MODELLING THE HYDROLOGY OF WATERSHED BY USING HEC-HMS

by

MAKKENA JYOTHI

(2014 - 18 - 118)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR- 679573, MALAPPURAM

2016

DECLARATION

I, hereby declare that this thesis entitled "**Modelling the hydrology of watershed by using HEC-HMS**" is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date:
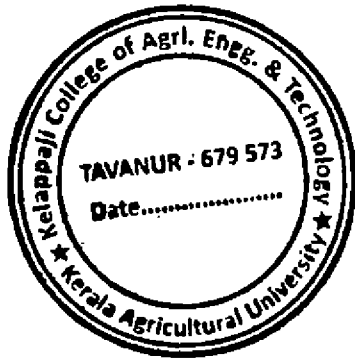
Makkena Jyothi.

(2014 - 18 – 118).
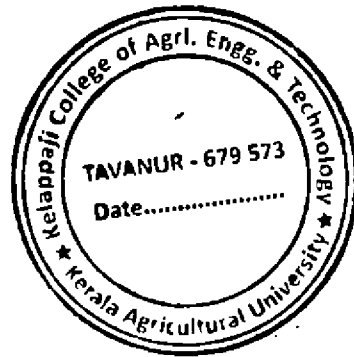
CERTIFICATE

Certified that this thesis, entitled **"Modelling the hydrology of watershed by using HEC-HMS"** is a record of research work done independently by **Er. Makkena Jyothi** (2014-18-118) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Tavanur,
Date:

Er. Vishnu, B.
Associate Professor
Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering & Technology
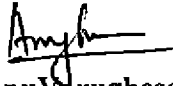Tavanur, Malappuram- 679573

CERTIFICATE

We the undersigned members of the Advisory Committee of **Er. Makkena Jyothi** (2014–18–118) a candidate for the degree of **Master of Technology in Agricultural Engineering**, agree that the thesis entitled **"Modelling the hydrology of watershed by using HEC-HMS"** may be submitted by **Er. Makkena Jyothi**, in partial fulfilment of the requirement for the degree.
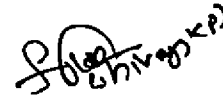
Er. Vishnu B.
(Chairman, Advisory Committee)
Associate Professor
Department of IDE
KCAET, Tavanur

Dr.Sasikala D.
(Member, Advisory Committee)
Professor and Head
Department of IDE
KCAET, Tavanur

Er. AnuVarughese
(Member, Advisory Committee)
Assistant Professor
Department of IDE
KCAET, Tavanur

Er. Shivaji K.P.
(Member, Advisory Committee)
Assistant Professor
Department of FPME
KCAET,Tavanur

EXTERNAL EXAMINER

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

i

Dedicated
to
My mother

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

HEC	Hydrologic Engineering Center
HMS	Hydrological Modeling System
RS	Remote Sensing
GIS	Geographical Information System
HSU	Hydrological Similar Unit
GEOHMS	Geospatial Hydrological Modeling System
ARC-GIS	Aeronautical Reconnaissance Coverage-Geographical Information System
HEC-RAS	Hydrological Engineering Center's river analysis system
DEM	Digital Elevation Model
SCS	Soil Conservation Service
PEP	Percentage Error in peak
PEV	Percent Error in volume
SCS-CN	Soil Conservation Service-Curve Number
SRTM	Shuttle Radar Topographic Mission
TOPAZ	Topographic parameterization
SWAT	Soil and Water Assessment Tool
MS-Excel	Micro Soft-Excel
USDA	United States Department of Agriculture
WMS	Watershed Modeling System
CN	Curve Number
NSE	Nash Sutcliffe Model Efficiency
R^2	Coefficient of Determination
SMA	Soil Moisture Accounting
RMSE	Root Mean Square Error

GW1	Ground water1
GW2	Ground water2
FEWS	Flood Early Warning Systems
USGS	United States Geological Survey
WGS	World Geodetic Survey
USACE	Unites States Army Corps of Engineers
UH	Unit Hydrograph
SCS-UH	Soil Conservation Service
TC	Time of Concentration
PET	Potential Evapotranspiration
PEPF	Percent Error in peak flow
RRMSE	Relative Root Mean Square Error
R^2	Coefficient of Correlation
ELE-UP	Elevation-up
ELE-DS	Elevation-down stream

INTRODUCTION

CHAPTER I
INTRODUCTION

Water is an essential resource for human life and all other spheres of his activity like agriculture, industries etc. Water is becoming scarcer due to the increasing consumption of exploding world population and due to the decreasing quality of water by various contaminations. A judicious use of this scarce resource requires scientific management by way of conservation and planning. Water resources conservation and management plans are made on a watershed basis as it is the basic unit for the water balance studies. Rivers, around which all the major civilizations in the world arose, play a major role in the hydrological response of a watershed. The ever-growing demand of water in domestic, agricultural and industrial sectors calls for better management of the water available in the rivers. This requires the study of precipitation, hydrological response of the catchment and its relation to the catchment characteristics.

Kerala, situated on the south-west corner of India, receiving an average rainfall of about 300 cm and blessed with 40 minor and 4 medium rivers, and the chain of backwater bodies, ponds, tanks, springs and wells are often considered as a land of water. However, Kerala experience severe shortage of water during the summer months. This is due to the peculiar topography of Kerala in which most of the rivers flow towards the West in a short length with a steep slope, emptying them in a short span. At the same time, Kerala has 3.6 times more population per square km when compared to Indian national level scenario. Hence only the proper management of water resource of Kerala could make the situation comfortable. Bharathapuzha is one of the medium rivers which supplies water to a considerable part of Kerala and understanding its hydrological response is quite important for the sustainable management of water resources in this area. Hence, Thuthapuzha river, a tributary of Bharathapuzha river was chosen for this study.

Hydrological phenomena are very complex, highly non-linear and highly variable in space and time (Patel 2014). A hydrological model is the mathematical representations of the response of a catchments system to hydrologic events during the time period under deliberation. Hydrological models are the paradigms used for the analysis and forecast of stream flow for the purposes of estimating it for sustaining not only human life but also to furnish the needs of industries (Narasayya 2015). Here, a most widely used model suited for varying geographical locations was selected for this study.

1.1 HYDROLOGIC MODELLING SYSTEM (HEC-HMS)

Hydrologic Modelling System (HEC –HMS) is developed by the US Army Corps of Engineers' Hydrologic Engineering Centre (HEC). It is calculated to simulate the precipitation runoff processes of watershed systems in a large range of geographic areas such as large river basins and small built-up or natural watersheds. The system encompasses losses, runoff transform, open channel routing, and analysis of meteorological data, rainfall-runoff model, and parameter estimation. HEC-HMS uses different models to represent each component of the runoff process, models including that compute runoff volume, models of direct runoff, and models of base flow. Each one model run combines a basin model, meteorological model, and control specifications with run options to obtain results (Kumar 2011, Majidi and Shahedi, 2012, Halwatura and Najjim, 2013). It can provide information about current and future runoff from watersheds, including estimates of runoff volumes, of peak flow rates, and of timing of flows.

1.2 USE OF HEC-HMS

HEC-HMS is a numerical model (computer program) that includes a large set of methods to simulate watershed, channel, and water-control structure behaviour, thus predict flow, stage, and timing. The HEC-HMS simulation methods represent:

1.2.1 Watershed Precipitation and Evaporation

These describe the spatial and temporal distribution of rainfall on and evaporation from a watershed.

1.2.2 Runoff Volume

These address questions about the volume of precipitation that falls on the watershed: How much infiltrates on pervious surfaces? How much runs off from the impervious surfaces? When the runoff does occur?

1.2.3 Direct runoff (Including overland flow and interflow)

These methods describe what happens as water that has been stored ornot infiltrated on the watershed and it moves over or just beneath the watershed surface.

1.2.4 Base flow

These simulate the slow subsurface drainage of water from a hydrologic system into the watershed's channels.

1.2.5 Channel flow

These are also called routing methods simulate one-dimensional open channel flow, thus predicting time series of downstream flow, stage, or velocity, given upstream hydrographs. (Ford *et.al* 2008)

1.3 MODEL CALIBRATION AND VALIDATION

The calibration is a process whereby the model parameter values are adjusted so as to match the predicted model outputs, as closely as possible, with observations from the study site. It is usually formulated as an optimization problem to determine the best set of model parameter values in order to minimize the differences between the observed and simulated. The calibration and validation of the model are essential and critical steps in any model application. For most of the watershed models, the

iterative procedure of parameter evaluation and refinement is calibration, a result of comparing predicted and observed values of interest (Donigian and Rao 2014). The data from a different time period or from the different locations can be used in the validation process, using the calibrated parameter values, in which measures of goodness-of-fit are used to measure the similarity between the observed and simulated data

The model validation is actually a part of the calibration process. Its purpose is to assure that the calibrated model suitably assesses all the variables and conditions which can affect model results, and express the ability to predict field observations for periods separate from the calibration effort. The model performance after the calibration and validation are evaluated through quantitativeandqualitative measures, involving both graphical comparisons and statistical tests.

Steps involved in using a hydrological model for a watershed can be summarised as follows:

➢ Model setup: Data collection, model input preparation, and parameter evaluation, i.e. the steps needed to setup a model, characterize the watershed, and prepare for model executions.

➢ Model testing: Involves calibration, validation and if possible post audit also.

➢ Analysis of alternatives: The step is used for the ultimate use of the model, as a decision support tool for management and regulatory purposes

1.4 RESEARCH OBJECTIVES

The main objective is to calibrate and validate a hydrological model, HEC-HMS for the Thuthapuzha sub-basin of Bharathapuzha river basin in India. Thespecific objectives of thestudyare:

- ➢ To calibrate HEC-HMS, a physically based deterministic hydrological model for Thuthapuzha basin
- ➢ To validate HEC-HMS for Thuthapuzha basin

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A review of previous research works related to modelling of hydrological response of watersheds, calibration, sensitivity, and validation are presented in this chapter.

A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place. According to John Wesley Powell a watershed is that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community. Hence watershed is adopted as a basic developmental planning or management unit especially for natural resources. The hydrology as well as the developmental strategy depends on the size of the watershed. The sizes of the watersheds vary from a few hectares to thousands of hectares. Watersheds can be classified on the basis of area as: micro watershed (0 to 10 ha), small watershed (10 to 40 ha), mini watershed (40 to 200 ha), sub watershed (200 to400 ha), macro watershed (400 to 1000 ha), river basin (above 1000 ha).

Indian River basins are classified as major, medium and minor river basins respectively based on the size of the catchment area being more than 20,000 km^2, between 20,000 km^2 and 2,000 km^2, and less than 2,000 km^2. (Jain et al., 2007)

Watersheds have distinct characteristics and those characteristics influencing the runoff production are important in hydrologic analyses.

2.1ROLE OF REMOTE SENSING AND GIS IN HYDROLOGICAL MODELLING

Su et.al (1992) used RS and GIS functions for estimating the parameters for the distributed hydrological modelling. Here they have used two case studies. In one

study, they were used RS & GIS for integrating and developing some techniques. For the estimation of the model parameters for the second study they have taken satellite imagery, digital elevation model as well as digitized thematic data. Since this type of information provides a very high resolution in space it was necessary to aggregate small area elements into so called hydrological similar units (HSUs) in GIS. The most difficult problem caused by large dimensions of river basin was to cope with the enormous amount of data resulting from the high spatial resolution. So, the application of RS and GIS is essential in hydrological modelling. This coupling of the two models will allow the running of the model with future scenarios of a changed climate. The impact of hydrological processes can be analysed with the aid of these two models.

Geographic InformationSystem (GIS) has emerged over the past decade as widely used software systems for input, storage, manipulation and output of the geographically referenced data. (Stewart and Goodchild 1993). GIS was currently used to assemble and manage the large databases to manage to perform the spatial and statistical analysis and to produce effective visual representation of the model results.

❖ GIS was used as a preprocessor of data, making the use of its functions for projection change, re sampling, generalization, windowing and other data extraction tasks, map digitizing and editing. Reformatting was often needed to meet the requirement of simulation packages.

❖ GIS was used for storage of data, database management facilities of GIS for keeping track automatically of many housekeeping functions such as simple documentation and provide a uniform mode of access.

❖ GIS was used for statistical analysis of data and for the model results.

❖ GIS was used for visualization, particularly for presenting the results of simulations in map form often in combination with other data.

Finally, this study examined the status of GIS as a technology to support environmental simulation modeling in the atmospheric, hydrologic and ecological sciences.

Ravinder Kaur *et.al* (2002) made a study on GIS based digital delineation of watershed and its advantage over conventional manual method in Hazaribagh and Bankura district of Jharkhand and West Bengal. The study indicated that automatic digital delineation of watershed boundaries avoids the subjectivity in locating the ridge lines in the manual method and thus gives more accurate shape and size of the delineated watershed.

Gangodagamage (2001) used the RS and GIS techniques to extract the land surfaces, which exist as a threshold in early days to approach reasonable results in hydrological modeling.Accurate modeling will require estimation of the spatial and temporal distribution of the water resource parameters. GIS and RS have become efficient tools to integrate the spatial and non-spatial databases for the hydrologic modeling. In this study, hydrologic model was developed for the Bata river basin, which is one of the tributary of the Yamuna river basin India. Infiltration losses, unit hydrograph and river routing were the main components of the model. ILWIS, ERDAS and AUTOCAD software were used. (SOI) topo maps, field data, IRS LISS III multi temporal satellite for Rabi and kharif seasons and IRS pan data were used. SCS CN method, unit hydrograph is used for infiltration losses and synthesis of unit hydrographs respectively. Watershed was divided into 10 sub areas. Muskingum method was used for river routing. Finally, the model was capable of forecasting the runoff for given event of rainfall and deriving hydrographs for the required duration.

Upadhye *et.al*(2005) used remote sensing and GIS technique for prioritization of watershed for development and management. Selvi *et.al* (2006) studied about the utilities and limitations of remote sensing and GIS applications in micro-watershed planning of Kuruthukuli watershed in Kundah basin of the Nilgiris district, Tamil Nadu. Asis Mazumdar and Sujana Dhar (2007) have conducted a study to quantify the impact of climate change on the water resources of the Jamtara watershed, West Bengal using a distributed hydrological model HEC-HMS.

The Geographic information systems (GIS) evolution facilitated the use digital terrain data for topography based hydrological modelling. (Kherde and Shawant 2013). The use of spatial data for hydrological modelling emerged from the great capability of GIS tools to accumulate and handle the data related to the hydro-morphology of the basin. For converting rainfall into surface runoff these models utilize the spatially variable terrain data. In analysing and designing large scale water resources projects manual map manipulation has always posed difficulty.

2.2. HEC-HMS

Ford *et.al* (2008), used the HEC- HMS program for hydrological modelling in a watershed.

2.2.1. Applications of HEC- HMS

Fleming (2004) described the Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) program and its application in the watershed studies. HMS has the capability to serve as a keystone program with respect to the watershed point of approach. It can simulate the rainfall-runoff at any point within a watershed for the given physical characteristics of the watershed. The HMS Program is a valuable tool for forecasting and for managing human impact on the rainfall-runoff response at points of interest within a watershed. The study showed that the results from the program can be used directly or in coincide with other software for studies

of water availability, drainage from urban, forecasting of flow, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation.

Yener *et.al* (2006) used HEC HMS for floodplain management and flood damage assessment studies of the Yuvacik basin. They report that missing data and bad data must be calibrated periodically to avoid errors in flow gages and precipitation stations.

Bakir and Xingnan (2008) used HEC-HMS for hydrological modelling. The performance of HEC-HMS was compared with that of the Xinanjiang conceptual model by using historical flood data from the Wanjiabu catchment in China. The results obtained in this study indicated that HEC-HMS was more convenient for flood simulation especially in optimizing parameters. But these are not accurate as compared with Xinanjiang model. HEC-HMS is a very powerful and flexible software and it provided enough and accurate hydrological data which is needed to run multiple models inside it. HMS provides precipitation- requirement options, loss models which can estimate the volume of runoff, and direct runoff and hydrologic routing models, and also used for the calibration optimization

Fleming *et.al* (2010) used HMS to estimate stream flow as a source for drinking water and the water effluent treatment works, such as shipping, receiving, navigation. However, analysis of the water of a river plays a key role in the development of plans for protecting the city. Analysis of the typical components such as pump stations adjacent to the holding ponds and river banks are expensive.

Razi *et.al* (2010) developed the flood model by using HEC-HMS for the Johar river in Kotta Tinggi watershed. Calibration and validation procedures were carried out using different sets of data. The evaluation and performance of the model was carried using HEC-HMS yield a correlation coefficient close to 1. The percentage of

error values were 4% and R^2 was 0.905. Based on these findings, they suggested HEC-HMS can be used as a tool for estimating the Q_{peak}.

Martin *et.al* (2012) performed the hydrological modelling using HEC-HMS software, by delineating the catchment using HEC-GEOHMS in Arc-GIS environment, populating the meteorological model with design storm data, and defining control specifications. The 10, 50, 100, 250, and 500-year design storms data input into the model generated design floods of 71.8 m^3/s, 123.0 m^3/s, 138.5 m^3/s, 163.9 m^3/s, and 183.4 m^3/s magnitudes respectively. Hydraulic modelling was performed using HEC-RAS software. The model output channel flood depths at the gauging station were 5.21 m, 6.53 m, 6.84 m, 7.31 m, and 7.65 m for simulated 10, 50, 100, 250, and 500-year design floods respectively. Flood hazard maps were generated by exporting the HEC-RAS model output results to Arc-GIS where they were processed to identify the flood prone areas. The most flood prone areas were found around the river middle reach by using flood hazard maps

The flood frequency analysis allows the estimation of design floods with hydrological modelling for poorly observed basins considering change and also taking into account the flood protection measures (Haberlandt and Radtke, 2014) There are several possible choices related to precipitation input, discharge output and consequently for the model calibration. The main aim of their study was to compare different calibration strategies for a hydrological model by considering various types of rainfall input and runoff output data sets to propose the most suitable approach. One main purpose of that paper was to introduce the idea of calibrating a hydrological model based on flood frequency distributions using stochastic rainfall and to evaluate it against classical strategies in an empirical case study. The results have shown the suitability of this approach. Generally, this approach may also be suitable in climate impact studies where hydrological models could be calibrated directly using the simulated precipitation from regional climate models against observed flow statistics.

Kabiri *et.al* used HEC-HMS and HEC-GEOHMS for the accurate calculations and predictions for flooding events in the Kuala Lumpur watershed. That is located in Klang basin of Malaysia. The main aim of their research was to estimate the peak flow in the Klang watershed by using Green-Ampt method as a major component in runoff and flood modelling. The flow data anddaily surface runoff were compared to observed values at the outlet of the watershed. The catchment delineation of the Klang watershed to obtain the sub-watershed parameters by using HEC-GEOHMS extension in ARC-GIS. The results showed that the flow measured at a high accuracy and the discharge at the outlet of the tank showed a good fit.

Twumasi *et.al* (2015) used the hydrological modelling with remote sensing data and GIS techniques for flood volume computation in Dikpe Catchment using temperature, rainfall and flow rate values. Many different methodologies have been tried for using Digital Elevation Model (DEM) for hydrological modelling and watershed delineation. The magnitude of flood in the delineated catchment area is calculated using the HEC- HMS.

2.3 HEC-HMS FOR THE PARAMETER ESTIMATION

Kumar (2011) prepared a hydrological model using remote sensing and GIS technique. Three methods viz. SCS unit hydrograph transform method, SCS curve number method, constant monthly method were used to compute the direct surface runoff hydrograph, runoff volume and base flow separation. Both lumped and distributed models were simulated and validated by using the rainfall stream flow data. From the observations, it was found that for estimating infiltration parameters and also for simulating daily stream flow the HEC-HMS model is consistent.

Arekhi (2012) used the HEC-HMS model and results of evaluation of different methods for runoff losses (Green and Ampt, Initial and constant loss rate and Deficit and Constant loss) He considered different objective functions (percent error in peaks and volumes) to classify the methods. The method with less difference

between percent of observed and simulated discharges got 1st preference and other methods were given subsequent preferences. Results showed that constant rate and initial loss had better result for six events, (4 events-PEP, 5 events- PEV), while Deficit and Constant loss had less changes rather than Green and Ampt method in (2events-PEP, 3events-PEP). So, Initial and constant loss rate method is the 1st preferred and for the simulation of surface runoff and Green & Ampt and Deficit and Constant loss methods took the next preferences.

Majidi and Shahedi (2012) used the HEC-HMS hydrological model 3.4 version to simulate rainfall-runoff process in Abnama watershed in southern Iran. To compute infiltration, rainfall excess conversion to runoff and routing of flow, methods like Green-Ampt, Unit hydrograph of SCS and Muskingum routing were chosen. Rainfall-runoff simulation was con-ducted with five events, and starting results for the first four events showed differences between simulated and observed discharges.

Rafi *et.al* (2012) used HEC-HMS model for comparison and classification of precipitation loss estimation methods with the hold of two objective functions for selection of the best method. Selected methods for runoff loss evaluation were Initial and constant, Green & Ampt, and SCS curve number in relation to various functions (PEP, Peak-Weighted Root Mean Square Error). With respect to the Root Mean Square Error of the peak weighted and Sum of Absolute Residuals, Green & Ampt method had better results than SCS and Initial and constant rate methods.

Asadi and Boustani (2013) used hydrologic model HEC-HMS along with the geospatial hydrologic model extension, HEC-GEOHMS. By using historical observed data, the model was carefully calibrated and verified. A local sensitivity analysis was also adopted for evaluating the event model. The results showed that in both the lumped and distributed models, the maximum difference between the baseline peak hydrographand hydrograph was caused by initial abstraction I_a.It was also found that

semi-distributed model captured the runoff of peak discharges and total volume of runoff these are better than the lumped model.

Chatterjee *et.al* (2014) stated that the rate of infiltration and percent of impervious area are the two sensitive parameters for the simulation of stream flow using HEC-HMS. In their study Nash-Sutcliffe model efficiency criterion of percentage error in volume, percentage error in peak and net difference of observed and predicted time to peak were used for performance evaluation. The model established good performance, with above-mentioned performance indices for simulation of stream flow

Choudhari *et.al*(2014) selected SCS curve number and SCS unit hydrograph methods for calculating runoff volume, peak runoff rate and base flow. Mean absolute relative error and root mean square error were the statistical tests for calibrating the model. The results indicated values of MARE of 0.2 and 0.25 for runoff depth and peak discharge, respectively. Similarly, the values of RMSE are 2.30 mm and $0.28m^3/s$ for runoff depth and peak discharge respectively. After parameter optimization, the error functions reduced to 0.10 mm, $0.12m^3/s$, 0.75 mm and $0.09m^3/s$ in sequence. Also, the model validation was also found to be satisfactory with low values of statistical error functions.

Narasayya (2015) used a GIS based hydrological model to study the stream flow estimation. Based on the statistical results and graphs, it was evident that the SCS-CN loss approach gives higher stream flow volumes than initial and constant loss method from both Muskingum and Lag routing methods. Ultimate peak flows and maximum stream flows in Muskingum and Lag routing methods are possible by taking into consideration of SCS-CN loss method. Stream flow volume can also be assessed by taking into consideration the higher spatial resolution of DEM and temporal resolution of satellite imageries is the final conclusion drawn from this study.

Sampath *et.al* (2015) used a hydrological modelling system HEC-HMS 3.0.1 to estimate runoff in the Deduru Oya river. Long-time daily rainfall data in several rain gauge stations, land use, and soil data in the river basin were selected. Five-layer soil moisture accounting loss method, Clark unit hydrograph transformation method, and base flow of recession method of the HEC-HMS model were used. The results depict the capability of HEC–HMS to repeat stream flows in the basin to a high accuracy with computed averaged by using Nash Sutcliffe efficiencies of 0.80. In the Deduru Oya river basin the model developed is a tool for water management.

2.4 WATERSHED DELINEATION BY USING DEM

Oloche *et.al* (2010) used the hydrologic model HEC-HMS (Hydrologic Engineering Center, Hydrological Modelling System), in combination with the geospatial hydrologic modelling system, (HEC-GEOHMS. HEC-HMS is seldom applied in chain for flood forecasting. The model is calibrated and verified using historical data. Flood events had the coefficient of determination above 0.9, and peak discharges of virtual flows were all in acceptable range.

Bhatt *et.al* (2012) used the HEC-HMS in Bhagirathi basin along with historically recorded rainfall and flow data. A digital elevation model (DEM) map was obtained from the SRTM (Shuttle Radar Topography Mission). Topographic Parameterization (TOPAZ) computer program was used to create the basin boundary from flow accumulation. Daily rainfall data over the years 1992-2002 at the outlet point (Tehri Dam) was analysed for the same years, in addition to the daily flow of data. Daily stream of data from the point of outlet flow hydrographs were used for the calibration and verification purposes.

Nag *et.al* (2013) studied rainfall runoff model using HEC-HMS and remote sensing and GIS techniques in the lower basin of Woochu river in the Paro Dzongkhag, Bhutan. Precipitation data for 10 years, topographic map, DEM, and Landsat images of the study area were collected. Time series data of rainfall and

discharge was analysed in MS-Excel. For the automatic delineation of the watershed Arc-GIS has been used with the SWAT tool. Calibration parameters have been validated for the coming 10 years.

Hashemyan *et.al* (2015) investigated the behaviour of the rivers flood and how to use in a reach of Khoshke Rudan river, located in the Chaharmahal and Bakhtiari province, Iran by using HEC-HMS and HEC-RAS. It was calibrated by data from rainfall gauging stations in the neighbouring basin. 10, 20, 50 and 100-year-long relationship with the precipitations in flood zones were determined using the extension HEC-GeoRAS using GIS environment. The results obtained from the study confirmed the ability of the combination of GIS and HEC-RAS model and performance model.

Yasin *et.al* (2015) created a hydrological model by using HEC-HMS and HEC-Geo-HMS for Mithawan watershed. DEM and HEC-GEOHMS was used to extract a watershed model. Frequency analysis of Mithawan basin rainfall and run-off during different periods of time was conducted using the simulation output from HEC- HMS model. The results of the study in Darraha Mithawan watershed showed agreement in the accuracy of peak discharge of the model simulation.

Gautam (2014) used the GIS based semi-distributed model named HEC-HMS in the Narayani river basin. It was analysed by using DEM, evapotranspiration, soil type, and land use data. The GIS based extension tool HEC-GEOHMS and HEC-GEORAS were mainly used for the preparation of inputs for HEC-HMS. The model provides the best result as a function of peak flow and time to peak. Hydrologic model parameters can be derived from historic stream flow, precipitation and GIS database.

2.5 RUNOFF ESTIMATION BY USING CN METHOD

Al-Jabari *et.al* (2009) used watershed modelling for the estimation of the runoff for the Wadi Su'd Watershed. So Many methods were used to estimate the runoff from a watershed. The curve number method, also known as the hydrological soil cover complex method, was a flexible and widely used method for runoff estimation.This method includes several important properties of the watershed specifically, soils permeability, land use and antecedent soil water conditions. The study estimated the flow of data on rainfall and land use classification and infiltration rate of the soil for the use of the experimental data. In the present study area (using Su'd basin), the results showed that the average annual runoff depth of 36.3 mm. This approach could be applied in other Palestinian watersheds for planning of various conservation measures.

This study reports the approach of remote sensing and GIS-based hydrological model for the urbanization and its impact to water resource. i.e. runoff (Abas and Hashim 2012).The runoff estimation was based on the Soil Conservation Service Curve Number (SCS-CN) model developed by the USDA-Soil Conservation Service(SCS) in 1972. The use of this model in relation to the curve of the earth Numbers (CN), soil type, soil moisture, runoff water is counted on the situation. For the Water resource management,remote sensing technique was widely used to determine the surface runoff. The main inputsfor this model were rainfall and CN. The CN represents the runoff potential those were based on the natural factors such as land use/cover, soil type, antecedent soil moisture and rainfall (amount, timing and magnitude) may influence runoff. Kuala Lumpur revealed that urbanization due to human activities could lead to greater runoff and risk of flood disasters.

For any hydrological studies in an un-gauged watershed, A methodology has to be selected for the determination of watershed characteristics and runoff at its outlet (Al-Jabari *et al.*, 2012). And a number of methods were used to determine the

morphological parameters to estimate the runoff in the watershed. The Soil Conservation Service (SCS) curve number method and Watershed Modeling System (WMS) are versatile and widely used procedure for watershed hydrological studies. These methods include several important properties of watershed namely, soils permeability, land use and antecedent soil water conditions which were taken into consideration.Geographical Information System (GIS) was used to estimate the runoff from a small agricultural watershed as well as the morphological features of these watersheds.

Gajbhiye 2015 used the CN method for estimating the surface runoff in the Kanhaiya Nala watershed located in Satna district of Madhya Pradesh. In this the total area of watershed was 19.53km^2. Land Use,Soil map and slope map were generated in GIS Environment. Since the curve number method was used here as a distributed model, it is required to get information regarding a large number of sub-catchments in the basin.Direct runoff in a catchment depends on type of soil, land cover and rainfall. Out Of the available methods (SCS-CN) was the most popular method for estimating runoff from rainfall. The thematic layers like soil map, elevation map, rainfall map and land cover maps were created in Arc GIS 9.3. In present study, the runoff varies from 1196.93 mm to 1551.17 mm of the study area.

2.6 CALIBRATION AND VALIDATION OF HYDROLOGICAL MODEL

Alaghamand et.al (2011) studied the evaluation of different sets of calibrated and validated data by using HEC-HMS 3.1.0 for the Sungai Kayu Ara river basin, which was located in the west part of the Kuala Lumpur in Malaysia was the case study of this research. In this research imperviousness, lag time and peaking coefficient had taken as the calibrated parameters. Average, median and mode were calculated for selecting best set among these values. The results showed that R^2 values for average median and mode were 0.8922, 0.8954, and 0.8678respectively. It can be concluded that average and median parameter values for the calibration set

was more accurate and reliable compared to the mode of parameter values of validation.

Ali *et.al* (2011) was used the HEC- HMS (rainfall runoff model) to quantify the effects of land use changes in the Lai Nullah basin.The model was calibrated and validated for the five storm events and the results showed good consistency between the simulated and observed hydrograph from 76 to 98% of the Nash - Sutcliffe model efficiency at the outlet of the basin. The future land use scenario was forecasted based on Islamabad Master Plan and growth pattern.The anticipated results of the master plan for land use in the futureincreased runoff between 51.6 and 100% and peak discharge between 45.4% and 83.3% that the total flow was expected to increase. The results provided the useful information for land use planning and management and these methods applied can serve as a useful tool for future land use impact studies.

Abood *et.al* (2012) used the hydrological model (HEC-HMS) to evaluate the performance of the Kenyir catchment and Berang catchment in simulating the rainfall-runoff using two different infiltration methods for estimating infiltration parameters (abstraction losses, rainfall). These methods include SCS Curve Number method and the Green and Ampt method. Statistical analysis functions they have used were coefficient of determination (R^2), the mean square error (MSE) and mean absolute percentage error (MAPE).And also, they have used HEC- HMS for the accuracy of simulations. The results of the simulation using the SCS Curve Number method mistakes output was 6.5%, 8.2%, respectively for Berang, Kenyir catchmentsand also for the errors of Green and Ampt method was 9.13%, 11.11%. As a conclusion, it was found that the output of the program was found to be in agreement with the historical record of data and they were suggested that to use the SCS Curve Number infiltration method for the humid catchment was due to its low error in simulation output.

Asadi and Boostani (2013) used HEC-HMS for the rainfall runoff process in small sub basin Delibajak and Kabkian basin in combination with HEC-GEOHMS. SCS curve number method of rainfall - runoff modelling and model was considered to be carefully calibrated with the simultaneous. The review of the historical data was verified using the sub-basin. Flood events and deal with all the points for the determination of the coefficients were above 0.9, and the highest percentage of errors in the flow and volume are in the acceptable range. As well, in these two basins the hydrologic parameters i.e. curve number and initial abstraction were compared.

Majidi and Vagharfard (2013) analysed surface run-off simulation in Abnama watershed with Green-Ampt method and Soil Conservation Service (SCS) methods using HEC-HMS hydrological model. After the input parameters to determine the methods for selecting the appropriate method for two different managed using the HEC- HMS model was calibrated and validated for hydrograph and related hyetograph had been used for four events. Model calibration and validation results of the Green Ampt method to estimate the difference in the lower peak discharge and time to peak was less than the SCS system. Minitab software, as well as their values and the correlation between simulated and observed hydrographs Green Ampt method of comparison based on the results of the SCS method has been shown to correlate with more than SCS method. It can be concluded that simulation using Green-Ampt method was more precise than SCS method

Roy *et.al*(2013) used the soil moisture accounting algorithm (SMA) method for the predictionof the response of the watershed by using HEC-HMS.It has been calibrated and validated for Subarnarekha river basin in Eastern India. The analysis shows that the soil storage, tension zone storage and groundwater 1 storage coefficient to be the sensitive parameters for the simulated stream flow. The Nash - Sutcliffe model efficiency criterion, percentage error in volume, the percentage error in peak, and net difference of observed and simulated time to peak, which were used for performance evaluation, have been found to range from (0.72 to 0.84), (4.39 to

19.47%), (1.9 to 19%) and (0 to 1day) respectively, indicating a good performance of the model for simulation of stream flow and thereby quantification of available water.

Kabiri (2014) had investigated that the assessment of the SCS CN loss method in Klan-g watershed to evaluate the performance of the SCS CN loss method. They concluded that SCS-CN loss method can be used for Klan-g watershed due to its good agreement between observed and modelled in HEC-HMS. The results revealed that a modified CN of initial abstraction ratio of 0.5 gives better fit than 0.2. Therefore, $CN_{0.05}$ can be used for the runoff simulation of SCS method in Klan-g watershed.

Yao $et.al$(2014) used the study to assess the impact of underlying surface change on catchment hydrological response using the Hydrologic Modelling System (HEC-HMS). Twenty-one flood events were selected for calibration and validation of the model parameters. Using the satisfactory results HEC- HMS model used to simulate the response of Dong-wan watershed to show that the runoff in the catchment rainfall

Legesse (2015) used HEC-HMS3.5 hydrologic model HMS for the calibration and validation of the upper Blue Nile River Basin by using soil moisture accounting algorithm-SMA. The Nash-Sutcliff (E) and Coefficient of determination (R^2) used to evaluate the performance of the model. The results obtained are suitable and accepted for simulation of runoff, some of the best fit performed methods of the hydrological processes of direct runoff transformation, infiltration loss and base flow are the deficit and constant loss method, Snyder unit hydrograph method and exponential recession methods. By analysing these results he suggested that HEC-HMS simulation model was suitable for the upper Blue Nile river Basin.

Rahul $et.al$ (2015) used HEC-HMS by using SMA method to model stream flow in the Vamsadhara River Basin in India. The SMA algorithm was calibrated using data from 1984 to 1989 by using HEC-HMS and between1990 to 1993 at a

fixed time period had been validated. Using statistical and visual research Vamsadhara River basin will be carried out to determine the performance of HEC-HMS model. The arrangement of the sample period, which ranges from a peak performance of 0.21 % (R^2-0.71, Nash - Sutcliffe Efficiency EFF - 0.701, percentage error in volume PEV = 2.64% percent error in peak PEP= 0.21% and index of agreement -0.94) Similarly, as long as the ranges from the validation model, was good to very good (R^2-0.78, EFF - 0.762, PEV - 12.33%, PEP- -15. 2% and D-0.93).

Supe *et.al*(2015) used HEC-HMS model to simulate continuous rainfall-runoff modelling for Wan river basin, Akola, Maharashtra.Rainfall-runoff relationship was modelled using soil-moisture accounting method (SMA). The calibrated model parameters *i.e.* Groundwater 1, Groundwater 2, GW1 coefficient and GW2 coefficient were fixed as 72, 10, 387 and 1010, respectively, for the model performed well in terms of RMSE, R^2_{NS}, CRM (0.12 m3/s,0.93 and -0.02). Considering the performance of model in simulating the runoff, it is suggested that the calibrated HEC-HMS model could be used to predict runoff for the rainfall events for Wan river basin.

2.7 WATERSHED MANAGEMENT

Assessment of watershed management operation is one of the main subjects for future planning of practical projects and natural resources management. Flood damage was one of the most important problems in countries same as Iran, which was mostly effected and caused the hazards (Golrang *et al.*, 2013). Therefore, the identification of the area with high potential risk of flood occurrence was the main purpose is to the flood control and reducing its damage.

The purpose of this study was evaluation of watershed management activities in Kushk-Abad Watershed by HEC-HMS (Hydrologic Modelling System). HEC-HMS is one of the computer models for simulation of its ability for the short timeperiod events. HEC – HMS was physically processed using extension and

divided into 6 sub-basins. The main aim of the study was evaluation of HEC-HMS model using SCS unit hydrograph method in basins, and results showed that in the bell form (Normal) hydrographs. These parameters were imported to HEC-HMS to find out the effects of watershed practices and then flooding condition was simulated. For assessment purposes, peak discharge and flood volume were calculated for "before" and "after" construction conditions. Results showed that check dams as mechanical measures had low effect on time of concentration while biological practices lead to decrease in curve number with an average value of 4.5. This results in decrease of peak flow and flood volume meanly 19% and 14% respectively.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 STUDYAREA

The watersheds from the central part of Kerala State, India have been used in this study. Among these ,one is the sub basin of a major river 'Bharathapuzha'.

3.1.1 Thuthapuzha sub basin

Thutha River is one of the main tributary of the Bharathapuzha (Nila River). This is the second longest river on the south west coast of India. Bharathapuzha originates from the Western Ghats and has a total catchment area of $6400km^2$,of which about70%spreadin Kerala and remaining in Tamilnadu. Thuthapuzha watershed lies between $10^0 50'$ to $11^0 15'$ North latitude and $76^0 5'$ to $76^0 40'$East longitude. The watershed has a total area of 1018 km^2 and covers 27 panchayats 6 blocks and two districts. This river is the main tributary which supplies water to Bharathapuzha river especially during summer. Catchment area at Pulamanthole river gauging station ($10^0 53'50''$N,$76^0 11'50''$E) manned by Central Water Commission, Indiais822 km^2.
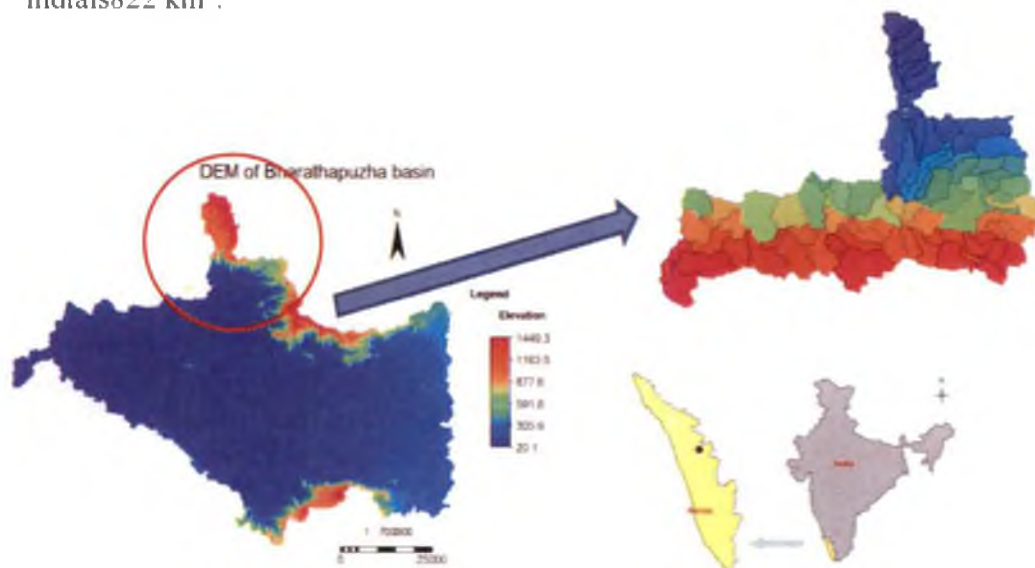
Fig 3.1 Location of Thuthapuzha watershed

3.2 PHYSIOGRAPHIC AND METEOROLOGICAL INFORMATION IN THUTHAPUZHA WATERSHED

3.2.1 Rainfall

Daily rainfall data and also climatic parameters such as temperature, humidity, wind speed, solar radiations and sunshine hours have taken from the RARS Pattambi.

3.2.3 River flow

Daily river flow has been collected from Central Water Commission i.e. Pulamanthole gauging station and that was managed by the central Water Commission.

3.2.4 Soil data

Soil map and attribute information have been collected from the Kerala State Land Use Board (KSLUB), Trivandrum.

3.2.5 Land Use

Land use map and attribute information have been collected from the Kerala State Land Use Board (KSLUB), Trivandrum. The land cover consists of the residential, commercial and services, strips mines quarries and pits etc.

3.2.6 DEM

DEM of the study area has taken from the Cartosat-1: DEM - Version-3R1 1 arc sec (~ 32 m) resolution was downloaded from ISRO, National Remote Sensing Centre's (NRSC), India Geo-platform Bhuvan website (http://bhuvan.nrsc.gov.in)

3.3 GIS APPLICATIONS IN HYDROLOGY

3.3.1 GIS (Geographic Information System)

Geographic information system can be defined as a computer data base system for the capture, storage, retrieval analysis and display of tabular data and spatial data. GIS has a wide application in a variety of civil and environmental applications, including demography, meteorology, transportation, urban planning, and hydrology. In the past three decades, hydrologic applications have been revolutionized by GIS, making it an indispensable technology for digital terrain and hydrologic analysis of watersheds. The role and usage of GIS technology, software, data formats, and sources of geospatial data are essential to hydrologic analysis. It Includes

➢ Attribute or feature information in a database format

➢ Location information for these attributes or features

➢ Analysis functions for deriving new information on spatial relationships

Active involvement in the hydrology by the GIS community is represented today by the user groups devoted to GIS technology applications to the hydrology, natural resources management, or urban planning. National hydro graphic and elevation datasets are available from the U.S geological survey (USGS), digital soils data from the natural resources conservation service (NRCS). GIS is used for watershed delineation, runoff estimation, flood plain modelling and hydrologic and hydraulic modelling in hydrology. Digital representation of topography, soils, land use/land cover, and precipitation may be accomplished using GIS data and methodology. The applications are enhanced through the use of GIS, because hydrology is inherently spatial in nature.

3.3.2 Raster and vector data

GIS data are usually formatted in a vector or raster structure. A vector dataset maps a geographic feature using lines drawn between points or coordinate pairs. An

advantage of vector formats is that a database containing multiple attributes may be associated with any given point, line, or polygon. Whereas in the raster format, only a single attribute is usually associated with a grid cell. Vector data sets are used to show rain gages as points, streams as lines, and the watershed boundary as a polygon. A raster of grid cells represents rainfall in relation to the watershed and other features in the map

3.3.3 Map scale and spatial detail

The scale and resolution at which the data are collected or measured on a map is termed as resolution (or)native scale. If the mark or point elevations are surveyed in the field on a grid of 100 m, then this is its native resolution. A small-scale map is one in which features appear small. Conversely, large-scale maps have features that appear large and show significantly more detail.

E.g.: If a paper USGS quad sheet is digitized, the native scale will be 1: 24000, as a result performing analysis of this data at a 1:1000 scale could adversely influence the accuracy of the analysis.

3.3.4 Datum and spheroid

Geodesy is the branch of applied mathematics concerned with determining the size and shape of the earth and the exact location of the points on its surface. The earth is often treated as a sphere to make mathematical calculations easier, but it is actually a spheroid.

The earth must be treated as a spheroid to maintain accuracy in maps of large spatial extent, and numbers of standard spheroids are commonly used to describe its shape. In North America, these include the Clarke 1866 spheroid and the GRS80 (Geodetic reference system of 1980). A horizontal datum is a reference frame used to measure locations on the surface of the earth. It defines the origin and orientation of the lines of latitude and longitude. A horizontal datum is always related to a specific spheroid. There are two types of datum available - those that are earth centred

(geocentric) and local. Local datum is NAD27 (North American datum). Earth centred (geocentric datum) is NAD83.

3.3.5 Geographic and Cartesian Coordinate Systems

A geographic coordinate system is based on latitude and longitude. A transformation or projection from a curved geographic coordinate system to a Cartesian coordinate system is necessary to view all or part of the earth as a flat map. Because it is impossible to represent a three-dimensional figure such as the earth as a two-dimensional map with minimal distortion, various projections have been developed to preserve one or more of the following properties: shape, area, distance, and direction. No projection maintains all of the above four characteristics, but some projections maintain more than one. For Example: The Universal Transverse Mercator (UTM) projection commonly used in the United States.

3.3.6 Land use/land cover

Land use/cover may be used to develop evapotranspiration rates or estimates of hydraulic roughness from a raster array or from polygonal areas of remotely sensed substitute measures. A GIS map of the land use and associated cover is an important descriptor of the hydrology, whether it is vegetative, such as pasture or forest, or the surface is modified with asphalt or concrete pavement. Land use and land cover (LULC) GIS data are compiled for many applications and may be useful for hydrologic modelling.

General purpose LULC maps may or may not contain sufficient details or classification to be useful for deriving hydrological model parameters. LULC classification maps can be used to develop hydrologic parameters such as hydraulic roughness, Aledo or aerodynamic roughness height, which influences evapotranspiration

Hydraulic roughness is a parameter that controls the rate of runoff over the land surface. Classification codes from the Anderson classification scheme are listed below.

Table 3.1Anderson Land Use Land Cover Classification Codes: First- and Second-Level Categories

1. Urban or Built-Up Land	6. Wetland
11 Residential	6 1 Forested Wetlands
12 Commercial Services	6 2 Non forested Wetlands
13 Industrial	**7. Barren Land**
14 Transportation, Communications	71 Dry Salt Flats
15 Industrial and Commercial	72 Beaches
16 Mixed Urban or Built-Up Land	73 Sandy Areas Other than Beaches
17 Other Urban or Built-Up Land	74 Bare Exposed Rock
2. Agricultural Land	75 Strip Mines, Quarries, and Gravel Pits
21 Cropland and Pasture	76 Transitional Areas
22 Orchards, Groves, Vineyards, Nurseries	77 Mixed Barren Land
23 Confined Feeding Operations	**8. Tundra**
24 Other Agricultural Land	81 Shrub and Brush Tundra
3. Rangeland	82 Herbaceous Tundra
31 Herbaceous Rangeland	83 Bare Ground
32 Shrub and Brush Rangeland	84 Wet Tundra
33 Mixed Rangeland	85 Mixed Tundra
4. Forest Land	**9. Perennial Snow and Ice**
41 Deciduous forest land	91 Perennial Snow fields
42 Evergreen forest land 43 Mixed forest land **5. Water** 51 Streams and canals 52 Lakes 53 Reservoirs 54 Bays and estuaries	92 Glaciers

30

3.3.7 Soil mapping unit

Computation of direct runoff requires an estimate of infiltration characteristics for the different soil types in a drainage area. A soil-mapping unit is the smallest unit on a soil map that can be assigned a set of representative properties. Soil maps and the associated soil properties form a major source of data for estimating infiltration. Some adjustments are needed when estimating the infiltration parameters from generalized soil databases. Obtaining infiltration parameters from soil properties requires reclassification of the soil mapping unit into a parameter meaningful to the hydrological model. Soil-type data were widely available for the United States and can be downloaded from the Natural Resources Conservation Service at (www.nrcs.usda.gov.in).

a) Deriving hydrologic parameters from GIS maps of land use and soils

Generalized land use/cover maps are now available for most locations. Such maps may be useful for hydrologic analysis if the mapped categories are representative of current conditions or those present during a particular storm event. To obtain hydraulic or hydrologic parameters from such a map, reclassification is necessary to convert the dominant land use/cover into hydrologic model parameters.

Interpretation of the dominant land use category is needed to express the category in terms of an appropriate value of the corresponding hydraulic roughness parameter. Because a particular land use category may be heavily or lightly vegetated, the assigned hydraulic roughness should be adjusted to represent this in the model. Similarly, soil maps can be reclassified based on soil texture into infiltration parameters for use in the Green–Ampt equation. Hydrologic Parameters from GIS Maps of Land Use and Soils may be found on the textbook website along with sample data.

The steps followed in the presentation are:

- Reclassify land use/soils datasets to hydrologic parameters defining hydraulic roughness and infiltration.

- Use multiplicative factor when reclassifying integer-based land use/soils classes, then divide out multiplicative factor with Raster Calculator (RC).

- Resample roughness/infiltration values to desired model grid resolution.

- Clip the re sampled grid to a specific model domain.

- Export roughness/infiltration grids and load in as ARC-GIS Grids or ASCII files

The resulting watershed maps demonstrate the reclassification of GIS maps of land use/cover and soils into hydraulic and hydrologic model parameters. The resulting maps are for use in the distributed hydrologic model, alternatively, the same approach to reclassification can be applied to obtain parameters for input to HEC-HMS by averaging the distributed values over each sub basin area within the watershed.

3.3.8 Digital elevation model (DEM)

One of the most useful types of geospatial data is digital terrain.Hydrologic quantities can be derived from a DEM. The terrain attributes such as slope and drainage direction are derived from a DEM. A model of terrain traditionally relies on contours of equal elevation that define watershed boundaries, channel slope, and other features.

Within a GIS, representation of terrain can be accomplished with contours. gridded elevations (also known as a raster DEM), and triangular irregular networks (TIN). Watershed characteristics such as slope and drainage length can be derived from a digital model of the terrain. A raster DEM consists of groupof numbers indicating the spatial distribution of elevations.

3.3.8.1 GIS Processing of digital terrain

A basic application of GIS in hydrology is the delineation of watershed boundaries and corresponding stream network. Several modules are available for automatic delineation from a DEM. Because a vector map of the watershed boundary or stream channel location may have more accuracy than the DEM, the automated

delineation can be improved using the vector maps to constrain the delineated boundary and stream channel location. Constrained watershed delineation helps ensure that the resulting maps are consistent with the watershed boundary and stream channel mapped in vector format. This example provides an overview of how to burn in a DEM with a stream network and use the watershed boundary to constrain the watershed delineation. The watershed delineation relies on the Arc Hydro tools extension in Arc-Map.

The steps followed in the presentation are:

- Re project original DEM to the desired projection with horizontal and vertical units of meters.

- Resample original DEM to a selected resolution.

- Merge stream network and basin/sub basin outline into a DEM to ensure proper flow direction.

- Use Arc Hydro Tools extension to produce flow direction, flow accumulation, and a stream grid.

The resulting watershed maps demonstrate the burn-in procedure using a combination of raster and vector map information. The flow direction map is for use in the distributed hydrologic model. An alternative approach is to use the HEC-GEOHMS processing module to process the DEM and to produce sub basin boundaries and stream channel map information for input to HEC-HMS.

3.3.9 Triangulated Irregular Network (TIN)

It represents a surface as a set of non over lapping contiguous triangular facets of varying size and shape. Generally, a TIN is produced from a DEM through GIS software and has several distinct advantages over contour and raster representations of surfaces. The primary advantage is that the size of each triangle may be varied such that broad flat areas are covered with a small number of large triangles, while vastly variable or steeply sloping areas are covered with many smaller triangles. This provides some storage and detail efficiency over raster data structures, since the

element may vary in size according to the variability of the surface. TINs have become increasingly popular because of their efficiency in storing data and their simple data structure for accommodating irregularly spaced elevation data.

3.4 TOOLS AND TECHNIQUES USED IN THIS STUDY

3.4.1 HEC-GEOHMS

The Geospatial Hydrologic Modeling Extension (HEC-GEOHMS) has been developed as a geospatial hydrology tool kit for hydrologists and engineers with limited GIS experience. HEC-GEOHMS uses Arc-GIS and the Spatial Analyst extension to develop a number of hydrologic modelling inputs for the Hydrologic Engineering Center's Hydrologic Modeling System, HEC-HMS. ARC-GIS and its Spatial Analyst extension are available from the Environmental Systems Research Institute, Inc (ESRI). The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate sub basins and streams. Working with HEC-GEOHMS through its interfaces, menus, tools, buttons, and context-sensitive online help allows the user to expediently create hydrologic inputs for HEC-HMS.

(a) Data Management

The USGS digital elevation model (DEM) contains terrain cells of surface elevations at a spacing of 30 meters in both the horizontal and vertical direction. This DEM data was used to generate the stream network and sub basin areas within the watershed. All data layers were projected to the WGS 84 Northern hemisphere Plane coordinate system.

(b) Terrain Pre-processing

Before hydrologic modelling with HEC-HMS was possible, the terrain model is used to derive eight datasets described in proceeding sections. These processes were performed using HEC-Geo-HMS in Arc-Map. The steps involved delineation of the Thutha river, its tributaries, watershed, and watershed properties (i.e. runoff curve

number, time of concentration). With the DEM and GIS tools, the watershed properties were extracted using automated procedures (USACE 2009).

The spacing of elevations in the DEM was not sufficient for the stream centreline; therefore the DEM was modified to be consistent with the input vector stream network. This DEM reconditioning increases the degree of agreement between stream networks delineated from the DEM and input vector stream network shape file. If the reconditioning process was not applied, the path of the Thutha river would be too crude

Meaning is that the reach lengths generated in Arc-Map would not represent site conditions. This is mainly due to the precision of elevation data along the stream in the initial DEM. By manually detailing, or burning in the stream network, a distinct stream profile was created and a new DEM was created. If a cell is surrounded by higher elevations, the water is trapped and cannot flow out of the sink.

After the terrain pre-processing, the reconditioned DEM is the starting point for delineating sub basins and river reaches. The first five of the eight datasets are grid layers that represent:

- Flow Direction, defines the direction of steepest descent for each terrain cell

- Flow Accumulation, determines the number of cells upstream draining to a given cell (upstream drainage area can be calculated by multiplying the flow accumulation value (number of cells) by the grid cell area (30m x 30m)

- Stream Definition, the generation of a stream defined by the number of Flow Accumulation cells

- Stream Segmentation, divides the grid of streams into segments, these are sections of the stream that connect two joining streams (junction), junction and an outlet, or junction and the drainage divide.

- Catchment Delineation, creates a grid layer that delineates a sub basin for each stream segment

After the terrain processing is completed, the first watershed project was defined by identifying the downstream outlet area. The catchment polygons were either merged or subdivided until the area of the sub basins were comparable to the drainage area size

Next, it was possible to extract physical characteristics of the streams and sub basins. These characteristics included computed length of the river segments, upstream and downstream elevations of the reach and the slope of the river segments. Basin slope uses the slope grid to determine the average slope for the sub basin. Longest flow path creates a polyline that stores the upstream and downstream elevations and slope between endpoints. The Basin Centroid, Centroid Elevation, and Centroidal Flow Path are hydrologic elements easily performed in GIS. Some techniques for estimating flood-peak discharges require this data. Although these characteristics were generated, the rainfall-runoff methodology employed in this research did not require this attribute information.

3.4.2 HYDROLOGICAL MODELING IN ARCHYDROTOOLS ANDHEC-GEOHMS
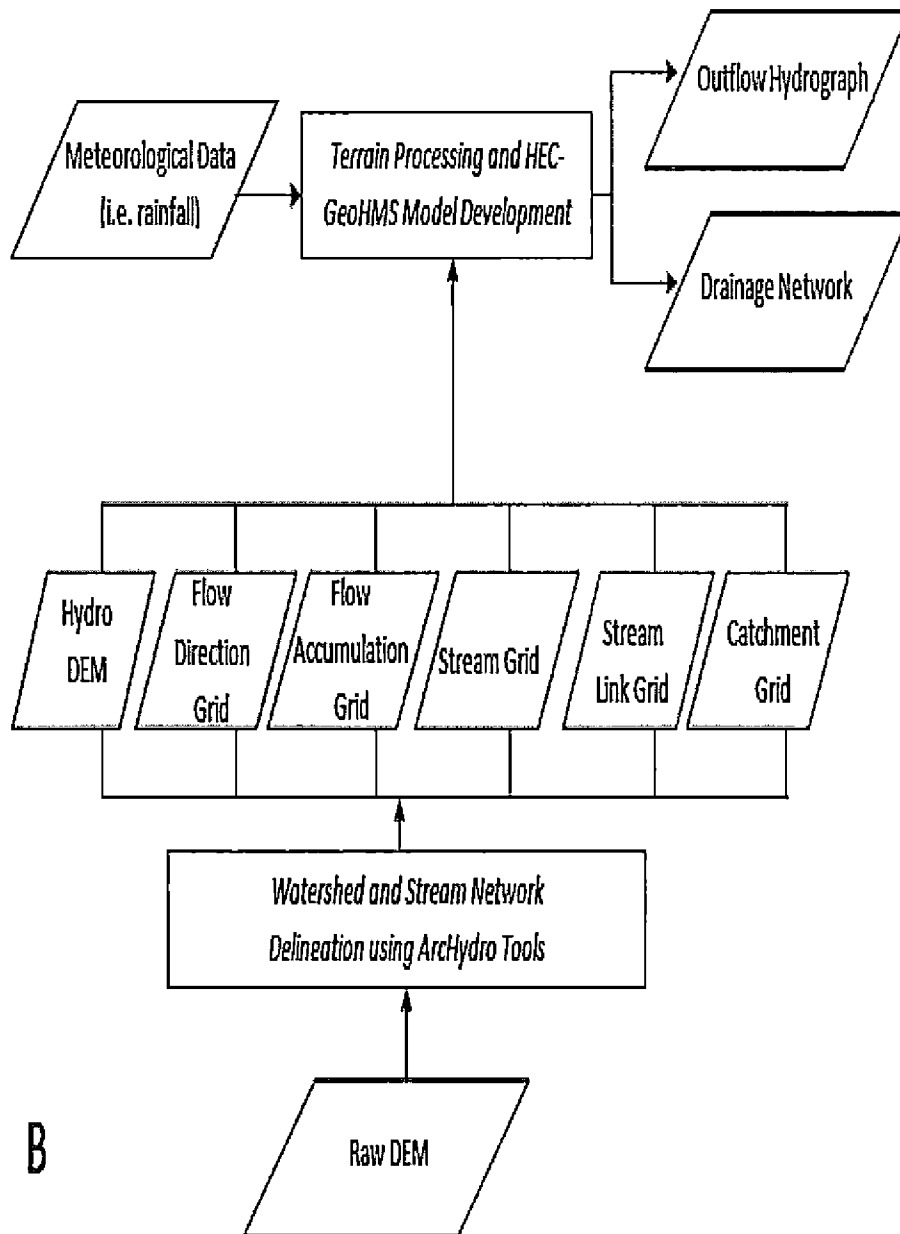
Fig3.2. Flow chart of HEC-GEOHMS

3.4.3 WATERSHED AND STREAM NETWORK DELINEATION USING ARCHYDRO TOOLS

Open Arc Map. Create a new empty map. Right click on the menu bar to see the context menu showing available tools and then check the Arc hydro tools to add the toolbar to the map document. We can see the Arc Hydro toolbar added to ArcMap.

The Spatial Analyst Extension has to be activated, by clicking Customize->Extensions..., and then check the box next to Spatial Analyst.

3.4.4 Terrain Pre-processing

3.4.2.1 Hydro DEM, Flow Direction Grid, Flow Accumulation Grid, Stream Definition Grid, Stream Segmentation Grid, Catchment Grid Delineation.

Arc Hydro Terrain Pre-processing should be performed in chronological order. All of the pre-processing must be completed before watershed processing functions using in the model. DEM reconditioning and filling sinks might not be required depending on the quality of the initial DEM. DEM reconditioning involves modifying the elevation data to be more consistent with the input vector stream network. This shows, an assumption that the stream network data is more reliable than the DEM data, so we need to use the knowledge of the accuracy and reliability of the data sources when deciding whether to do DEM reconditioning. By doing the DEM reconditioning we can increase the degree of agreement between stream networks delineated from the DEM and the input vector stream networks.

Click on the Add icon to add the raster data. In the dialog box, we can locate the data; select the raster file containing the DEM for Thuthapuzha and click on the Add button. The added file will then be listed in the Arc Map Table of contents. Similarly add stream.shp, and save the map document.

a) Hydro DEM

DEM Reconditioning:

The function needs input as raw DEM and a linear feature class (like the river network) that both have to be present in the map document. On the Arc Hydro toolbar, select Terrain Pre-processing->DEM Manipulation->DEM Reconditioning.

Select the appropriate Raw DEM (Thuthapuzha_dem) and here AGREE stream feature (stream). Set the Agree parameters as shown. Then we can reduce the Sharp drop/raise parameter to 10 from its default value 1000. The output is a reconditioned Agree DEM (default).

After that click ok and then it will process successfully after that message box will come. Examine the folder where we are working; we will notice that a folder named Layers has been created. This is where Arc-Hydro will store its grid results

b) Fill sinks

Fill sinks function fills the sinks in a grid. If the cells with higher elevation surround a cell in model, the water is trapped in that cell and it cannot flow. This Fill sink function modifies this elevation value to eliminate these problems.

On the Arc-Hydro Toolbar, select Terrain Pre-processing->Data Manipulation->Fill Sinks

Confirm that the input for DEM is Agree DEM (or your original DEM if reconditioning was not implemented). The output is the Hydro DEM layer (Named default Fil). This Leave the other options unchanged.

Then Press ok. Upon completion of the successful process, the Fil layer is added to the map. This process takes a few minutes.

c) Flow Direction Grid

Flow direction computes the flow direction for a given grid. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

On the Arc-Hydro Toolbar, select Terrain Pre-processing->Flow Direction.

Confirm that the input for Hydro DEM is Fil. The output is the Flow Direction Grid, (default Fdr). And then Press ok. Upon completion of the successful process, the flow direction grid Fdr is added to the map.

d) Flow Accumulation Grid

This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.

On the Arc-Hydro toolbar, select Terrain Pre-processing -> Flow Accumulation

Confirm that the input of the Flow Direction Grid is Fdr. The output is the Flow Accumulation Grid (default name Fac).Press OK. Upon successful completion of this process, the flow accumulation grid Fac is added to the map. This process may take several minutes for a large grid.

e) Stream Definition Grid

On the Arc-Hydro toolbar, select Terrain Pre-processing -> Stream Definition. Confirm that the input for the Flow Accumulation Grid is Fac. The output is the Stream Grid named Str (default)

Objective methods for the selection of the stream delineation threshold to derive the highest resolution network is consistent with geomorphologic river network properties. It has been developed and implemented in the TauDEM software (http://www.engineering.usu.edu/dtarb/taudem). For this exercise, we have chosen 25 km^2 as the threshold area, and then click ok.
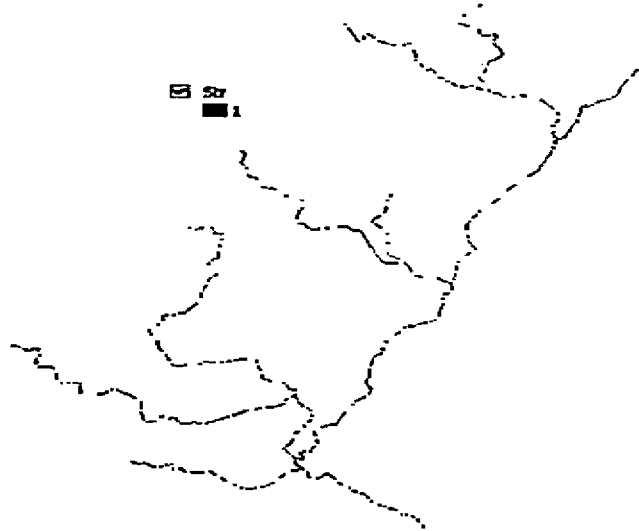
Fig: 3.3 Stream grid

f) Stream Segmentation Grid

This function creates a grid of stream segments that have a unique identification. Here either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment.

On the Arc-Hydro toolbar. Select Terrain Pre-processing -> Stream Segmentation.

Confirm that Fdr and Str are the inputs for the Flow Direction Grid and the Stream Grid respectively. Otherwise if we are using our sinks for inclusion in the stream network delineation, the sink watershed grid and sink link grid inputs are Null. The output is the stream link grid (default name StrLnk).

And then Press ok. Upon successful completion of this process, the link grid StrLnk is added to the map. At this point, we can notice how each link has a separate value. Then Save the map document.

g) *Catchment grid delineation*

This function creates a grid in which each cell carries a grid code (value) indicating that to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid.

On the ArcHydro toolbar, select Terrain Pre-processing -> Catchment Grid Delineation.

Fig3.4 Catchment grid delineation

Confirm that the input to the Flow Direction Grid and Link Grid are Fdr and Lnk respectively. The output is the Catchment Grid layer. The default name (Cat).Press OK. Upon successful completion of this process, the Catchment grid Cat is added to the map. If we want to recolour the grid with unique values to get a nice display (use properties->symbology)

3.4.5 Catchment Polygon Processing Drainage line, Adjoint catchment, Drainage point

The Three functions Drainage Line Processing Adjoint Catchment Processing and Drainage Point Processing convert the raster data developed to the vector format. The rasters created up to now have all been stored in a folder (i.e. Layers). The vector data will be stored in a feature dataset also named Layers within the geo-database associated with the map document. Except that otherwise specified under AP Utilities-Set Target locations the geo-database inherits the name of the map document (Terrain.mdb in this case) and the folder and feature dataset inherit their names from the active data frame which by default is named Layers.

On the Arc-Hydro toolbar, select Terrain Pre-processing -> Catchment Polygon Processing. Catchment polygon processing converts catchment grid into catchment polygon feature.

Confirm that the input to the Catchment Grid is Cat. The output is the Catchment polygon feature class, having the default name (Catchment).

Press ok. Upon successful completion of this process, the polygon feature class Catchment is added to the map. Open the attribute table of Catchment we can notice that each catchment has a Hydro ID assigned that is the unique identifier of each catchment within the Arc Hydro. Each catchment also has its Length and Area attributes. These quantities are automatically computed when a feature class becomes part of a geo-database.

a) Drainage Line

This function converts the input Stream Link grid into a Drainage Line feature class. Each line in the drainage feature class carries the identifier of the catchment in which it resides. On the ArcHydro toolbar, select Terrain Pre-processing -> Drainage Line Processing.

Confirm that the input to Link Grid is Lnk and to Flow Direction Grid Fdr. The output Drainage Line has the default name (Drainage Line).
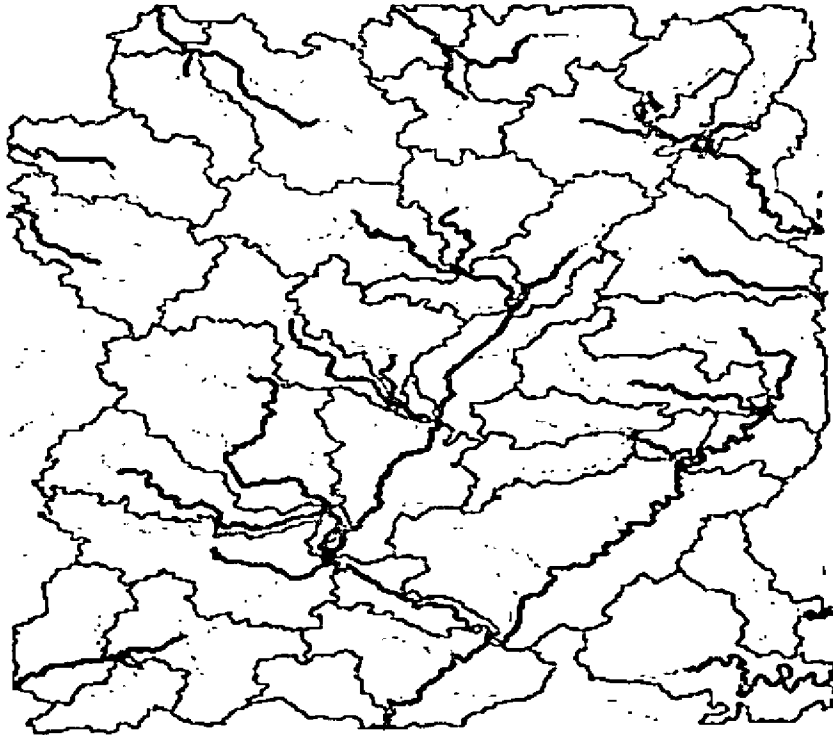
Fig: 3.5   Drainage line map

Press OK. Upon successful completion of this process, the linear feature class Drainage Line is added to the map.

b) Adjoint Catchment

This function generates the aggregated upstream catchments from the Catchment feature class. For each catchment that is not a head (starting) catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an adjoint catchment tag. This feature class is used to speed up the point delineation process.

On the Arc Hydro toolbar, select Terrain Pre-processing -> Adjoint Catchment Processing. Confirm that the inputs to Drainage Line and Catchment are respectively

Drainage Line and Catchment. The output is adjoint Catchment, with a default name (Adjoint Catchment).

Press ok. Upon the successful completion of this process, we will see a message box similar to the one below that will give you a summary of the number of catchments that were aggregated to create the adjoint catchments.click ok, and a polygon feature class named Adjoint Catchment is added to the map.

c) Drainage Point

This function allows generating the drainage points associated to the catchments.

On the Arc Hydro toolbar, select Terrain Pre-processing -> Drainage Point Processing. Confirm that the inputs are as below. The output is Drainage Point with the default name (Drainage Point).

Press ok. Upon the successful completion of this process, the point feature class "Drainage point" is added to the map.

3.4.6 Watershed Processing

Arc Hydro toolbar also provides a widespread set of tools for delineating watersheds and sub watersheds. These tools rely on the datasets derived in terrain processing. This part of the exercise will expose you to some of the Watershed Processing functionality in Arc Hydro tools.

3.5 TERRAIN PROCESSING AND HEC-GEOHMS MODEL DEVELOPMENT

Open Arc-Map. Create a new empty map. Right click on the menu bar to see the context menu showing available tools and check the HEC-GEOHMS menu. And now we can see the HEC-GEOHMS toolbar added to Arc-Map.

Click on the Add icon to add the raster data. In the dialog box, we can navigate to the location of the data; select the raster file Thuthapuzha_dem containing

the DEM for Thuthapuzha and click on the Add button. The added file will then be listed in the Arc Map Table of contents. Similarly add stream.shp, and save the map document. Save the map document as Thuthapuzha.mxd.

3.5.1*Terrain Pre-processing*

Creation of Slope Grid

Terrain processing involves using the DEM to create a stream network and catchments.

Towards the end of the section we will have the following datasets:

Raster Data:

1. Raw DEM (File name: Thuthapuzha_dem)

2. HydroDEM (File name: Fil)

3. Flow Direction Grid (File name: Fdr)

4. Flow Accumulation Grid (File name: Fac)

5. Stream Grid (File name: Str)

6. Stream Link Grid (File name: StrLnk)

7. Catchment Grid (File name: Cat)

Vector Data:

1. Catchment Polygons (File name: Catchment)

2. Drainage Line Polygons (File name: Drainage Line)

3. Adjoint Catchment Polygons (File name: Adjoint Catchment)

In addition to this datasets, we can also get the slope grid by using the Arc Hydro toolbar.

To create a slope grid using Arc Hydro tools, select Terrain pre-processing -> Slope. Confirm that the input as Thuthapuzha_dem, slope type is percent rise, and the output will be a slope grid with the default name (Wsh Slope).

This concludes the terrain processing part. What we have produced is a hydrologic skeleton that now we have used to delineate watersheds or sub-watersheds for any given point on delineated stream network. The next part of this tutorial

involves delineation of a watershed to create a HEC-HMS model using HEC-GeoHMS. Save your map document.

3.6. HEC-HMS MODEL DEVELOPMENT USING HEC-GEOHMS

Before we continue, please make sure that we have the following datasets in the map document from the previous part.

Raster Data:

1. Raw DEM (File name: Thuthapuzha_dem)

2. HydroDEM (File name: Fil)

3. Flow Direction Grid (File name: Fdr)

4. Flow Accumulation Grid (File name: Fac)

5. Stream Grid (File name: Str)

6. Stream Link Grid (File name: Str Lnk)

7. Catchment Grid (File name: Cat)

8. Slope Grid (File name: Wsh SlopePct)

Vector Data:

1. Catchment Polygons (File name: Catchment)

2. Drainage Line Polygons (File name: Drainage Line)

3. Adjoint Catchment Polygons (File name: Adjoint Catchment)

Save the map document.

3.6.1 HEC-GEOHMS Project Setup

The HEC-GEOHMS project setup menu has tools for defining the outlet for the watershed, and delineating the watershed for the HEC-HMS project. As multiples of HMS basin models can be developed by using the same spatial data, these models are managed by defining two feature classes: Project Point and Project Area.

Management of models through Project Point and Project Area. Let users see areas for which HMS basin models are already created, and also allow users to rebuild models with different stream network threshold. It is also convenient to delete projects and associated HMS files through Project Point and Project Area option.

Dataset Setup: Select HMS Project Setup -> Data Management on the HEC-GeoHMS Main View toolbar. Confirm/define the corresponding map layers in the Data Management window as show. Click OK.

To create a new HMS Project, click on Project Setup->Start New Project. Confirm Project Area for Project Area and Project Point for Project Point, and click OK.

Note: For some reason, if you get an error message about accuracy/resolution of the data, this has to do with tolerances for x, y, m, z coordinates in your spatial coordinates which you need to fix in Arc-Catalog).

This will create Project Point and Project Area feature classes. In the next window, provide the following inputs:

If we click on Extraction Method drop-down menu, we will see another option "A new threshold" that will delineate streams based on this new threshold for the new project. For now accept the default original stream definition option. We can write some metadata if we need, and finally choose the outside Main view Geodatabase for Project data location, and browse to your working directory where Thoothapuzha.mxd is stored. Click ok on the message regarding successful creation of the project. We will see that new feature classes Project Area and Project Point are added to Arc Maps table of contents. These feature classes are added to the same geo-database Thoothapuzha.gdb.

Next Zoom-in to downstream section of the Thuthapuzha to define the watershed outlet as shown below:
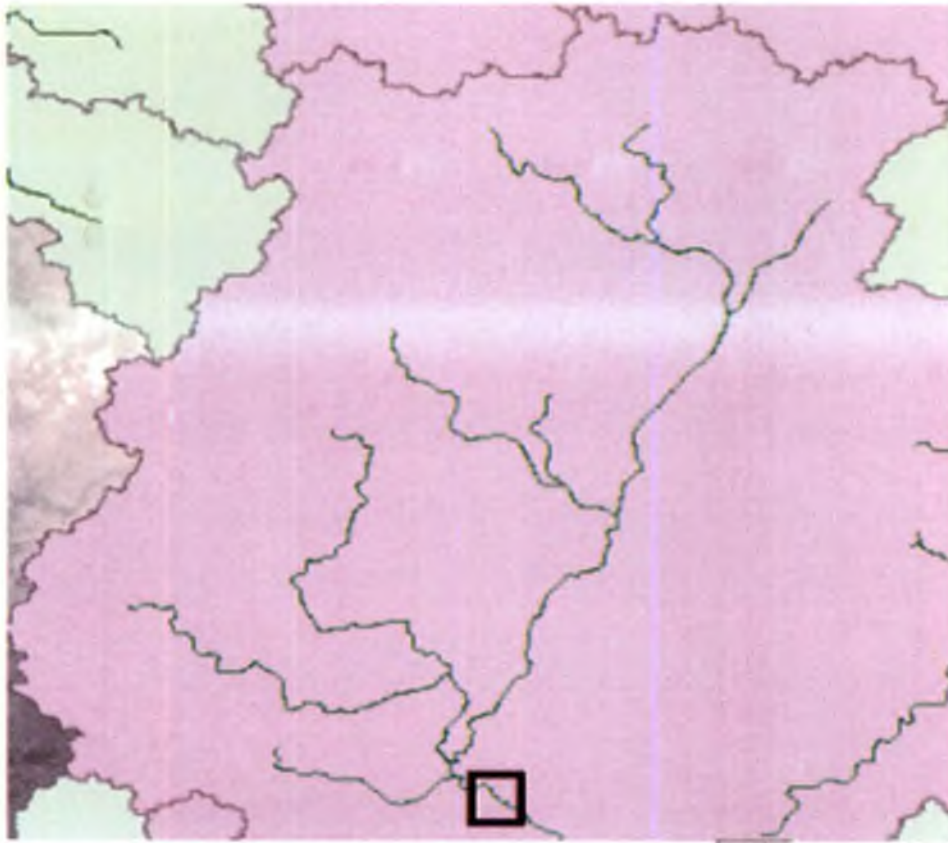
Fig 3.6 DEM for selecting watershed outlet

Select the Add project Points tool on the HEC-GEOHMS toolbar, and then click on the downstream outlet area of the Thuthapuzha to define the outlet point as shown below as red dot:

Then accept the default Point name and description (Outlet), and click ok. This will add point for the watershed outlet in the Project Point feature class. Save the map document.

Next, select HMS Project Setup->Generate Project. This will create a interlock (by delineating watershed for the outlet in Project Point), and then display a message box. If we want to create a project for this hatched area as shown below:

Fig 3.7 Selecting watershed Outlet
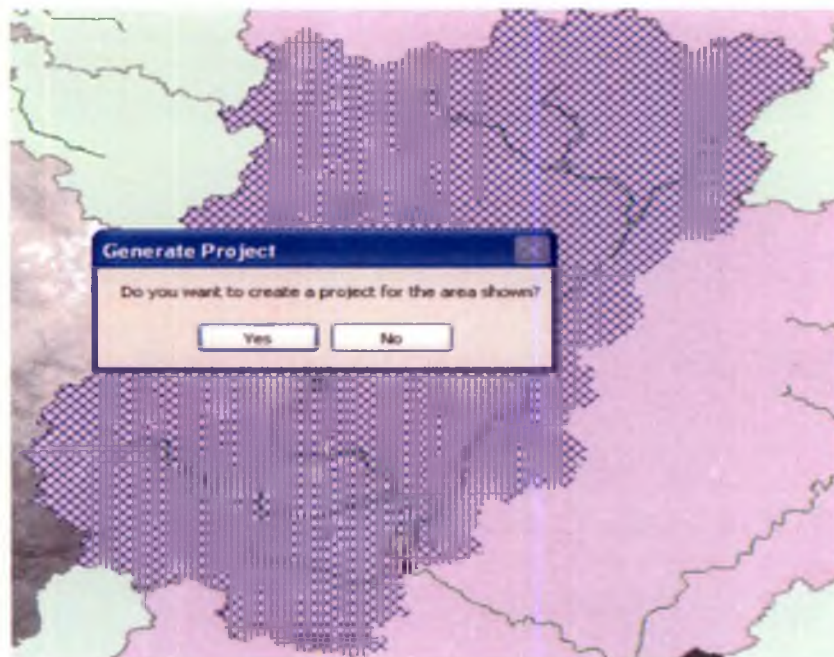
Fig 3.8 Selecting area of sub basin

(Note: This part could be challenging sometimes. If we face any problem in creating Project Area, just delineate a watershed (using the point delineation tool) in Arc Hydro for the Project Point feature, and load this watershed polygon into Project Area feature class. Make sure the Hydro ID of Project Area is same as Project ID of Project Point. Also we need to make sure the name and description match with each other).

Click yes on the message box. And next confirm the layer names for the new project (leave default names for Sub basin, Project point, River and Basin header), and then Click ok. This will create a new folder inside your working folder with the name of the project

3.6.2 Basin Processing

The basin processing menu has features such as revising sub-basin delineations, dividing basins, and merging streams. For merging basins, we will follow the process that allow us to merges two or more adjacent basins into one. Zoom-in to the area marked in the rectangle below:

Select the three adjacent basins (shown above) using the standard select tool. Click on Basin processing-> Basin merge.

We will get a message asking to confirm the merging of selected basins (with basins hatched in background), then click Yes. Similarly merge two more sub-basins as shown below:
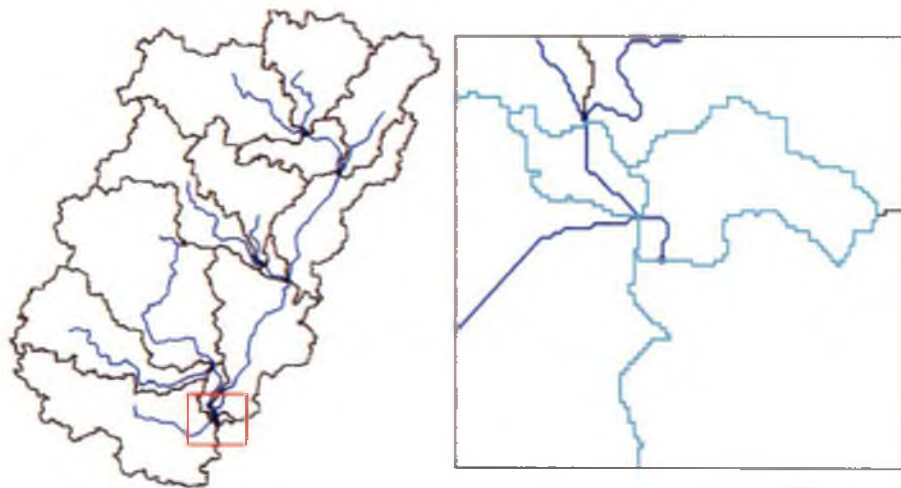
Fig 3.9 Sub basin delineation, Merging streams

As a result of this merging, we now have 12 sub-basins and 15 river segments in the project. Save the map document.

3.7. HMS INPUTS/PARAMETERS: RIVER AUTO NAME, BASIN AUTO NAME, HMS UNITS

The hydrologic parameters menu in HEC-GeoHMS provides tools to estimate and assign a number of watershed and stream parameters for use in HMS. These parameters include SCS curve number, Time of concentration, channel routing coefficients, etc.

We can specify the methods in the HMS. It will use for transform method (rainfall to runoff) and routing (channel routing) using this function. There is a choice, this can be modified and/or assigned inside of HMS.

Select Hydrologic parameters->Select HMS processes. Confirm the input feature classes for Sub basin and River, and then click ok. Choose SCS for Loss method (attaining excess rainfall from total rainfall), SCS for Transform method (for converting excess rainfall to direct runoff), none for Base flow type, and Muskingum for Route method (channel routing). Then click ok.

You can open the attribute table of sub basin feature class to see that the sub basin methods are added to Loss method, Transform method, and Base method fields, respectively. The Muskingum method is added to Route method field in the River feature class. You can treat these methods as tentative which can be changed in HMS model. Save the map document.

a) HMS Schematic

This tool creates a GIS representation of the hydrologic system using a schematic network with basin elements (links/nodes or junctions/edges) and their connectivity. Select HMS->HMS Schematic. Confirm the inputs, and click ok.
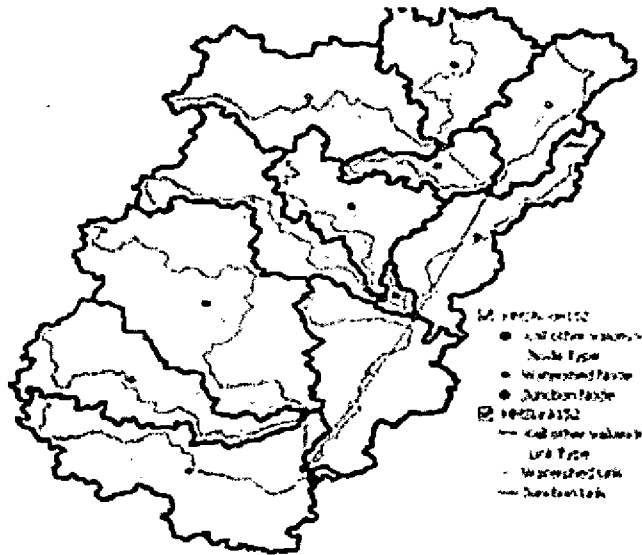
Fig 3.10 HEC-HMS Model

After the schematic is created, you can get a feel of how this model will look like in HEC-HMS by toggling /switching between regular and HMS legend. Select HMS
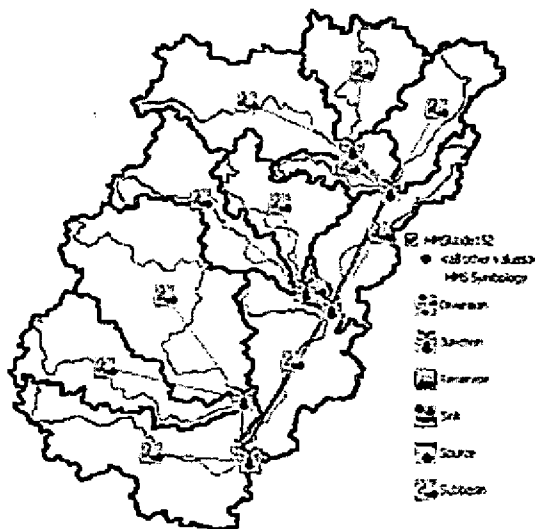
Fig: 3.11 Legends of HEC-HMS

>Toggle HMS Legend->HMS Legend. we can keep whatever legend we like.

Save the map document.

b) HMS Project

This function copies all the project specific files that we have created (.met, .map and .met) to a specified information book, and creates a .hms file that will contain information on other files for input to HMS. Select HMS->Create HMS Project.

Provide locations for all files. Even if we did not create a gage file, there will be a gage file created when the met model file is created. Give some name for the Run, and leave the default information for time and time interval unchanged. This can be changed in HEC-HMS based on the event we will simulate. Then Click ok.

If an.hms file already exist in that folder, we will get a message asking that we have to respond to that message a project file report will be displayed as shown below:

c) *Opening the HMS Model*

This section briefly explains how to interface or open the project files created by GeoHMS using HMS.

Open HEC-HMS, and select File->Open. Browse to Thuthapuzha.hms file, and click Open. We will see that two folders: Basin models and Meteorologic models will be added to the Watershed Explorer (window on top-left) in HEC-HMS. Expand the Basin models folder and click on Thuthapuzha. This will display the Thuthapuzha schematic. And then click on View->Background map, and then add the river and basin shapefiles to see the watershed as shown below.

If you expand the Thuthapuzha basin in watershed explorer, we will see the list of junctions, reaches and sub basins. You can click on any reach and see its associated methods. For example, when you click on a Reach, we will see that Muskingum routing method is associated with it. Similarly, if we click on a Watershed, we will see SCS Curve Number (for abstractions) and SCS Unit Hydrograph (for runoff calculations) are associated with it.

Again, if you click on SCS Curve Number, we will see corresponding parameters in the Component window as shown below. All this information, which is now independent of GIS, which is extracted from attributes that we created in HEC-GEOHMS.

3.7.1 (c) Hydrologic parameter estimation

After extraction of the physical characteristics of the streams and sub basins, a number of hydrologic parameters are estimated. These are the model input parameters used in HEC-HMS. HEC-GEOHMS has the tools to estimate and assign a number of watershed and stream parameters (i.e.CN, loss rates, reach routing, and time of concentration). In order to simulate the process of direct runoff of excess precipitation on the watershed, the specifications for this project included a loss and transform method

The SCS CN loss method was selected to determine the loss of total precipitation for the watershed during rainfall events. This loss method equates the sum of infiltration and precipitation left on the surface equal to the total incoming precipitation.

A precipitation transform method (converting rainfall to runoff) is selected to generate actual surface runoff. Several HMS options are available and this research used the SCS unit hydrograph (UH) method. The basic concept of the SCS UH is a dimensionless, single-peaked UH that when watershed lag time is specified, an entire

hydrograph can be generated from precipitation. Lag is the time separation between the centroid of the rainfall excess hyetograph and the peak of the hydrograph. Lag is empirically related to time of concentration by: Lag = 0.6(T_C).

Channel characteristics for the reach routing is an estimated parameter in GIS and performed in the same way the NRCS channel flow regimes; however, the parameter needs to be entered manually into the HEC-HMS model. The Muskingum method was selected for reach routing as a placeholder until the simulated parameter in the channel reaches are established through HEC-HMS optimization trials

(d) HEC-HMS Model File

Upon completion of the previous steps, HEC-GEOHMS verifies all the data for consistency. The two data project files were checked for unique names us for river reaches and sub basins in order to keep data separated and not risk any overwriting or loss of information. Additionally it confirms that river reaches and centroids are contained within each sub basin and that there is connectivity between the stream segments, sub basins and the outlet point. Once confirmed, the project schematic of the hydrologic system was generated to show sub basin nodes and reach links/junctions. Geographic coordinates are tabulated for each hydrologic feature to maintain the geospatial information after export. Finally a background map to capture the geographic information of the sub basin boundaries and stream reaches is prepared for export. A HEC-HMS basin file was generated containing all the hydrologic elements, their connectivity, and related geographic information

3.8. WATERSHED DELINEATION

HEC-HMS uses parameters averaged in space and time to simulate the runoff process. The size of sub basins, routing reaches, or computation interval is selected based on the basin physiographic, available rainfall data, available stream flow data, and required accuracy. A watershed is subdivided into small and relatively homogeneous sub basins according to drainage. It provides based on mapped or digital topography. The size of a sub basin should generally be in the range of 1–10

mi ^{2} because of limitations of UH theory, especially in urban areas. Routing reaches are identified, and the overall order of the runoff computation is defined (from upstream to downstream) for input to HEC. Routing reaches should be long enough so that a flood wave will not travel faster than the computation time step.

3.8.1 Steps in watershed modelling

With so many hydrologic models available to the hydrologist or civil engineer, very little new model development is currently being supported. Rather, one must select one of the available simulation models based on characteristics of the system to be studied, the objectives to be met, and the available budget for data collection and analysis. Once the model is selected, the steps involved in watershed simulation analysis generally follow the sequence of order.

Steps in watershed modelling

1. Select the model based on study objectives and watershed characteristics, availability of data, and project budget.

2. Obtain all necessary input data-rainfall data, digital topography, land use and soils, infiltration, channel characteristics, stream flow data, design floods, and reservoir data.

3. Evaluate and refine study objectives in terms of simulations to be performed under various watershed environments.

4. Choose methods for determining sub basin hydrographs and channel routing

5. Calibrate model using historical rainfall, stream flow and existing watershed conditions. Verify model using other events under different conditions while maintaining same calibration parameters.

6. Perform the model simulations using historical or design rainfall various conditions of land use and various control scheme for reservoirs, channels or diversion to the extent possible.

7. Perform the sensitivity analysis on input rainfall, routing parameters and hydrograph parameters as necessary.

The selection of a model is a very difficult and important decision, since the success of the analysis hinges on accuracy of the results. In general, unless digital watershed data are extensive in space and time, the usual approach to watershed analysis is to use a deterministic event model with lumped parameter concepts for developing hydrographs and flood routing

Advances in computer hardware and software since the 1970s combined with larger and more extensive hydrologic data-monitoring efforts allowed for the development and application of a number of models in hydrology. These computer models can be used for a variety of purposes in simulating hydrologic response under a number of assumptions within a watershed area. Such models incorporate various equations to describe hydrologic transport processes and storages and to account for water balances in space and time. Complex rainfall patterns and heterogeneous basins can be simulated with relative ease if watershed and hydrologic data are sufficient, and various design and control schemes can be tested with hydrologic mode

Table 3.2 Hydrological Models

Model Type	Example of Model
Lumped parameter	H EC-HMS, Snyder or Clark UH
Distributed	Vflo, MIKE URBAN, MIKE FLOOD
Event	H EC-HMS, SWMM, SCS TR-20
Continuous	S WMM, HSPF, Vflo
Physically based	H EC-HMS, SWMM, HSPF, Vflo
Stochastic	Synthetic stream flows

Distributed parameter models attempt to describe physical processes and mechanisms in space, as evidenced by certain classes of hydrologic simulation models. Kinematic wave methods have become very popular to compute both overland flow and channel routing. This is due to heightened interest in distributed hydrologic modelling with the advent of GIS and digital elevation data for watersheds that has become available since the mid1990s.

3.8.2 Advantages of simulation models

- A major advantage of simulation models is that the insight gained by gathering and organizing data required as input to the mathematical algorithms that comprise the overall model system.

- This exercise can often guide the collection of additional data or direct the improvement of mathematical formulations to better represent watershed behaviour.

- Another advantage is that many alternative schemes for water supply systems, for urban development, or flood control options can be quickly tested and compared with simulation models.

3.8.3 Limitations of simulation models

- The major limitation of simulation models is the inability to properly calibrate and verify applications in which input data are lacking.

- Current practice assumes that the simplest model that will satisfactorily explain the system for the given input data should be used.

- Model accuracy is largely determined by available input data and observed input and output time series at different locations in a watershed.

- Modern radar rainfall, hydrologic, and topographic datasets are now available for many areas, and model accuracy has increased accordingly.

Despite their limitations, simulation models still provide the most logical and scientifically advanced approach to understanding the hydrologic behaviour of

complex watershed and water resources systems. (Maidment 1993, DeVries and Hromadka 1993, Hoggan 1997, James and James 1998a, and McCuen 2005).

3.9 HEC-HMS MODEL

3.9.1 HEC-HMS 4.0

The hydrological modeling system (HEC-HMS) is designed to simulate the precipitation-runoff processes. It is designed to be applicable in a wide range of ecological areas for solving the widest possible range of problems. This includes the large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for the studies of water availability, future urbanization impact, reservoir spillway design, urban drainage flow forecasting, flood damage reduction, flood plain regulation system approach. The basin model consists of mainly two models such as basin model and meteorological model.

3.9.2 Program setup and application

- Create a new project.
- Enter Time-series, paired data, and grid data.
- Create a basin model.
- Create a meteorological model.
- Create control specifications.
- Create and compute a simulation run.
- View results.
- Create other alternatives, compute, and compare results.
- Save the project and exit.

3.9.3 Basin model in HEC-HMS

The physical representation of a watershed is related with a basin model. Hydrologic elements are connected in a dendrite network to simulate the runoff process. Available elements are sub-basin, reach, junction, reservoir, diversion, source and sink. Computation proceeds from upstream elements in a downstream

direction. A classification of different methods is available to simulate infiltration losses. Options for event modelling include Initial constant, SCS curve number, and Gridded SCS curve number, Exponential, Green-Amp, and Smith Parlange.

The one-layer deficit constant method can be used for simple continuous modelling. The five-layer soil moisture accounting method can be used for simple continuous modelling of complex infiltration and evapotranspiration environments. Gridded methods are available for both the deficit constant and soil moisture accounting methods. There are seven methods are included for transforming excess precipitation into surface runoff. Unit hydrograph method includes the Clark, Snyder and SCS techniques. User-specified unit hydrograph or S-graph ordinates can also be used. The modified Clark method, Mod-Clark is a linear quasi-distributed unit hydrograph method that can be used with gridded meteorological data. The performance of kinematic wave method with multiple planes and channels is also included.

Sub basin soil types can be divided into Pervious Surface and Directly-connected Impervious Surface in HEC-HMS. With Impervious Surface, all the precipitation transforms to the runoff and is expressed in the percentage of basin area. In this research, we used the SCS CN method, which was developed by U.S. Soil Conservation Service to estimate direct runoff. The SCS curve number method is a simple, widely used and efficient method for determining the nearly equal amount of runoff from a rainfall, even in a particular area. Although the methods designed for a single storm event, it can be scaled to find average yearly runoff values.

3.9.4 Sub basin

It represents the physical areas within the basin and produce a discharge hydrograph at the outlet of their respective areas. The hydrograph produced is calculated from precipitation data minus the losses. The resulting precipitation excess is transformed using a UH methodology to compute runoff at the outlet, which is then added to base flow. Each component can be calculated using several methods. The

area, loss rate, runoff, and base flow inputs for each sub basin are entered into the basin model for each one using the Watershed Explorer.

3.9.5 Loss rates

It can be simulated by one of several methods. For event modelling, techniques include initial and constant, SCS curve number, gridded SCS curve number and Green and Ampt methods.

The one-layer deficit and constant model can be used for simple continuous modelling. For modelling of complicated infiltration and evapotranspiration environments, the five-layer soil moisture accounting model can be used. The method is changed in a simple menu-driven window, and the input data are entered on the "Loss" tab in the editor.

Table 3.3 HEC-HMS loss rate methods

Method	Description
Initial and constant	Initial loss volume is satisfied and then constant loss rate begins.
HEC exponential	Loss function is related to antecedent soil moisture condition and is a continuous function of soil wetness.
SCS curve number	Initial loss is satisfied before calculating cumulative runoff as a function of cumulative rainfall using SCS methods
Holtan method	Infiltration rate is computed as an exponential function of available soil moisture storage from Holtan's equation.
Green and Ampt	Infiltration rate is computed from the Green and Ampt equation as a function of soil moisture and hydraulic conductivity
Deficit/Constant	First an initial deficit storage is filled, and then infiltration rates can be specified on a monthly basis.

SMA	Soil moisture accounting assigns a value of initial storage to all layers of the ground using a gridded method.

3.9.6 Transform methods

Transform method which convert rainfall excess into surface runoff, it can also be simulated using a variety of tools. HEC-HMS includes the popular Clark TC & R and SCS UH techniques, as well as the Snyder Method or user specified UH. Spatially distributed runoff can be computed with the quasi-distributed linear transform of cell-based precipitation and infiltration.

The Modified Clark method (Mod Clark) is a linear quasi-distributed UH method that can be used with gridded precipitation data. If the Mod-Clark transform with gridded rainfall is used, a file that contains characteristics of sub basin grid cells is required. HEC-HMS can handle grid cell depiction of the watershed for distributed runoff computations. The kinematic wave method with multiple planes and channels is also included.

Table 3.4 Surface runoff methods in HEC-HMS

Unit hydrograph input directly
Clark hydrograph method ($TC\&R$ method Snyder unit hydrograph method)
SCS method (CN method + SCS UH)
Kinematic wave for overland hydrograph
Mod-Clark
User-specified S-graph

3.9.7 Base flow

It takes into account normal flow through a channel or the effects of ground water. HEC-HMS offers two methods for base flow calculation: recession and constant monthly. The recession method is an exponential decay function of a defined starting base flow. For the constant monthly method, the user simply enters a constant

base flow value for each month. No base flow is also an option, and in simple hydrologic models over short time periods or highly urbanized basins with channels, base flow can usually be neglected.

3.9.8 Flood routing

In HEC-HMS offers a number of options for the reaches and routing of flood hydrographs. The Muskingum method can be used for general routing; routing with no attenuation can be modelled with the lag method. The most popular and accurate is the Modified Pul's method, which can be used to model a reach with a user-specified storage–outflow relationship.

Table 3.5 Flood Routing in HEC-HMS

Method	Description
Muskingum	Storage coefficient (x) plus travel time (K) through each reach
Modified Pul's	Table of storage vs. outflow for each reach based on HEC-RAS water surface profile information—various storages are plotted vs. peak flows in the reach
Kinematic wave	Channel shape, length, slope, and n ; outflow from each reach based on depth of flow in continuity equation and Manning's equation
Muskingum–Cunge 8-point	Same equations and technique as the Muskingum– Cunge but channel is described with 8 station-elevation values
Lag	Direct lag of flow through channel with translation accounted for but not attenuation

3.9.9 Reservoirs

It stores the inflow from upstream elements and produces an outflow hydrograph based on a monotonically increasing storage–outflow relationship. A reservoir can be entered with one of three possible types of relationships: storage vs.

outflow, elevation vs. storage vs. outflow, or elevation vs. area vs. outflow. The outflow structure must be well understood in order to develop an accurate storage–discharge relation. The inflow entering the reservoir must be contained with the minimum and maximum values of the data entered. The user must also select an initial condition of storage, elevation, outflow, or select inflow equal to outflow. The model assumes that elements have a level pool, such as ponds, lakes, or reservoirs. The effect of adding a detention pond to a basin can be modelled by using a reservoir. The input window for a reservoir is used to relate storage to outflow. A reservoir icon is used to represent storage at any point in the watershed and is then connected downstream to a junction.

3.9.10. Sources

These are elements that represent a discharge into the basin as an observed hydrograph or a hydrograph generated by a previous simulation.

They often are used to represent inflow from reservoirs; un modelled headwater regions, or a watershed outside the region. This may be entered as gage data or a constant discharge.

3.9.11 Sinks

These are elements that have an inflow and no outflow. The only inputs are the name and description of the sink. It may represent the lowest point of the drainage area or the outlet.

3.9.12 Diversions

Diversions for hydrologic models use a simple table relating from the inflow to diverted flow and finally to the routed flow. These relationships can be determined using geometric calculations and hydraulic models. Diversions will have two "downstream" connections, one being the routed path and the other the diverted path. The user specifies the diverted flow through the use of a table (inflow-diversion), and whatever flow is not diverted will travel the main path. If the "connected" option is

selected, then the diverted flow will return to the watershed at the downstream location.

3.9.13. Meteorological model

For the meteorological model in HEC-HMS, we considers only about the precipitation influence in HEC-HMS. The duration of the storm events may be too short, and the simulation can ignore the evapotranspiration influence in this model. In HEC-HMS there are7 methods are available in the precipitation those are, Frequency storm, gage weights, Gridded precipitation, SCS storm, inverse distance, Specified hyetograph, and standard project storm. In this study we have used SCS storm is the precipitation method.

3.9.14 Control specifications

Control specification in HEC-HMS set up the duration time and the time interval for simulation. It includes the starting date and time, ending date and time and Computation time Step.

3.9.15 Time-series data

In Time-series data, we needed to set up the discharge gage and precipitation gage in the simulation.

The observed runoff data was inputted in the discharge Gage to compare with the simulated runoff data after the rainfall–runoff model was setup. Thiessen's Polygon method was chosen to divide the represented weight for each rainfall station, we obtained the average rainfall in each sub basin and inputted it in the precipitation data.

3.10 PENMAN'S EQUATION (EVAPOTRASPIRATION)

Penman's equation is based on a combination of the energy-balance and mass-transfer approach. Penman's equation, incorporating some of the modifications recommended by other investigators is

$$PET = \frac{AH_n + E_a\gamma}{E + \gamma}$$

Where,

PET = Daily potential evapotranspiration in mm per day

A=Slope of the saturation vapour pressure vs. temperature curve at the mean air temperature, in mm of mercury per ^0C

H_n = Net radiation in mm of evaporable water per day

E_a=parameter including wind velocity and saturation deficit.

γ =psychrometric constant= 0.49 mm of mercury/ ^0c

The net radiation is estimated by the following equation

$$H_n = H_a(1-r)(a+b\frac{n}{N}) - \sigma T_a^4(0.56-0.092\sqrt{e_a})(0.10+0.90\frac{n}{N})$$

Where,

H_a=incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day.

a = a constant depending upon the latitude ϕ and is given by a=0.29 cosϕ

b= a constant with an average value of 0.52

n = actual duration of bright sunshine in hours

N = maximum possible hours of bright sunshine

r = reflected coefficient (albedo).

Table 3.6 Usual ranges of values r are given below

Surface	Range of r values
Close Ground Crops	0.15-0.25
Bare Lands	0.05-0.45
Water Surface	0.05
Snow	0.45-0.95

3.10.1 Capability of Arc-View 10.3

Arc-View is full-featured geographic information system (GIS) software for visualizing, managing, creating and analysing geographic data. Application of GIS in the geosciences has grown explosively over the past few years as scientists and land-use specialists have been able to prepare thematic maps and determine spatial relations among multiple datasets. Although GIS applications hold great potential for most organizations, their availability and application have largely been limited to institutions that can afford and assemble the necessary hardware, software, datasets and hard-to-find technical expertise.

People can understand the geographic context of data and see relationships and identify pattern in new ways by using Arc-View. A lot of GIS data can be integrated by Arc-View for visualization and analysis, and Arc-View can also help to author maps using simple wizards and an extensive suite of map elements

3.10.2. Mapping Quality by Arc-View Software

The rich set of map interaction tools in Arc View allows navigating and querying a map as well as creating additional information such as hyperlinks that

integrate a map with other information. Arc View allows users to easily build quality maps in many different styles, from base-maps to thematic classifications, and also allows using and composing thousands of symbols and provides a robust labelling environment, including on-the-fly automatic labelling based on attribute values.

3.10.3 Advanced Spatial Analysis

Arc View includes a set of tools and procedures that can analyse spatial data and derive answers from data of a location-dependent nature, utilizing an extensive set of analysis tool in a comprehensive framework that facilitates the creation, use, documentation, and sharing of geo-processing models. We have adjusted the attribute tables of land use and soil data in Arc-GIS.

3.11 HYDROLOGIC SIMULATION

The time span of a simulation is managed by control specifications, which include a starting date and time and an ending date and time, and a time interval. A simulation run is created by combining a basin model, meteorological model and control specifications. Run options include a precipitation or flow ratio capability to save all basin state information at a point in time and ability to begin a simulation run from previously saved state information. Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow and total volume. A time-series tables and graphs are available for the elements. The results from multiple elements and multiple simulation runs can also be viewed.

3.11.1 Running HEC-HMS and viewing results

The user may specify different data sets for each component within a project and then run the hydrologic simulation using different combinations of models.

For example, one can run a 10-year or a 100-year frequency storm model using the same basin model and control specifications to compare the resulting flows. Or, one can model the effects of adding diversions and reservoirs to a basin by saving it under a different name, altering the new basin model, and running the simulation under the same precipitation and control specifications.

With several basin models saved in the same project, running simulations with various models is a simple task. In order to create the scenario for a particular run, go to "Simulation run" under Compute in the main file menu. Select one basin model, one meteorological model, and one control specification. Then run the scenario by selecting "Select run," and subsequently "Compute run," both of which are under Compute in the main file menu. If changes are made to one of the models after a run with the same configuration has been calculated, select the correct run to recalculate. Note that the "Compute" tab beneath the Watershed Explorer allows the user to easily select different runs.

Results can be viewed by going to the "Results" tab beneath the Watershed Explorer, clicking on any object (e.g., sub basin or junction) in the basin model, and selecting from the menu. The program gives the resulting times and flows for each basin element and its immediate upstream elements in the form of a graph, summary table, or time-series table.

3.11.2 Other features

HEC-HMS includes advanced features such as parameter estimation with optimization, soil moisture accounting, GIS and grid-cell hydrology, snowmelt simulation, and improved hydraulics. HEC-GEOHMS is a companion program that allows for the creation of HEC-HMS projects from GIS sources, including digital elevation models, land use data, and other electronic sources.

The parameter estimation and optimization function is used to compare resulting hydrographs to observed hydrographs, so at least one element in the basin must have observed data.

The program automatically estimates the parameters in order to find the best fit of the generated hydrograph to the observed one for one element. It allows the user to set initial values for the parameters of each element along with maximum and minimum values so that the parameter values estimated by the program must fall in a reasonable range.

3.12 MODEL CALIBRATION

The goal of calibration is to identify parameter value adjustments so that the simulated results match the observed hydrographs. The mathematical search is a trial and error analysis (optimization trials) that iterates until the simulated measurements: runoff volume, peak flow, time of peak, and time of centre of mass, is within an acceptable error range (less than 5%) of the observed hydrograph. By comparing measured discharge from a significant event to the model, the reliability of the model is improved.
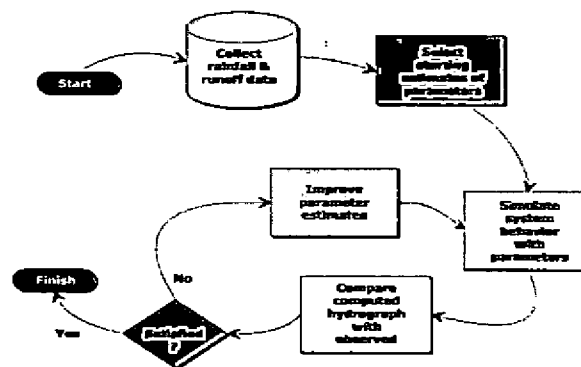

Fig 3.12 Schematic calibration procedure

3.13 MODEL OPTIMIZATION

It describes how observed stream flow can be used to optimize the model performance by automatically estimating the parameters. The optimization process begins with initial parameter estimates and adjusts them so that simulated results match with the observed stream flow as closely as possible. Two different search algorithms are provided that move from the initial parameter estimates to the final best parameter results. A variety of objective functions are provided to measure the goodness of fit between the simulated and observed stream flow in different ways, while parameter estimation using the optimization does not produce perfect results, it can be a valuable aid for calibrating the model.

The quantitative measure of the goodness of fit between the computed result from the model and observed flow is called objective function. An objective function measures the degree of variation between the computed and observed hydrograph.

Optimization trials are the one of the component that can compute the results. Each trial is composed of basin model, meteorological model and time of information. The trial includes the selections for the objective function, search method and parameters to be adjusted in order find an optimal model.

The iterative parameter estimation procedure is used by the program is often called optimization. Initial values for all the parameters are required at the start of the optimization window. A hydrograph is computed at a target element by computing all the parameters.

3.14 MODEL PERFORMANCE AND EVALUATION METHODS

The Criteria for using and evaluating the performance of the models are the overall agreement between predicted and measured runoff discharges, and the model's ability to predict time and magnitude of hydrograph peaks and runoff volume. The following statistical measures were used to quantify the performance

and accuracy of both models during each simulation periods, and combined over all periods:

1. Percent error in peak flow (PEPF): The PEPF considers only the magnitude of computed peak flow and does not account for total volume or timing of the peak flow.

$$\text{PEPF}=100\left|\frac{Q_0(peak)-Q_S(peak)}{Q_Q(peak)}\right| \quad \text{........(1)}$$

Where Q_0, (Q_S) is the observed (simulated) flow.

2. Percent error in volume (PEV): The PEV function considers only the computed volume and does not account for the magnitude or timing of the peak flow

$$\text{PEV}=100\left|\frac{V_0-V_S}{V_S}\right| \quad \text{.........(2)}$$

3. Coefficient of correlation (R), the lag-0 cross correlation coefficient was calculated as:

$$R=\frac{\sum_{t=1}^{N}(O_t-\overline{O})\times(S_t-\overline{S})}{\sqrt{\sum_{t=1}^{N}(O_t-\overline{O})^2\times(S_t-\overline{S})^2}} \quad \text{......(3)}$$

Where, O_t (S_t) is the observed (simulated) flow at time t, and $\overline{O}$, $\overline{S}$ is the average observed (simulated) flow during the calibration.
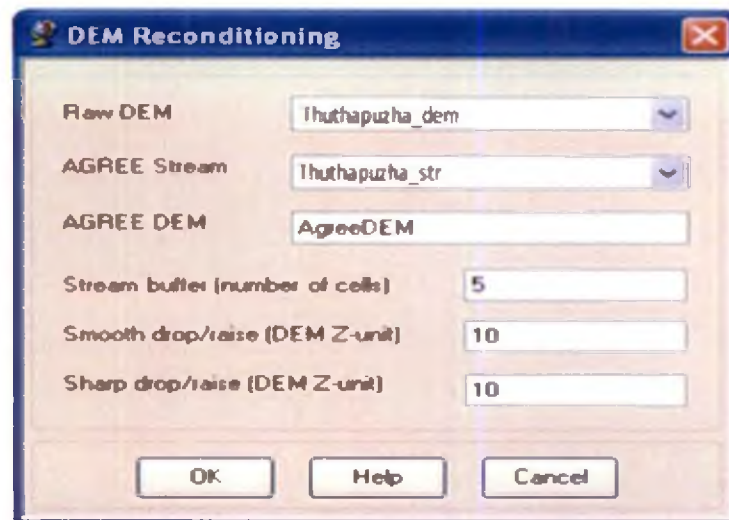
4. The relative root mean squared error, RRMSE, were calculated as:

$$\text{RRMSE}=100\times\sqrt{\frac{1}{N}\sum_{t=1}^{N}\left(\frac{S_t-O_t}{S_t}\right)^2} \quad \text{...(4)}$$

Where, N is the number of stream flow ordinates and the meaning of the remaining symbols is the same as in Equation (3).

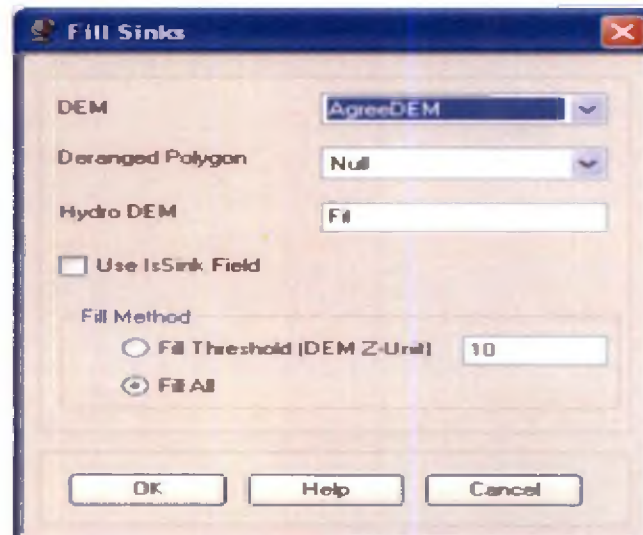Screen shots Related to this Study

DEM reconditioning

Fill Sinks

Fig 3.13. Snapshots of dem reconditing, fill sinks operation
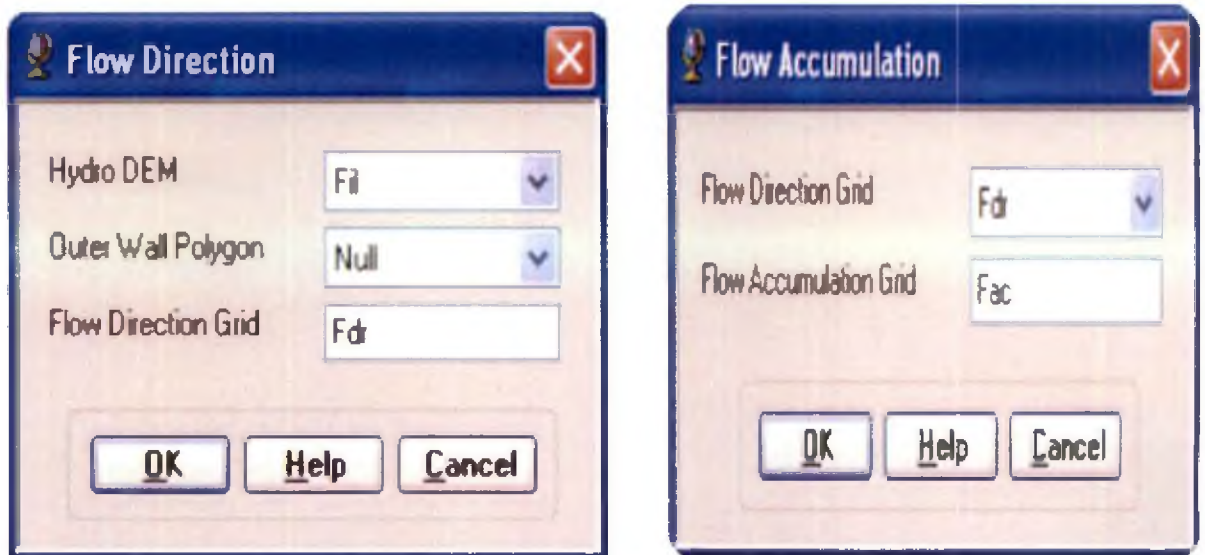
2. Creation Of Flow Direction, Flow Accumulation Map

Fig 3.14 Snapshot of creation of flow direction, flow accumulation in HEC-GEOHMS

3. Creation of Stream, Stream segmentation map
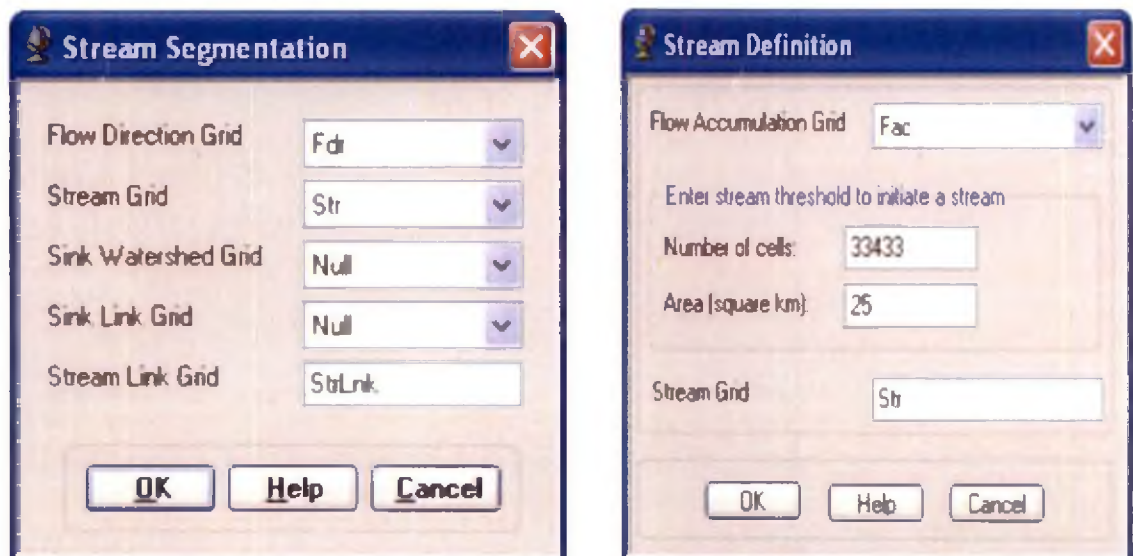
Fig 3.15 Snapshot of creation of stream, stream segmentation map in HEC-GEOHMS

4. Creation of Catchment Grid Delineation, Catchment Polygon Processing

Fig 3.16. Snapshot of creation of catchment grid delineation, catchment polygon processing in HEC-GEOHMS

5.Creation of Adjoint catchment Processing
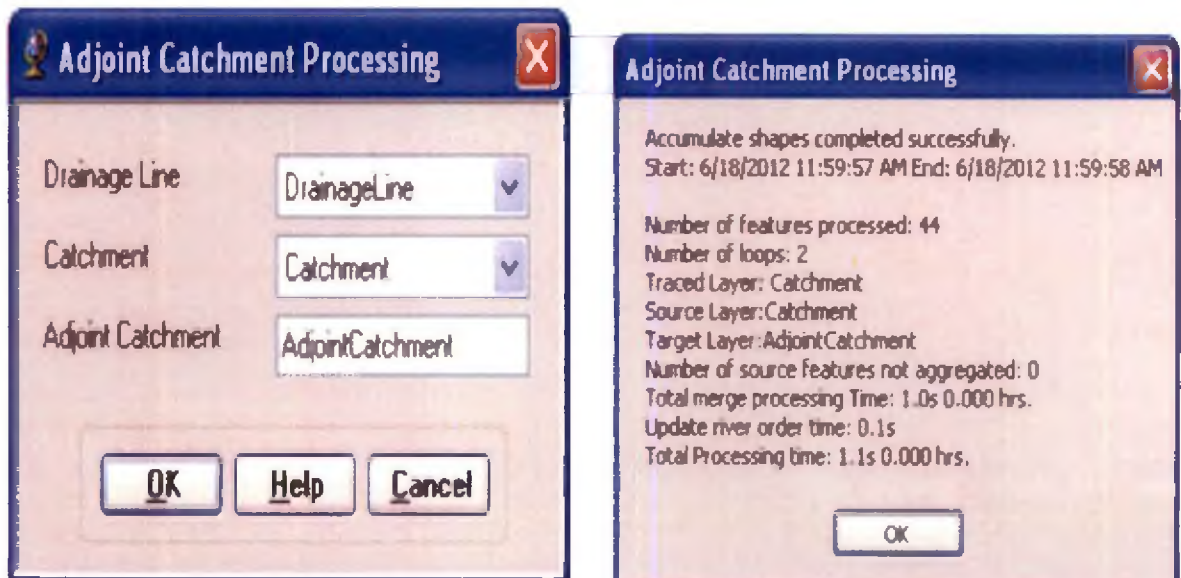
Fig 3.17. Snapshot of creation of   Adjoint catchment processing in HEC-GEOHMS

6. Creation of Drainage Point, Drainage Line Map

Fig 3.18.Snapshot of creation of drainage point, drainage line processing in HEC-GEOHMS

7. Creation of Slope Map

Fig 3.19. Snapshot of creation of slope map

1. HEC-GEOHMS Project Setup

Fig 3.20.Snapshot of HEC-GEOHMS project setup

9. Basin processing

HMS process

Fig 3.21. Shows that snapshot of HMS process

10. Create HMS Project

Fig 3.22.Snapshot of creating HMS project

11. Opening the HMS Model

Fig 3.23. Shows Snapshots of opening the HMS project

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSIONS

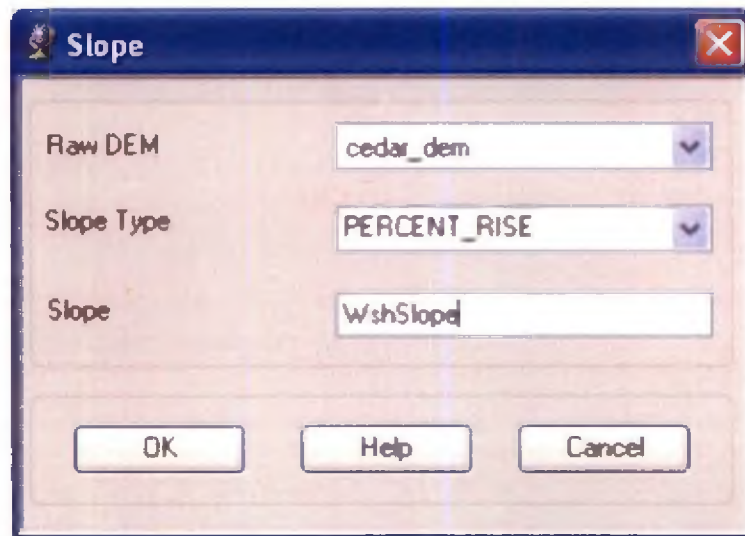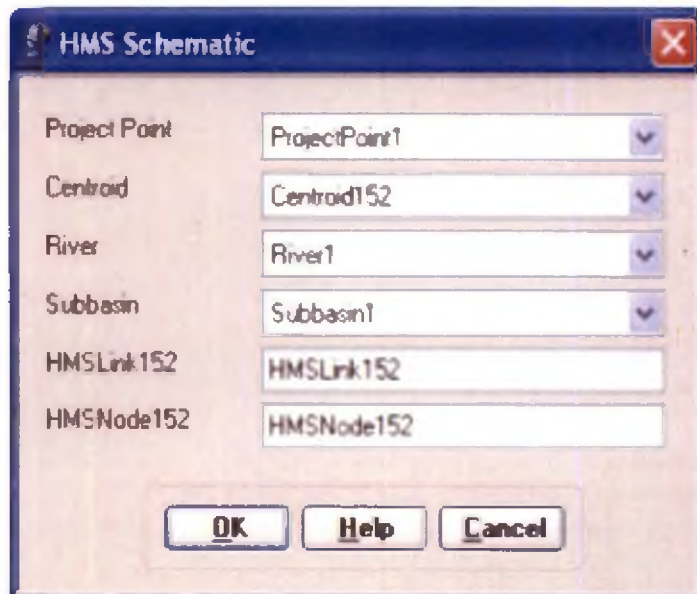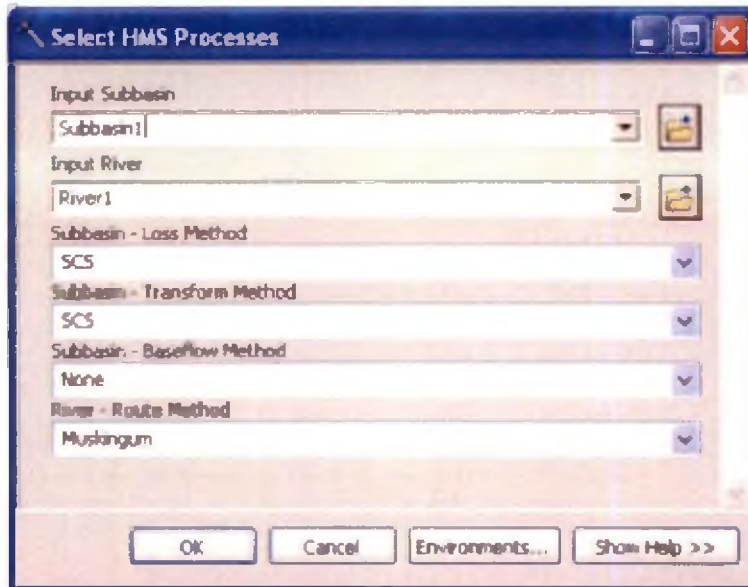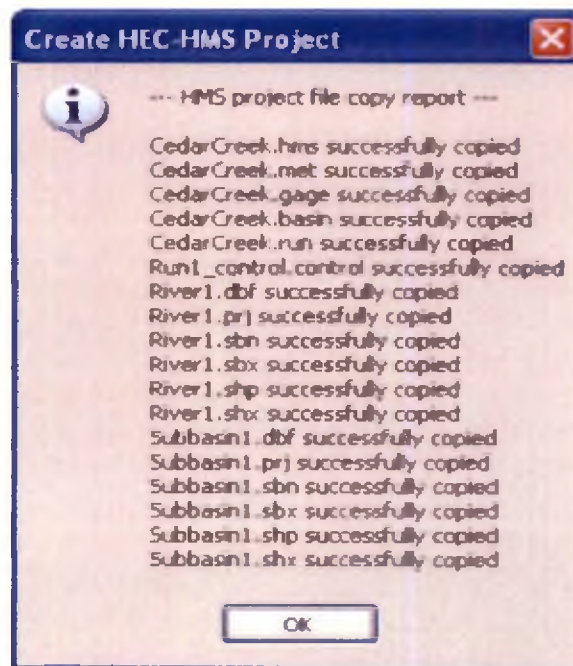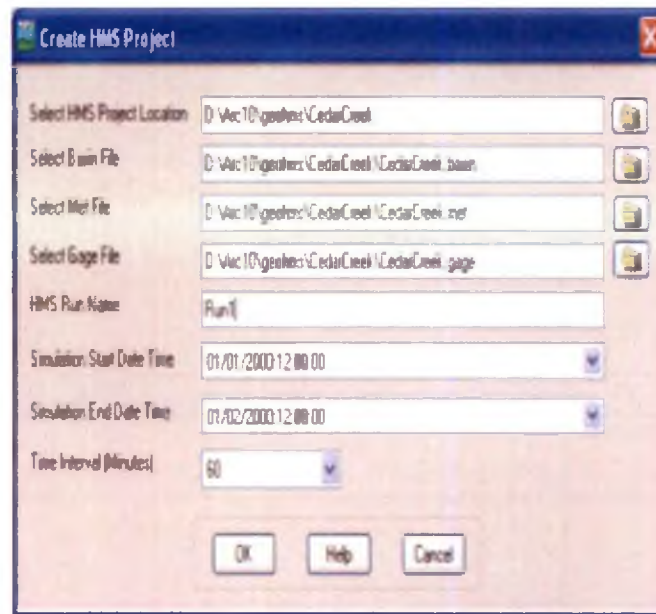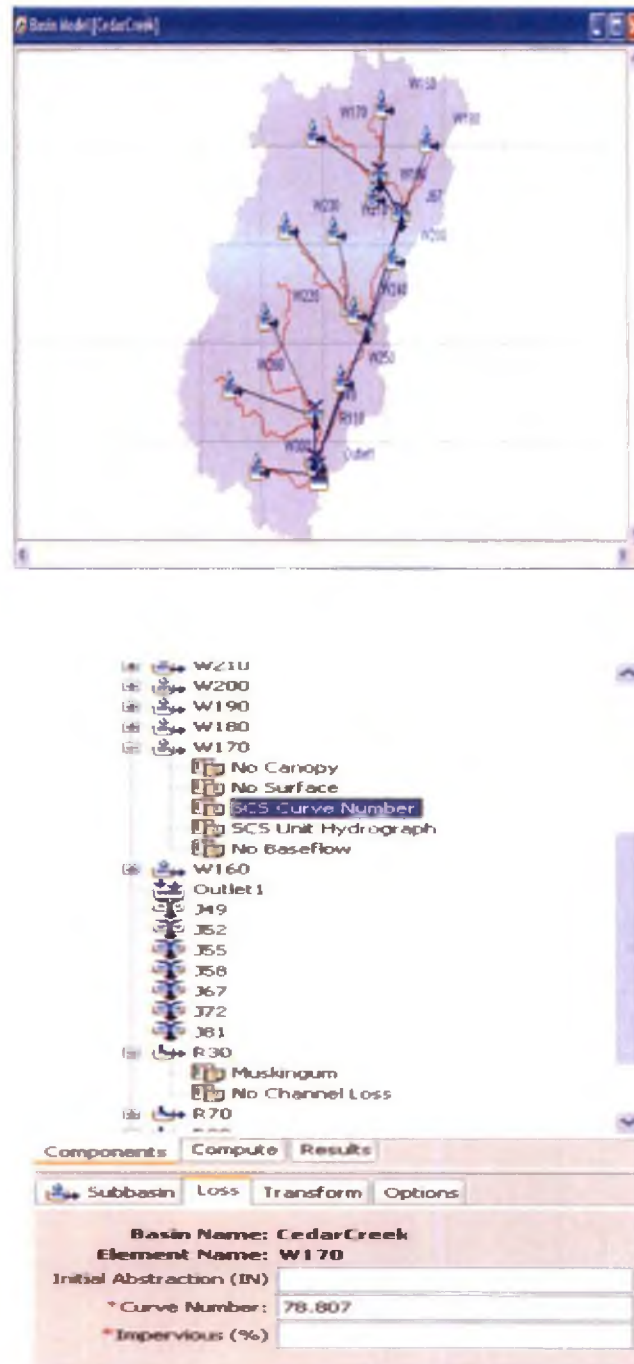Basin model is the most important input to run the model and simulate the rainfall runoff based over the entire watershed to create the basin model in the Thuthapuzha watershed. Here the work was done on the analysis of watershed by using observed rainfall and river flow data for estimating the stream flow discharge in Thuthapuzha watershed. Calibration and validation of watershed was done by using hydrological modelling system HEC-HMS with that extension HEC-GEOHMS was used.

4.1 CATCHMENT CHARACTERISTICS

The digital elevation model of the Thuthapuzha watershed is presented in fig 4.1. The study area falls within three physiographic zones of Kerala state namely the high lands elevation(600-2500m)above mean sea level, the midlands elevation (300–600m) above mean sea level and the low lands elevation (10-300m) above mean sea level. The Silent valley reserve forestis located at the northeastern corner of the Sub-basin(i.e. The core of the Nilgiri Biosphere reserve). The study area experiences a humid tropical climate and wide variation in rainfall varies from 2800 mm to more than 5000mm/year, the rainfall is higher towards the north eastern part. Like this the other part of Kerala State region also experiences two distinct monsoons, namely the south-west monsoon (June-September) and north-east monsoon (October-December). The south west monsoon accounts for about 65% of the annual rainfall, the north east monsoon and the summer showers contribute the rest total annual rainfall in the Sub Basin.

The hypsometric curve of the watershed which shows the area elevation relationship is presented in figure 4.3. The curve shows that about 70% of the basin lies within an elevation band of 20 to 170m and the remaining 30% area is above

170m and has high relief. The digital soil map showing different soil series are shown in the table 4.2. The land use map developed through supervised classification of the satellite imagery shows that there are 29 different land use classes. Major land use types developed in the watershed are rice, mixed crop, forest, range land and urban settlement.
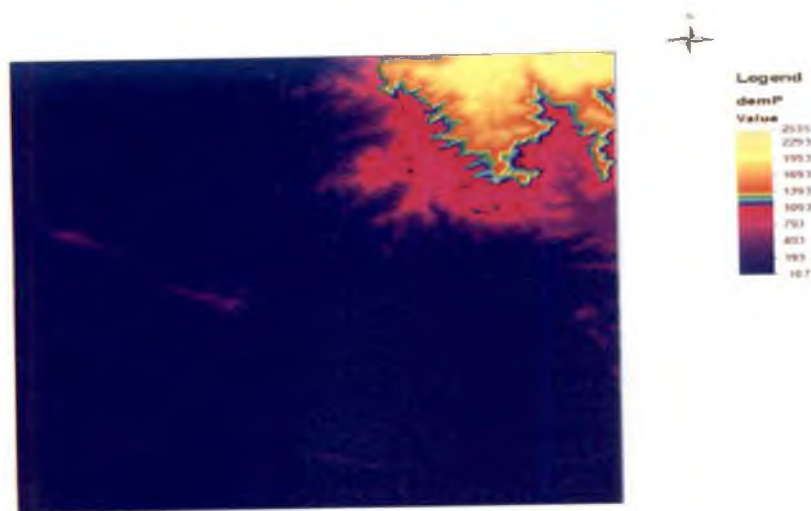
Fig. 4.1 Dem of Thuthapuzha
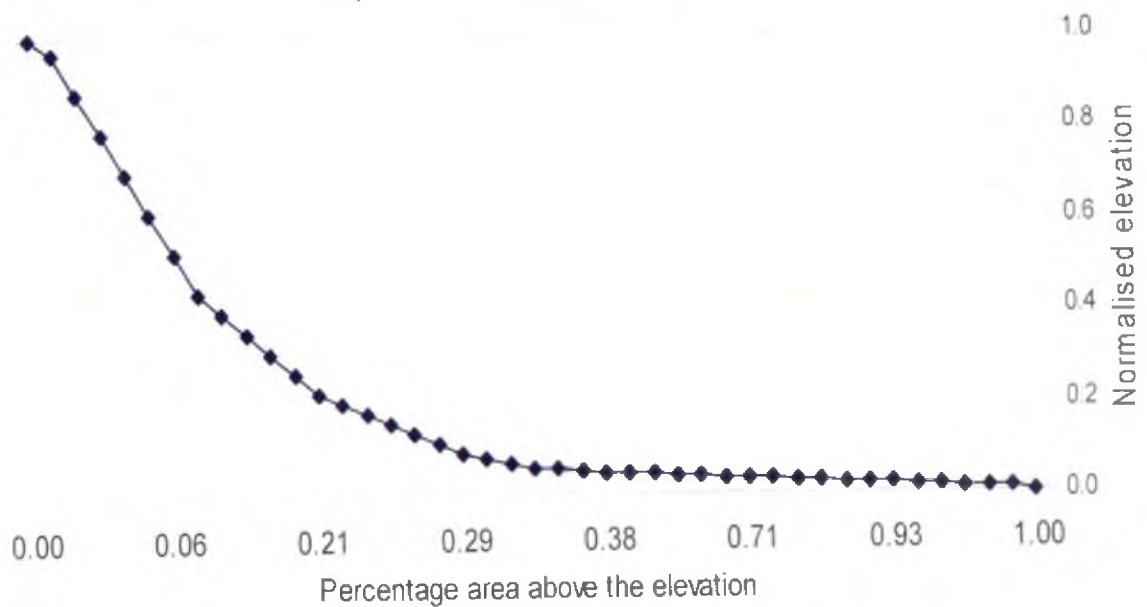
Fig4.2. Hypsometric curve of Thuthapuzha sub basin

Table 4.1. The name and the area of each Gram Panchayat within Thuthapuzha sub basin

Sl. No	Name of the Panchayat	Name of the block	Area(km^2)
1	Kulukkallur	Pattambi	22.8
2	Koppam	Pattambi	20.9
3	Nellaya	Pattambi	27.4
4	Vilayur	Pattambi	17.7
5	Thiruvengapura	Pattambi	20.4
6	Cherupulassery	Sreekrishnapuram	27.6
7	Kadambazipuram	Sreekrishnapuram	39.7
8	Karimpuzha	Sreekrishnapuram	47.4
9	Pookkattukadavu	Sreekrishnapuram	22
10	Sreekrishnapuram	Sreekrishnapuram	29.5
11	Thrikkadivi	Sreekrishnapuram	26.3
12	Vellinezi	Sreekrishnapuram	26.8
13	Alanellur	Manarkkad	58.3
14	Karakurissi	Manarkkad	27
15	Karimba	Manarkkad	69.2
16	Kottappadam	Manarkkad	29.8
17	Kumaraputhur	Manarkkad	37.2
18	Manarkkad	Manarkkad	63.4
19	Kanhirapuzha	Manarkkad	58.4
20	Thachannattukara	Manarkkad	35
21	Tachanpara	Manarkkad	54
22	Thazhekode	Perinthalmanna	45
23	Aliparamba	Perinthalmanna	20.2
24	Elamkulam	Perinthalmanna	21.3
25	Pulamanthole	Perinthalmanna	33.7
26	Moorkannad	Perinthalmanna	11.7
27	Irimbilam	Kuttipuram	24

4.2 SOIL MAPPING UNITS

Based on depth, texture, slope and drainage characteristics the soils of the study area falls into 12 soil mapping units namely K08, K09, K10, K13, K20, K22, K25, K26, and K28 & K30 (KSLUB,1995). The description of the soil mapping units is

presented in Table.4.2 The map showing these units (Fig.2) depicts the spatial distribution of each soil type in the study area.
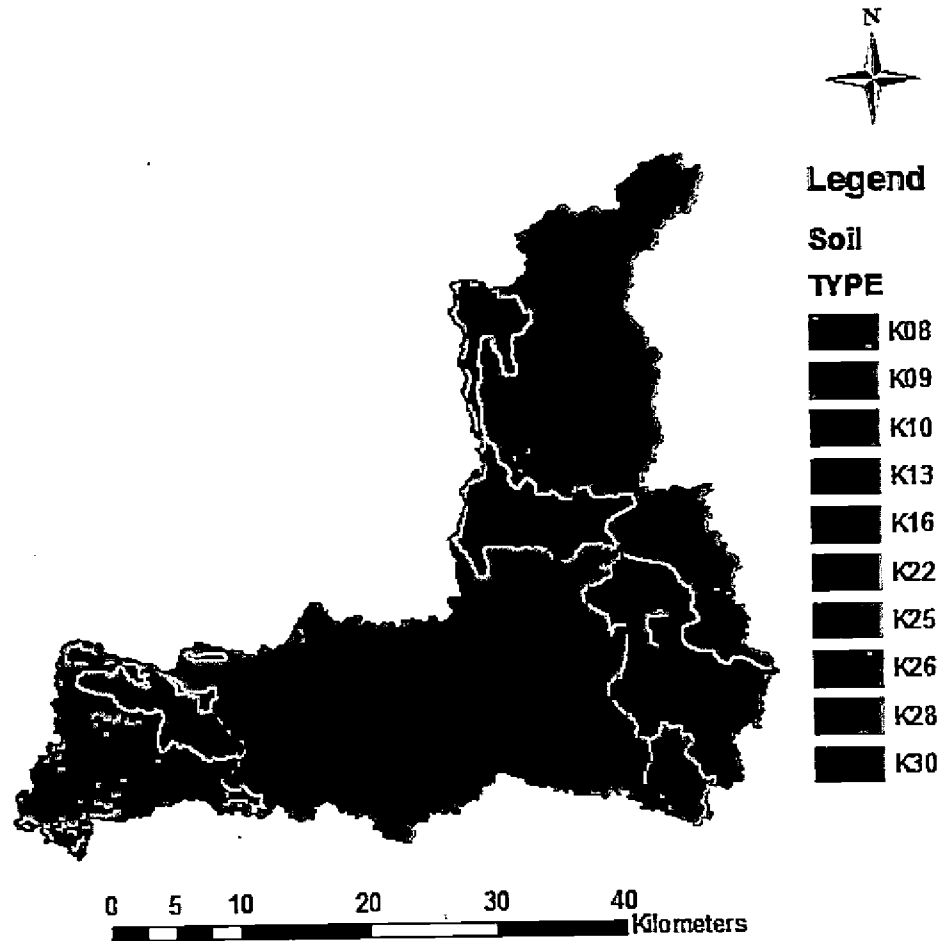
Fig. 4.3 Soil map of Thuthapuzha sub basin

Table.4.2. Description of soil mapping units of Thuthapuzha sub basin

Soil mapping unit	Texture	Description
K08	Clayey	Very deep, moderately well drained, clayey soils with moderately shallow water table in nearly level narrow valleys, with slight erosion associated with imperfectly drained, very deep, clayey soils with moderately shallow water table on nearly level lands.
K09	Gravelly clay	Very deep, well drained, gravelly clayey soils with moderate surface gravelliness on moderately steeply sloping laterite

		mounds, with moderate erosion; associated with deep, well drained, gravelly clay soils on gentle slopes.
K10	Gravelly clay	Very deep, well drained, gravelly clay soils on gently sloping midland laterites with valleys of northern Kerala, with moderate erosion, associated with deep, well drained, gravelly clay soils with moderate surface gravelliness and ironstone layer at 100-150 cm on nearly level lands, slightly eroded.
K13	Gravelly clay	Deep, well drained, gravelly clay soils with moderate surface gravelliest on ironstone layer at 100-150 cm on gently sloping midland laterites, with moderate erosion; associated with laterite outcrops.
K16	Fine loamy	Very deep imperfectly drained loamy soils with moderately shallow water table in nearly level board valleya of palghat gap, with slight erosion associated with moderately deep, moderately well drained, gravelly loamy soils with coherent material at 75-100cmon gentle slopes, moderately eroded
K20	Gravelly clay	Deep, somewhat excessively drained, gravelly clay soils with moderate surface gravelliness on steeply sloping high hills with thick vegetation, with moderate erosion; associated with very deep, well drained, clayey soils on gentle slopes.
K22	Clayey	Very deep, well drained, clayey soils on gently sloping low hills with isolated hillocks, with moderate erosion; associated with deep, well drained, gravelly clayey soils on moderately steep slopes
K25	Gravelly clay	Very deep, well drained, gravelly clayey soils with strong surface gravelliness on moderately sloping medium hills with moderate erosion, thin vegetation, associated with rock outcrops.
K26	Clayey	Very deep well drained clayey soils with loamy soils on gently sloping medium hills with thick vegetation, with moderate erosion, associated with rock outcrops.
K28	Gravelly loam	Moderately deep, well drained, moderately calcareous, gravelly loam soils with moderate surface gravelliness on gently sloping foot hills and valleys, with moderate erosion; associated with moderately shallow, somewhat excessively drained, gravelly clay soils with strong surface gravelliness and coherent materials at 50 to 75 cm on moderate slopes, severely eroded.
K29	Loam	Very deep, well drained, loamy soils on gently sloping uplands with valleys, associated with very deep, with moderate erosion, well drained, loamy soils on gentle slopes
K30	Clayey	Very deep, well drained, clayey soils on moderately sloping high hills with thick vegetation, with moderate erosion; associated with deep, well drained, gravelly clayey soils with moderate surface gravelliness on moderately steep slopes.

(Source: Land Resources Map of Kerala State, Kerala State Land Use Board, 1995)

4.3 PREPARATION OF SOIL MAP

The soil map of the watershed (indicating soil type and Series Name) was traced and the boundaries of different hydrologic soil groups viz., A, B, C, and D were delineated. The soils of group A were of shallow, well drained, the soils of group B were of moderate infiltration rate, moderately well drained. The soils of group C of the moderately fine to moderately coarse textures, water transmission of moderate rate and the soils of group D were of very deep ,slow infiltration and high runoff potential

4.4 LAND USE PATTERN

The land use pattern of the study area varied according to the local physiography. The high land areas are mainly occupied by forests. The forest area contributes 30% of the land area of Thuthapuzha Sub Basin. The Silent Valley Reserve Forest which forms the core of Nilgiri Biosphere Reserve and is one of the best representative evergreen forests in the country is located towards the northern part of the study area. The region has an exceptional diversity ofbiotic communities, forest ecosystem and species of flora and fauna. A large percentage of the species recorded from this forest especially plants and lower animals, are endemic species occurring only at a few locations in the Western Ghats. There is no recorded history of human settlements within the Silent Valley Reserve Forests, but there are nine tribal settlements along the fringes. Rubber plantation also occupies the high land region and contributes about 10% of the study area.

The low land and mid land areas are utilized for agricultural purpose and settlement. Mixed crops of coconuts, banana, tapioca, seasonal vegetables etc. are cultivated in the midland region and accounts to approximately 65% of the study area. Only 5% of the study area is utilized for single crop cultivation.
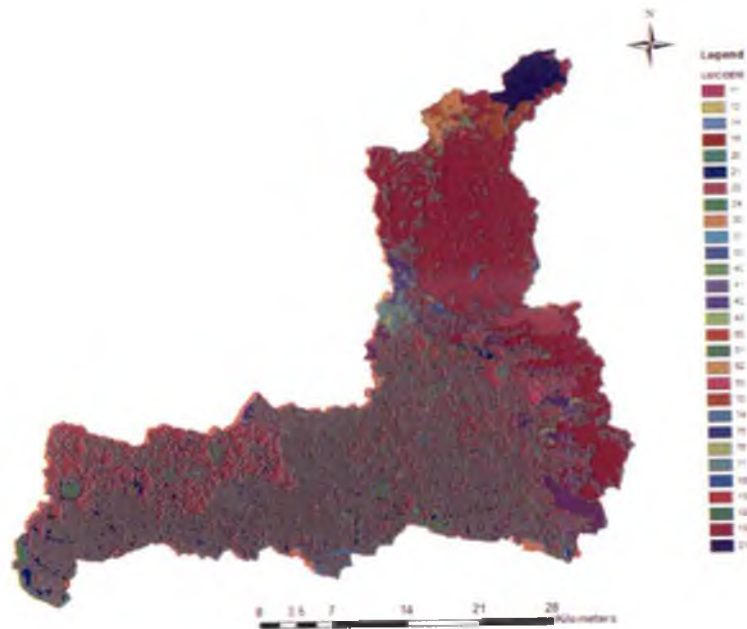
Fig. 4.4. Land use map of Thuthapuzha sub basin

4.5 TERRAIN PREPROCESSING

Terrain processing involves using the DEM to create network of stream and catchments. The Processing menu (shown below) in HEC-GEOHMS is used for terrain processing.

Raster Data

1. Raw DEM
2. Hydro DEM (DEM after reconditioning and filling sinks)
3. Flow Direction Grid
4. Flow Accumulation Grid
5. Stream Grid
6. Stream Link Grid
7. Catchment Grid

<u>Vector Data</u>

1. Catchment Polygons
2. Drainage Line Polygons
3. Adjoint Catchment Polygons
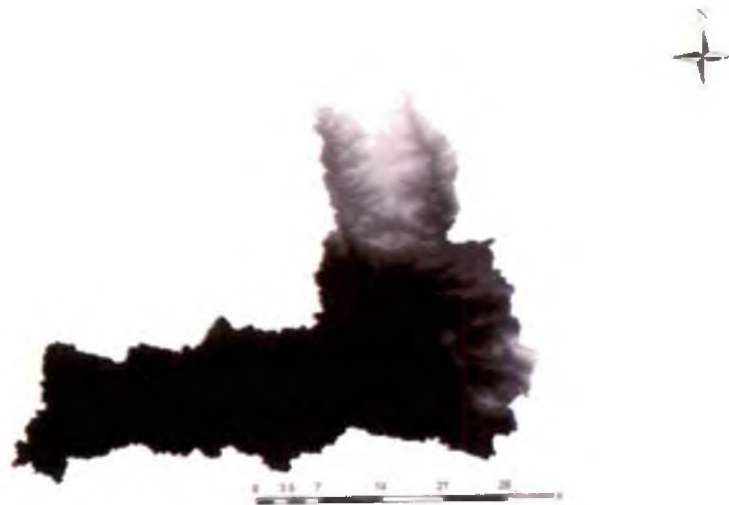
Fig. 4.5. Fill sink map
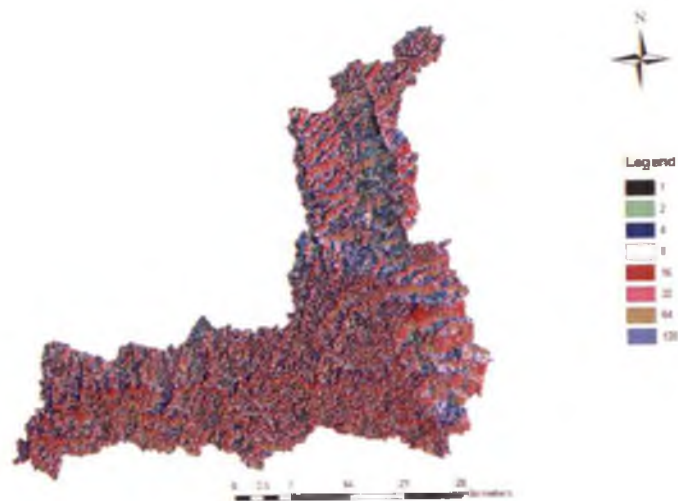
Fig. 4.6. Flow direction map
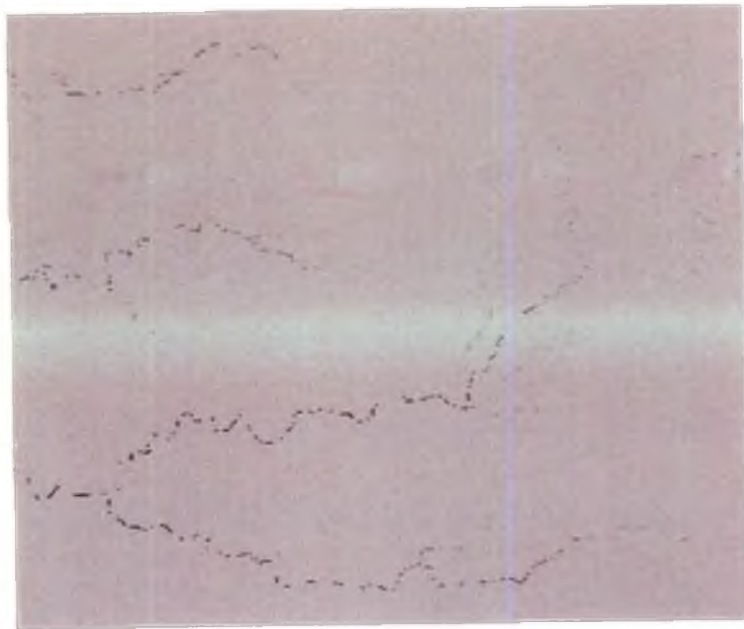
Fig. 4.7. Flow accumulation map
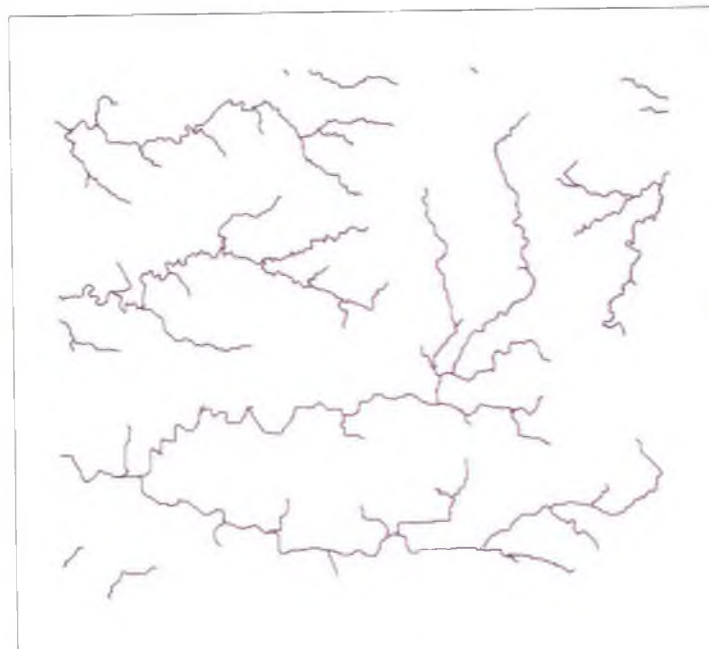
Fig. 4.8. Drainage line map

4.6 BASIN PROCESSING

The basin processing menu has features such as revising sub-basin delineations, dividing basins, and merging streams. For merging basins, we will follow the processthat allow us to merges two or more adjacent basins into one. Zoom-in to the area marked in the rectangle below:

Select the three adjacent basins (shown above) using the standard select tool. Click on Basinprocessing-> Basin merge. After that we will get a message asking to confirm the merging of selected basins, then click Yes. Similarly merge two more sub-basins as shown below. Then the resulting picture is like this:
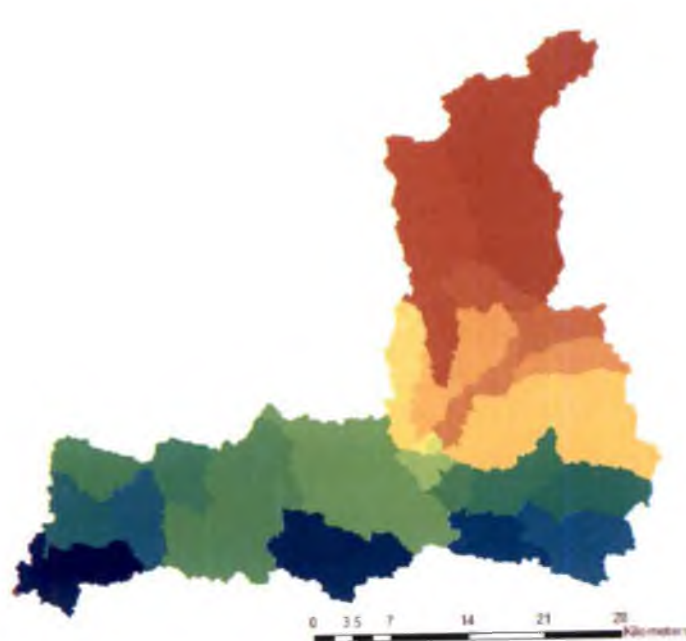
Fig. 4.9 Catchment extraction map
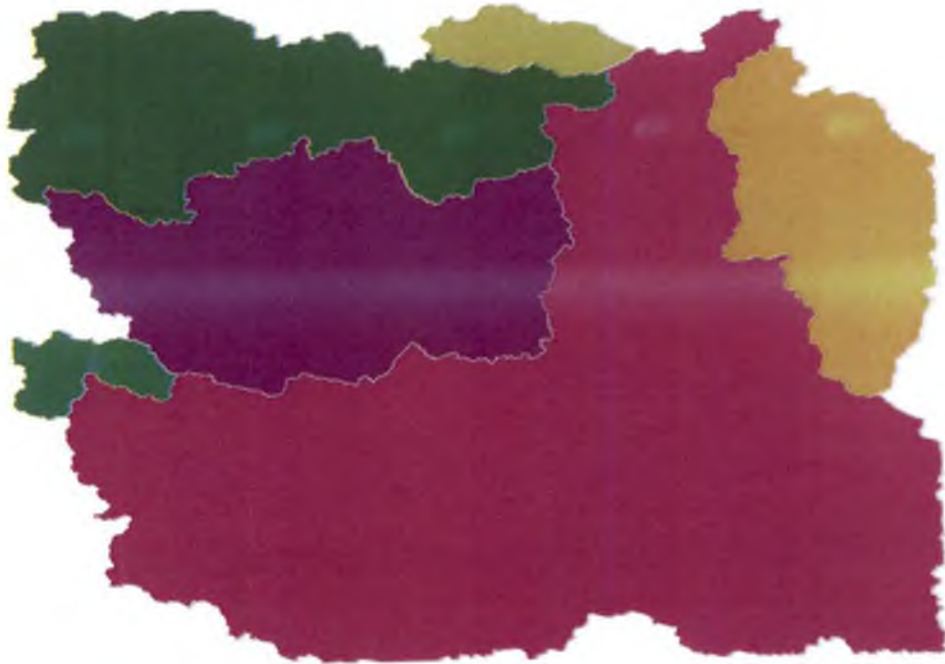
Fig. 4.10 Adjoint catchments map

4.7 EXTRACTING BASIN CHARACTERISTICS

The basin characteristics menu in the HEC-Geo HMS Project vision provide tools for extracting physical characteristics of streams and sub-basins into attribute tables.

a) River Length

The river length tool computes the length of river segments and stores them in River length field. Select river length. Confirm the input River name, and click OK.-Characteristics. You can check the River length field in the input River1 (or whatever name we have inputtedfor river) feature class is populated. Save the map document.

b) River Slope

River slope tool computes the slope of the river segments and stores them in Slope field. Select- characteristics- Basin River Slope. Confirm inputs for Raw DEM and River, and click OK. You can check the Slp field in the input River1 (or whatever name you have for your input river) feature class is populated. Fields ElevUP and ElevDS are also populated during this process. Slope = (Elev UP – Elev DS)/River Length.

Fig. 4.11. River map

c) Basin Slope

The basin slope tool computes average slope for the sub-basin using the slope grid and sub-basin polygon. Add (percent slope for watershed) grid to the map

document. Select – characteristics- Basin Slope. Confirm the inputs for Sub basin and Slope Grid, and then click OK.
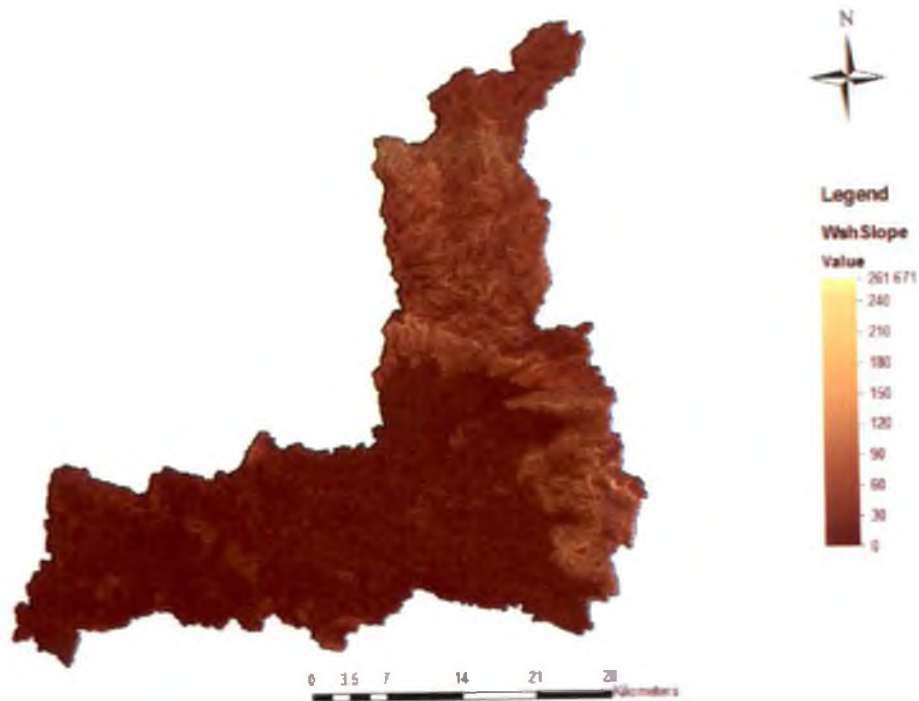
Fig. 4.12. Slope map of Thuhapuzha basin

d) Longest Flow Path

This will create a feature class with poly line features that will store the longest flow path for Longest flow path. Confirm the inputs, and leave theeach sub-basin. Select_ Characteristics_ default output (Longest Flow Path) unchanged. Click OK.

e) Basin Centroid

This will create a Centroid point feature class to store the centroid of each sub-basin. Select input Sub basin Characteristics _Basin Centroid. Choose the default. Center of Gravity Method, leave the default name (Centroid). Computes the method Click OK.

f) Basin Centroid Elevation

This will compute the elevation for the each centroid point using the underlying DEM. Select Characteristics _Centroid Elevation update. Confirm the input DEM and centroid feature class, and click OK.

g) Centroidal Longest Flow Path

Select-Characteristics-Centroidal Longest Flow Path. Confirm the inputs, and leave theSelect Characteristics default name for output Centroidal Longest Flow Path, and Click OK.

Fig. 4.13 Longest flow path map

Fig. 4.14 Stream extraction map
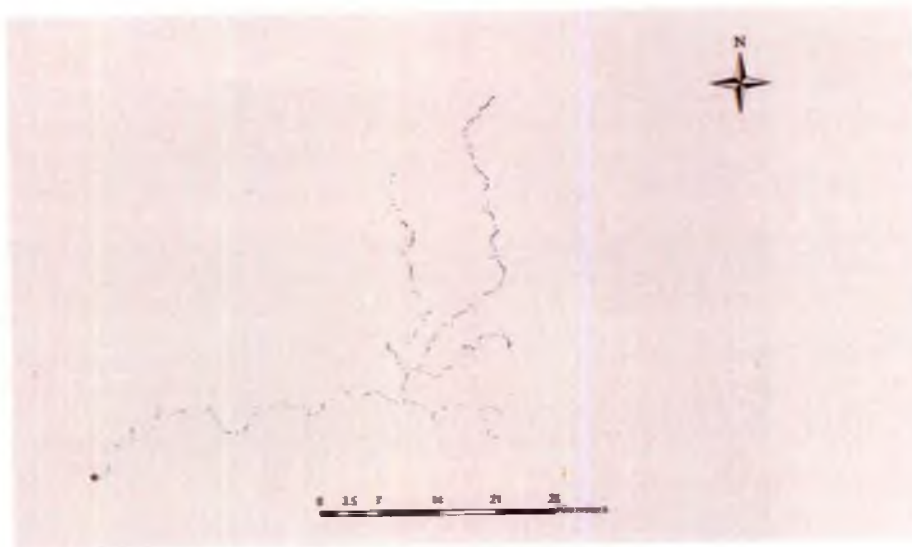
Fig. 4.15 Stream linking

4.7.1 HMS

The HMS menu has tools for creating input files fromHEC-GEOHMS. Confirm the input feature classes. Click ok on HMS process

Fig. 4.16. HMS Project Area

4.7.2 HMS Schematic

This tool creates a GIS representation of the system using (hydrologic) a schematic network with basin elements (nodes/links or junctions/edges) and their connectivity. Select HMS- HMS Schematic. Confirm the inputs, and then click ok.

Fig. 4.17. HMS model area

4.8 PARAMETER SENSITIVITY

The sensitivity analysis has carried out and the sensitive parameters shown in Table4.3. Here sensitive parameters related to study are Initial abstraction, followed by CN, and followed by lag time and remaining parameters are given in sequence Initial discharge, recession constant, and Muskingum X and K values.

Table 4.3Calculated initial and optimized parameters for the watershed

No	parameters			Initial value	Optimized value
1	Initial abstraction	I_a	mm	17.23	13.10
2	Curve number	CN		63.15	65.90
3	Lag time	T_{lag}	min	18.51	17.90
4	Initial discharge	Q	m³/sec	0.0774	0.069
5	Recession constant			0.746	0.627
6	Threshold flow	Q	m³/sec	0.0564	0.055
7	Muskingum	K	hr	0.378	0.292
8	Muskingum	X		0.287	0.301

4.9. MODEL CALIBRATION AND VALIDATION

The calibration of the model has been carried out by suitably modifying the sensitive parameters, within the range suggested by the uncertainty analysis. It is emphasized here that the calibration effort was very much reduced when the optimum parameter search was limited to the parameters suggested by the sensitivity analysis and their ranges suggested by the uncertainty analysis as described in sections respectively. First the calibration was attempted to annual time series and then it was extended to monthly basis. The summary statistics is given in table 4.4.

The comparison of monthly average flow for calibration and validation period is shown in figures 4.18 & 4.20 to 4.19 & 4.21. Very high NSE of 0.77 and 0.82 and R^2 of 0.88 to 0.91 have been obtained for the calibration period. However, the simulations under estimate the peak values and this under estimation has been reported by other researchers (Chatterjee*et.al* 2014, Roy*et.al* 2013)). Similarly the

corresponding NSE values were increased from0.86 to 0.91 and R^2 were 0.86 & 0.93 for the validation periods. So, this flow prediction information can be utilized for the reservoir planning at any section of the stream along its course within the river basin.

The above said calibration and validation is applicable for the total river flow. Since, HEC-HMS predicts the hydrologic processes in component way, it may be better, if different hydrologic processes are compared separately with their measured or alternatively computed counterparts. Hence, to validate the model output in a more detailed manner, the simulated base flow was compared with the observed counterpart. As such there is no observed base flow. But the summer river flow is considered as the soul contribution of base flow and that has been matched with the simulated one. Very close similarity was observed for all the years under study as shown in previously mentioned figs. The corresponding descriptive statistics is presented in table 4.6. NSE of maximum 0.91 and an R^2 of maximum 0.93 are obtained.
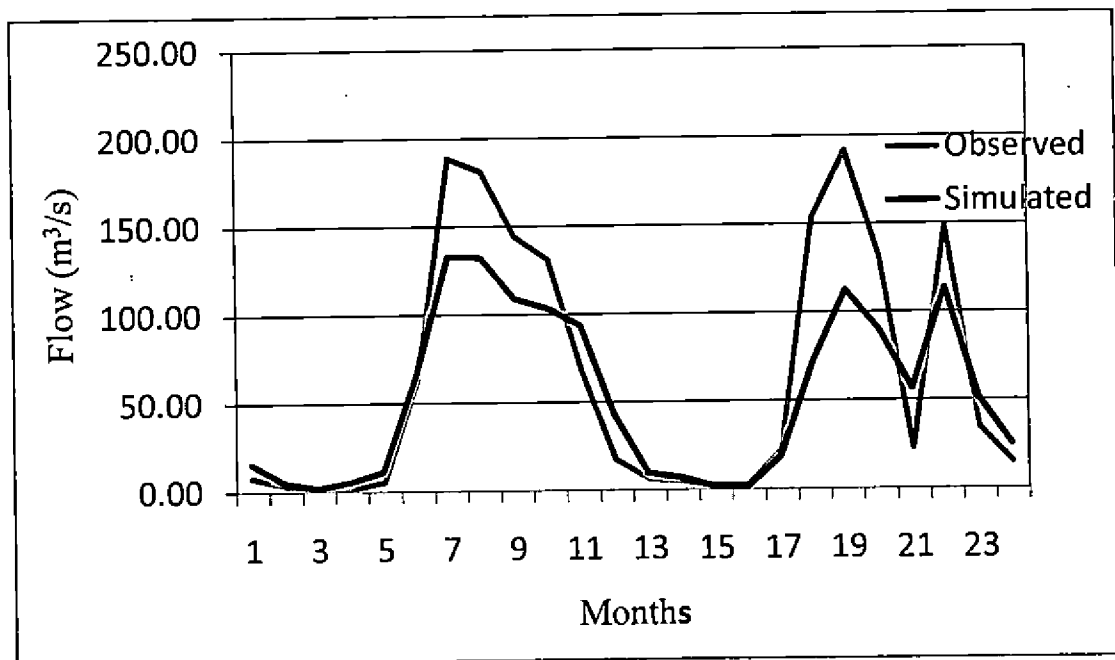
Fig4.18. Observed and simulated flow before calibration (monthly average flow for calibration)
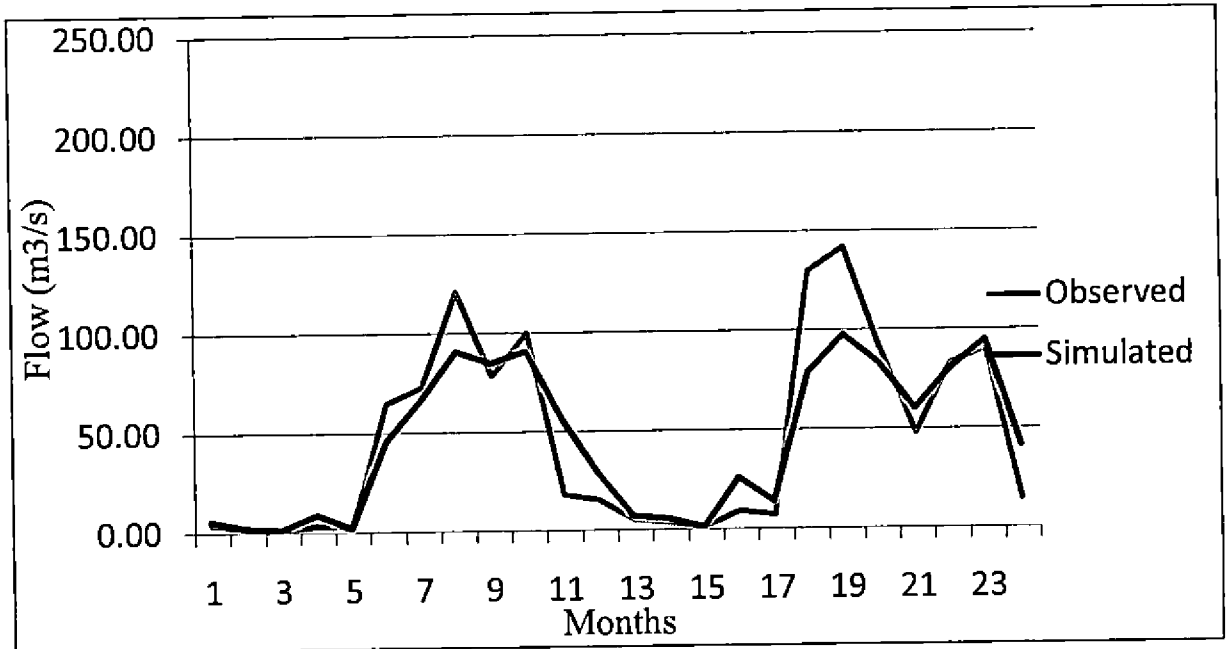
Fig4.19. Observed and simulated flow before calibration (monthly average flow for
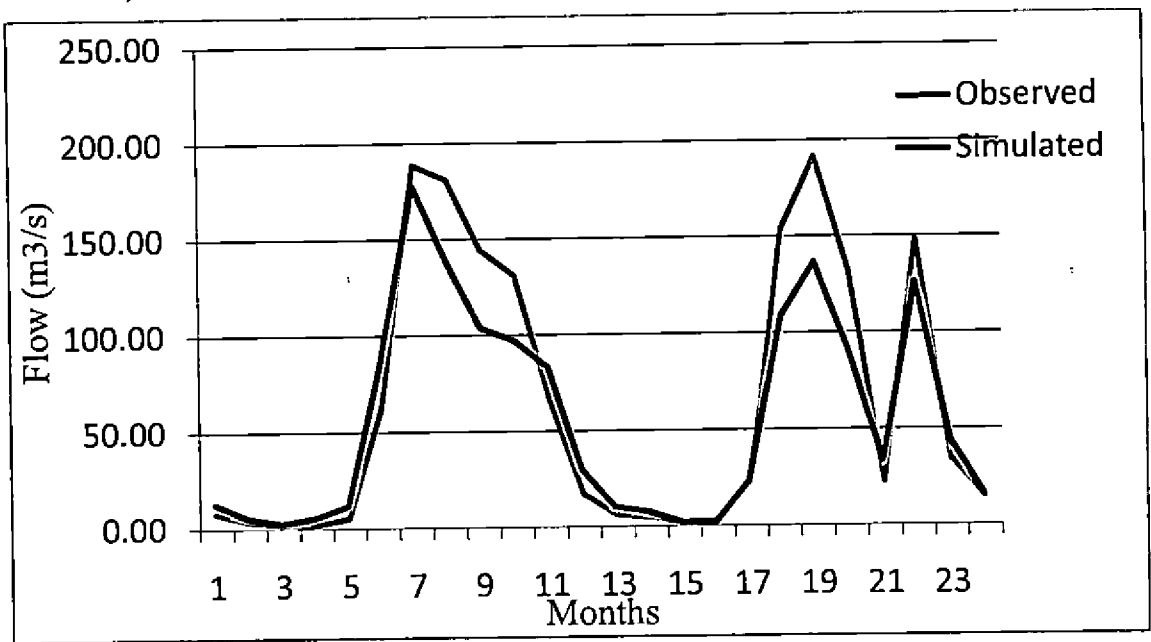
validation)

Fig 4.20. Observed and simulated flow after calibration (monthly average flow for
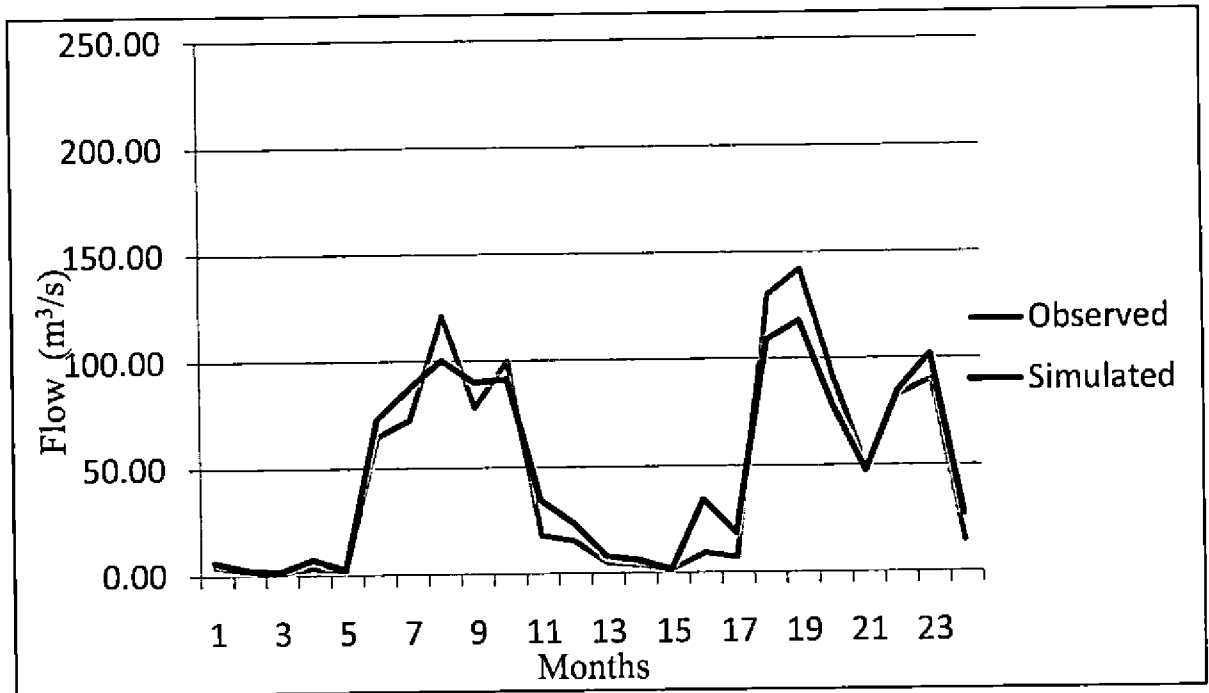
calibration)

Fig4.21. Observed and simulated flow after calibration (monthly average flow for validation)

Table4.4. Observed and simulated flow before and after calibration/validation

Statistics	Calibration period(before)		Validation period	
Flow(m³/sec)	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	64.46	53.16	46.05	44.63
SD	71.50	46.97	47.84	36.42
Nash Efficiency		0.77		0.83
Coefficient of determination		0.88		0.86
Statistics	Calibration period(After)		Validation period	

Flow(m³/sec)	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	64.46	56.34	46.05	48.04
SD	71.50	54.76	47.84	41.42
Nash Efficiency		0.82		0.91
Coefficient of determination		0.91		0.93

HMS model has been successfully set up for an important river basin, Thuthapuzha of Kerala state in India by overcoming all odds regarding the availability of basic data and information in the ready to use format. With 7 years of daily rainfall and river flow, the model has been calibrated and validated. Parameter sensitivity analysis was carried out to identify the most sensitive parameters towards river flow. It was followed by an uncertainty analysis to determine the feasible range of parameter variation. Using the results of sensitivity and uncertainty analysis, the model was calibrated using 5 years of observed river flow. Validation of the calibrated model was attempted with separate data set of two years not used in calibration

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The U.S. Army Corps of Engineers' Hydrologic Engineering Centre - Hydrologic Modeling System (HEC-HMS) is designed to simulate for the complete hydrologic processes of dendritic watershed systems. HEC-HMS is widely used under various widely varying geographic conditions and includes both traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing as well as continuous simulation procedures including evapotranspiration, snowmelt, and soil moisture accounting. It can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

The hydrologic and hydraulic model provide updated conditions for the Thuthapuzha river reach. HEC-HMS uses separate mathematical models to represent each component of the runoff process, like models to compute runoff volume, models to compute direct runoff and base flow. Hydrology was modelled with a rainfall runoff analysis in order to generate direct runoff from the land use condition. The Soil Conservation Service Curve Number method developed by the U.S. Soil Conservation Service was used for the loss method in this study.

In the present study Hydrologic Modeling System (HEC-HMS) is calibrated and validated for Thuthathapuzha subbasin of Bharathapuzha river basin in Kerala. The input data required for the model like precipitation, meteorological parameters, river discharge, soil characteristics, land use characteristics and topographical characteristics of the study area were collected from various agencies like Central Water Commission (CWC), Kerala State Land Use Board (KSLUB), RARS Pattambi and the Bhuvan geo-data portal of National Remote Sensing Centre (NRSC).

The watershed was divided into homogeneous sub-basins using WMS and HEC-GEOHMS to get the sub-basin geometric data and then hydrological model was developed in HEC-HMS.The analysis showed that CN, lag time are the sensitive parameters for the simulation of stream flow. Then optimization trials in HEC-HMS was conducted to generate a calibrated model.

The model performance of the calibrated HEC-HMS model for Thuthapuzha watershed was evaluated using the statistics - Nash Sutcliffe- model efficiency criterion, coefficient of determination and simulated time to peak. The analysis showed that CN, and lag time are the most sensitive parameters for the simulation of stream flow. The Nash-Sutcliffe model efficiency (E) was (0.77-0.8) and (0.86-0.88) and the coefficient of determination was (0.82-0.91), and (0.91-0.93) before and after the calibration respectively, indicating the good performance of the model.

REFERENCES

REFERENCES

Abas, A.A. and Hashim, M. 2012. Estimation of impervious surface using multi temporal land sat imagery and its impact to the runoff.

Abood, M.M., Mohammed, T.A., Ghazali, A.H., Mohamud, A.R., and Sidek, L.M. 2012. Impact of infiltration methods on the accuracy of rainfall-runoff simulation. *Res. J. Appl. Sci. Eng. Tech.* 4(12): 1708-1713.

Alaghamand, S., Abullah, R., and Abustan, I. 2011. Selecting the best set value in calibration process for the validation of hydrological modelling (Kayu Ara river basin, Malaysia.*Res. J. Environ. Sci.* 5(4): 354-365.

Alaghamand, S., Abullah, R., and Abustan,I. 2010. GIS-based river flood hazard mapping in urban area (a case study in Kayu Ara river basin, Malaysia). *I. J. Eng. Technol.* 2(6): 488-500.

Al-Jabari, S., Sharkh, M.A., and Al-Mimi, Z. 2009. Estimation of runoff for agricultural watershed using SCS curve number and GIS. *Int. Water. Technol. conf.* 1213-1229

Al-Jabari, S., Sharkh, M.A., and Al-Mimi, Z.2012. Management of agricultural watershed using GIS in Palestine. *Int. water. Technol.conf.* 1-10.

Ali, M., Jamal, S., Aslam, I., and Khan, Z. 2011. Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan. *Natl. Uni Sci. Technol.* 102: 271-279.

Asadi A.,and Boostani F. 2013. Application of HEC-HMS for flood forecasting in Kabkian basin and Delibajak sub basin in Iran. *IOSR J. Eng.* 3 (9): 2250-3021.

Asadi, A. and Boustani, F. 2013. Performance evaluation of the HEC-HMS hydrological model for lumped & semi-distributed storm flow simulation. *Am. J. Eng. Res.* 2(11):115-121.

Asis Mazumdar and Sujana Dhar (2007) have conducted a study to quantify the impact of climate change on the water resources of the Jamtara watershed, West Bengal using a distributed hydrological model HEC-HMS.

Arekhi, S. 2012. Runoff modelling by HEC-HMS model (Case study: Kan watershed, Iran). *Int. J. agric. crop sci.* 4(23): 1807-1811.

Bakir, M and Xingnan, Z. 2008. GIS-based hydrological modelling: A comparative study of HEC-HMS And the Xinanjiang model. *Int. water Tech. conf.IWTC12* Alexandria, Egypt.

Bhatt, A., Yadav, H.V., Kumar, D. 2012. Estimation of the infiltration parameter for Tehri Garhwal catchment. *Int. J. Eng. Res. & Tech.* 1(7).

Chatterjee, M.,Rumpa, D., Roy, D., Das, S. and Mazumdar, A. 2014. Hydrological modelling studies with HEC-HMS for Damodar basin, India. *J. word appl. sci.* 31(12): 2148-2154.

Choudhari, K., Panigrahi, B., and Paul, J. C. 2014. Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. *Int J. Geomatics and Geosciences.* 5(2).

Devries, J.J and Hromdaka, T.V 1993, computer models for surface water. In handbookof hydrology D.R Maidment (Ed), Mc Graw-Hill, New York

Donigian., A.S Watershed model calibration and validation. The HSPF experience AQUATERRA Consultants 2685 Marine Way, Suite 1314Mountain View, CA 94043

Fleming, M. 2004. Description of the hydrologic engineering center's hydrologic modelling system (HEC-HMS) and application of watershed studies. *Smart Tech. Notes Collection*, ERDC/TN SMART: 4-3.

Ford, D., Pingel, N., Devries,J.J. 2008. Hydrologic modelling system (HEC-HMS) Application guide. US Army Corps of Engineers Hydrologic Center.

Gangodagamage. C 2001. Hydrological modeling using remote sensing and GIS. *Asian Conf. Remote Sensing.*5-9.

Gautham, N.P. Flow routing with semi-distributed hydrological model HEC- HMS in case of Narayani river basin. *J. Inst.Eng.* 10(1): pp. 45-58.

Gajbhiye, S. 2015. Estimation of surface runoff using Remote Sensing and Geographic Information System. *Int. J. U and eService, Sci. Tech.* 8(4): pp. 113-122.

Golrang, B.M., Lai, F.S., Sadeghi, S.H.R., Khamurdin, M.N., Abdkudus, K Mashayekhi. K. Bagherian, R. 2013. Assessment of the watershed management implemented on sprinkle peak flood discharge and flood volume, using HEC-HMS model (Case study: KushkAbad sub basin in Iran). *B M Golrang etc. Sci. and nature.* 2(2):59-64.

Hoggan, D.H., 1997, computer assisted floodplain hydrology and hydraulics, 2nd ed., Mc-Graw-Hill, New York

Kabiri. 2014. Simulation of the runoff using modified SCS-CN method using GIS system. *Res. J. Environ. Sci.* 8(4): 178-192.

Kabiri using Green-Ampt loss method in surface runoff simulation (Klang watershed in west Malaysia). *Adv. Environ. Computational Chemistry Bio sci.* 217-221.

Kaur, R., Kumar,S and Gurung, H. P.2002. A pedo-transfer function (PTF) for estimating soil bulk density from basic soil data and its comparison with existing PTFs.*Australian J. of Soil Res.* 40(5) :847 – 858.

Kherde, R. V. and Sawant., P.H. 2013. Integrating geographical information systems (GIS) with hydrological modeling- Applicability and limitations. *Int. J. Eng. and Tech.* 5(4).

Kumar, D. 2011. Distributed rainfall- runoff modelling. *Int. J. of Earth Sci. Eng.*4(6):270-275.

Haberlandt, U.and Radtke I. 2014. Hydrological model calibration for derived flood frequency analysis using stochastic rainfall and probability distributions of peak flows.*Hydrol. Earth Syst.* Sci. 18: 353–365.

https://www.westernwatersheds.org/issues/issuesprotecting-watersheds.

Legesse. S. 2015. Application of the HEC-HMS model for runoff simulation of Upper Blue Nile River Basin. *Hydrol. Curr. Res.*6(2).

Maiden, D.R., 1993, Handbook of hydrology, Mc-GRAW-Hill, New York

McCuen, R.H., 2005, Hydrologic analysis and design, 3rd ed., prentice Hall, Upper Saddle River, NJ

Majidi, A. and Shahedi, K. 2012. Simulation Of rainfall-runoff process using Green- Ampt method and HEC-HMS model (A case study: Abnama Watershed, Iran). *Int.J.Hydrol. Eng.* 1(1): 5-9.

Majidi, A., and Vagharfard, H. 2013. Surface runoff simulation with two methods using HEC-HMS model. *Curr. Adv. in Environ. Sci.* 1(1): 7-11.

Martin, O., Rugumayo, A. and Ovcharovichova, J. 2012. Application of HEC-HMS/RAS and GIS tools in flood modelling: A case study for river Sironko-Uganda. *Glo. J. Engi. Des& Tech.* 1(2): 19-31.

Narasayya, K. 2015. A Geo-Informatic approach to estimate stream flow of an un developed catchment-a hypothetical research. *Int. J. Advmtin Remote Sensing GIS and Geography.* 3(1): 22-31.

Oloche, O.J, Zhi-jia LI. 2010. Application of HEC-HMS for the flood forecasting in Misai and Wan a catchment in China. *Water Sci. Eng.* 3(1):14-22.

Patel M.M.,Gandhi H.M., and Shrimali N.J. 2014. Literature study on application of HEC-HMS for the event and continuous based watershed modeling. *I. J. Sci. Res. Dev.* 1: 2321-0613.

Rafiei, E., Rostami,N., Khalighi, S., and Tahei, S. 2012. Calibration of loss estimation methods in HEC-HMS for simulation of surface runoff. *Adv. in Environ. Biol.* 6(1): 343-348.

Rahul, W.S. and Jain., M.J. 2015. Continuous hydrological modeling using soil moisture accountingalgorithm in Vamsadhara river basin, India. *J. water. Resour. Hydraulic. Eng.* 4(4): PP. 398-408.

Razi M.A.M., Ariffin. J., Tahir. W., and Arish, M.A.M. 2010. Flood estimation studies using hydrological modelling system (HEC-HMS) in Johor river, Malaysia. *J. Appl. Sci.* 10(11): 930-939.

Roy, D., Begam, S., Ghosh, S., and Jana, S. 2013. Calibration and Validation of HEC-HMS model for a river basin. *J. Eng and Appl. Sci.* 8(1).

Sampath, D.S., Weerakoon, S.B., and Herath, S. 2015. HEC-HMS model for runoff simulation in a tropical catchment with Intra-Basin diversions - Case study of the Deduru Oya river basin, Sri Lanka. *The Inst. Eng.*1 pp (1-9).

Scharffenberg, W.A 2013 US army corps of the engineers. Hydrological engineering centre Hydrologic modelling system (HEC-HMS): user manual 4.0.

Sinha, R., Kumar, R., Sinha, S. Tandon, S.K. and Gibling, M.R. (2007) Late Cenozoic fluvial successions in India: an overview and synthesis. Quaternary Science Reviews, 26, 2801-2822.

Stewart, L.T., and Godchild, M. F.1993. Integrating geographic information systems and environmental simulation models. *Environ. Modeling With GIS*: 16-30.

Supe, M.S., Taley, S.M., and Kale,M.U. 2015. Rainfall-runoff modelling using HEC-HMS for Wan river basin. *Int. J. Res. Eng. Sci.Tech.* 1(8): 21-28.

Su, Z., Neumann, P., Schumann F.A., and Schultz G.A. 1992. Application of remote sensing and geographic information system in hydrological modeling. *Earsel. Adv.remote sensing. 1: 3-7.*

Twumasi, Y. D., John Ayer, R., and Mathew, E. 2015. Computing flood volume Of Dikpe Catchment using HEC-HMS. *Glob J. Of Hum-Social Sci:* B Geography, Geo-Sciences, Environmental Science &Disaster Management. 15 (2).

Upadhyay, T.P., B. Solberg and P.L. Sankhayan, 2005. A review of carbon sequestration dynamics in the Himalayan region as a function of land-use change and forest/soil degradation with special reference to Nepal. Agric. Ecosyst. Environ., 105: 449-465. DOI: 10.1016/j.agee.2004.09.007

Yasin, Z., Nabi, G., and Randhawa, S. M. 201. Modeling Of hill torrent using HEC Geo-HMS and HEC- HMS Models: A Case Study of Mithawan Watershed. *Pakistan.J. Meteorol. 11(22).*

Yener, M.K., Şorman, A.U., Şorman, A.A., Şensoy, A., and Gezgin, T. 2006. Modeling Studies With HEC-HMS and runoff scenarios in Yuvacik basin, Turkiye. *Int. Congr. River Basin Manag.* 623-634.

APPENDICES

APPENDIX-I

Anderson Land Use Land Cover Classification Codes:

First- and Second-Level Categories

1. Urban or Built-Up Land	6. Wetland
11 Residential	6 1 Forested Wetlands
12 Commercial Services	6 2 Non-forested Wetlands
13 Industrial	7. Barren Land
14 Transportation, Communications	71 Dry Salt Flats
15 Industrial and Commercial	72 Beaches
16 Mixed Urban or Built-Up Land	73 Sandy Areas Other than Beaches
17 Other Urban or Built-Up Land	74 Bare Exposed Rock
2. Agricultural Land	75 Strip Mines, Quarries, and Gravel Pits
21 Cropland and Pasture	76 Transitional Areas
22 Orchards, Groves, Vineyards, Nurseries	77 Mixed Barren Land
23 Confined Feeding Operations	8. Tundra
24 Other Agricultural Land	81 Shrub and Brush Tundra
3. Rangeland	82 Herbaceous Tundra

31 Herbaceous Rangeland	83 Bare Ground
32 Shrub and Brush Rangeland	84 Wet Tundra
33 Mixed Rangeland	85 Mixed Tundra
4. Forest Land	**9. Perennial Snow and Ice**
41 Deciduous forest land	91 Perennial Snow fields
42 Evergreen forest land 43 Mixed forest land **5. Water** 51 Streams and canals 52 Lakes 53 Reservoirs 54 Bays and estuaries	92 Glaciers

APPENDIX-II

Hydrological models

Model Type	Example of Model
Lumped parameter	H EC-HMS, Snyder or Clark UH
Distributed	Vflo, MIKE URBAN, MIKE FLOOD
Event	H EC-HMS, SWMM, SCS TR-20
Continuous	SWMM, HSPF, Vflo
Physically based	H EC-HMS, SWMM, HSPF, Vflo
Stochastic	Synthetic stream flows

APPENDIX-III

HEC-HMS loss rate methods

Method	Description
Initial and constant	Initial loss volume is satisfied and then constant loss rate begins.
HEC exponential	Loss function is related to antecedent soil moisture condition and is a continuous function of soil wetness.
SCS curve number	Initial loss is satisfied before calculating cumulative runoff as a function of cumulative rainfall using SCS methods
Holtan method	Infiltration rate is computed as an exponential function of available soil moisture storage from Holtan's equation.
Green and Ampt	Infiltration rate is computed from the Green and Ampt equation as a function of soil moisture and hydraulic conductivity
Deficit/Constant	First an initial deficit storage is filled, and then infiltration rates can be specified on a monthly basis.
SMA	Soil moisture accounting assigns a value of initial storage to all layers of the ground using a gridded method.

APPENDIX-IV

Surface runoff methods in HEC-HMS

Unit hydrograph input directly
- Clark hydrograph method (TC&R method Snyder unit hydrograph method   - SCS method (CN method + SCS UH)   - Kinematic wave for overland hydrograph   - Mod-Clark   - User-specified S-graph

APPENDIX-V

Flood Routing in HEC-HMS

Method	Description
Muskingum	Storage coefficient (x) plus travel time (K) through each reach
Modified Pul's	Table of storage vs. outflow for each reach based on HEC-RAS water surface profile information—various storages are plotted vs. peak flows in the reach
Kinematic wave	Channel shape, length, slope, and n; outflow from each reach based on depth of flow in continuity equation and Manning's equation
Muskingum–Cunge 8-point	Same equations and technique as the Muskingum– Cunge but channel is described with 8 station-elevation values
Lag	Direct lag of flow through channel with translation accounted for but not attenuation

APPENDIX-VI

The name and the area of each GramaPanchayat within Thuthapuzha sub basin

Sl. No	Name of the Panchayat	Name of the block	Area(km^2)
1	: Kulukkallur	Pattambi	22.8
2	Koppam	Pattambi	20.9
3	Nellaya	Pattambi	27.4
4	Vilayur	Pattambi	17.7
5	Thiruvengapura	Pattambi	20.4
6	Cherupulassery	Sreekrishnapuram	27.6
7	Kadambazipuram	Sreekrishnapuram	39.7
8	Karimpuzha	Sreekrishnapuram	47.4
9	Pookkattukadavu	Sreekrishnapuram	22
10	Sreekrishnapuram	Sreekrishnapuram	29.5
11	Thrikkadivi	Sreekrishnapuram	26.3
12	Vellinezi	Sreekrishnapuram	26.8
13	Alanellur	Manarkkad	58.3
14	Karakurissi	Manarkkad	27

15	Karimba	Manarkkad	69.2
16	Kottappadam	Manarkkad	29.8
17	Kumaraputhur	Manarkkad	37.2
18	Manarkkad	Manarkkad	63.4
19	Kanhirapuzha	Manarkkad	58.4
20	Thachannattukara	Manarkkad	35
21	Tachanpara	Manarkkad	54
22	Thazhekode	Perinthalmanna	45
23	Aliparamba	Perinthalmanna	20.2
24	Elamkulam	Perinthalmanna	21.3
25	Pulamanthole	Perinthalmanna	33.7
26	Moorkannad	Perinthalmanna	11.7
27	Irimbilam	Kuttipuram	24

APPENDIX-VII

Description of soil mapping units of Thuthapuzha sub basin

Soil mapping unit	Texture	Description
K08	Clayey	Very deep, moderately well drained, clayey soils with moderately shallow water table in nearly level narrow valleys, with slight erosion: associated with very deep, imperfectly drained, clayey soils with moderately shallow water table on nearly level lands.
K09	Gravelly clay	Very deep, well drained, gravelly clayey soils with moderate surface gravelliness on moderately steeply sloping laterite mounds, with moderate erosion; associated with deep, well drained, gravelly clay soils on gentle slopes.
K10	Gravelly clay	Very deep, well drained, gravelly clay soils on gently sloping midland laterites with valleys of northern Kerala, with moderate erosion, associated with deep, well drained, gravelly clay soils with moderate surface gravelliness and ironstone layer at 100-150 cm on nearly level lands, slightly eroded.
K13	Gravelly clay	Deep, well drained, gravelly clay soils with moderate surface gravelliest on iron stone layer at 100-150 cm on gently sloping midland laterites, with moderate erosion; associated with laterite outcrops.
K16	Fine loamy	Very deep imperfectly drained loamy soils with moderately shallow water table in nearly level board valleya of palghat gap, with slight erosion associated with moderately deep, moderately well drained, gravelly loamy soils with coherent material at 75-100 cm on gentle slopes, moderately eroded
K20	Gravelly	Deep, somewhat excessively drained, gravelly clay

	clay	soils with moderate surface gravelliness on steeply sloping high hills with thick vegetation, with moderate erosion; associated with very deep, well drained, clayey soils on gentle slopes.
K22	Clayey	Very deep, well drained, clayey soils on gently sloping lands having low hills with isolated hillocks, with moderate erosion; associated with deep, well drained, gravelly clayey soils on moderately steep slopes
K25	Gravelly clay	Very deep, well drained, gravelly clayey soils with strong surface gravelliness on moderately sloping medium hills with moderate erosion, thin vegetation associated with rock outcrops.
K26	Clayey	Very deep well drained clayey soils with loamy soils on gently sloping medium hills with thick vegetation, with moderate erosion, associated with rock outcrops.
K28	Gravelly loam	Moderately deep, well drained, moderately calcareous, gravelly loam soils with moderate surface gravelliness on gently sloping foot hills and valleys, with moderate erosion; associated with moderately shallow, somewhat excessively drained, gravelly clay soils with strong surface gravelliness and coherent materials at 50 to 75 cm on moderate slopes, severely eroded.
K29	Loam	Very deep, well drained, loamy soils on gently sloping uplands with valleys, associated with very deep, with moderate erosion, well drained, loamy soils on gentle slopes
K30	Clayey	Very deep, well drained, clayey soils on moderately sloping high hills with thick vegetation, with moderate erosion; associated with deep, well drained, gravelly clayey soils with moderate surface gravelliness on moderately steep slopes.

APPENDIX-VIII

Calculated initial and optimized parameters for the watershed

No	Parameters			Initial value	Optimized value
1	Initial abstraction	I_a	mm	17.23	13.10
2	Curve number	CN		63.15	65.90
3	Lag time	T_{lag}	min	18.51	17.90
4	Initial discharge	Q	m^3/sec	0.0774	0.069
5	Recession constant			0.746	0.627
6	Threshold flow	Q	m^3/sec	0.0564	0.055
7	Muskingum	K	hr	0.378	0.292
8	Muskingum	X		0.287	0.301

APPENDIX-IX

Observed and simulated flow before and after calibration/validation

Statistics	Calibration period(before)		Validation period	
Flow(m³/sec)	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	64.46	53.16	46.05	44.63
SD	71.50	46.97	47.84	36.42
Nash–Sutcliffe Efficiency		0.77		0.83
Coefficient of determination	.	0.88		0.86
Statistics	Calibration period(After)		Validation period	
Flow(m³/sec)	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	64.46	56.34	46.05	48.04
SD	71.50	54.76	47.84	41.42
Nash–Sutcliffe Efficiency		0.82		0.91
Coefficient of determination		0.91		0.93

MODELLING THE HYDROLOGY OF WATERSHED BY USING HEC-HMS

By
MAKKENA JYOTHI
(2014 - 18 - 118)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR- 679573, MALAPPURAM

KERALA, INDIA

2016

ABSTRACT

A hydrological model is a commonly used tool to estimate the hydrological response of a watershed to precipitation. Hydrologic Modeling System (HEC-HMS) is a physically based semi-distributed hydrologic modelling software developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. It is designed to simulate the complete hydrologic processes of dendritic watershed systems under various widely varying geographic conditions. HEC-HMS is widely used and includes both traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing as well as continuous simulation procedures including evapotranspiration, snowmelt, and soil moisture accounting. It can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

In the present study, Hydrologic Modeling System (HEC-HMS) is calibrated and validated for Thuthapuzha sub basin of Bharathapuzha river basin in Kerala. The input data required for the model like precipitation, meteorological parameters, river discharge, soil characteristics, land use characteristics and topographical characteristics of the study area were collected from various agencies like Central Water Commission (CWC), Kerala State Land Use Board (KSLUB), RARS Pattambi and the Bhuvan geo-data portal of National Remote Sensing Centre (NRSC). The model performance of the calibrated HEC-HMS model for Thuthapuzha watershed was evaluated using the statistics -Nash Sutcliffe- model efficiency criterion, coefficient of determination and simulated time to peak. The analysis showed that CN, and lag time are the most sensitive parameters for the simulation of stream flow. The Nash-Sutcliffe model efficiency (E) was (0.77-0.8) and (0.86-0.88) and the coefficient of determination was (0.82-0.91) and (0.91-0.93) before and after the calibration respectively, indicating the good performance of the model.