      2.05   16
17 Wetlands-Non-Forested --> WETN/Chromic vertisols/0-5           2037.6232         5035.0688     1.28      7.20   17
18 Wetlands-Non-Forested --> WETN/Eutricfluvisols/5-10            4330.4661        10700.7983     2.72     15.31   18
19 Wetlands-Non-Forested --> WETN/Eutricfluvisols/0-5             4135.4437        10218.8882     2.60     14.62   19
20 Wetlands-Non-Forested --> WETN/Eutricfluvisols/10-20           1738.2430         4295.2855     1.09      6.14   20
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                                              Area [ha]        Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                    2         79469.1000         196372.1196     49.97

LANDUSE:
                     Agricultural Land-Generic --> AGRL          57117.0491         141139.0841     35.91     71.87
                       Wetlands-Non-Forested --> WETN           22129.4716          54683.0309     13.91     27.85
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SOILS:

Pellicvertisols        69908.8070         172748.1575     43.96     87.97

Eutricfluvisols          6595.8204          16298.6020     4.15      8.30

Orthicsolonchaks          2741.8933           6775.3555      1.72      3.45

SLOPE:

                                   0-5         51713.6399         127786.9899    32.52     65.07

                                   5-10         23811.1776          58838.6105    14.97     29.96

                                  10-20          3721.7032           9196.5146    2.34      4.68

HRUs

 21 Agricultural Land-Generic --> AGRL/Pellicvertisols/0-5     40846.6438         100934.0991     25.68     51.40    1

 22 Agricultural Land-Generic --> AGRL/Pellicvertisols/5-10    16270.4053          40204.9850     10.23     20.47    2

 23 Wetlands-Non-Forested --> WETN/Eutricfluvisols/10-20         681.3116           1683.5550     0.43      0.86    3

 24 Wetlands-Non-Forested --> WETN/Eutricfluvisols/0-5          3234.5324           7992.6912     2.03      4.07    4

 25 Wetlands-Non-Forested --> WETN/Eutricfluvisols/5-10          2679.9764           6622.3558      1.69      3.37    5

 26 Wetlands-Non-Forested --> WETN/Orthicsolonchaks/5-10       1163.2619           2874.4782      0.73      1.46    6

 27 Wetlands-Non-Forested --> WETN/Orthicsolonchaks/10-20       601.4915           1486.3156      0.38      0.76    7

 28 Wetlands-Non-Forested --> WETN/Orthicsolonchaks/0-5          977.1400           2414.5617      0.61      1.23    8

 29 Wetlands-Non-Forested --> WETN/Pellicvertisols/5-10          3697.5340           9136.7915      2.32      4.65    9

 30 Wetlands-Non-Forested --> WETN/Pellicvertisols/0-5          6655.3238          16445.6379      4.18      8.37   10

 31 Wetlands-Non-Forested --> WETN/Pellicvertisols/10-20        2438.9001           6026.6441      1.53      3.07   11

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                                              Area [ha]          Area[acres] %Wat.Area %Sub.Area
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SUBBASIN #                              3        28331.3700        70008.2318    17.81


LANDUSE:

          Agricultural Land-Generic --> AGRL        20850.3864        51522.3474    13.11    73.59

            Wetlands-Non-Forested --> WETN          7667.6945        18947.2566     4.82    27.06


SOILS:

Pellicvertisols        28518.0810        70469.6041    17.93    100.66


SLOPE:

                              0-5        20764.1885        51309.3479    13.06    73.29

                              5-10        6924.1594        17109.9441     4.35    24.44

                              10-20        829.7331         2050.3120     0.52     2.93

HRUs

 32 Agricultural Land-Generic --> AGRL/Pellicvertisols/0-5      16170.8641        39959.0138    10.17    57.08   1

 33 Agricultural Land-Generic --> AGRL/Pellicvertisols/5-10      4679.5223        11563.3336     2.94    16.52   2

 34 Wetlands-Non-Forested --> WETN/Pellicvertisols/0-5           4593.3243        11350.3341     2.89    16.21   3

 35 Wetlands-Non-Forested --> WETN/Pellicvertisols/10-20          829.7331         2050.3120     0.52     2.93   4

 36 Wetlands-Non-Forested --> WETN/Pellicvertisols/5-10          2244.6371         5546.6105     1.41     7.92   5
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                                             Area [ha]         Area[acres] %Wat.Area %Sub.Area
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SUBBASIN #                          4        22952.9700         56717.9365     14.43


LANDUSE:

          Agricultural Land-Generic --> AGRL        23108.2000         57101.5175     14.53    100.68


SOILS:

Orthicsolonchaks          3304.4800          8165.5352      2.08     14.40

Pellicvertisols         16943.4868          41868.2030     10.65     73.82

Verticcambisols          2860.2332          7067.7793      1.80     12.46


SLOPE:

                                        0-5        16377.5459         40469.7347     10.30     71.35

                                        5-10        6294.8140         15554.8003      3.96     27.42

                                       10-20         435.8400          1076.9826      0.27      1.90

HRUs

 37 Agricultural Land-Generic --> AGRL/Orthicsolonchaks/0-5          1775.1974      4386.6015      1.12      7.73    1

 38 Agricultural Land-Generic --> AGRL/Orthicsolonchaks/5-10          1093.4425        2701.9512      0.69  4.76    2

 39 Agricultural Land-Generic --> AGRL/Orthicsolonchaks/10-20 435.8400          1076.9826      0.27      1.90    3

 40 Agricultural Land-Generic --> AGRL/Pellicvertisols/5-10       4044.0718          9993.1036      2.54     17.62    4

 41 Agricultural Land-Generic --> AGRL/Pellicvertisols/0-5       12899.4150         31875.0994      8.11     56.20    5

 42 Agricultural Land-Generic --> AGRL/Verticcambisols/5-10       1157.2997          2859.7454      0.73      5.04    6

 43 Agricultural Land-Generic --> AGRL/Verticcambisols/0-5       1702.9335          4208.0338      1.07      7.42
```
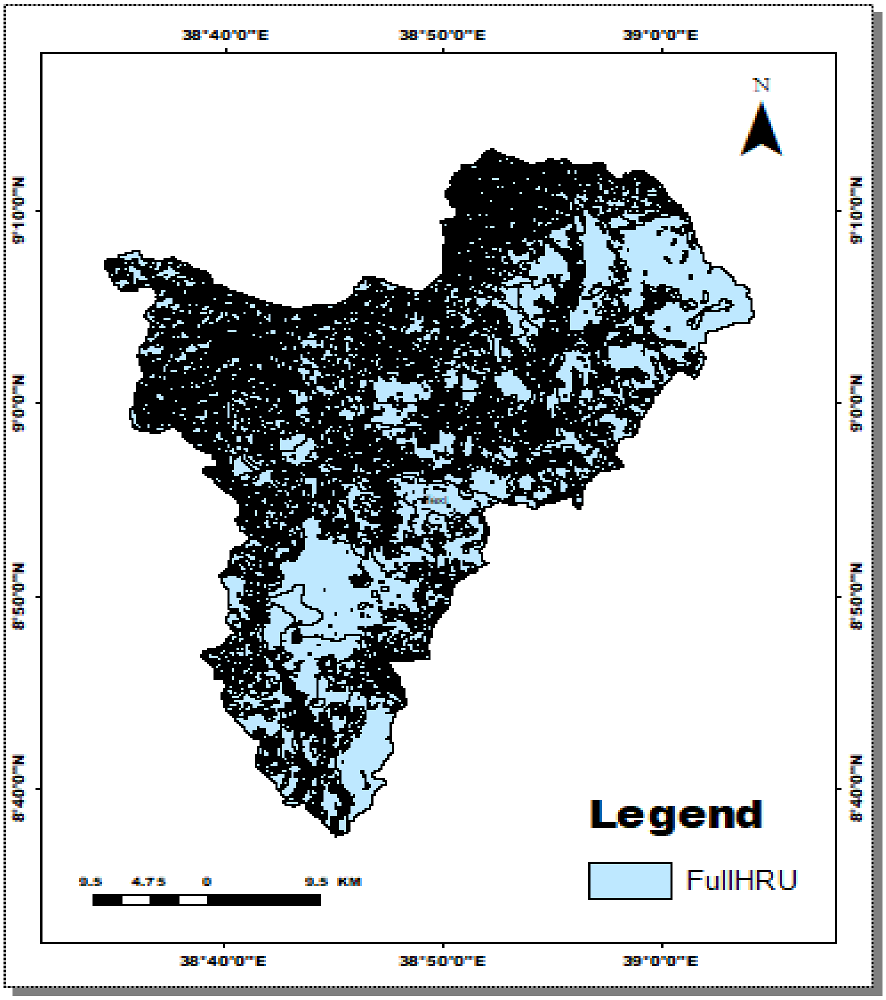

Appendix E: Average Daily Precipitation in MonthAkaki Catchment(source WWIS).

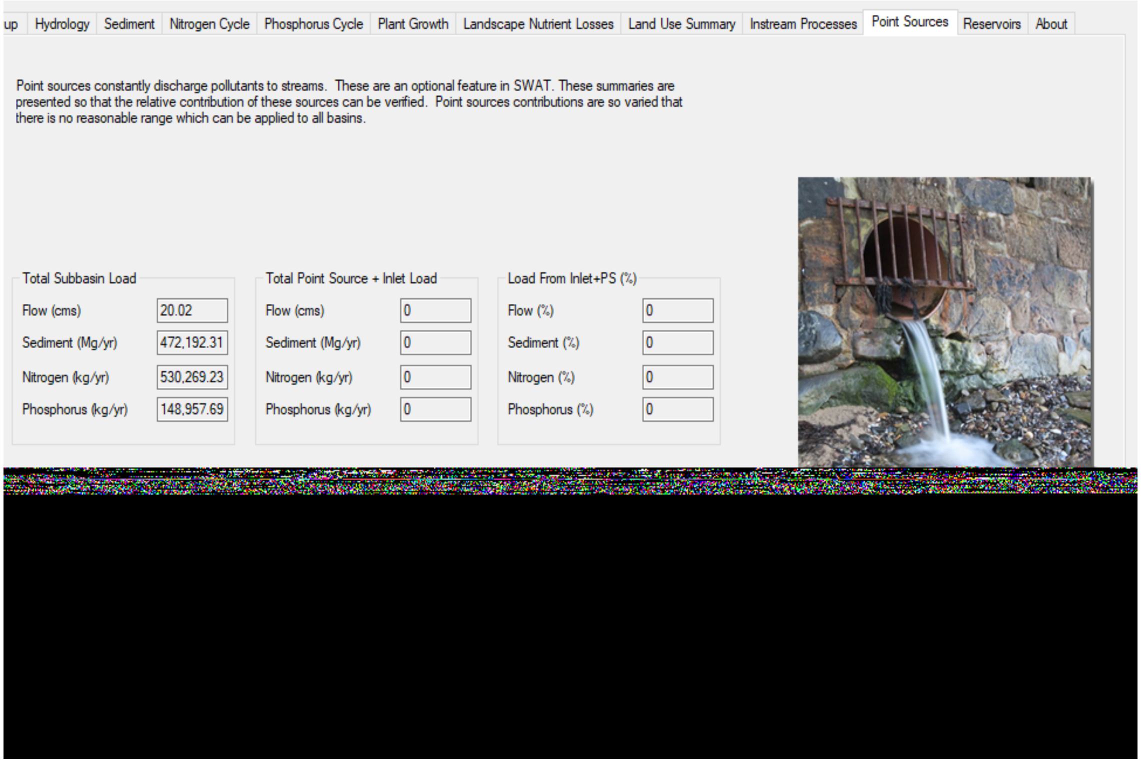
Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1992	0.76	1.16	0.65	1.37	1.68	3.64	8.02	9.51	6.98	2.25	0	0.09
1993	0.35	2.4	0.52	5.26	3.14	6.94	8.84	13.76	8.11	2	0	0.15
1994	0	0	2.66	2.74	2.04	4.11	9.96	7.26	4.73	0.02	0.49	0
1995	0	2.46	1.34	5.81	2.2	3.43	6.14	10.16	4.54	0	0	1.56
1996	0.91	0.18	3.45	4.27	3.94	8.62	8.59	10.93	9.81	0.01	0.01	0
1997	1.26	0	0.79	1.71	1.24	3.47	8.79	6.27	3.79	2.01	1.68	0.05
1998	1.78	0.73	1.58	1.62	4.97	4.15	9.21	8.39	7.12	4.09	0	0
1999	0.09	0.01	0.93	0.54	0.77	3.99	8.66	9.85	2.95	2.43	0	0
2000	0	0	0.57	1.66	3.55	4.82	7.9	9.88	8.35	1.5	0.7	0
2001	0	0.44	6.8	0.83	5.42	7.21	13.81	7.95	4.39	0.44	0	0
2002	0.47	0.75	2.91	1.88	2.04	5.75	8.29	6.96	3.63	0.01	0	0.53
2003	0.34	1.9	2.02	3.31	0.65	5.06	9.41	7.53	6.44	0.03	0.05	1.77
2004	0.8	0.7	1.6	4.66	0.97	4.73	7.69	8.79	5.47	2.48	0	0
2005	1.48	1.84	2.68	5.36	4.31	5.99	7.94	10.17	5.42	0.41	0.15	0
2006	0.02	0.4	4.01	2.63	2.41	5	11.49	7.86	7.97	1.74	0.01	0.26
2007	1.65	0.68	1.93	2.46	3.87	5.64	8.45	12.15	4.98	0.69	0	0
2008	0	0.45	0.07	1.6	3.45	3.21	8.25	11.96	8.23	2.89	2.6	0.74
2009	0.69	0.1	0.92	2.69	1.9	2.77	11.45	12.5	3.6	1.48	0.16	2.09
2010	0.07	2.85	1.79	3.26	2.4	9.07	10.1	7.1	7.45	0.06	0.86	0.48
2011	0.45	0.47	1.43	1.01	1.89	6.07	6.51	10.64	4.54	0.03	1.38	0
2012	0	0	0.51	2.38	1.62	2.6	10.21	9.61	7.16	0.07	0	0.32

2013	0.14	0	1.51	3.08	2.87	5.66	7.13	10.95	7.05	1.39	0.74	0
2014	0.05	1.69	2.13	0.74	3	2.27	7.14	8.4	9.45	0.49	0.06	0
2015	0	0	0.88	0.5	3.55	7.53	6.59	10.09	4.87	0	0.26	0
2016	1.93	0.42	1.67	4.84	3.88	6.48	5.71	9.7	4.76	0.4	0.12	0.06
2017	0	0.74	1.18	1.12	2.09	10.19	10.31	12.26	0	0	0	0.3

Appendix F: Hydraulic unit of catchment.



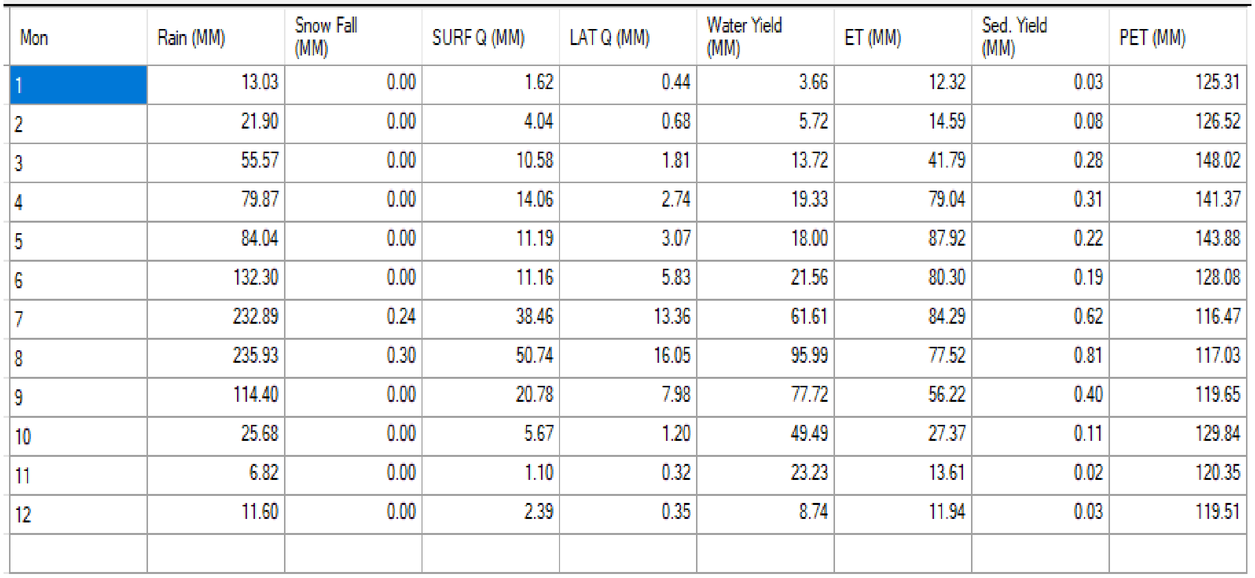
Appendix G : Total Sub basin Load.



Point sources constantly discharge pollutants to streams. These are an optional feature in SWAT. These summaries are presented so that the relative contribution of these sources can be verified. Point sources contributions are so varied that there is no reasonable range which can be applied to all basins.

Total Subbasin Load		Total Point Source + Inlet Load		Load From Inlet+PS (%)	
Flow (cms)	20.02	Flow (cms)	0	Flow (%)	0
Sediment (Mg/yr)	472,192.31	Sediment (Mg/yr)	0	Sediment (%)	0
Nitrogen (kg/yr)	530,269.23	Nitrogen (kg/yr)	0	Nitrogen (%)	0
Phosphorus (kg/yr)	148,957.69	Phosphorus (kg/yr)	0	Phosphorus (%)	0

Appendix I: Average Monthly Basin Value.



Mon	Rain (MM)	Snow Fall (MM)	SURF Q (MM)	LAT Q (MM)	Water Yield (MM)	ET (MM)	Sed. Yield (MM)	PET (MM)
1	13.03	0.00	1.62	0.44	3.66	12.32	0.03	125.31
2	21.90	0.00	4.04	0.68	5.72	14.59	0.08	126.52
3	55.57	0.00	10.58	1.81	13.72	41.79	0.28	148.02
4	79.87	0.00	14.06	2.74	19.33	79.04	0.31	141.37
5	84.04	0.00	11.19	3.07	18.00	87.92	0.22	143.88
6	132.30	0.00	11.16	5.83	21.56	80.30	0.19	128.08
7	232.89	0.24	38.46	13.36	61.61	84.29	0.62	116.47
8	235.93	0.30	50.74	16.05	95.99	77.52	0.81	117.03
9	114.40	0.00	20.78	7.98	77.72	56.22	0.40	119.65
10	25.68	0.00	5.67	1.20	49.49	27.37	0.11	129.84
11	6.82	0.00	1.10	0.32	23.23	13.61	0.02	120.35
12	11.60	0.00	2.39	0.35	8.74	11.94	0.03	119.51