

Hydrological Modeling using HEC-HMS Model for Marchula Watershed in Uttrakhand

काशी हिन्दू
विश्वविद्यालय



BANARAS HINDU
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SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
Master of Technology
in
Agricultural Engineering
(SOIL & WATER CONSERVATION ENGINEERING)

Submitted by

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Dear Sir,

We have great pleasure in forwarding the thesis entitled **“Hydrological Modeling using HEC-HMS Model for Marchula Watershed in Uttrakhand”** submitted by **Mr. Subodh Hanwat, I.D. No.: SWCE-15304, Enrolment No.: 381502** in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Agricultural Engineering (Soil and Water Conservation Engineering)**, Department of Farm Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

This is to certify that the work has been carried out solely by **Mr. Subodh Hanwat** under my supervision and guidance and his findings and data presented herein are genuine and original to the best of my knowledge and belief and no part of the work has been submitted for any other degree or distinction.

Thanking you,

Yours faithfully,

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ABBREVIATIONS

AMC	Antecedent Moisture Conservation
AMSL	Average Mean Sea Level
cumec	Cubic Meter Per Second
CN	Curve Number
CWC	Central Water Commission
DEM	Digital Elevation Model
DSS	Data Storage System
et al.	And Others
ESRI	Environmental Systems Research Institute
ET _o	Evapotranspiration
FAO	Food and Agriculture Organization
FPS	Foot Pound Second
Geo-HMS	Geospatial Hydrologic Modeling System
GIS	Geographic Information System
GUI	Graphic User Interface
GWDS	Global Weather Data for SWAT
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
ISRO	Indian Space Research Organisation
km	Kilo Meter
LiDAR	Light Detection and Ranging
m	Meter
mm	Milli Meter
NED	National Elevation Dataset
NSE	Nash Sutcliffe efficiency
NEXRAD	Next Generation Radar

PEPF	Percentage error in peak flow
PEV	Percentage error in volume
PET	Potential Evapotranspiration
R^2	Coefficient of Determination
RAS	River Analysis System
RRMSE	Relative Root Mean Square Error
SI	International System of Units
SCS	Soil Conservation Service
SUH	Synthetic Unit Hydrograph
SWM	Stanford Watershed Model
SWAT	Soil and Water Assessment Tool
T_c	Time of concentration
US	United States
UH	Unit Hydrograph
USGS	United States Geological Survey
USDA	United States Department of Agriculture
VIC	Variable Infiltration Capacity

INTRODUCTION

1.1 General

Water is the most essential element to life on earth. Every living thing needs water for sustenance and without water an ecosystem would not exist. At present day's increasing water demand day by day due to vast agriculture practices, increasing population, rapid urbanization and improper water resource management. The shortage in water supply often leads to an adverse effect on the population and ecosystem. People's livelihoods are threatened or even diminished completely, leaving behind a weakened, deteriorating society that can barely recover. Due to increasing water demand there is necessity of better management planning option for the utilization of available natural resources. Where agriculture sector is play an important role in their economic growth and management of water resource in their development activities. The basic concept of evaluation of water resources are from the hydrological parameter and the subject hydrology form the core in evaluation and development of water resource.

1.2 Watershed Hydrology

A watershed is a complex system consisting of various hydrologic processes such as precipitation, interception, surface runoff, infiltration, groundwater percolation and evapotranspiration that occur at different spatial and temporal scales. The interaction among all watershed components is collectively represented by watershed response in the form of runoff hydrograph. Watershed response depends upon watershed topography (shape, size, slope, and orientation), land use pattern, soil types, magnitude and timing of rainfall events and human interventions. For example, when land surface is parched after summer, even intense precipitation in fall season may not produce high runoff, but during winter or spring, such precipitation can causes flooding because of soils are either saturated or greater moisture content to convert most of precipitation to surface runoff. Similarly a poorly managed agricultural farm can cause excessive erosion from fields and contribute nutrients and pesticides to streams, creating water quality problems in a watershed.

The following parameters have effect on watershed hydrology

1. Size
2. Shape
3. Physiography
4. Climate
5. Drainage
6. Land use
7. Vegetation
8. Geology and Soils
9. Hydrology
10. Hydrogeology
11. Socioeconomics

1.2.1 Modeling approach in hydrologic processing

Simulation models have been developed to simulate watershed-scale hydrologic processes and the hydrologic effects of different management scenarios. Watershed models are effective tools for investigating the complex nature of those processes that affect surface and subsurface hydrology, soil erosion and the transport and fate of chemical constituents in watersheds. A watershed model can be used to achieve a better understanding of the effect of land use activities and different management practices on these hydrologic processes. Due to the increased spatial and temporal data availability, more distributed hydrological models are in use. For example, from 2004 to 2011, as part of the overall Conservation Effects Assessment Project, thirteen projects on agricultural watersheds in the United States were funded jointly by the United States Department of Agriculture (USDA), National Institute of Food and Agriculture and the Natural Resources Conservation Services (Golmohammadi *et al.*, 2014). The Geographic Information System (GIS) has provided another useful basis for spatially distributed physical processes, including watershed models. Selecting the proper model to simulate the hydrologic processes of a specific watershed has always been a challenge and field testing of the hydrologic components of watersheds could help researchers to use the proper model for their purposes.

1.3 Water resource management

Water resource management is the activity of planning, developing, distributing and managing the optimum use of natural water resource. It is a part of hydrology. Ideally, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. Water occurs on the earth in all its three states i.e. liquid, solid and gaseous and is stored in earth and earth atmosphere. Water is an essential resource for all life on the planet. The total water quantity on the earth about 1386 M km³ in which about 97% of this water is contain in ocean as saline water. Over the total water resources on the Earth only 3% of it is fresh water and two-thirds of the fresh water is contained in ice caps and glaciers. Remaining one percent, inaccessible areas and much seasonal rainfall in monsoonal deluges and floods cannot easily be used. As time advances, water is becoming scarcer and having access to clean, safe, drinking water is limited among countries. At present only about 0.08 percent of all the world's fresh water is exploited by mankind in ever increasing demand for sanitation, drinking, manufacturing, leisure and agriculture. Due to the small percentage of water remaining, optimizing the fresh water left from natural resources has been a continuous difficulty in several locations worldwide.

1.3.1 Water demand and its present scenario

Agriculture is the largest user of the world's fresh water resources, consuming 70 per cent (Grafton, Q. R., and Hussey, K., 2011). As the world population rises it consumes more food (currently exceeding 6%, it is expected to reach 9% by 2050), the industries and urban development expand and the emerging bio fuel crops trade also demands a share of fresh water resources, water scarcity is becoming an important issue. An assessment of water resource management in agriculture was conducted in 2007 by the International Water Management Institute in Srilanka to see if the world had sufficient water to provide food for its growing population or not (Molden, D., 2007). It assessed the current availability of water for agriculture on a global scale and mapped out locations suffering from water scarcity. It was found that one-fifth of the world's people (more than 1.2 billion) live in areas of physical water scarcity where there is not enough water to meet all their demands. A further 1.6 billion people live in areas experiencing economic water scarcity where the lack of investment in water or

insufficient human capacity makes it impossible for authorities to satisfy the demand for water. A situation of water scarcity, the importance of how it is managed grows vastly. Finding a balance between what is needed by humans and what is needed in the environment is an important step in the sustainability of water resources. For sustainable fresh water systems has been seen on a national level in countries to set models for proper planning and management of natural resources.

1.4 Hydrological modelling

Hydrology is the scientific study of the occurrence, circulation, distribution and quality of water on earth and its atmosphere, including the water cycle, water resource and environmental watershed sustainability. Using various analytical methods and scientific techniques, we collect and analysed data to solve water related problems such as environmental preservation, natural disasters and water management.

Hydrological modelling is performed in order to predict direct runoff, total runoff volume, effective rainfall, base flow and important information from a flood event including the extent of inundation and water surface elevations at specific locations. A hydrological model is essentially a representation of the processes that occur during a flood event. The processes needing to be modelled are as many different simplifications and assumptions have been made to create models capable of accurately representing overland flow and compound channel flow while being computationally efficient. If a catchment area receiving precipitation for a period, the evaporation, transpiration, initial loss, infiltration and surface storage will have to be first satisfied before the beginning of runoff. After the initial losses are satisfied, the excess precipitation moves over the land surface. Overland flow joins small channel and contribute the runoff in steam channel. When the depth of flow during a flood event exceeds the height of the main channel, the flow expands into the relatively flat flood plains. In practice, high flows are often simulated using one-dimensional or two-dimensional models with a steady-state assumption. Flow processes in small channels include momentum exchange between fast moving flow in the main channel and slower moving flow in the flood plains, formation of turbulent eddies, and formation of shear layers between the main channel flow and storage areas in the flood plain (Bates *et al.*, 2005).

1.4.1 Hydrologic model

Watershed based hydrologic models are important tools in operational hydrology and water resources planning and management. A watershed scale hydrologic model is a simplified description of the hydrologic system of a watershed. Traditionally, statistical and conceptual hydrologic models have treated input parameters as lumped over the entire study watershed by ignoring the spatial variability of the physical system and its processes. Specifically, these models cannot accurately represent and model the spatial variation in meteorological and land surface conditions that affect various hydrologic processes and therefore cannot assure realistic simulations. With the availability of DEM (Digital Elevation Model) and next generation radar (NEXRAD) rainfall data, grid based hydrologic models are more effective in representing the variations of meteorological forcing and land surface parameters. Also, geographic information system (GIS) allows processing of grid and vector data, which has led to rapid progress in distributed hydrologic modelling. However, an existing problem in hydrologic modelling is that the available software for handling spatial information and for model simulation is not integrated in the same environment.

1.4.2 HEC-HMS Model

HEC-HMS is a physically based, semi-distributed hydrologic model developed by the US Army Corps of Engineers to simulate the hydrologic response of a watershed subject to a given hydro-meteorological input (scharffenber *et al.*, 2010). The model uses underlying DEM information to partition the basin into sub-watersheds. The size of the sub-watershed is determined a priori by the modeller, and few or no guidelines are available for sub-watershed selection. In most cases, the balance between the resolution of the distributed information and the computation time required for simulation is the main factor considered for this selection. The model can simulate individual storm events as well as continuous precipitation input at minute, hourly or daily time steps (zhang *et al.*, 2013). The HEC-HMS offers a variety of model options to simulate runoff production, at the hill slope scale and flow channels. These include SCS (Soil Conservation Service) curve number, SCS unit hydrograph, and baseflow estimation methods which are necessary to calculate water losses, runoff transformation, and

baseflow rates. The Muskingum and constant loss method are used to calculate flood routing and water losses along the channel.

1.5 Objectives of study

In the present study, the Geographic Information System (GIS) has been used to integrate the geographic data for Marchula watershed. These data include land cover land use, distribution of soil-types and digital terrain model. With the help of HEC-GeoHMS we get visualised spatial information, watershed characteristics, perform spatial analysis, delineated sub-basin and stream network and create input files for HEC-HMS model. HEC-HMS (Hydrologic Engineering Centre–Hydrologic Modelling System) is used to simulate the storm events to set up the rainfall-runoff model in Marchula watershed. The main objectives of study are following

- I. To create spatial and temporal database for the Ramganga basin up to Marchula.
- II. To simulate rainfall-runoff process of the Marchula watershed using HEC-HMS model.

REVIEW OF LITERATURE

2.1 General

In alignment with the purpose and methods of this thesis, the following literature review was carried out to examine about hydrological modelling and its effect on watersheds, give an overview of the Army Corps of Engineer's Hydrologic Modelling System (HEC-HMS) and discuss methods in hydrologic modelling. Ultimately this review will help to clarify where the Marchulla watershed hydrological modelling stands in the realm of current research and modelling practice.

2.1.1 Hydrological models

A hydrologic model represents a complex hydrologic system in simple and readily comprehensible manner to permit hydrologic simulation and prediction by establishing relationships between different watershed components (Black, 1991). Watershed models have come a long way since their inception in 1960's from lumped rainfall-runoff model such as Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), to more process based semi-distributed models such as SWAT that is capable of simulating runoff, sediment, nutrient and pesticide at various points in a watershed (Arnold *et al.*, 1998).

Blaney *et al.* (1930) detected an ET-induced diel signal in the stage values of the Santa Ana River in California and found a strong correlation with the diurnal cycle of air temperature and pan evaporation. They concluded that less than 6% of the total daily ET takes place between 8 p.m. and 8 a.m. and that between midnight and dawn the ET intensity is extremely low.

Meyboom *et al.* (1965) calculates the water volume of stream flow used by ET as a difference between the curve connecting the maximum stream flow rates and the actual diurnal hydrograph. He describes a drastic decrease of river discharge in the summer dry periods when the water uptake of the riparian vegetation exceeds

groundwater-flow rates to the riparian zone, causing the originally gaining stream reach to become a losing one.

Barry and Bajracharya (1995) channel routing is an important component of a hydrologic simulation and several models have been developed to perform this function. The Muskingum Cunge method [Cunge, 1969] is one such model that has a wide range of applicability and provides reasonably accurate results when deriving the outflow hydrograph from a given inflow hydrograph and channel properties.

Ponce and Hawkins (1996) the SCS Curve Number method has become a ubiquitous method in science and engineering due to its straight forward conceptual basis of precipitation storage and its computational simplicity. It is a deterministic method based on the catchment properties of antecedent moisture, land use, soils and surface condition.

Kilgore et al. (1997) Sherman (1932) introduced the unit hydrograph technique. It was the first attempt to predict an entire hydrograph instead of just the peak flow and time to peak. The unit hydrograph was the first model to estimate the entire shape of the hydrograph rather than simple hydrograph peak value. During the 1950s, hydrologist began to develop "conceptual model". Unit hydrograph produce direct runoff of 1 cm excess rainfall occurring uniform over that basin and at a unit rate for specified duration.

Paudel et al. (2009) the Clark method [Clark, 1945] describes how a watershed moves excess rain to its outlet. More recently, the Modified Clark method has come into use as a quasi-distributed version of the model for performing this function. The Clark method utilizes basin shape, temporary storage and timing in order to describe a catchment's hydrologic response.

Grzebinoga and Paluszkiewicz (2011) suggested that to analysis about the suitability of Snyder's and Clark's models to simulate flood discharges in the Grabinka river basin, with slightly better results being obtained using the former model. The efficiency coefficient values of 89% for Snyder's SUH model and 87% for Clark's SUH model seem to attest it. For both SUH the times to culmination were the same as the observed one, while the culmination flow discharge was 0.11% higher in Snyder's

model and 1.9% lower in Clark's model, compared to the observed discharge. For limited data the objective function based on peak values of discharge gives better results than the objective function based on the complete hydrograph. To confirm the correctness of the results obtained in this study it is necessary to continue research on greater data set. Snyder's model, owing to the limited number of parameters it comprises and a relative ease of their acquirement, shall be especially recommended for practical use.

Okkan and Serbes (2012) application of the least squares version of support vector machines (LS-SVM) model compared with those of feedforward neural networks (FFNN) and traditional methods such as autoregressive moving average (ARMA) and multiple linear regressions for modeling of monthly runoff of the Tahtali and Gordes watersheds, on the basis of the meteorological data and antecedent runoff data. The results of different performance measures show that the LS-SVM models have higher nonlinear mapping capabilities and thus can more easily capture monthly runoff data. These results were improbable; however, the explanation may be that LS-SVM is able to simulate highly nonlinear of rainfall–runoff relationships in these arid watersheds that are located at the Aegean coast of Turkey and have typical Mediterranean climate characteristics.

Zhang *et al.* (2015) when using observed data, the optimization results were different when using different objective functions and were even different when using the same objective function. The values were significantly different because of the influence of errors in the data and model structure. Although the data length had no effect when using ideal data, when using observed data the parameter optimization results were different. That is, the parameter optimization did not converge to a certain value as the length of the measured data increased.

Najmaddin *et al.* (2017) this study suggest that runoff dynamics in this catchment are principally controlled by the soil moisture balance and that groundwater dynamics and snow melt make relatively small contributions to the shape and magnitude of the hydrograph (although snow melt is predicted to be significant in spring and baseflow is important in the dry season). However, significant uncertainty exists in the model simulations reported, manifested as equifinality. Component of this

uncertainty could be quantified using Generalised Likelihood Uncertainty Estimation (GLUE) which defines uncertainty bounds on predicted flows (resulting, in part, from poorly constrained calibration) but epistemic uncertainty is unknown and likely to be significant

2.1.2 HEC-HMS model

The Army Corps of Engineers' Hydrologic Engineering Centre (HEC) created the Hydrologic Modelling System (HEC-HMS) as a versatile runoff modelling software package [USACE, 2000]. It replaces the popular HEC-1 program and is capable of modelling a wide range of watersheds by offering several different mathematical models, all of which are deterministic in nature [USACE, 2000]. Improvements over HEC-1 include a graphical user interface that allows for convenient editing and result viewing (Viessman and Lewis, 2003).

Refsgaard *et al.* (1987) HEC-HMS offers model configurations that range from lumped to distributed model. Lumped models use composite parameters for large, grouped areas of land while distributed models keep parameters spatially variable. The configuration chosen depends on the end goals of the study and the available data. Generally, lumped models avoid problems with over-parameterization and data limitations, but they may fail to sufficiently explain changing landscapes.

Legesse *et al.* (2003) conversely distributed models can deterministically account for varying parameters in the watershed, but describing all of the required parameters accurately can be challenging and computationally expensive. Specific knowledge of each modelling case must be taken into account when determining how best to represent specific watershed models can deterministically account for varying parameters in the watershed, but describing all of the required parameters accurately can be challenging and computationally expensive.

Nawaz and Han (2006) concluded that if the proper storage facility and modernized structures are provided in hill torrent affected areas then not only the flood is controlled but also the drought conditions can be mitigated and the crops yield can be enhanced. Roy *et al.*, 2013 concluded that the stream flow simulation performed well

with calibrated HEC-HMS model in different watersheds of Subarnarekha river basin and other hydro meteorologically similar river basin.

Chang *et al.* (2009) if we used Clark's Unit Hydrograph to be the transform method in simulation. When the retention time was longer, there was much inaccuracy in the peak flood time. However, when the retention time was shorter, the Clark's Unit Hydrograph was more effective in commanding peak flood time. The excessive development in the watershed will cause the reduction of storage ability in the watershed. Over-exploitation will cause serious flood problems.

Majidi and Shahedi (2012) studied, surface runoff simulation of Abnama watershed was conducted with Green-Ampt method and soil and water conservation service (SCS) method using for hydrological modelling with help of HEC-HMS software. For choosing appropriate method after determining the input for both of method, HEC-HMS model has been separately run, calibrated and validated for four events for that have hydrograph and corresponding hydrograph. After the model calibration and validation showed the Green-Ampt method estimated peak discharge with lower difference and it's time to peak was less then SCS method. Also comparison of simulated and observed hydrographs and correlation between their value in Minitab software showed that result based on the Green-Ampt method have a higher correlation ($R^2 = 0.71$, Pearson correlation = 0.84) than SCS method ($R^2 = 0.46$, Pearson correlation = 0.7) and it can be concluded that simulation using Green-Ampt method is more precise than SCS method.

Choudhari *et al.* (2014) studied that the initial calibration parameters are derived with the help of geomorphologic characteristics. By obtaining optimization technique, final validation parameter were derived and considered as global values for the model. The HEC-HMS model used for rainfall-runoff simulation in the selected watershed shows RMSE as 0.09 ceme and MARE as 0.06 for peak discharge and RMSE as 0.70 mm and MARE as 0.05 for runoff depth. These obtained square functions in the validated model indicate satisfactory performance of HEC-HMS model in simulation runoff hydrograph. Despite difficulties, limitations and uncertainties associated with obtaining observations and measured parameters, this study ended-up with optimistic results for the simulation of rainfall-runoff process. The model can help to save time

and money in obtaining the runoff data rather than measurement of runoff in the watershed. Moreover, it may help to simulate runoff in un-gauged watershed where there is no gauging station to measure runoff.

Skhakhfa and Ouerdachi (2016) concluded that to ensure the overall consistency of simulated results, it is necessary to develop a validation process, particularly in regions where data are scarce or limited and unreliable. Calibration and validation processes were carried out using different sets of data (CN, SCS Lag and Muskingum K). Evaluation on the performance of the developed flood model derived using HEC-HMS (hydrologic modelling system) yield a correlation coefficient R^2 close to 1 and the Nash-Sutcliffe efficiency. We limit ourselves to modeling flood of short duration for which the process of evapotranspiration is negligible. Several events have been tested, including two to calibrate and one to validate the model. So it can be said that using the HEC-HMS model had the highest efficiency in with the values of these parameters calibrated, based on objective functions (percent error in peaks), with 8.8 percent difference between of observed and simulated discharges with R^2 value is 0.87 and the Nash-Sutcliffe efficiency value is 0.99.

HEC-HMS is an important tool for forecasting and quantifying the effects of different inputs for a watershed. When compared to field experiments, hydrological models, like HEC-HMS, are more flexible and economical (Li *et al.*, 2007). Models in general broaden the range of hydrologic investigations through predictive capabilities and can show the sensitivity of a watershed's response when subjected to situations like changing land use, varying climate conditions, or the addition of reservoirs (Bhaduri *et al.*, 2000). The study determined urbanization substantially raises peak flow rates and flood risk and future urbanization will have to take into account careful water planning to mitigate such issues.

HEC-HMS is a graphic-oriented, hydrologic software program that offers a range of model components. Its user-friendly and flexible setup has led to its widespread use, but its capabilities are still not fully developed. HEC-HMS could benefit from stochastic approaches that look at parameter uncertainty. Despite this weakness, it still provides a valuable deterministic tool for investigating watersheds and predicting the implications of changing landscapes.

2.2 Role of GIS, Geo-HMS and Remote Sensing

Hydrologic modelling has undergone large advancements from the incorporation of spatial data software, and the use of geographical information systems (GIS) has become commonplace in the preparation of data intended for use in a hydrologic model. GIS has greatly expedited analysis of watersheds of all sizes and has been shown to be very adaptive to the needs of the hydrologic model

Kite and Pietroniro (1996) studied have suggested that the use of remotely sensed data in hydrology and water resources could yield benefit cost ratios in the order of 100:1 from savings in flood damage and in improved planning of irrigation and hydroelectric production. Such applications are well suited for hydrological modeling. However, the current use of remotely sensed data in modeling is low. The main reason for this is that there are few universally applicable operational methods of deriving the hydro-logically important variables from the remotely sensed data. It is really no use having vast quantities of data available if there are no suitable techniques to use them.

Hoblit and Curtis (2001) physically based hydrological model using GIS software package is the recent development of HEC-Geo HMS by the US Army corps of Engineers Hydrological Engineering Centre (HEC). Digital Elevation Model (DEM) can be easily downloads and used in HEC-GeoHMS package for watershed delineation based on topographic data. HEC-GeoHMS and HEC-HMS collectively used for the prediction of runoff from available rain fall data. It is concluded that the HEC-GeoHMS and HEC-HMS could be used to create hydrological models for most of the watershed in the United States. These models required physical data as input which were freely available.

Alemaw et al. (2003) mentioned that GIS has the capability of handling large amounts of spatially detailed information derived from various sources such as remote sensing and ground surveys. With the advent of increasing computing power and GIS techniques, physical-based hydrologic modeling has become important in contemporary hydrology for assessing the impact of human intervention and/or possible climatic change on basin hydrology and water resources.

Hashmi et al. (2005) used HEC-Geo-HMS and HEC-HMS for rainfall-runoff modeling for Kaha Hill Torrent watershed D.G. Khan District. Calibration of HEC-HMS model carried out using daily historic rainfall data of Murange rain gauge station compared well with observed flood peak at Darraha gauging station.

Seth et al. (2009) GIS has evolved as a highly sophisticated data management system to put together and store the voluminous data typically required for hydrological studies. Thus remote sensing and GIS together provide information base for efficient management of water resources. The synoptic view provided by satellite remote sensing and the analysis capability provided by GIS offer a technologically appropriate method for studying these resources.

Santillan et al. (2011) this study has demonstrated the usefulness of multi-temporal Landsat images in detecting land-cover change, in identifying areas for rehabilitation and in evaluating rehabilitation strategies for the management of tropical watersheds through its use in hydrologic modeling. Although the methods used in this study was applied in a relatively small watershed, its applicability to large watersheds and river basins is also possible as long as there are available Landsat images to derive land-cover information needed for detecting and locating the changes and for hydrologic modeling. Since Landsat images acquired since 1972 are now available over the internet, the methods employed in this study can be readily applied for watershed land-cover change monitoring, management and rehabilitation.

Singh et al. (2014) large scale watershed analysis using GIS, remote sensing data and Digital elevation Model (DEM) has efficient tools for understanding any terrain parameters such as nature of bedrock, infiltration capacity, surface run off etc., which helps in better understanding the status of land form and their processes, drainage management and evolution of groundwater potential for watershed planning and management.

Thakur et al. (2016) integration of remote sensing (RS), geographic information systems (GIS) and global positioning system (GPS) are emerging research areas in the field of groundwater hydrology, resource management, environmental monitoring and during emergency response. Recent advancements in the fields of RS,

GIS, GPS and higher level of computation will help in providing and handling a range of data simultaneously in a timeand cost-efficient manner.

MATERIALS AND METHODS

3.1 General

The following chapter provides a description of Marchula watershed and the monitoring of rain and runoff events. In addition to the climate characteristics of the area, the location soil type, land use land cover pattern and general physical attributes of the watershed are described. The description of various datasets used in the study and provide the various thematic maps prepared under GIS environment and extracting some of the model inputs such as area, slope, channel length and several others are describe in details. Overview and brief description of the model operation along with description of input files used for evaluating the models are also included. Procedure used for optimization, calibration and validation of the model and various criteria used for evaluating the model performances are given in chapter.

3.2 Description of study area

3.2.1 Location

The Ramganga river is one of the major tributary to joining the Ganga river in Ganga plan. The Ramganga river originates from Doodhatoli ranges in the district of Pauri Garhwal, Uttarakhand and run through the part of central Himalayas and Ganga flood plain before merging to the Ganga river and flows to south west from Kumaun Himalaya. The Kalagarh dam is situated an elevation of 365m (AMSL) at the Ramganga river for irrigation and hydroelectric generation. Ramganga basin is surrounded by ridge (water divide) like Chorara Khal Dhar (2363m AMSL), Diwali Khal (2442m AMSL), Inora Khal (2557m AMSL) and Khankra Kheti Ki Dhar (2784m AMSL) in the north, the water divide of kosi and Ramganga river, Chatkora Ka Tibba (1921m AMSL) in the south, the water divided of Nayar and Ramganga river, Dhangki Dhar (2591m AMSL) and Agarni Dhar (2250m AMSL) in the east, and by the water devide of Pindar and Ramganga river, Musa Ka Kotha (3119m AMSL), Dudhatoli Dhar (3098m AMSL) and Malkhori Dhar (2488m AMSL) in the

west. The Ramganga river covering a length of 158 km from its starting point, the river originate from the mountains at Kalagarh into the Ganga flood plains.

The present study area of Marchula watershed falls in the Chamoli district of Uttarakhand state in India with a geographical extent between $29^{\circ}33'57.50''$ to $30^{\circ}05'35''$ N latitude and $79^{\circ}0'37''$ to $79^{\circ}34'34''$ E longitude. The area of the watershed has almost fan shaped area covering about 2048 km^2 (Figure 3.1)

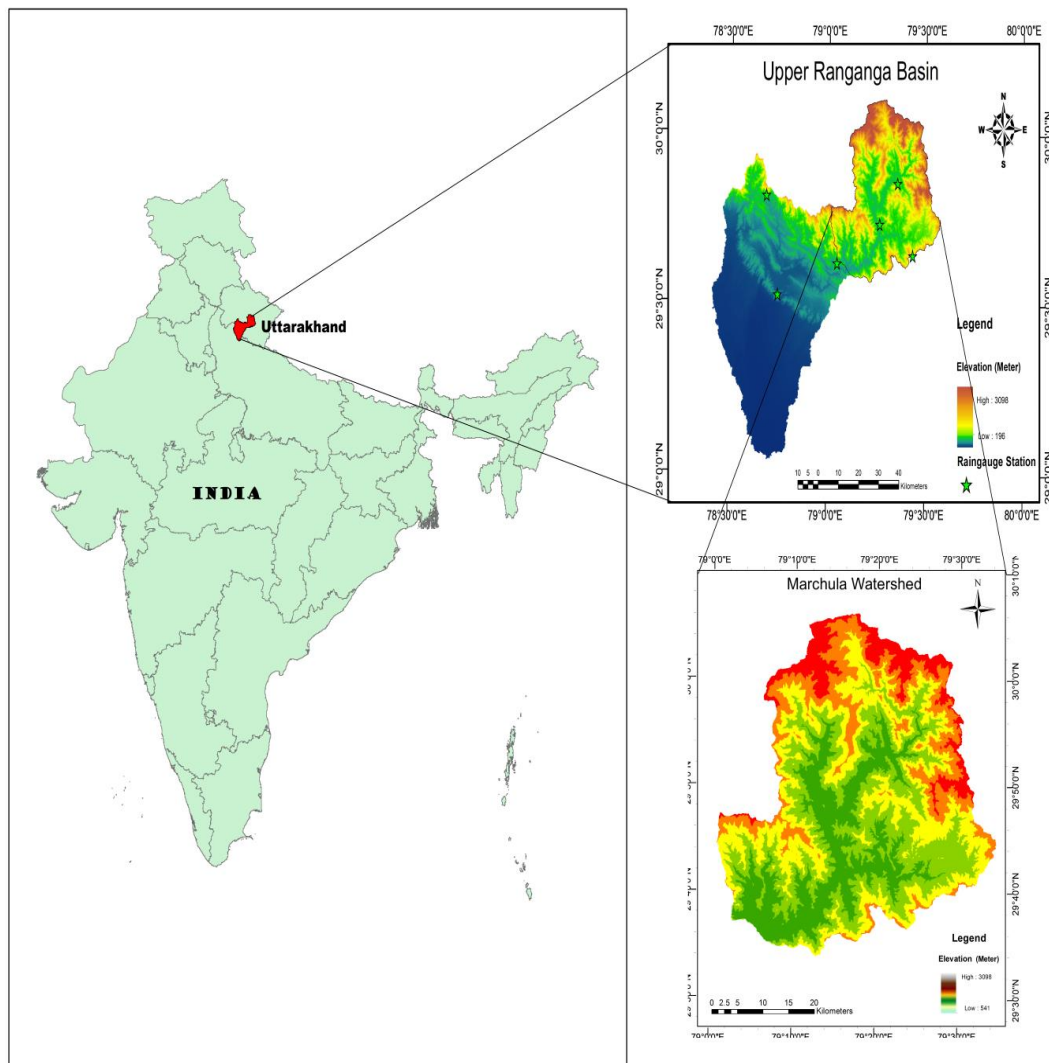


Figure 3.1: Location map of study area

3.2.2 Climate condition

Uttarakhand is characterized by two types of climate, sharply differentiated in the plains and the mountainous regions. The climate varies from sub-tropical

monsoon type (mild winter, hot summer) to tropical upland type (mild winter, dry winter, short summer). The climate in the northern part of Uttarakhand is typically Himalayan. This mountain range itself exerts an appreciable extent of influence on monsoon and rainfall patterns. Within the Himalayas, climate differs depending on altitude and position. The area studied witnesses three distinct seasons viz. winter, summer and rainy. Rainy season commenced during the month from Jun to September.

Climate ranges from subtropical in the southern foothills, averaging summer temperatures of about 30° C (about 86° F) and winter temperatures of about 18°C (about 64°F). Warm temperate conditions prevail in the Middle Himalayan valleys, with summer temperatures usually hovering about the mark of 25° C (about 77°F) and cooler winters. Cool temperate conditions dominate the higher areas of the Middle Himalayas, where the summer temperatures are usually around 15 to 18° C (59 to 64° F) and winters drop below the freezing point.

3.2.3 Rainfall

The Marchula watershed receives rainfall mainly from a single climatic system, i.e. southwest (SW) or summer monsoon with little bit of snow fall during winter at higher altitude of mountain slope especially up to Kalimat and Gairsain areas of Ramganga basin.

Monsoon currents can penetrate through trenched valleys, the rainfall reaches its maximum in the monsoon season that spans between June to September. October to November and March to May consider as post monsoon and premonsoon respectively. Rainfall is highly variable depending upon the altitude. Maximum rainfall occurs in foothill area of Himalayan and it's reduced to down in flood plan area of Kamganga basin. About 2100 mm maximum rainfall receives at Kalagarh site in upper Ramganga basin and minimum rainfall about 450 mm is linearly decreasing to downstream side of Ramganga basin. Rainfall trend also decreasing in upper part of Ramganga basin due to very high mountainous and low temperate region is shown in figure 4.3. In high altitude areas (1000-2000 m) maximum rainfall occurs about 70 to 80% July and August are the rainiest months. Rainfall rapidly decreases after September and it is the least in November. About 17% of the annual precipitation

occurs in winter season. The area receives about 1000 mm average rainfall annually (CWC 2012).

In present study area four rain gauge stations are installed namely as Marchulla, Naula, Ranikhet and Chaukutiya and three discharge gauge at Marchula, Chauktiya and Naula (Figure 3.2).

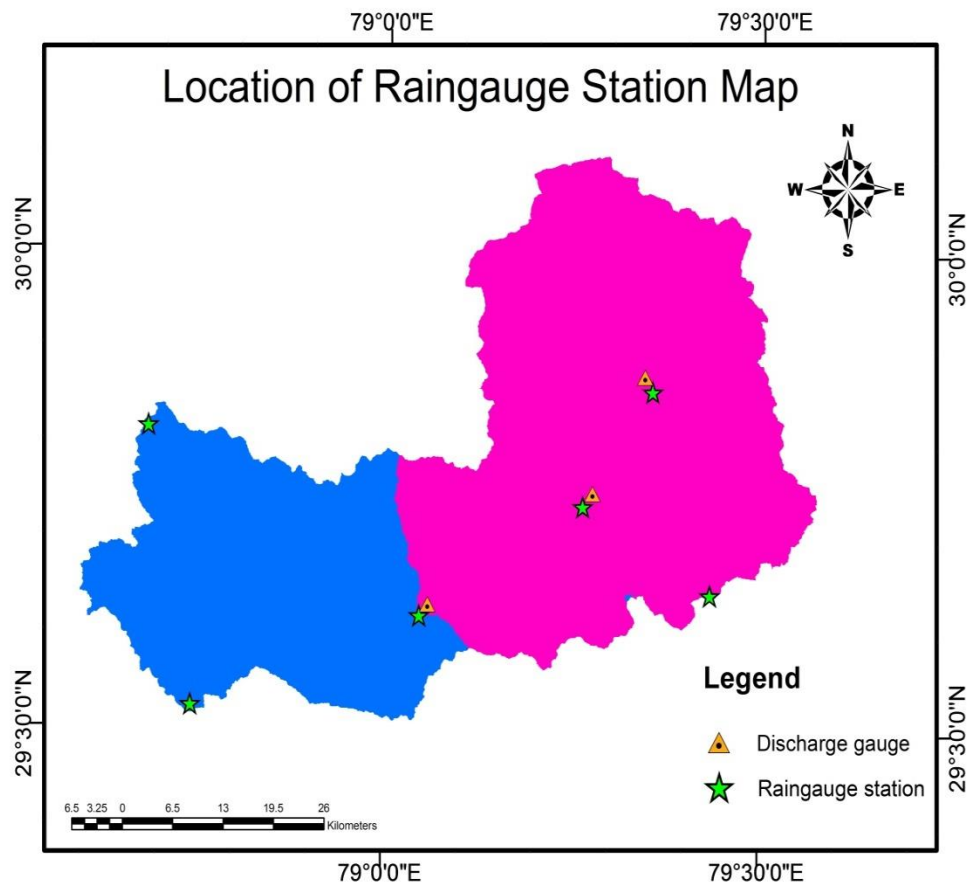


Figure 3.2: Map of hydro-meteorological stations in the study area

3.2.4 Physiography and relief

The Ramganga basin lying entirely between the middle Himalaya and Lesser Himalaya, exhibits high differences in altitude with very narrow valleys, deep gorges having very high gradient. It has average elevation of 1677.5 m above mean sea level (AMSL). Low elevation at Kalagarh Dam about 278.6m (AMSL) highest elevation of 3089 m (AMSL) at Musa Ka Kotha (3119m AMSL). The catchment is characterized by high hills, deep and narrow valleys (CWC 2012). The slope generally varies from below 10% to above 40%. Slope gradient and direction of slope governs the runoff

process. The slope amount has been calculated from Digital Elevation Model (DEM) and are grouped into five classes- i.e. 0-5%, 5-15%, 15-45%, 45-75% and > 75% and shown in Figure 3.3

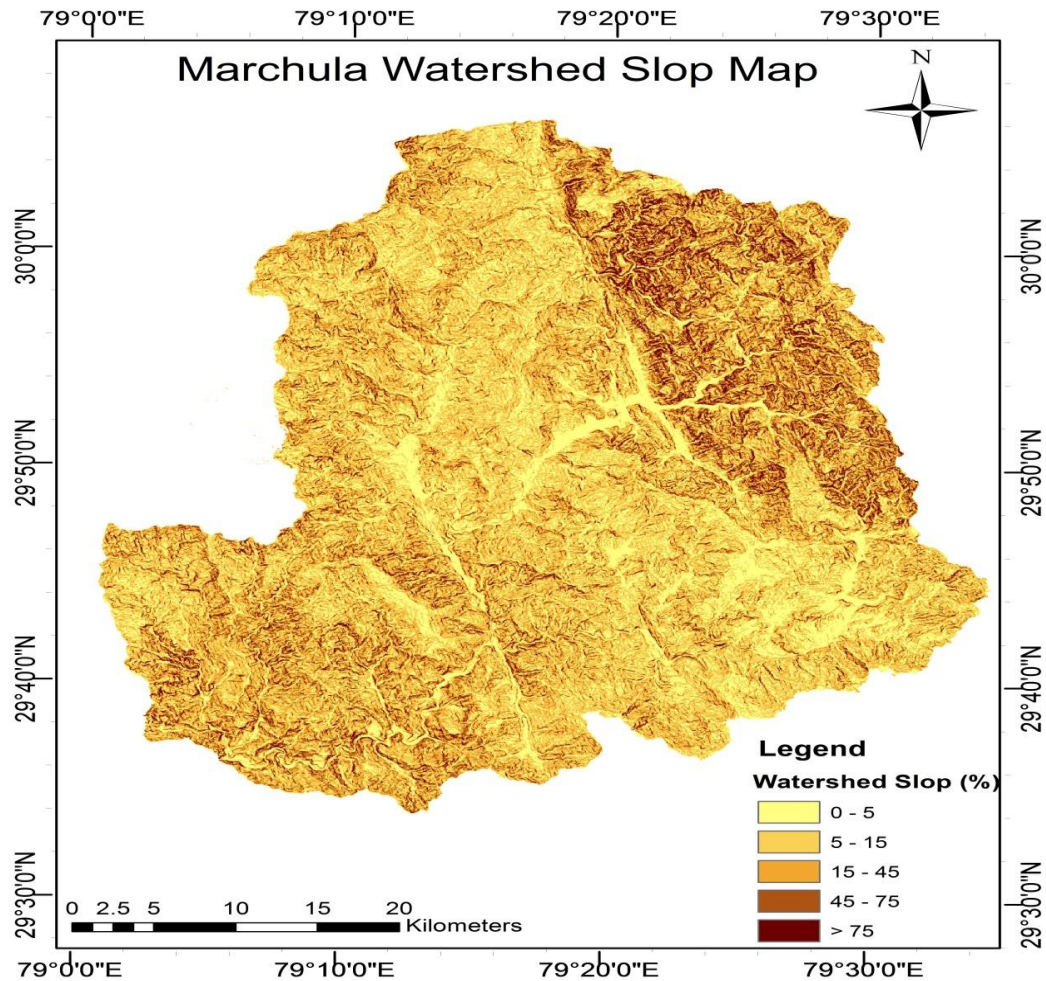


Figure 3.3: Watershed slope map at study area

3.2.5 Digital elevation model

A Digital Elevation Model (DEM) provides the base for most investigations in hydrology (Li and Wong, 2010). A DEM is in a raster form (a grid setup) or a triangular irregular network (a vector format) and represents ground elevation data. The United States Geological Survey (USGS) has developed several elevation maps at different resolutions, and their data is a part of the National Elevation Dataset (NED). On USGS website 30 meter resolution is available for the entire United States and other countries, and 10 m resolution is available for much of the United States. In

India ISRO also provide DEM data of different resolutions for hydrological modelling and other purpose. Moreover, 23m resolution gridded data is available on bhuvan website (Indian geo-platform of ISRO). This is a seamless data set and is available free to the public. Finer resolutions are available through Light Detection and Ranging (LiDAR) technology. The resolution refers to the grid size of a raster and a 10 meter DEM contains a single elevation value for a 10 meter by 10 meter square on the earth. The grid size of a raster data set has obvious implications to the outcomes of hydrological models that include accuracy and evaluation of parameter values. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) were used to prepare the digital elevation model (DEM) at 30-m resolution (Figure 3.4). These will cover digital topographic data for 80% of the earth's land surface. The highest and lowest point elevation values from DEM are 540 m and 3098 m respectively. The northern and eastern regions of the study area have higher elevation range while west-southern part is low altitude. DEM was used to derive slope, aspect, flow direction and accumulation, stream network and the watershed delineation.

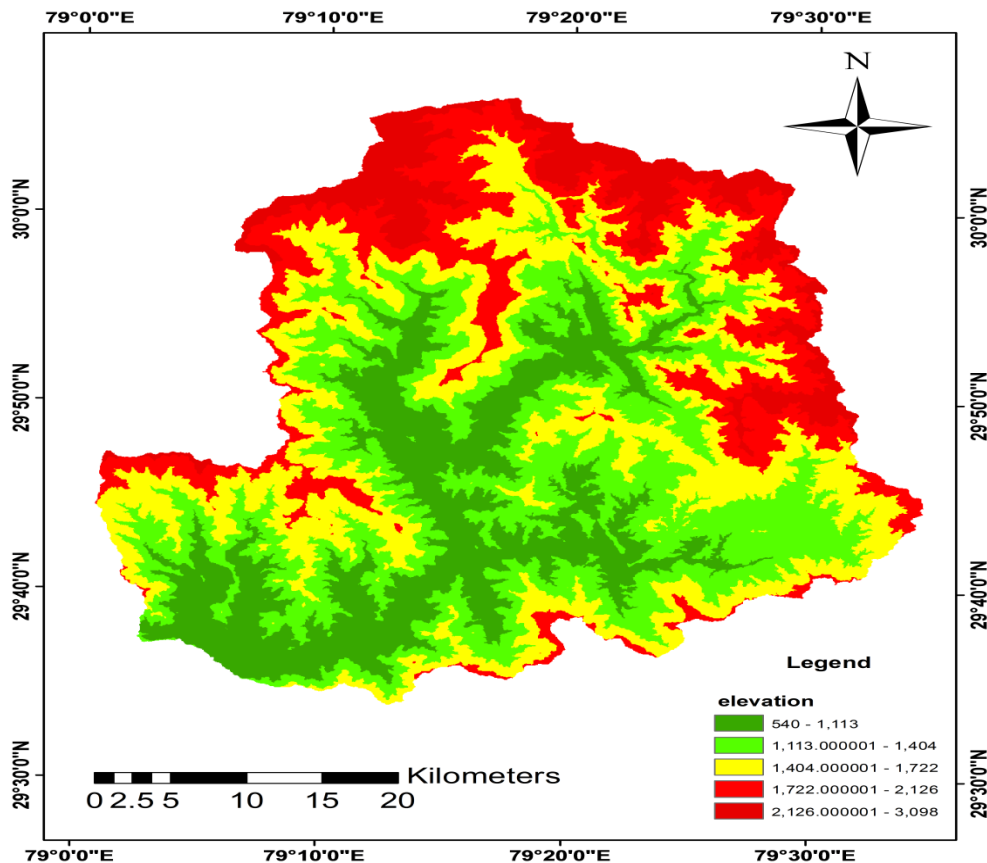


Figure 3.4: Digital Elevation Model Map

3.2.6 Landsat data

Landsat data was used to prepare the land use/land cover map with the help of ERDAS imagine at 30-m multispectral band resolution with map projection UTM. Landsat data scene ID is "LC08_L1TP_145039_20161224_20170315_01_T1" which shows the data acquisition date is 12-24-2016 by sensor OLI/TIRS of land set satellite 8 image, processing correlation level is precision terrain, path-145, row-039, collection no. 01 and collection category is tier-1 with cloud cover 8.238%. Land set data are available on USGS website with format GeoTIFF.

3.2.7 Drainage network

Drainage network is characterised as the greater the drainage density, the runoff yield at the outlet become more because rain water inter to drainage channels, immediately and reach to the outlet. Strahler's method is used for stream ordering of study area using DEM with 30m resolution in ArcGIS 10.2.2 (Figure 3.5). Drainage network map shows the drainage density is higher in upper part of watershed due to steep slope; does increase runoff velocity developed the drainage channel. Ramganga river stream order ranging from 1 to 3th order watershed having dendritic, sub-parallel, trellis and radial drainage pattern in the upper part of the basin, whereas in the Siwalik region, the lower part of the Ramganga basin, parallel and trellis drainage pattern exists. The number of drainage lines under various orders and their length are shown in Table 3.1. The important tributaries of Ramganga river are Khachyar Gad, Kuthar Gad, Bino river, Nayer Nadi, Badangarh, Dev Gad, Kali Nadi, Mandal Nadi, Palain Nadi and Sona Nadi etc. The Marchula has been grouped into 6 sub-watershed for rainfall-runoff analysis.

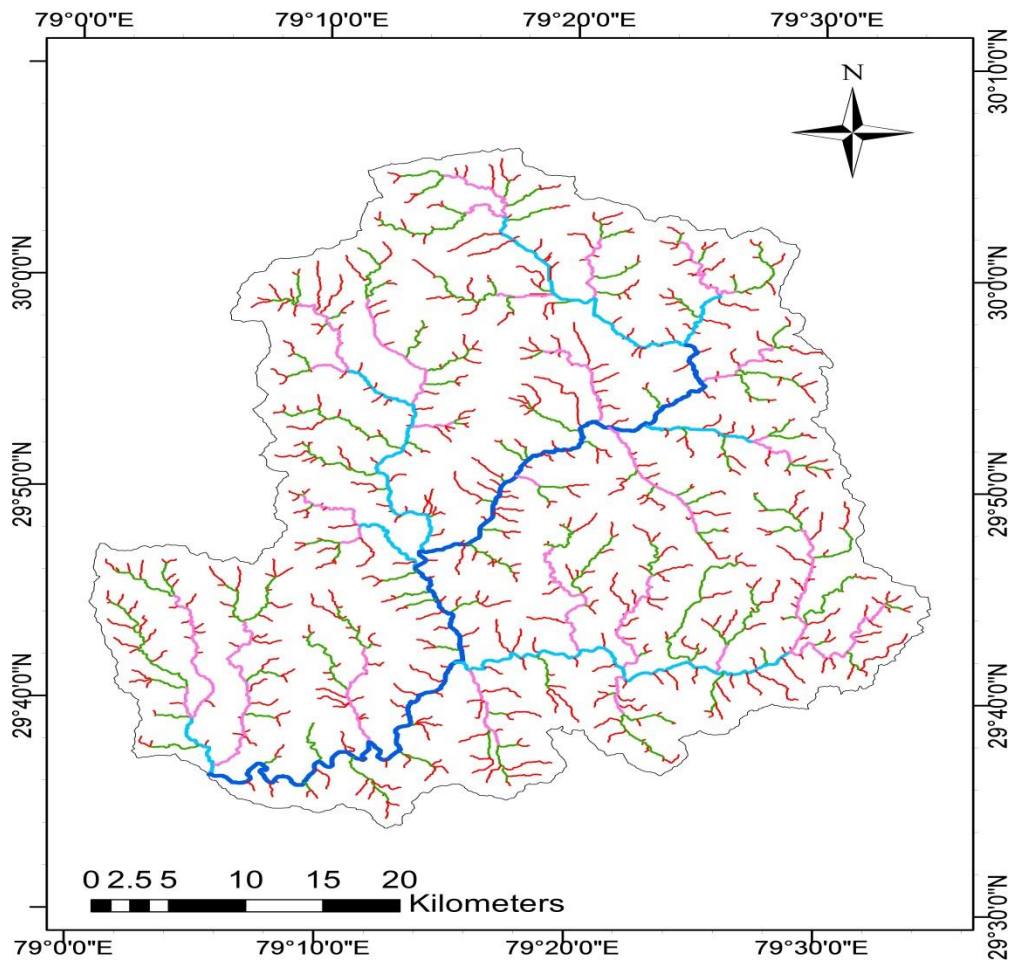


Figure 3.5: Drainage Network of Marchula Watershed

3.3 Soil characteristics

3.3.1 Soil texture

Soil texture is defined by size distribution or mass fractions of primary particles in soil (individual grains and particles). The foothill of Himalayan region is mainly alluvial soil and upper part of Himalaya's dominant in sandy loam soil. Marchula watershed soil has medium texture contain top layer, sand fraction 42%, silt fraction 36% and clay 22% with moderate drainable capacity (FAO 2002). The higher amount of sand present in soil is characterized by the higher rate of permeability and porosity and decreasing tendency of the soil cohesiveness. The finer particles present in soil sometime becomes mobile in presence of seepage water and disturbs the soil cohesiveness

3.3.2 Soil genesis

The soils have developed from rocks like granite, schist, gneiss, phyllites, shales, slate etc. under cool and moist climate. Very steep to steep hills and Glacio-fluvial valleys are dominantly occupied with very shallow to moderately shallow excessively drained, sandy-skeletal to loamy-skeletal, neutral to slightly acidic with low available water capacity soils. A major part of it is under forest. Intermittent sparse patchy terraced cultivation is also practiced on fairly steep hill slopes whereas dry and wet cultivation are prevalent on the uplands and low-lying valleys respectively. The broader valley slopes dominantly have deep, well drained, fine-loamy, moderately acidic and slightly stony. The soils of Marchula watershed are natural, dynamic, heterogeneous, non-renewable resource, which support plant and animal life.

3.4 Data inputs

3.4.1 Data collection and assembly

Spatial and temporal data is used for hydrological modelling which can be collected from various sources. While collecting the spatial data, accuracy, resolution, validity of data set etc. should be considered depending upon the scope of the study. In the present study, various types of data used are; digital elevation model (DEM), stream discharge gauge data, drainage facilities photographs, street data, soil type data, land use land cover data, global weather data, precipitation data etc. Depending upon the purpose of study, different combinations of above data set are required. All data sets used in spatial analysis should have same datum, projection and co-ordinate system. Various operations like geo-referencing of non-spatial data, file format conversion, transformations etc. are required while assembling data.

Table 3.1: Various data type and their sources

S.N.	DATA type	DESCRIPTION	SOURCE
1	ASTER DEM	For terrain processing	U.S.G.S
2	LANDSET 8	For preparing LULC Map	
3	SOIL DATA	For determination of curve no.	NBSS & LUP
4	PRECIPITATION	For simulation	N.I.H. Roorkee
5	DISCHARGE DATA	For calibration	
6	TEMPARETURE	For determination of evapotranspiration	
7	HUMIDITY		G.W.D.S
8	WIND SPEED		
9	SUNSINE HOUR		

3.4.2 Data base creation/preparation

30 m grid DEM data of the study area has been downloaded from the website of U.S. Geological Survey (<http://gdex.cr.usgs.gov/gdex/>). HEC-Geo HMS software has been used to prepare the input files for hydrological model. GIS based HMS input files of the study area namely background map file, meteorological model files and basin model files have been prepared using DEM terrain data with the help of HEC-Geo HMS software. Basin model file includes stream networks and their connectivity within the watershed, sub watershed and their boundaries. Further basin and terrain processing have been done in an Arc GIS Map. River networks and the catchments of the study area have been incorporated in the basin model and the hydrologic elements are linked.

The details of drainage area of sub watershed delineated using HEC-Geo HMS along with their time of concentration has been presented in Table 3.2.

Table 3.2: Details of sub-basin areas and their time of concentration

S.N.	Sub Basin Name	Sub basin area (sq.km)	Time of concentration (min.)
1	W80	707.53	219
2	W90	295.41	134
3	W100	143.75	126
4	W110	512.77	163
5	W120	191.57	85
6	W130	214.90	126
	Total	2065.93	

3.5 Analysis of Hydro-Meteorological data

3.5.1 Hydro-meteorological data

The hydro-meteorological data of temperature, rainfall and discharge used in the present study have been collected from National Institute of Hydrology Roorkee, Uttarakhand. The daily maximum and minimum temperature data series (2001-2015) for one stations namely Kalagarh was collected. The daily rainfall data series (2001-2015) of six stations Kalagarh, Marchulla, Naula, Chaukhutiya, Ranikhet and Lansdown, and the daily discharge data series of three station Marchulla, Naula and Chaukatiyahas been collected. The general details of hydro-meteorological stations are given in Table 3.3.

Table 3.3: Raingauge station and their location

S.N.	STATION	LONGITUDE	LATITUDE	ALTITUDE (m)
1.	Marchula	79°5'37"E	29°36'20"N	564.8
2.	Kalagarh	78°45'24"E	29°31'7"N	278.6
3.	Naula	79°14'47"E	29°44'7"N	903.7
4.	Chaukhutiya	79°20'55"E	29°50'10"N	1632.2
5.	Ranikhet	79°25'50"E	29°38'44"N	1788.0
6.	Lansdawn	78°40'36"E	29°49'57"N	1060.7

3.5.2 Thiessen polygon method

This method is an area based weighting method, based upon assumption that the rainfall depth at any point within a watershed is the same as the rainfall depth at the nearest raingauge station in the watershed. As shows in figure 3.5 the gauge nearest each point in watershed may be found graphically by connecting the gauge and constructing perpendicular bisector line. This forms of boundaries of polygon surrounding each gauge. So the gauge assigned to the each is the fraction of the total area that the polygon represents.

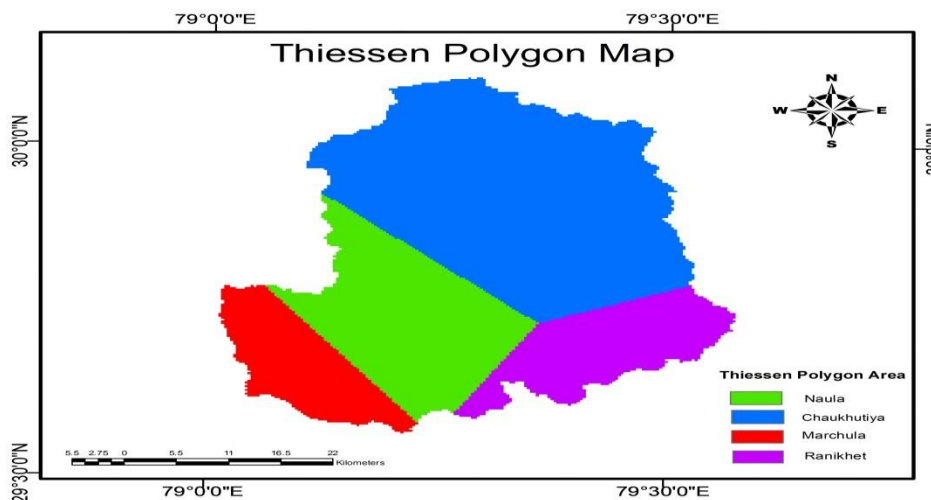
**Figure 3.6: Thiessen polygon map**

Table3.4: Weighted percentage area under raingauge station

S.N	Raingauge Station	Percentage Area (%)
1.	Marchula	11
2.	Naula	28
3.	Chaukhutiya	46
4.	Ranikhet	15

3.5.3 Potential evapotranspiration (PET)

There are a number of methods to estimate potential evapotranspiration. However, the methods based on climatic variables required for calculation. The temperature based method uses only temperature and day length; the radiation based method uses net radiation and air temperature and some other formula like, Penman requires a combination of the above net radiation, air temperature, wind speed and relative humidity.

The FAO Penman-Monteith method is recommended as ET_0 method for determining reference evapotranspiration when the standard meteorological variables including air temperature, relative humidity, and sunshine hours are available. In this study the potential evapotranspiration for each sub-watershed was computed by FAO Penman-Monteith method with the help of cropwat software. This data were collected from GWDS site, where all data are freely available.

Table 3.5: Monthly Potential Evapotranspiration by Penman Monteith method

S.N.	Month	Potential Evapotranspiration (mm)
1	January	59.52
2	February	72.52
3	March	118.73
4	April	157.5
5	May	187.24
6	June	175.66
7	July	164.92
8	August	154.67
9	September	127
10	October	110
11	November	78.9
12	December	58.59

3.6 Methodology

3.6.1 Arc-GIS Pre-processing with extension HEC-GeoHMS

3.6.1.1 Overview on GeoHMS

The Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) is a public-domain software package for use with the ArcView Geographic Information System. GeoHMS uses ArcView and Spatial Analyst to develop a number of hydrologic modelling inputs. Analysing the digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation.

In addition it create the HEC-HMS basin model, metrological model, control specification model, time series data file and background map file, Maidment and Djokic (2000).

3.6.1.2 Pre-processing with HEC-GeoHMS

1. Terrain Processing : The terrain pre-processing is the first step in using HEC Geo-HMS as an input device that describe the drainage patterns of the watershed that allows for stream and sub-watershed delineation. The working of Geo-HMS and HEC-HMS in pictorial form has been shown in Figure 3.7(a) and Figure 3.7 (b). The results acquired after Geo-HMS are the catchment area of each sub-basin, slope of each sub-basin, flow length, which will help us for the calculation of “Time of Concentration”. Six sub basins, two reaches, two junctions and one outlet have been finalized in Geo-HMS. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modelling System, HEC-HMS, where simulation is performed. Using the DEM data as input, terrain processing is a series of step to derived drainage network and related watershed

Steps:-

- a) fill
- b) flow direction
- c) flow accumulation
- d) steam definition
- e) steam segmentation
- f) catchment grid delineation
- g) catchment polygon processing
- h) drainage line processing

2. HMS project setup: The HMS project setup menu is used to define a study area that will be used to develop the input file for HEC-HMS project. It has tools for defining the outlet for the watershed, and delineating the watershed for the HEC-HMS project. As multiple 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 to see areas for which HMS basin models are already created and also allow to

recreates models with different stream network threshold. It is also convenient to delete projects and associated HMS files through Project Point and Project Area option.

3. Basin processing: After the terrain processing is completed we have new project is created, the basin processing menu can be used to revise the sub-basin delineation. Customized sub-basin and routing reach delineation should include points where information is needed. Its content data management processing include basin merge, sub-basin divided by maximum area, river merge, split basin at confluence. Import batch points and delineate batch points.

4. Stream and watershed characteristic: After the creation of stream and sub-basin we extract the physical characteristics. Physical characteristics of steam include the length, upstream and downstream elevation and slope. Similarly for sub-basin include longest flow lengths, centroidal flow lengths, and slops. This information is extracted from terrain data and stored in attribute table. These physical characteristics are exported and used to estimate hydrological parameter.

5. Hydrologic parameter: After extracting the physical characteristics we have the option to estimate value of various hydrologic parameter hydrologic parameter such as curve number, time of concentration and percentage impervious area can be computed from various data include terrain, precipitation , basin average , grid based quantities from soil and land use data.

6. Hydrological model file: HEC-GeoHMS produce number of input files that are used directly in HEC-HMS. These file include background shape files, the basin model file, the meteorological model file, control specification file, and time series data file. After that HEC-GeoHMS generated file brought into HEC-HMS project. We can also add or remove the hydrologic element and their connectivity to reflect difficulty in modeling area.

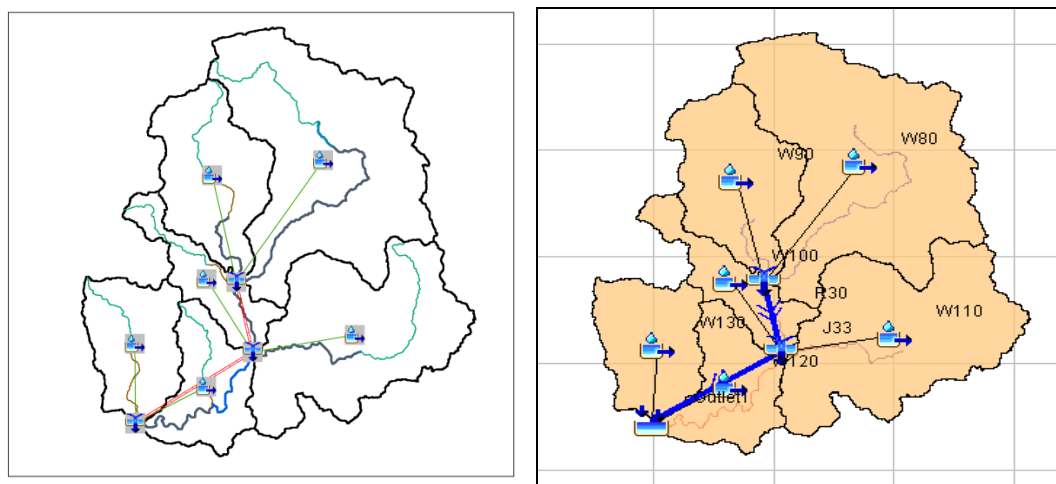


Figure 3.7: (a) Final shape of HEC-GeoHMS (b) HEC-HMS exerted from GeoHMS

3.6.2 Processing with HEC-HMS model General

3.6.2.1 General

HEC-HMS is an empirical watershed model that contains various methods to simulate surface runoff and river or reservoir flow in river basin. The hydrological model, together with flood damage computation (also include in model), provides a basis for evaluation of flood control project. The HEC-HMS model was originally developed in 1967 by Leo R. Beard and other staff member of the hydrologic Engineering Centre, with the U. S. Army Corps of Engineers, to simulate flood hydrograph in complex river basin (Singh 1982). Since then, the program has undergone a revision different versions of the model with greatly expanded capabilities have been released. This study used the HEC-HMS Version 4.2. The HEC model is designed to simulate the surface runoff response of a catchment to precipitation by representing the catchment with interconnected with hydrologic and hydraulic components. It is a primarily applicable for runoff and flood simulation. In HEC-HMS model, the basin model comprises with five processes, canopy loss method, surface method, loss method, transform method and base flow method. But first two methods (canopy and surface method) have no significant effect on simulation process. Each element in model performs different function of the rainfall-runoff process within in a portion of catchment or watershed as a sub-catchment or sub-watershed. An element may depict

a surface runoff or a stream channel. Each of the elements is assigned a variable which define a particular attribute of the element and empirical relationship between them and describe the physical processes. The result of modeling process is the computation of discharge hydrograph at the catchment outlet.

3.6.2.2 Components of HEC-HMS

1. Basin model: It is contain the elements of the basin, their connectivity and runoff parameters and gives the physical description of the watershed.
 - a) Sub-basin: contains data for sub-basins (losses, UH transform, and base flow
 - b) Reach: connects elements together and contains flood routing data of rivers and streams.
 - d) Junction: connection point between elements
 - e) Diversion: diverts a specified amount of runoff to an element based on a rating curve used for detention storage elements or overflows
 - f) Source: It has an outflow but no inflow
 - g) Sink: It has an inflow but no outflow
2. Metrological model: It is contains the rainfall and evapotranspiration data
3. Control Specifications: It is contains the start/stop timing and calculation intervals for the run.

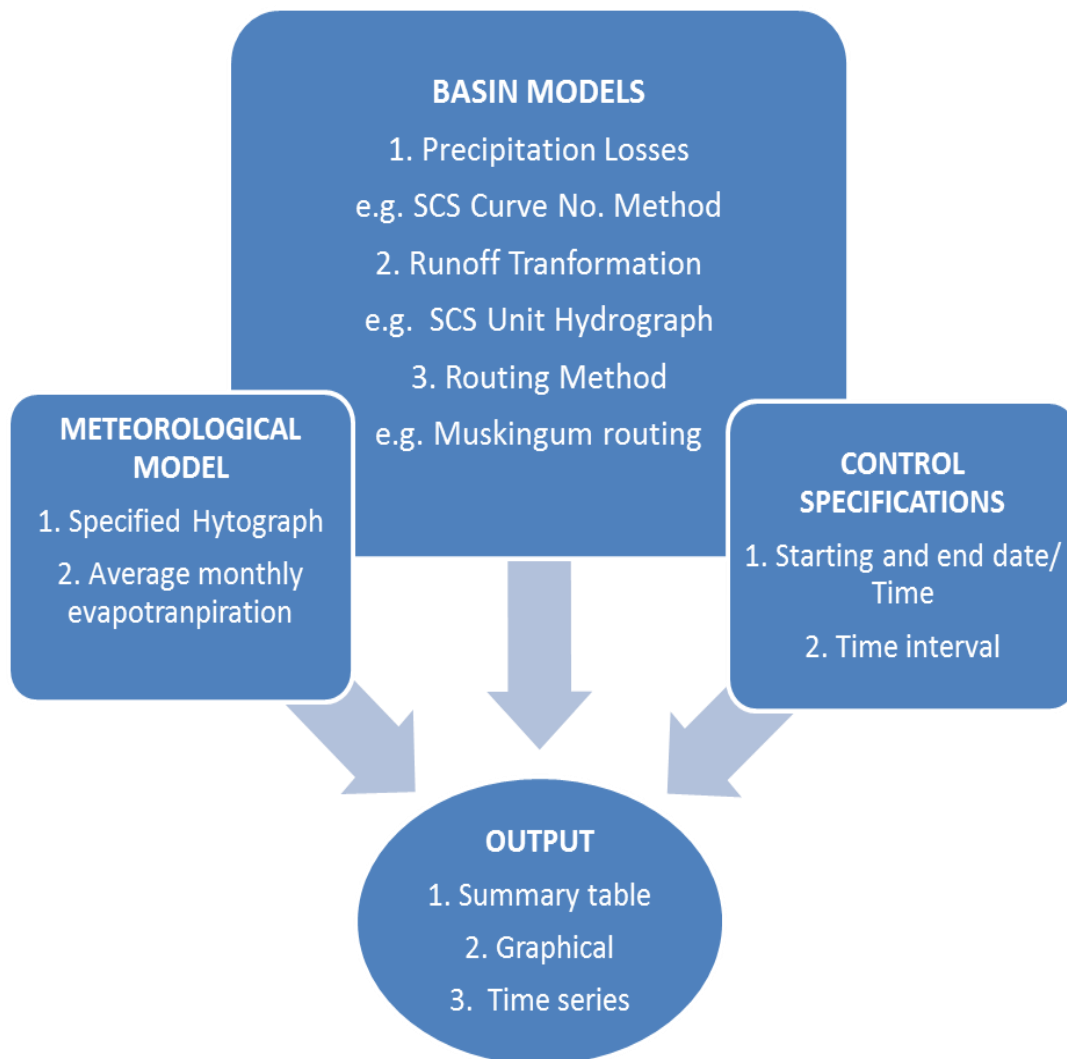


Figure 3.8: Processing with HEC-HMS model

3.6.2.3 Parameters for HEC-HMS

1. **Interception loss:** When rainfall before reaching to ground, a part of it may be caught by vegetation and subsequent evaporated that volume of water is called interception loss. The amount of interception loss in a given area is difficult to measure. It depends on the species composition, development stage, its density and also on storm characteristics.

2. **Surface storage:** When precipitation of storm reach to the ground surface, it must fill up all depressions before it can flow over the surface the volume of water trapped in depression is called surface storage. This amount is eventually lost to the runoff processes of infiltration and evaporation. Surface storage depend on vast number of factor, the chief of which are soil, condition of surface reflecting the amount and nature of depression, slope of catchment and soil moisture etc.
3. **Infiltration rate:** Infiltration is the flow of water into the ground though soil surface. Infiltration rate in soil is a measure of the rate at which soil is able to absorb rainfall or irrigation. the rate decreases as the soil becomes saturated. It is measured in inches per hour or millimeters per hour It is depend on characteristics of soil (texture, porosity and hydraulic conductivity), current moisture content, vegetative cover and soil temperature.

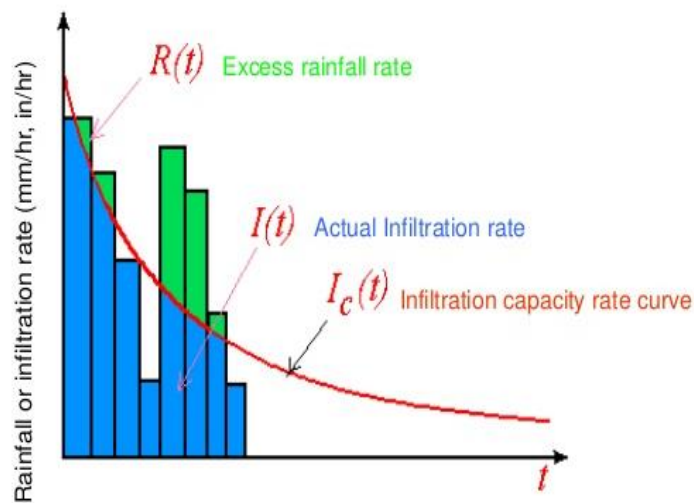


Figure 3.9: Infiltration Capacity curve

FAO has provided range of basic infiltration rate for different types of soil which has been shown in Table 3.6.

Table 3.6: Basic infiltration rate of different types of soil

SN	Type of soil	Infiltration rate (mm/hr)
1	Sand	> 30 mm
2	Sandy loam	20-30 mm
3	Loam	10-20 mm
4	Clay loam	5-10 mm
5	Clay	1-5 mm

4. **Available moisture content:** The available moisture content indicates the amount of water present the soil. The available water content for the different types of soil depends upon the soil texture and structure. FAO has provided the range for available moisture content for different types of soil which has been shown in Table 3.7.

Table 3.7: Available moisture content for different types of soil

S.N.	Type of soil	Available water content (mm/m)
1	Sand	25-100
2	Loam	100-175
3	Clay	175-200

5. **Lag time:** The measure of the time between the centre of mass of precipitation to the centre of mass of runoff (on the hydrograph) is called lag time or basin lag. Basin lag is a function of not only basin characteristics, but also of storm intensity and movement. Because of difficulty in determining the centroid of the direct

runoff hydrograph .it is defined for practical purpose as the elapsed time from the centre of mass of rainfall to the hydrograph peak.

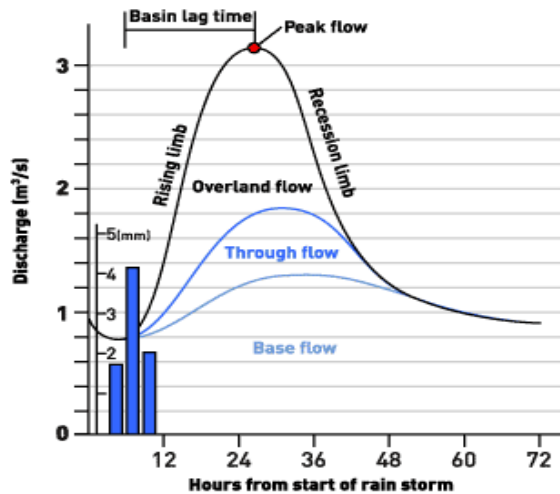


Figure 3.10: Hydrograph and its component

6. **Base flow:** The delay flow that is reach a stream essentially as groundwater flow is called base flow. Many time delay interflow is also include in base flow due to more time lag. In perennial stream the base flow is easily recognised as the slow decreasing flow of steam in rainless period.

There are three types of base flow separation techniques

- i) *Straight line method:* In this method, separation of base flow achieved by straight line is drawn from the point of beginning of direct runoff to the point on recession limb representing the end of direct runoff. Point C Marking the end of the direct runoff is difficult to locate accurately. An empirical relationship for the interval N (days) from peak to point C is

$$N = bA^{0.2}$$

Where b = content varies from 0.8 to 0.9 and A = drainage area in km²

- ii) *Fixed base method:* This method is based on the principal that as the stream flow increases, base flow decreases. To estimate base flow, draw a line AD from the point

where direct runoff starts to the point D below the hydrograph peak by projecting the flow line before runoff starts.

iii) *Constant slope method*: In this method a straight line AC is drawn from point A, representing the start of direct runoff to a point C, on recession limb of hydrograph representing the end of direct runoff

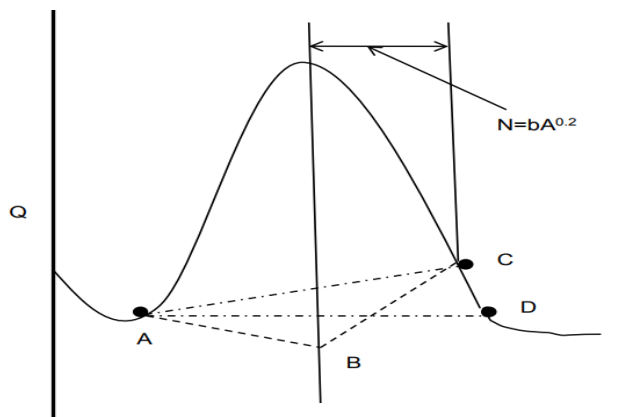


Figure 3.11: Base flow separation methods

3.6.3 Methods selected for simulation in HEC-HMS

3.6.3.1 Basin model

i) *Canopy Method*: The canopy method in the HEC-HMS model represents the presence of vegetation in the catchment. Some precipitation will intercept in the plants reducing the amount of precipitation available for surface runoff. The selected method is the simple canopy method. In the simple canopy method all the precipitation is intercepted until the canopy capacity is exceeded. The input parameters are the initial canopy storage and the maximum storage capacity.

ii) *Surface Method*: The surface method includes the water accumulated at the surface as depressional storage from the net precipitation when the infiltration capacity is exceeded. When the amount of precipitation rate exceeds the infiltration capacity and the surface storage is called, the surface runoff will begin. The maximum amount of water that can be stored on the surface before the surface runoffs begin is

determined by the maximum surface storage. This parameter is a part of the selected simple surface method. In addition to the maximum surface storage, the initial storage must be specified.

iii) Loss Method: Excess rain fall can be estimated by using loss method. In HEC-HMS model loss methods, initial constant, SCS curve number, gridded SCS curve number, exponential, Green-Ampt, one-layer deficit constant method and smith parlange can be used to compute excess rainfall. The SCS curve no method was selected as a loss method for computations of excess rainfall. This is the latest method for loss calculation and is widely used in USA and Pakistan. This model has been updated by panel of experts on yearly basis whereas other models do not have such facility

Basic concept and equation

The Soil Conservation Service (SCS) Curve Number (CN) method is based on the water balance equation of the rainfall is known interval of time t_p , which can be expressed as

$$P = P_e + I_a + F_a \quad \text{Eq. 3.1}$$

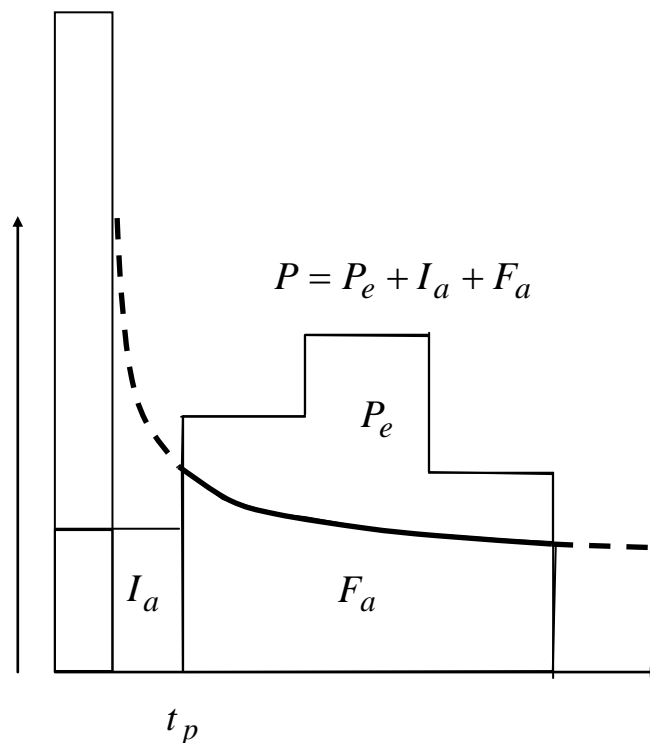


Figure 3.12: Various losses in SCS Curve no. method

Where, P = total rainfall, I_a = initial abstraction, F_a = cumulative infiltration excluding I_a and P_e = direct surface runoff (all in units of volume occurring in time t_p).

Two other concept is following are also used with Eq. 3.1

(a) The first concept is that the ratio of actual amount of direct runoff (P_e) to maximum potential runoff ($= P - I_a$) is equal to the ratio of actual infiltration (F_a) to the potential maximum retention (or infiltration), S .

$$\frac{P_e}{P - I_a} = \frac{F_a}{S} \quad \text{Eq. 3.2}$$

(b) The second concept is that the amount of initial abstraction (I_a) is some fraction of the potential maximum retention (S).

$$I_a = \lambda S$$

From analysis of result from many small experiment watershed , the SCS develop an empirical relationship of I_a and S

$$I_a = 0.2S \quad \text{Eq. 3.3}$$

Combination of Eq. 3.2 and Eq. 3.3, and using Eq. 3.1

we get

For $P > 0.2S$,

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$P_e = 0$ for $P \leq 0.2S$

For calculation of potential maximum retention we use the following formula

$$S = \frac{1000}{CN} - 10$$

(American Units; $0 < CN < 100$)

$$S = \frac{25400}{CN} - 254CN$$

(SI Units; $30 < CN < 100$)

Surface

- Impervious: CN = 100
- Natural: CN < 100

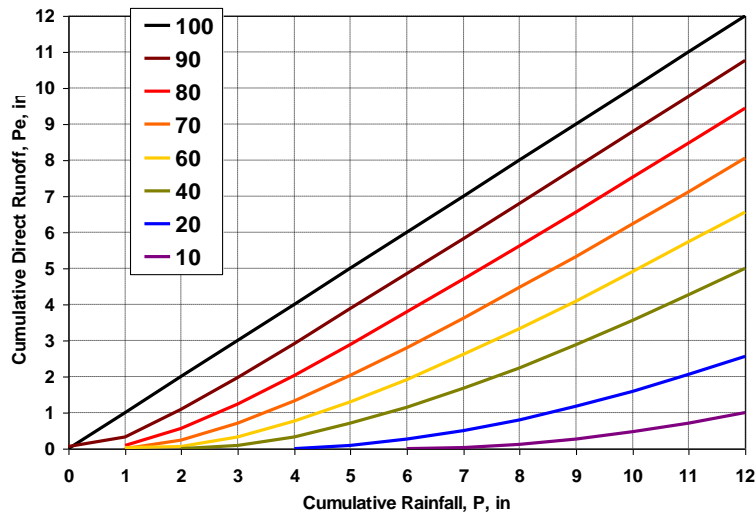


Figure 3.13: SCS Curve no. graph for runoff computation

Curve Number (CN)

The CN for a watershed can be estimated as a function of land use, soil type and antecedent watershed moisture, using table published by the SCS.

For this watershed that consist of several soil types and land uses, a composite CN is calculated as:

$$CN_{\text{composite}} = \frac{\sum_i^n A_i, CN_i}{\sum_i^n A_i}$$

in which $CN_{\text{composite}}$ = the composite CN used for runoff volume computations, i = an index of sub-watershed of uniform land use and soil type, CN_i = curve no. of individual sub-watershed i and A_i = area of individual sub-watershed i

Selection of Soil Type

SCS divides soil types into four major hydrological soil groups denoted by the letters A, B, C and D. The soil of the Marchula watershed area to be assessed as 42% sand fraction, 36% silt fraction and 22% clay fraction with medium porosity and less cohesiveness as characterised under soil group B.

Antecedent Moisture Condition (AMC)

Antecedent moisture condition shows the presence of moisture content in the soil at the before precipitation occurs at ground surface. For the practical application three level of AMC are categorized as follow

AMC-I: Soil are dry but not to wetting point. Satisfactory cultivation has take Place.

AMC-II: Average condition

AMC-III: Sufficient rainfall has occurred within the immediate past 5 days. Saturation soil condition prevail.

Table 3.8: Antecedent moisture condition for determination the value of CN

AMC TYPE	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 30 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53mm

According to information mentioned above we have selected the soil of Marchula watershed is the Antecedent moisture content II, which characteristics fallow the average condition.

Table3.9: Runoff curve no. for hydrological soil cover complex under AMC II

Land use	Cover		Hydrological soil group			
	Treatment or practice	Hydrological condition	A	B	C	D
Cultivated	Straight row		76	86	90	93
	Contour	Poor	70	79	84	88
		Good	65	75	82	86
Cultivated	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	77	81
	Bunded	Poor	67	75	81	83
		Good	59	69	76	79
Cultivated	Paddy		95	95	95	95
Orchard	With understory cover		39	53	67	71
	Without understory cover		41	55	69	73
Forest	Dence		26	40	58	61
	Open		28	44	60	64
	Scrub		33	47	64	67
Pasture	Poor		68	79	86	89
	Fair		49	69	79	84
	Good		39	61	74	80
Waste land			71	80	85	88
Road (dirt)			73	83	88	90
Hard surface area			77	86	91	93

Limitation of SCS CN : (Feldman, 2000)

- Prediction value not accordance with classical unsaturated theory.
- Infiltration rate will approach zero during a storm of long duration, rather than constant rate as expected.
- Develop with data from small agriculture watershed in Midwestern US, so applicability elsewhere in uncertainty.
- Default initial abstraction (0.2S) does not depend on storm characteristics or timing.
- Rainfall intensity not consider

iv) Transform Method: Following Seven different alternative models has been included in HEC-HMS model for transforming excess precipitation into surface runoff.

1. User Specified Unit Hydrograph model,
2. Parametric and Snyder unit hydrograph model,
3. Snyder Unit Hydro graph model,
4. SCS unit hydrograph model,
5. Clark unit hydrograph model,
6. Modclark model,
7. Kinematic Wave Model

In which above mentioned methods SCS unit hydrograph model has been selected as transform method.

SCS Unit hydrograph method

The Soil Conservation Service (SCS) dimensionless unit hydrograph procedure is one of the most well known methods for deriving synthetic unit hydrographs in use today (SCS 1972).

The dimensionless unit hydrograph used by the SCS was developed by Victor Mockus and was derived based on a large number of unit hydrographs from basins that varied in characteristics such as size and geographic location. The unit hydrographs were averaged and the final product was made dimensionless by

considering the ratios of Q/Q_p (flow/peak flow) on the ordinate axis and t/t_p (time/time to peak) on the axis, where the units of q and Q_p are flow/inch of runoff/unit area. This final, dimensionless unit hydrograph, which is the result of averaging a large number of individual dimensionless unit hydrographs, has a time-to-peak located at approximately 20% of its time base (t_b) and an inflection point at 1.7 times the time-to-peak. The dimensionless unit hydrograph is illustrated in Figure... Research by the SCS suggests that the SCS unit hydrograph peak are related to other parameter as:

$$Q_p = CA/t_p \quad \text{Eq. 3.4}$$

In which A = Watershed area and C = Conservation constant (2.08 in SI and 484 in FPS) time to peak is related to the duration of the unit of excess precipitation as:

$$t_p = \frac{\Delta t}{2} + t_L \quad \text{Eq. 3.5}$$

In which Δt = the excess rainfall duration and t_L = basin lag or lag time [note that for adequate definition of the ordinate on the rising limb of the SCS unit hydrograph, computational interval, Δt , that is less than 29% of t_p must be used. (USACE, 1990)

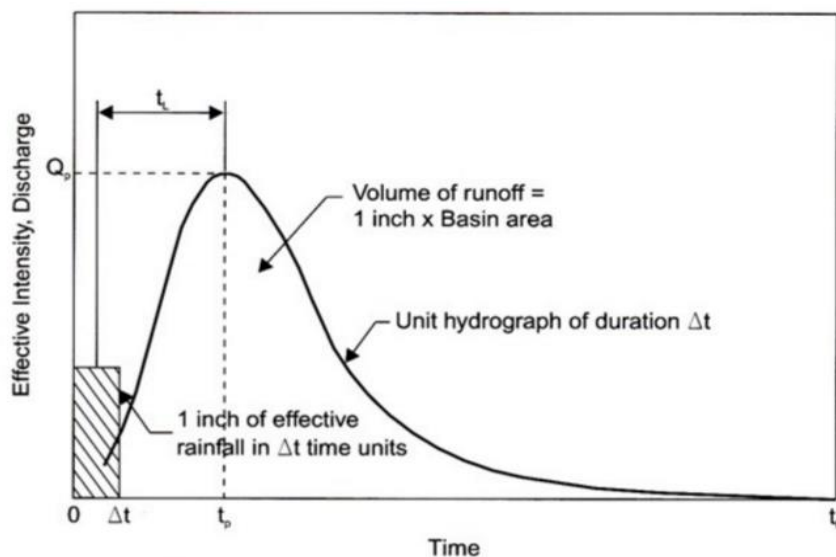


Figure 3.14: SCS Unit Hydrograph

For ungauged watershed, the SCS suggest that the lag time is computed using following Equation.

$$T_L = 0.6T_c \quad \text{Eq. 3.6}$$

Where, T_c = Time of Concentration in minutes

Time of Concentration

This is a time required for a rainfall drop to reach from the most remotest point in a watershed to the outlet. From the hydrograph it may be accessed as the time from the end of rainfall to the inflection point of a recession curve.

The time of concentration is the physical based parameters that can be calculate as:

$$T_C = T_{\text{sheet}} + T_{\text{shallow}} + T_{\text{channel}} \quad \text{Eq. 3.7}$$

Where T_{sheet} = sum of travel time in sheet flow segments over the watershed surface, T_{shallow} = sum of travel time in shallow flow segments, down street or in shallow rills and rivulets, and T_{channel} = sum of travel time in channel segments

If open channels cross section information is available. we can estimate the velocity of flow by manning's formula.

$$V = \frac{R^{.66} S^{.5}}{n} \quad \text{Eq. 3.8}$$

Where V = Average velocity, R = Hydraulic radius (define as the ratio of channel cross section area to the wetted perimeter), S = Slop of the energy grade line (approximate as channel slop). Value of "n" which is commonly known as manning's roughness coefficient varies with channel roughness.

To estimate the channel travel time (T_{channel}) as following equation

$$T_{\text{channel}} = \frac{L}{V} \quad \text{Eq. 3.9}$$

Where, L = channel length

Sheet erosion is flow over the watershed surface before water reach a channel. Distance is short on the order of 10-100 meter. The SCS suggest the sheet flow travel time (T_{sheet}) can be estimate as:

$$T_{sheet} = \frac{.007(NL)^{0.8}}{P_2^{0.5} S^{0.4}} \quad \text{Eq. 3.10}$$

In which N = an overland flow roughness coefficient, L = flow length $P_2 = 2$ year, 24-hour rainfall depth in inches, S = slop of the hydraulic grade line. Sheet flow usually turn to shallow concentrated flow after 100 meter. The average velocity for concentration flow can be estimated as:

$$V = f(x) = \begin{cases} 16.1345\sqrt{S} & \text{For unpaved surface} \\ 20.3283\sqrt{S} & \text{For paved surface} \end{cases} \quad \text{Eq. 3.11}$$

from this equation ,the travel time can be estimate

5. Base flow Model: The selected base flow model is the constant monthly base flow. This method is primary intended for continuous simulations where the base flow is approximated by a constant flow for each month. In the simulation it is assumed the same base flow for each month throughout the year.

6. Hydrologic Routing model: Different methods of hydrological routing are available in HEC-HMS. But the commonly used hydrological routing method is Muskingum routing method.

Muskingum Method

Muskingum routing method simply uses the equation of the continuity as;

$$I - Q = \frac{dS}{dt} \quad \text{Eq. 3.12}$$

Where I = Inflow rate, Q = Outflow rate, S = Storage

Storage in the reach is modelled as the sum of prism storage and wedge storage as shown in figure 3.15. Prism storage is the volume of defined by a steady flow water

surface profile, while wedge storage is the additional volume under the profile of the flood wave. During rising stage of flood wedge storage is positive and is added to the prism storage. During the wedge storage is negative and is subtracting from the prism storage.

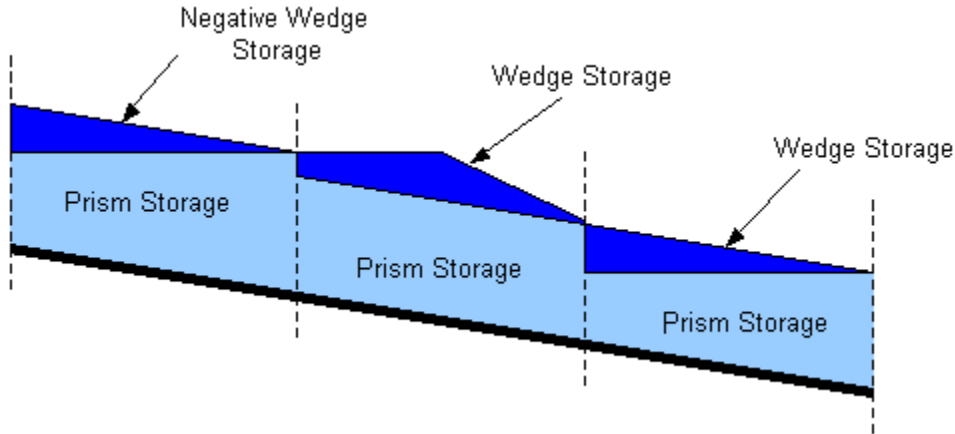


Figure 3.15: Graphical representation of prism and wedge storages

The volume of prism storage can be represented by KQ , where K represents the travel time of flood wave through the reach. Similarly the volume of wedge storage can be represented by $KX(1-Q)$, where X is a constant.

Thus the total storage in a reach can be represented by;

$$S = KQ + KX(1-Q) \quad \text{Eq. 3.13}$$

Value of X varies from 0 to 0.5. When $X = 0$, the storage is only dependent on outflow and if $X = 0.5$ the storage equally depends on inflow and outflow. For practical purpose in natural channel, the value of X varies from 0.1 to 0.3 and a mean value of 0.2 is considered.

From the continuity equation and storage equation above, Storage at time j and $j+1$ can be expressed as;

$$Q_{j+1} = C_1 I_{j+1} + C_2 I_j + C_3 Q_j \quad \text{Eq. 3.14}$$

Where,

$$C_1 = \frac{\Delta t - 2KX}{2K(1-X) + \Delta t} \quad \text{Eq. 3.15}$$

$$C_2 = \frac{\Delta t + 2KX}{2K(1-X) + \Delta t} \quad \text{Eq. 3.16}$$

$$C_3 = \frac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t} \quad \text{Eq. 3.17}$$

C_1, C_2 and C_3 are constants and $C_1 + C_2 + C_3 = 1$

Value of K and X should be determined before using Muskingum method of routing in HEC-HMS. These parameters are fitted in the model by calibrating the observed hydrograph.

3.6.3.2 Meteorological model

For the Meteorologic model in HEC-HMS, this study considers about the precipitation and potential evapotranpiration influence in HEC-HMS. The simulation for 5 year precipitation is used in this research. The duration of the storm events is too long, and the simulation can consider the evapotranspiration influence in this model. In HEC-HMS, there are 7 methods that can be selected in the precipitation method: Frequency Storm, Gage Weights, Gridded Precipitation, Inverse Distance, SCS Storm, Specified Hyetograph, and Standard Project Storm. This study used "Specified hyetograph" as the precipitation method in the simulation. It is contain the rainfall and evapotranspiration data.

3.6.3.3 Control specifications:

Control Specification in HEC-HMS sets up the duration time and the interval of simulation. The start and ending time depended on the storm event's time in runoff station, and the interval of simulation run has been 5 year .

3.6.3.4 Time Series data:

In time-series data, we needed to set up the precipitation gage and the discharge gauge for 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 set up. For the precipitation data, there were 6 subbasins in this study area. Thiessen's Polygon method was chosen to divide the represented weight for each rainfall station in the Marchula watershed. After using the Thiessen's Polygon Method, we obtained the average rainfall in each sub-watershed and inputted it in the precipitation data

3.6.4 Model calibration and validation

Hydro-meteorological data of the four stations within the study area have been used to calibration and validation the model. The parameters required for rainfall runoff transformation are initially estimated from the catchment properties, soil properties, land use land cover data etc. After infilling the parameters in the model, simulation has been done. After simulation, the initially taken parameters affecting the runoff directly are changed and the output of the model has been observed. The adjustment of the parameters like storage coefficient, initial storage, and maximum storage, constant rate of infiltration, Muskingum K and X etc. have been done in step by step procedure so that observed hydrograph matches with the simulated hydrographs. In HEC HMS there is option for optimization of the model parameters with defined numbers of iteration. Various statistical evaluations have been done to check the consistency of calibrated results. For the above study, rainfall runoff transformation has been done using SCS unit hydrograph. The loss method adopted is SCS curve number. Initial values of the parameters required for SCS unit hydrograph and SCS curve number loss method have been estimated from the physical characteristics of the catchment and the soil properties. The available hydro-meteorological data is split up in two parts for model calibration and model validation. 5 years discharge data on daily basis were selected for model calibration and 3 year precipitation data on daily basis for model validation. Same parameters used for validation period.

3.6.5 Evaluation of the model

The calibrated model performance has been evaluated on the basis of

- ✓ Nash Sutcliffe efficiency
- ✓ Percentage error in simulated and observed peak value
- ✓ Percentage error in simulated volume
- ✓ Coefficient of determination

3.6.6 Software used

- Arc GIS 10.2: it has been used for pre-processing of spacial data and create various thematic maps
- Erdas imagine 2009: for preparation of land use land cover map
- HEC-GeoHMS 10.2: create input file and background map for HEC-HMS
- HEC-HMS: for parameter optimization and simulation
- MS Excel: data arrangement and prepare input files for model

RESULTS AND DISCUSSION

4.1 Various thematic maps

In the present study to meet out the objectives, the Marchula watershed was delineated and various thematic maps were generated as inputs to the HEC-HMS model. Moreover, the data base allied to climate and soil were also prepared as per the input requirement of the model and to carry out for hydrological modeling for the Ramganga river at Marchula on daily time step.

4.1.1 Preparation of land use land cover map

With the help of remote sensing landset-8 data and software Arc GIS 10.2, prepared the land use land cover map for curve no. estimation.

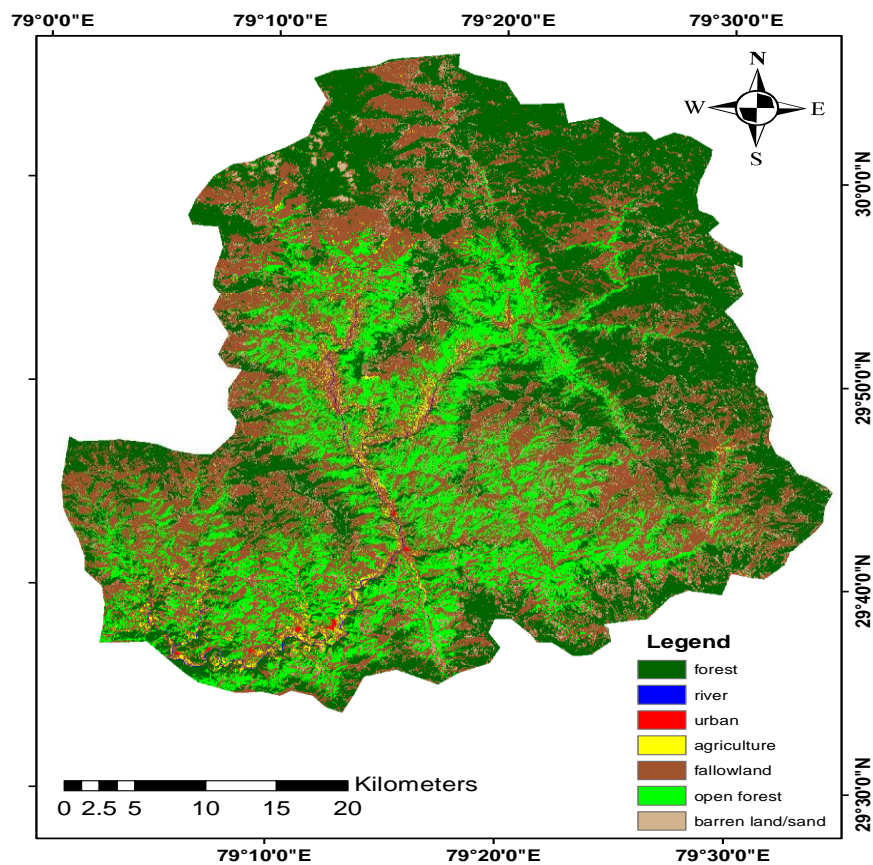


Figure 4.1: Land use and land cover map

It is revealed that the major portion of land use of the study area is under forest cover which is about more than 55% of the total geographical area of the study area (2065 km² area). Agriculture is the main occupation of the people. The agricultural activities are restricted to river terraces, gentle hill slopes and intermountain valleys. Spatial distribution of land use and land cover map shown in Figure 4.1 which shows major land use classes of the study area.

4.1.2 Preparation of soil map

The soil characteristics of Marchula watershed are very complex due to different slope, aspect, land use land cover, hydrological condition and its use and management practices. Soil map used in this study provided by National Bureau of Survey and Land Use Planning (NBSS & LUP) at scale 1:250000. Three type of soils have been identified on the basis of texture namely coarse loamy soil, fine loamy soil and sandy skeletal soil, where sandy skeletal soil has covered minimum upland Himalayan area and other two soil group are dominant in watershed area.

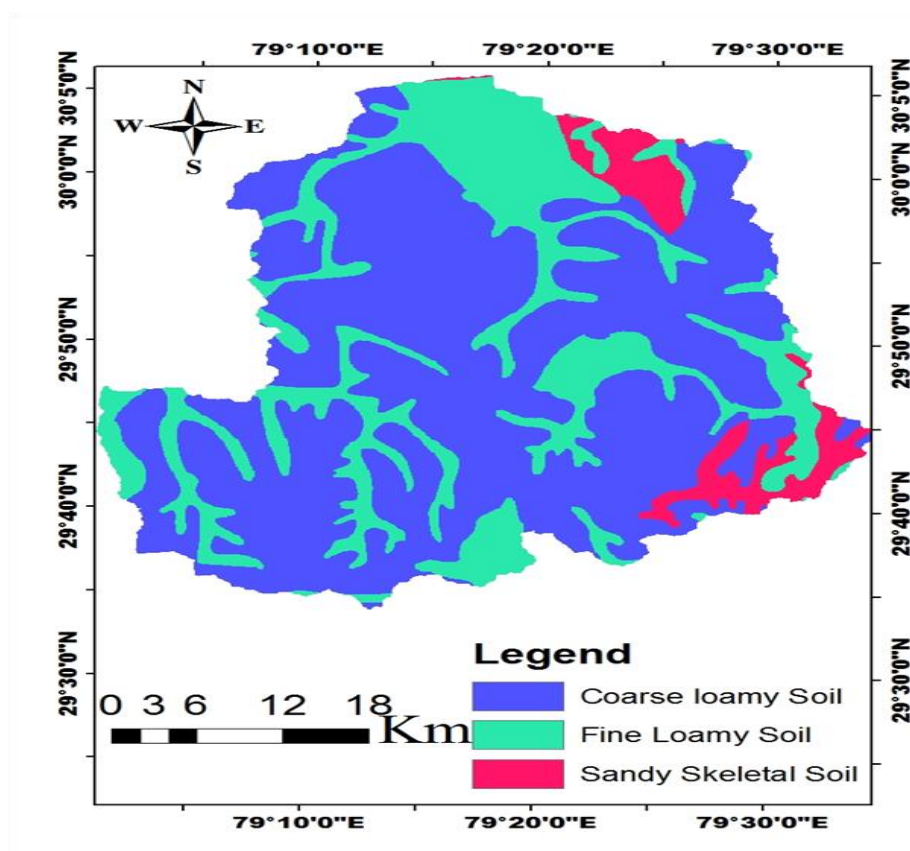


Figure 4.2: Distribution of soil at Marchula watershed

4.1.3 Spatial analysis of Rainfall and Temperature

Using the Kriging method for average rainfall, minimum and maximum temperature spatial distribution maps were generated using 31 year meteorological data of the Ramganga river basin upto Kalagarh dam. The average rainfall of the basin from the period of 1983-2013 is 1337 mm while average maximum and average minimum temperatures are 28.5 °C and 15 °C respectively. Figure 4.3 shows that the variation of rainfall and temperature in the Ramganga river basin.

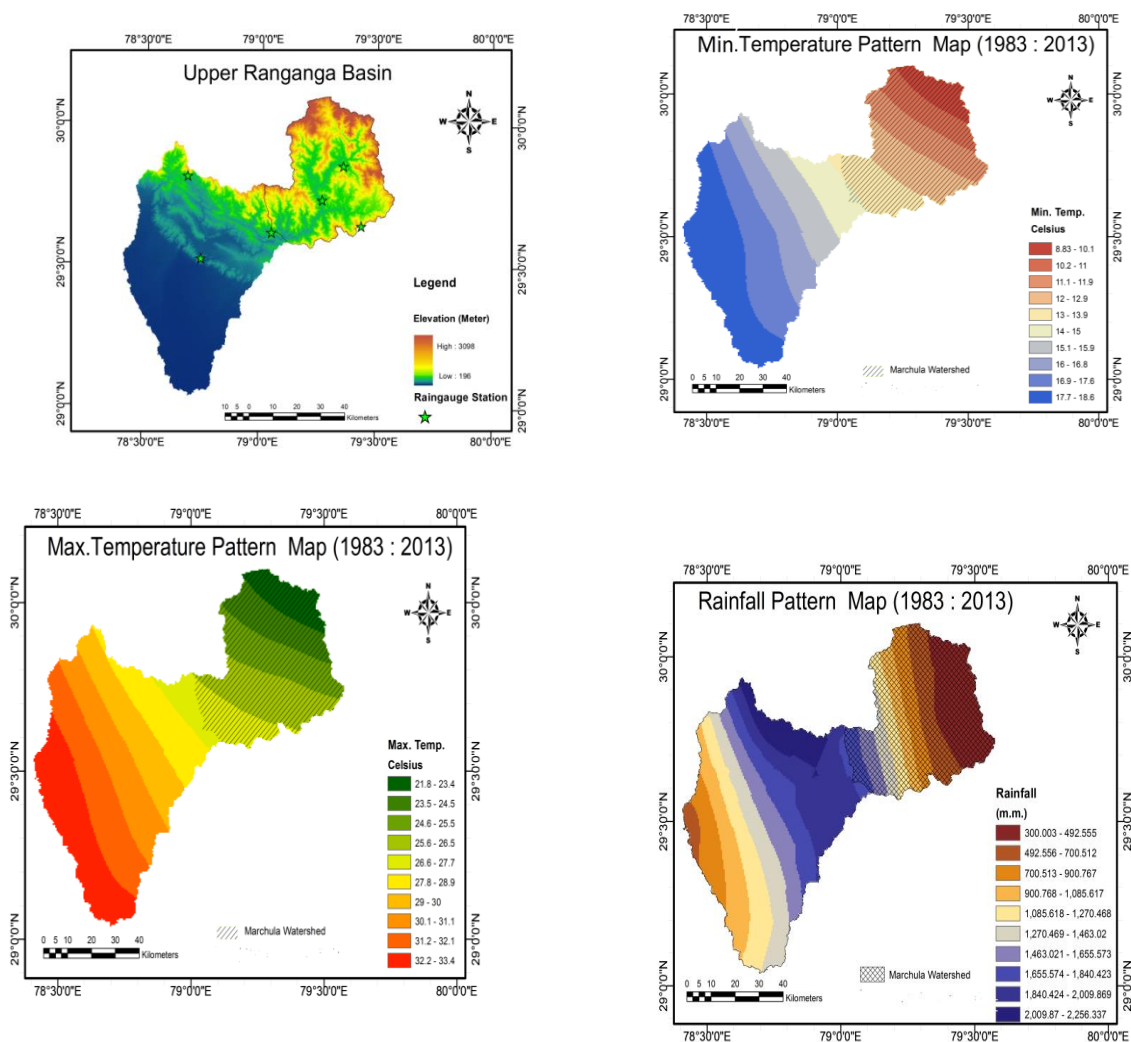


Figure 4.3: Spatial analysis maps over the upper Ramganga basin upto Kalgarh

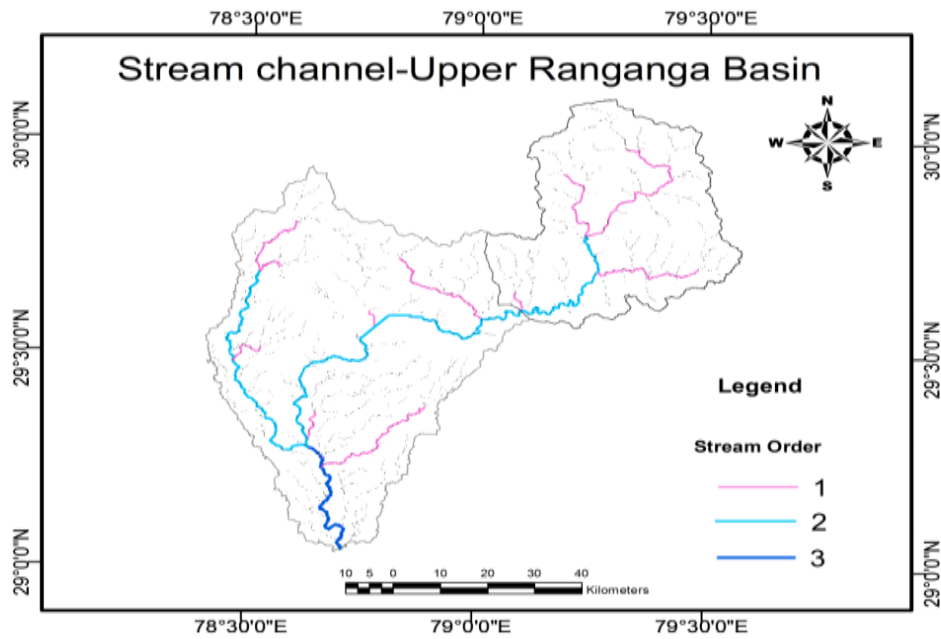


Figure 4.4: Stream channels at upper Ramganga basin

4.1.4 River Profile

The river profile is created by extracting elevation values from the terrain model along the stream line which, provides information on slopes and grade breaks that's useful for selecting delineation points

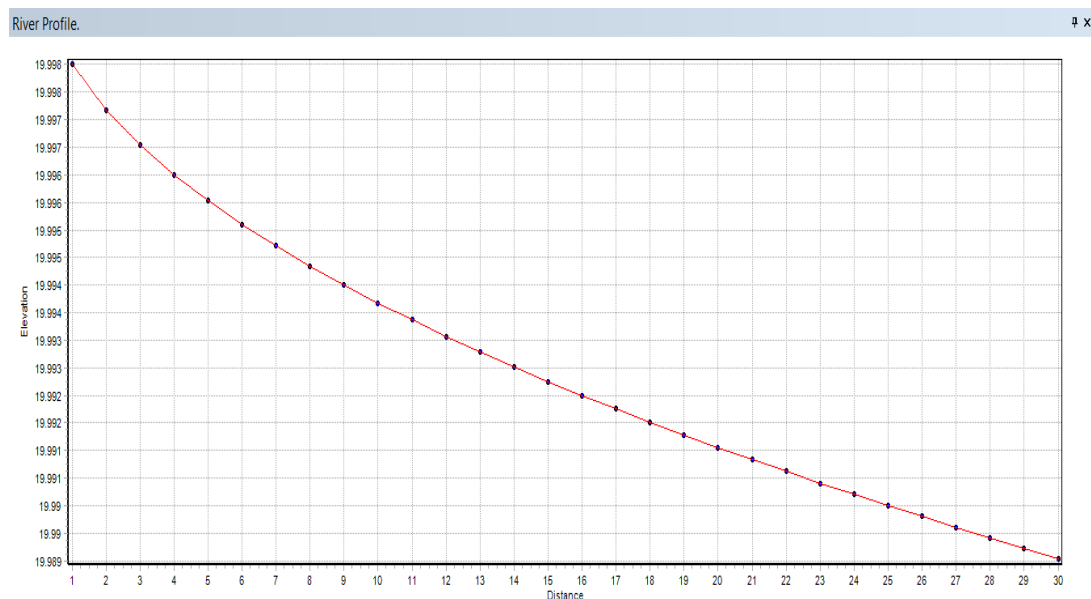


Figure 4.5: River slop at Marchula watershed

4.2 Model parameters optimization

The parameters have been optimized using the optimization tools available in HEC-HMS. The optimization was done manually by changing the parameters (initial abstraction, curve number, lag time, canopy parameters etc.) value used initially in the model that affects the runoff directly and observing the output of the model whether it matches to recorded hydrograph at the outlet or not. The optimization has been done in such a manner that resultant output i.e. the hydrograph at the outlet closely matches the recorded hydrograph.

Table 4.1: Initial and optimized parameter value for different sub-watershed

S.N	PARA-METERS	SUB-WATERSHED											
		W80		W90		W100		W110		W120		W130	
		INI T	OPT	INI T	OPT	INI T	OPT	INI T	OPT	INI T	OPT	INI T	OP T
1.	Max. canopy storage(m)	3	5	2	6	1	3	2	5	2	6	1.5	5
2.	Max. surface storage	13	20	9	15	7	12	12	17	6	13	10	14
3.	Lag time(min.)	37	21	22	13	21	16	27	12	21	14	14	85
		2	9	7	4	4	3	7	6	4	8	4	
4.	Curve Number	44	42	45	42	45	42	46	41	47	42	46	41

4.3 Calibration results

The application of hydrologic watershed modeling depends on model parameter, quality of available data and technical capability of hydrological model. Daily available rainfall and other hydro-meteorological, from year 2001 to 2003 were selected for calibration period. The calculated initial parameters (Table 4.1) were first used as input in model for calibration and different parameter like peak runoff, total volume, time to peak and discharge hydrograph were obtained. Then simulated discharge value compared with observed discharge value, it is found that large difference between observed and simulated value of all parameters. For getting satisfactory result, the initial parameters were optimized using optimized tool provide in model. Different optimized parameters show in Table 4.1. With the help of these optimized parameters the hydrograph parameter like peak discharge, total volume and time to peak were again calibrated. It is observed that the optimized value gave close value of different hydrograph parameter with observed value. Hence we consider the optimized value of initial parameter for model calibration. The evaluation of the calibrated model in terms of various efficiencies like Nash Sutcliffe, error in peak flow, error in peak flow and coefficient of determination has been presented in the Table 4.2 and .4.3

Table 4.2: Evaluation of the model in terms of various efficiencies during calibration

S.N.	Year	Nash Sutcliffe Efficiency	Error in Peak Flow (%)	Error in Volume (%)
1	2001	0.74	4.50	-5.89
2	2002	0.81	4.90	1.16
3	2003	0.77	2.30	-4.91
4	2001- 2003	0.71	2.70	6.20

Table 4.3: Evaluation of the model in terms of coefficient of determination during calibration

SN	Year	Coefficient of correlation (R^2)
1	2001	0.79
2	2002	0.85
3	2003	0.84
4	2001-2003	0.83

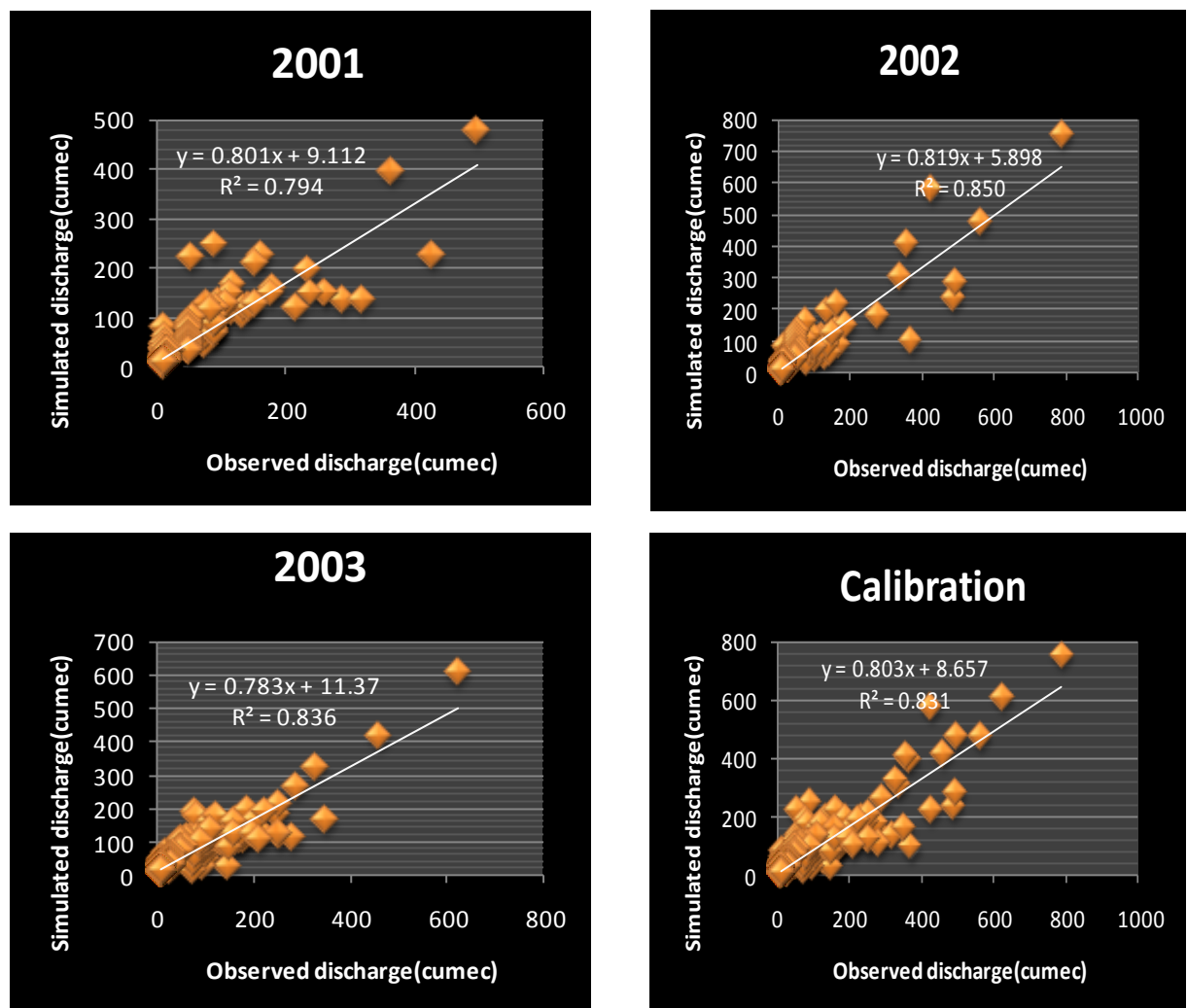


Figure 4.6: Graph plot between observed and simulated flow

The results show that in term of percentage error in peak flood is small and close to observed flood peak within accessible limit 10%. These result found that maximum peak discharge occurring between July and September months.

In terms of volumetric error the total volume discharge from watershed area after fulfillment of all losses is computed show that calibrated discharge volume is close to the observed discharge volume within accessible limit 20% of total volume which it is acceptable for continuous calibration.

And the Nash Sutcliffe Efficiency (NSE) for calibration period is 0.71 which is satisfactory.

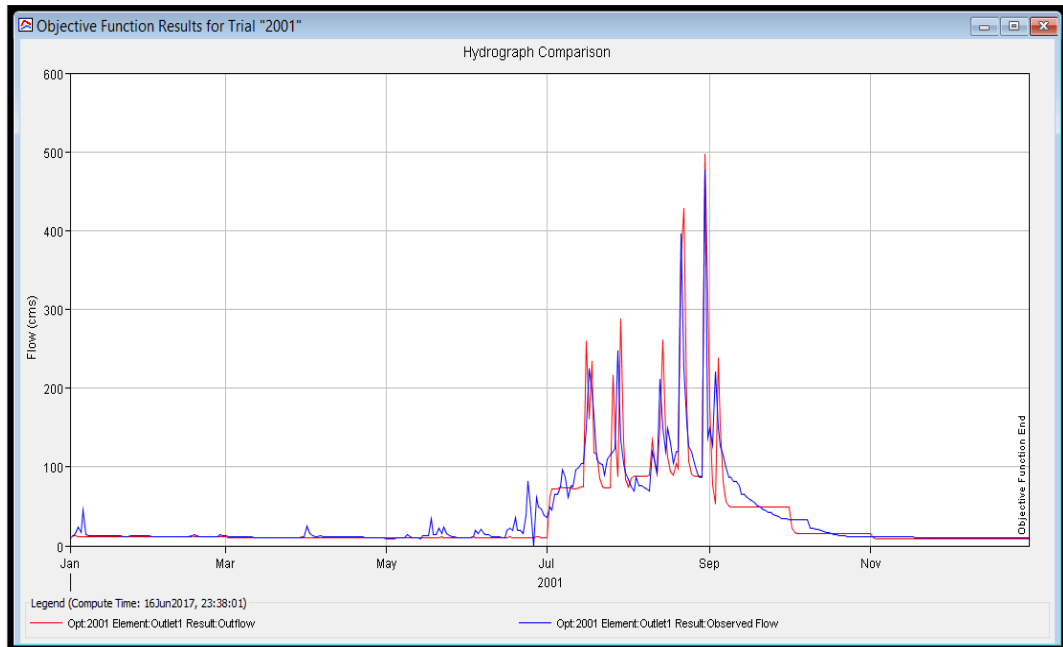


Figure 4.7: Simulated and observed hydrograph for the year 2001

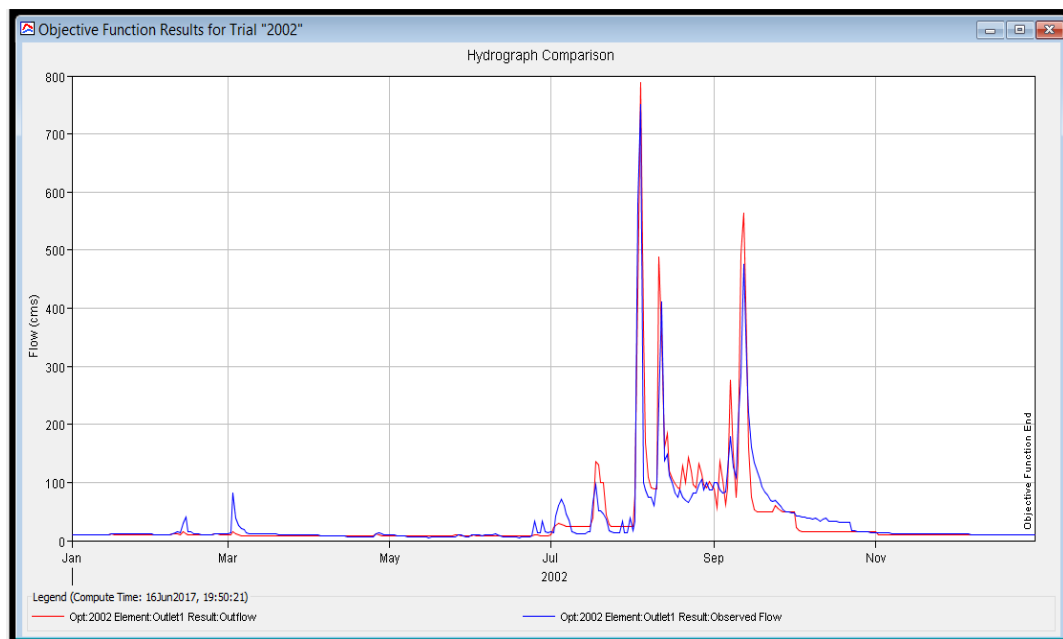


Figure 4.8: Simulated and observed hydrograph for the year 2002

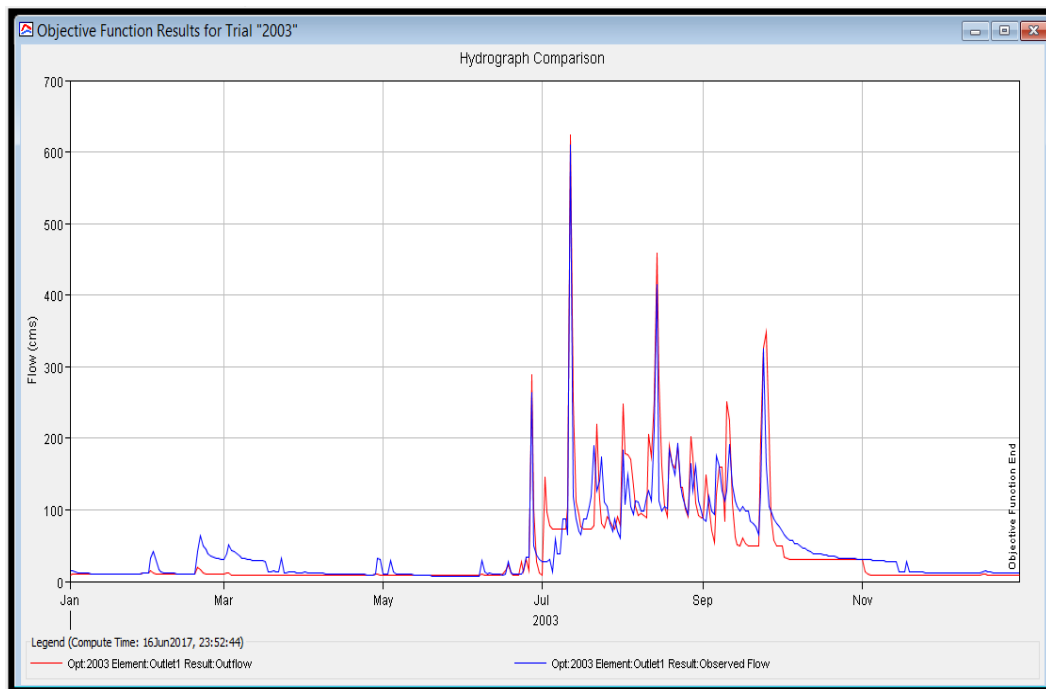


Figure 4.9: Simulated and observed hydrograph for the year 2003

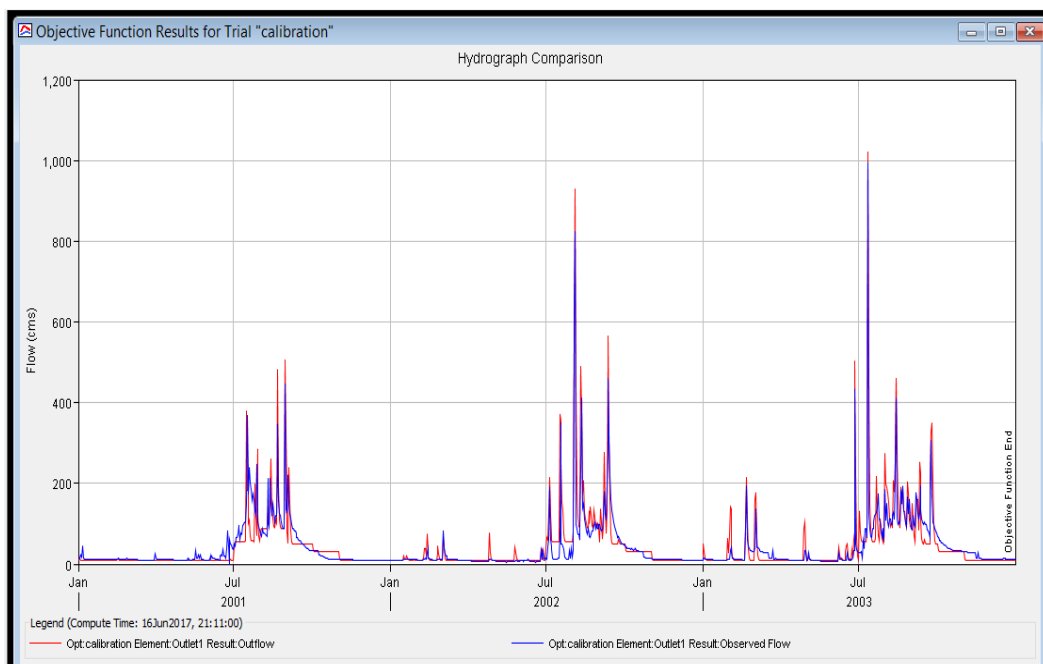


Figure 4.10: Simulated and observed hydrograph for the year 2001-2003

The graphical representation of hydrograph shows the calibrated and observed discharge at different time period. In summer season only base flow is contribute the

discharge to outlet due to no or minimum precipitation occur over the watershed area but in monsoon season maximum precipitation falling over the watershed area about 75%, thereby high discharge occur at outlet, which creates a situation of flood. The maximum peak discharge coming in calibration period is about 1021 cumec. Somewhere the calibrated peak of hydrographs are not match with the observed peak hydrographs because of watershed physical parameter are not suitable with watershed characteristics due to physical parameters vary with time to time and point to point in drainage area

Global Summary Results for Run "2001"

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W80	707.530	193.5	31Aug2001, 00:00	607.01
W90	295.410	139.0	21Aug2001, 00:00	655.34
J38	1002.940	282.2	31Aug2001, 00:00	621.25
R30	1002.940	215.1	31Aug2001, 00:00	469.37
W110	512.770	31.5	30Aug2001, 00:00	545.51
W100	143.750	8.7	23Aug2001, 00:00	515.74
J33	1659.460	254.7	31Aug2001, 00:00	496.92
R70	1659.460	181.1	31Aug2001, 00:00	376.67
W130	214.904	214.4	30Aug2001, 00:00	1089.37
W120	191.574	192.8	30Aug2001, 00:00	1111.98
Outlet1	2065.938	497.2	30Aug2001, 00:00	518.99

Global Summary Results for Run "2002"

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W80	707.530	428.4	11Sep2002, 00:00	632.05
W90	295.410	178.8	11Sep2002, 00:00	677.08
J38	1002.940	607.1	11Sep2002, 00:00	645.31
R30	1002.940	460.1	11Sep2002, 00:00	486.15
W110	512.770	307.1	04Aug2002, 00:00	696.72
W100	143.750	57.5	11Sep2002, 00:00	563.87
J33	1659.460	684.9	11Sep2002, 00:00	557.95
R70	1659.460	464.2	11Sep2002, 00:00	423.62
W130	214.904	223.3	11Aug2002, 00:00	965.09
W120	191.574	199.5	11Aug2002, 00:00	984.29
Outlet1	2065.938	787.5	04Aug2002, 00:00	531.93

Global Summary Results for Run "2003"

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W80	707.530	302.9	10Sep2003, 00:00	782.34
W90	295.410	126.4	10Sep2003, 00:00	836.37
J38	1002.940	429.4	10Sep2003, 00:00	798.25
R30	1002.940	320.8	10Sep2003, 00:00	608.50
W110	512.770	264.9	24Sep2003, 00:00	807.74
W100	143.750	83.3	12Jul2003, 00:00	699.81
J33	1659.460	491.9	14Aug2003, 00:00	677.97
R70	1659.460	333.3	14Aug2003, 00:00	519.64
W130	214.904	250.4	12Jul2003, 00:00	1160.71
W120	191.574	223.3	12Jul2003, 00:00	1182.36
Outlet1	2065.938	623.9	12Jul2003, 00:00	647.78

Global Summary Results for Run "calibration"

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W80	707.530	428.4	11Sep2002, 00:00	2410.47
W90	295.410	178.8	11Sep2002, 00:00	2563.45
J38	1002.940	607.2	11Sep2002, 00:00	2455.53
R30	1002.940	460.2	11Sep2002, 00:00	1873.95
W110	512.770	407.4	12Jul2003, 00:00	2395.27
W100	143.750	122.0	12Jul2003, 00:00	2126.23
J33	1659.460	850.5	12Jul2003, 00:00	2056.89
R70	1659.460	552.4	12Jul2003, 00:00	1577.16
W130	214.904	248.2	12Jul2003, 00:00	3518.21
W120	191.574	221.3	12Jul2003, 00:00	3562.90
Outlet1	2065.938	1034.8	12Jul2003, 00:00	1863.21

Table 4.4: Global summary for all, sub-watershed, reaches and junctions

In Table 4.4 the changing of initial loss, imperviousness and curve number to the sub-watershed area make some effect to junction, reach and sub-watershed itself.

Increasing impervious areas lead to reduce infiltration and thereby increased surface runoff within catchments. It makes an effect to volume and peak discharge. From these values make an effect to time of peak discharge. The bigger value of imperviousness and curve number make time of peak early. The bigger value of imperviousness and curve number, make bigger value of peak discharge and volume. It means that imperviousness correlates highly with changes in hydrological indicators time to peak, peak discharge and volume. As illustration, because there is no opportunity for plants to absorb the moisture that falls on pavement, a much larger volume of storm water drains into streams that flows from urban areas. This large quantity of water reaches streams too quickly, flowing across roads and through pipes that do not offer the resistance to surface flow that natural vegetation of meadow and forests. But in case of initial loss include interception loss and surface depressions are reduced the surface runoff because of more resistance occur in flow path and get more opportunity time for initial loss.

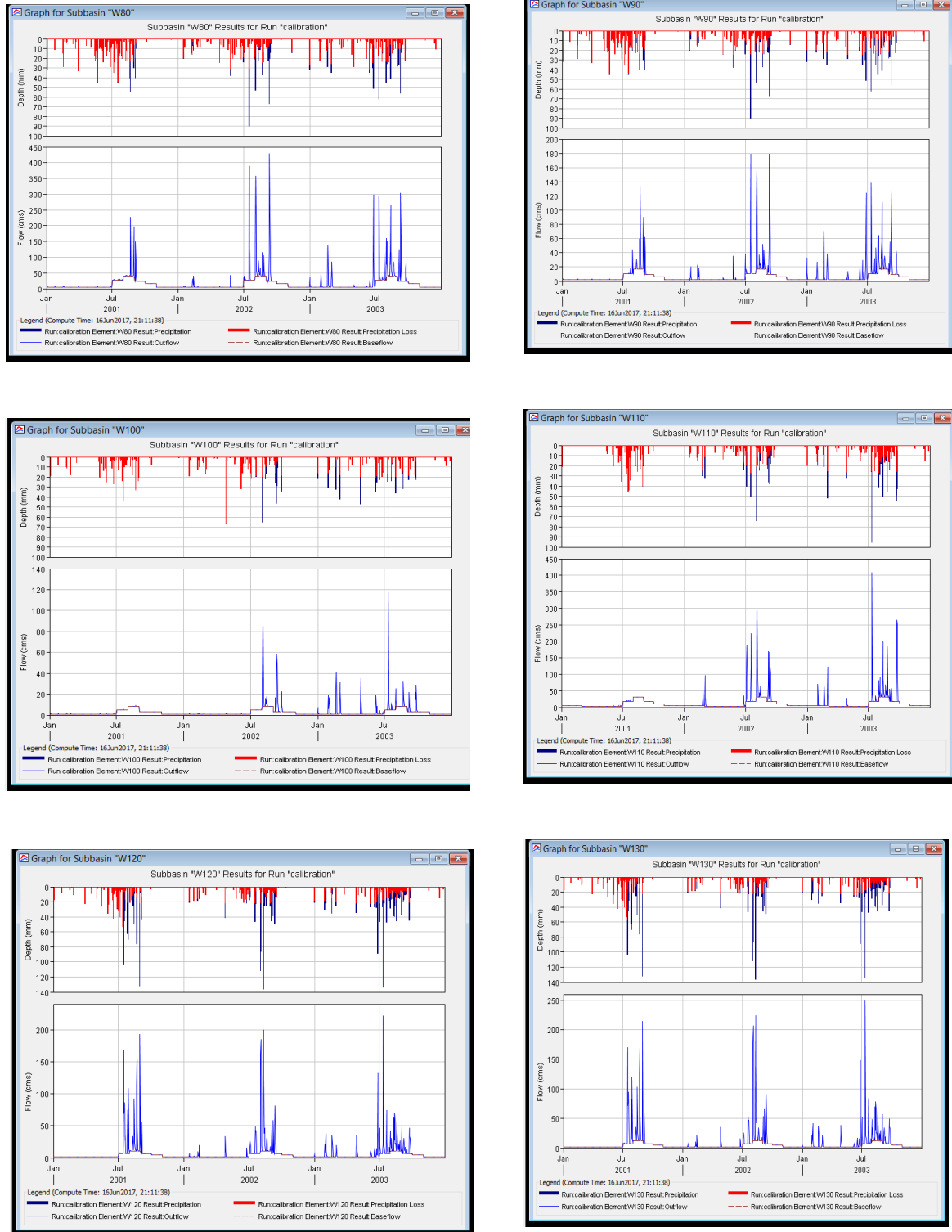


Figure 4.11: Graph show the precipitation, precipitation loss and outflow in different sub-watershed (2001-2003)

The above graphs shows that the contribution of discharge from the lower part of watershed is high as compared to upper part of watershed because of the time of concentration is small for water reached to outlet from the most remote point. Due to dense vegetation and greater time of concentration, surface runoff is small at upper part watershed. The precipitation loss from the all sub-watershed in calibration period (2001-2003) graph shows that the maximum precipitation loss from the watershed in month of May to July because of maximum evapotranspiration within the watershed in this period. Maximum precipitation occurs in watershed in month from July to September about 75% and in remaining period of the year show the absence or low precipitation.

Table 4.5: Objective function and summary result for 2001

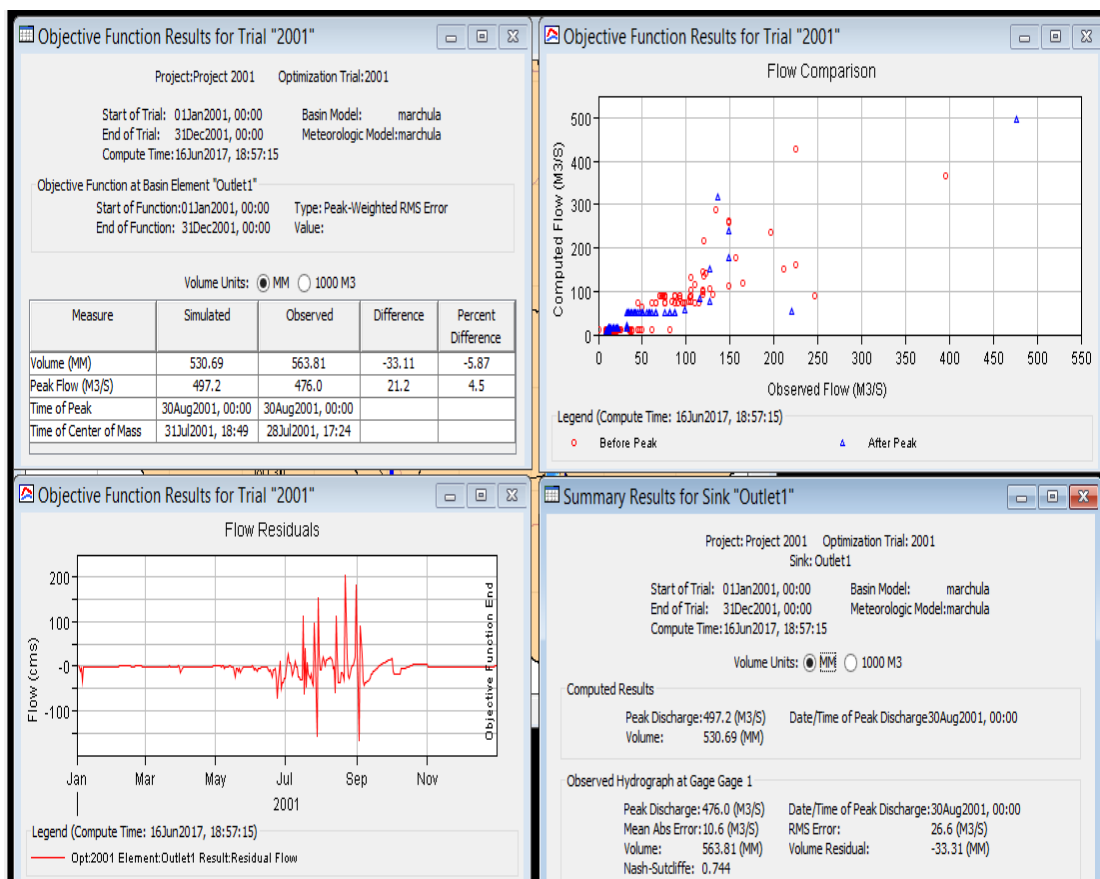


Table 4.6: Objective function and summary result for 2002

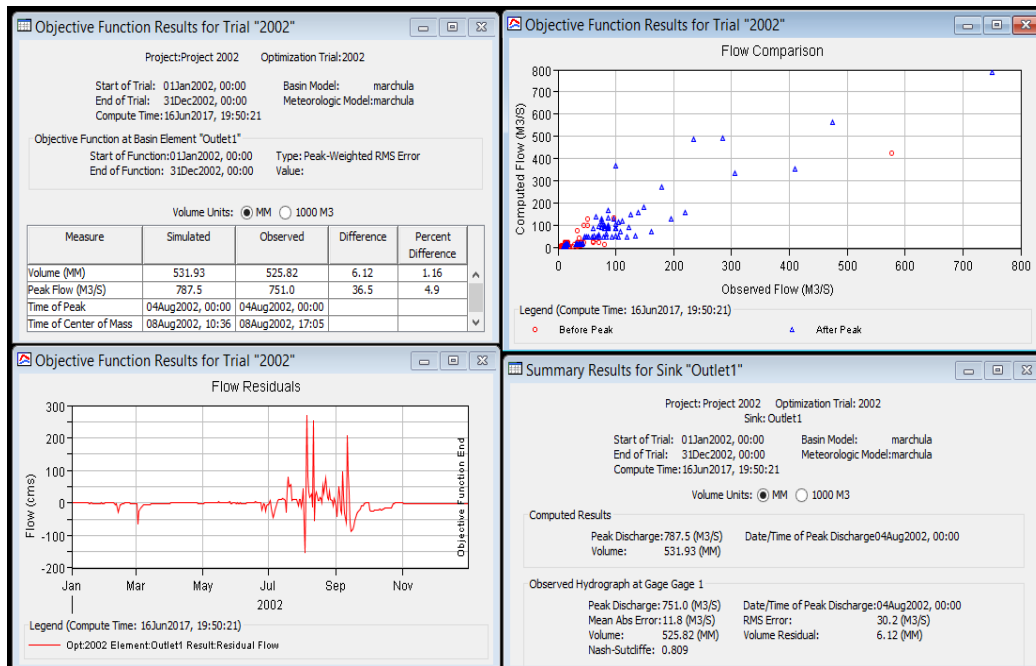


Table 4.7: Objective function and summary result for 2003

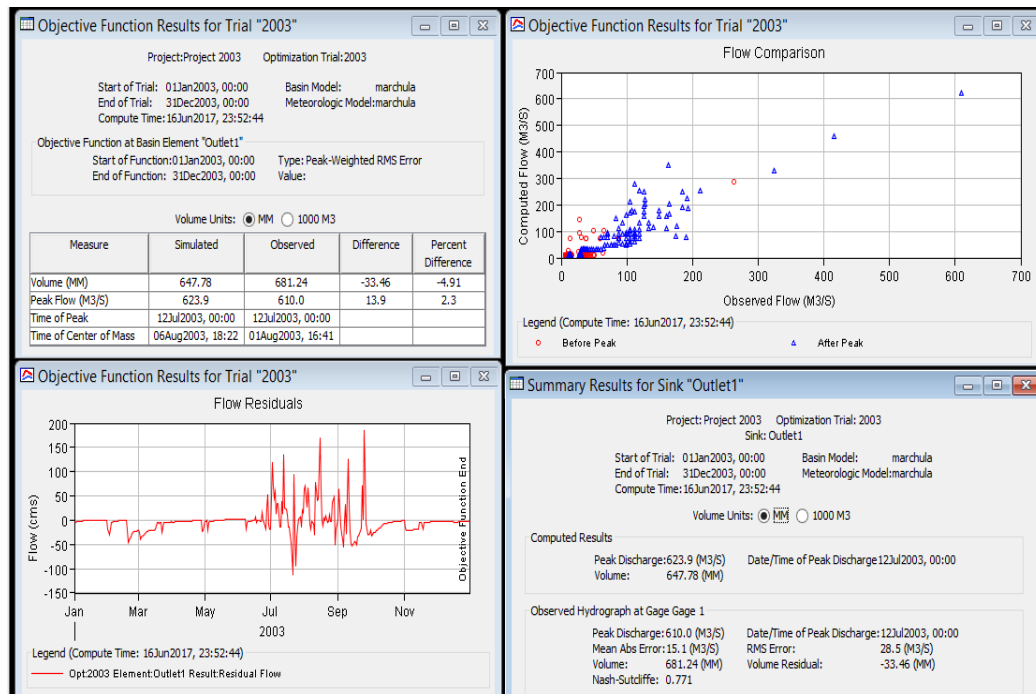
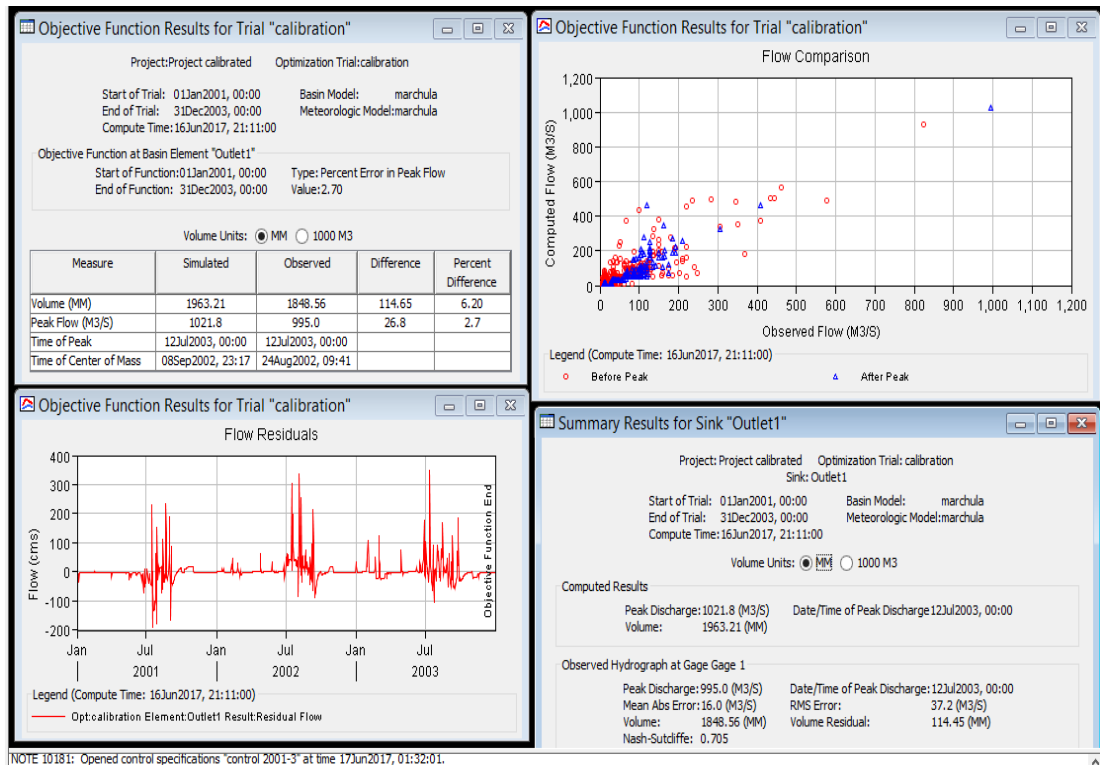


Table 4.8: Objective function and summary result for calibration



4.4 Validation result

The available 24 hour rainfall and discharge data of the year 2003-2005 have been used for validation purposes. Based on the calibrated parameters as described above, the resulting model output for the validation period has been estimated. The model performance estimated in terms of various efficiencies like Nash Sutcliffe, error in peak flow, error in peak flow and coefficient of determination has been presented in Table 4.9 and 4.10

Table 4.9: Evaluation of the model in terms of various efficiencies during validation

SN	Year	Nash Sutcliffe Efficiency	Error in Peak Flow (%)	Error in Volume (%)
1	2004	0.79	12.80	3.30
2	2005	0.77	6.00	11.84
3	2004- 2005	0.75	12.80	15.14

Table 4.10: Evaluation of the model in terms of coefficient of determination during calibration

SN	Year	Coefficient of determination (R^2)
1	2004	0.85
2	2005	0.86
3	2004-2005	0.86

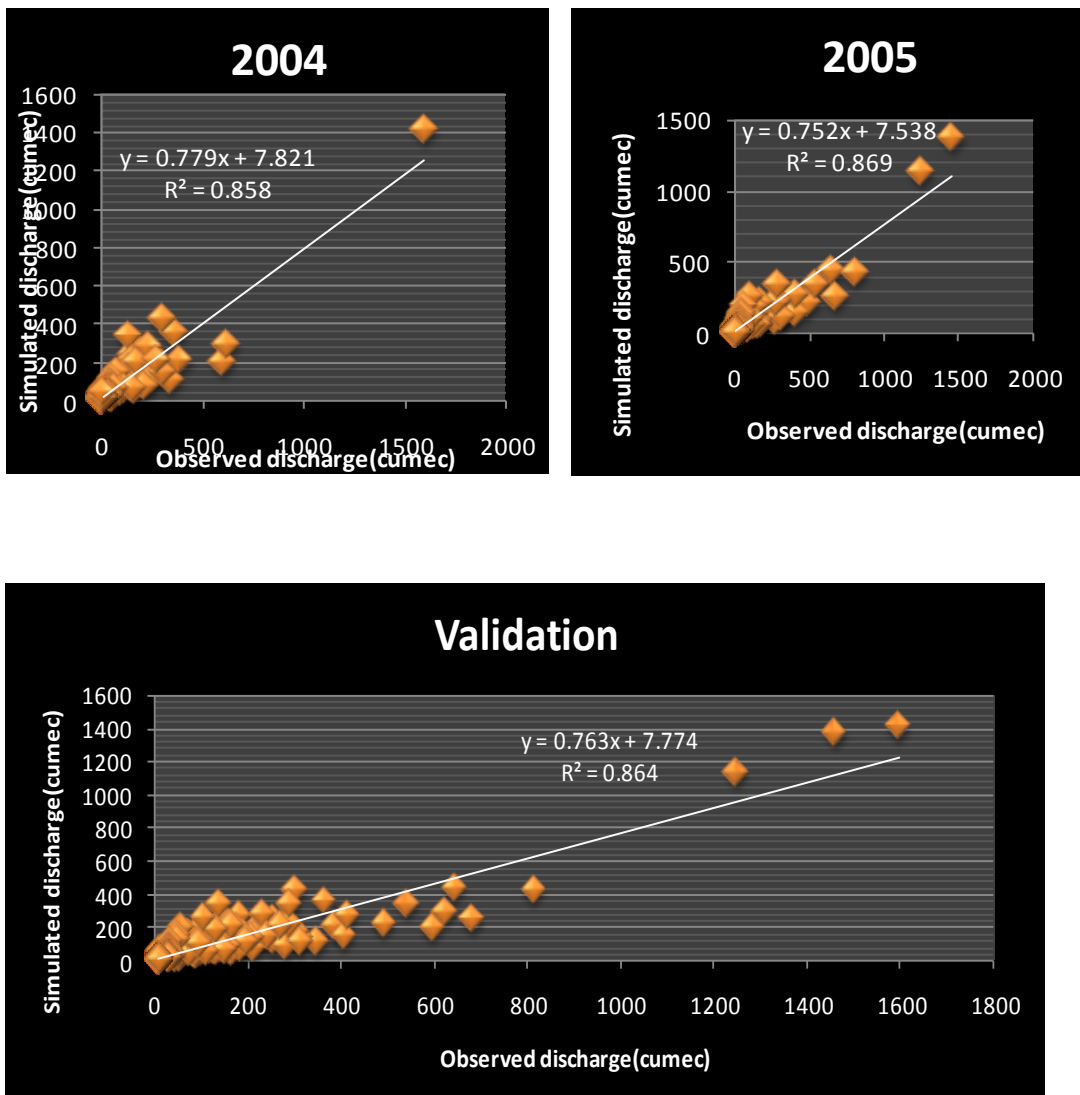


Figure 4.12: Graph plot between observed and simulated flow

The results show that in term of percentage error in peak flood is small and close to observed flood peak within accessible limit 10%. These result found that maximum peak discharge occurring between July and September months.

In terms of volumetric error the total volume discharge from watershed area after fulfillment of all losses is computed show that calibrated discharge volume is close to the observed discharge volume within accessible limit 20 % of total volume which it is acceptable for continuous calibration.

And the Nash Sutcliffe Efficiency (NSE) for calibration period is 0.75 which is satisfactory.

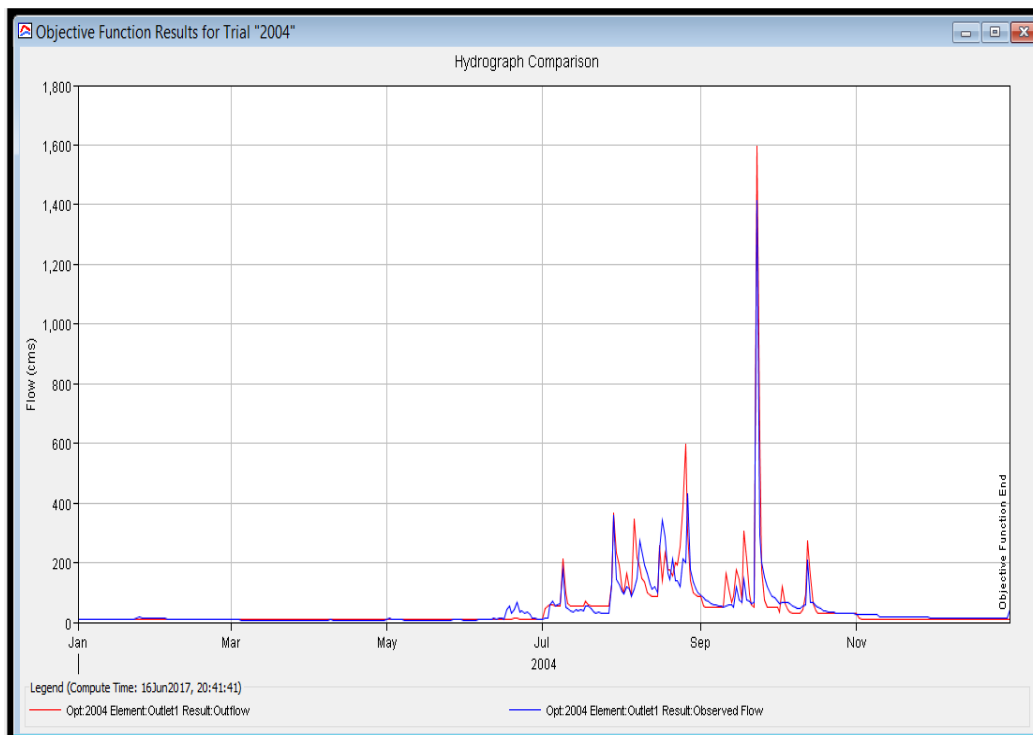


Figure 4.13: Simulated and observed hydrograph for the year 2004

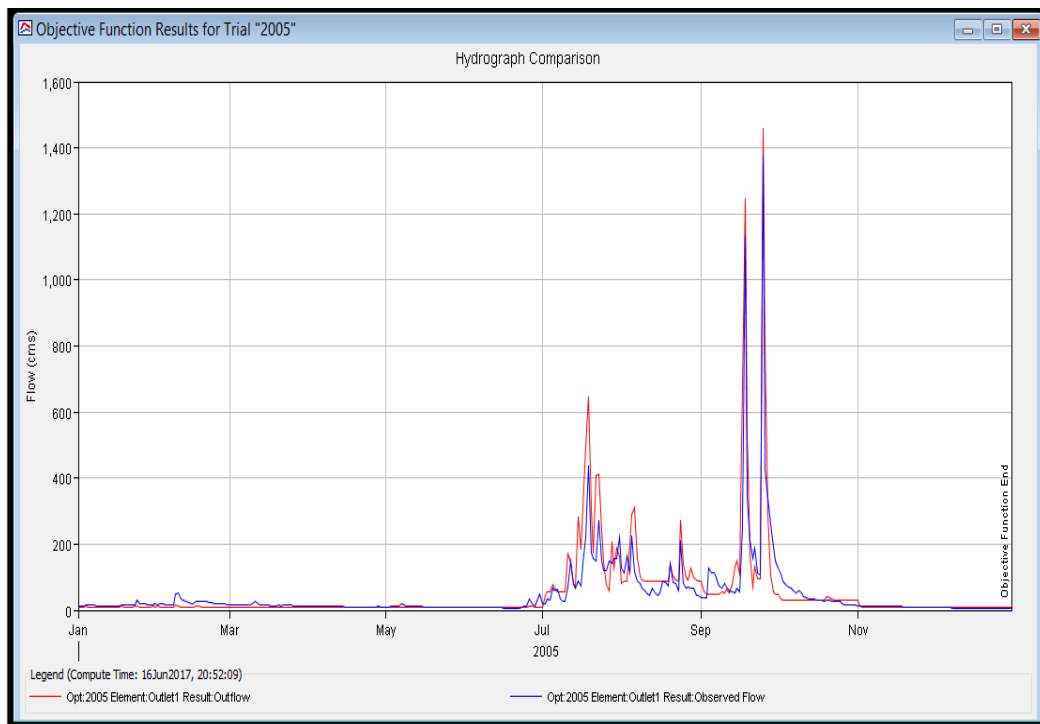


Figure 4.14: Simulated and observed hydrograph for the year 2005

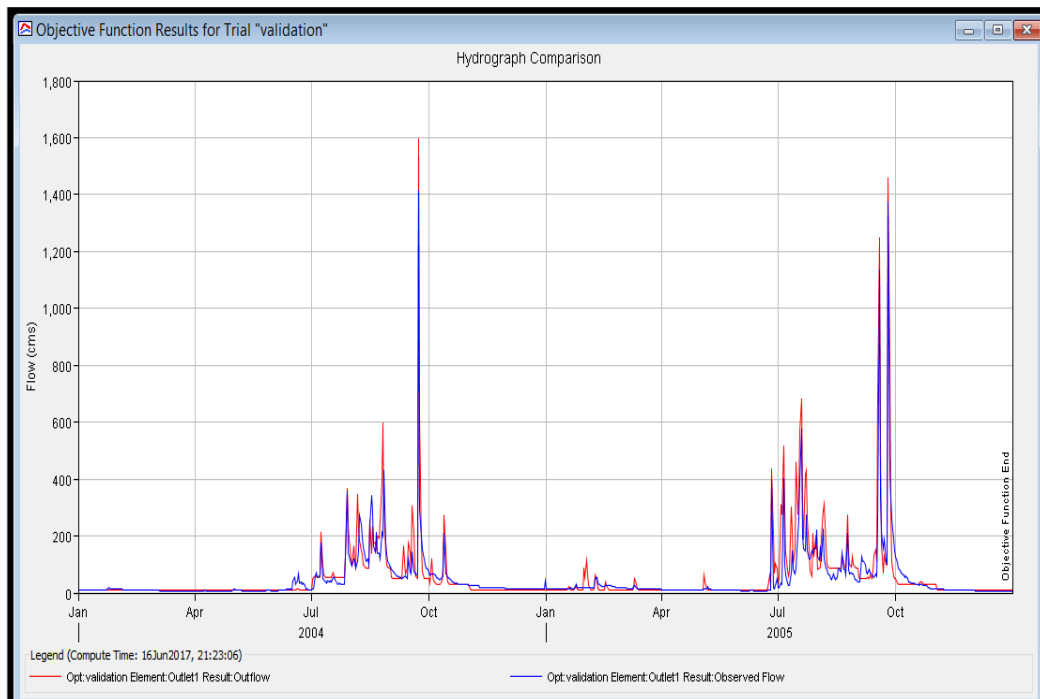


Figure 4.15: Simulated and observed hydrograph for the year 2004-2005

The simulated and observed hydrograph at the outlet has been presented in graphical form as shown in Figure 4.13 to 4.15. The graph shows that there is similarity of trend of simulated and observed hydrograph for relatively longer duration storm and also the estimated values are near to observed value. There is considerable difference in recorded and observed hydrograph for small storms because of variation in rainfall and individual sub- watershed area has not been represented by the their gauge record at that time

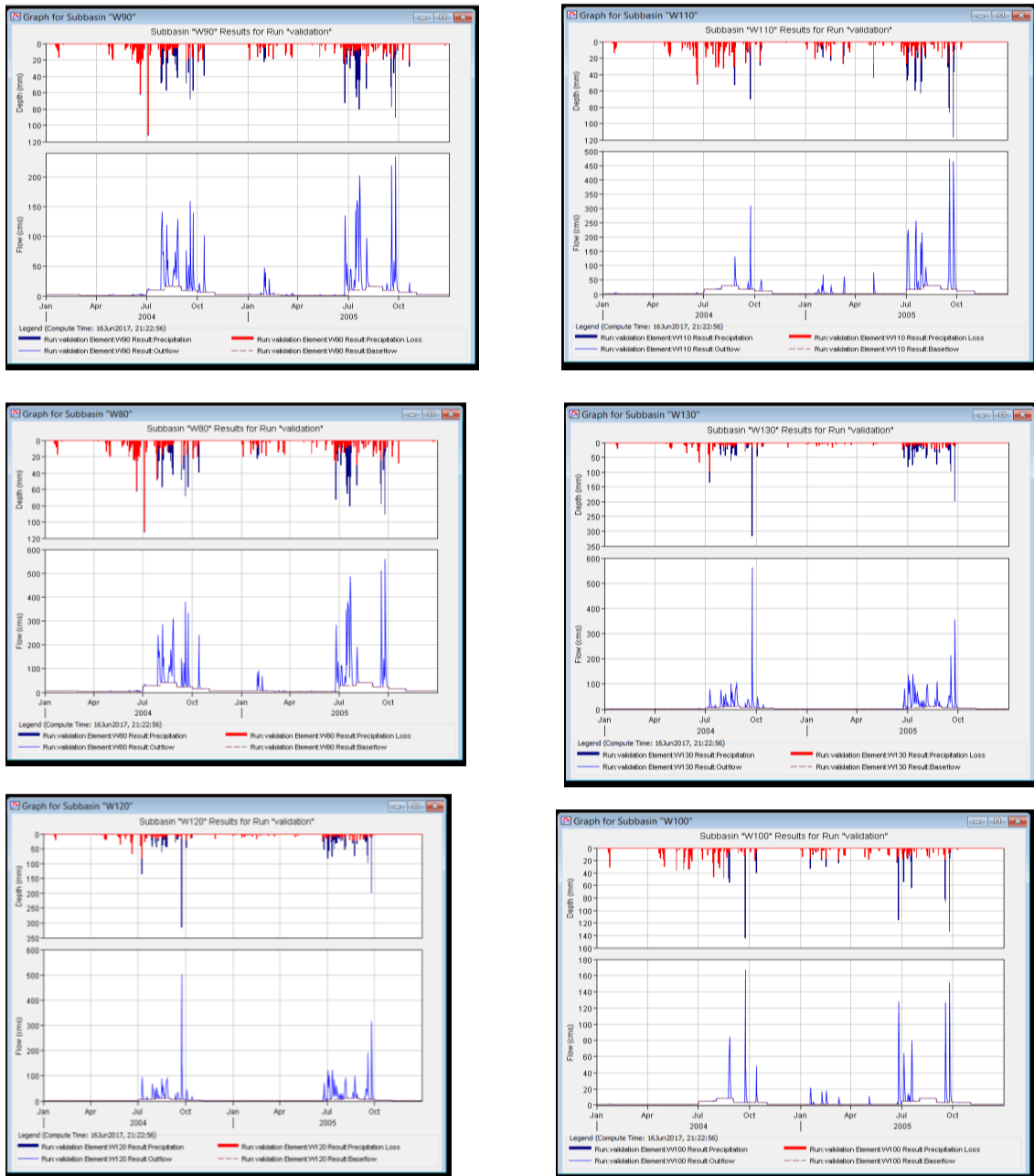


Figure 4.16: Graph show the precipitation, precipitation loss and outflow in different sub-watershed (2004-2005)

Table 4.11: Objective function and summary result for 2004

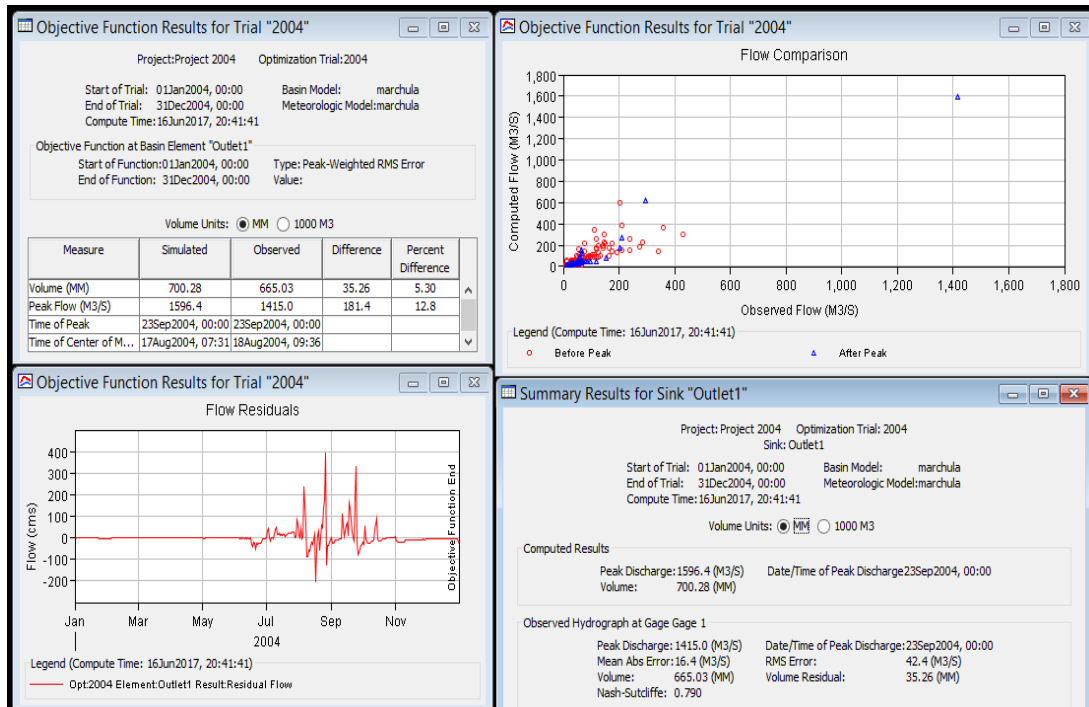


Table 4.12: Objective function and summary result for 2005

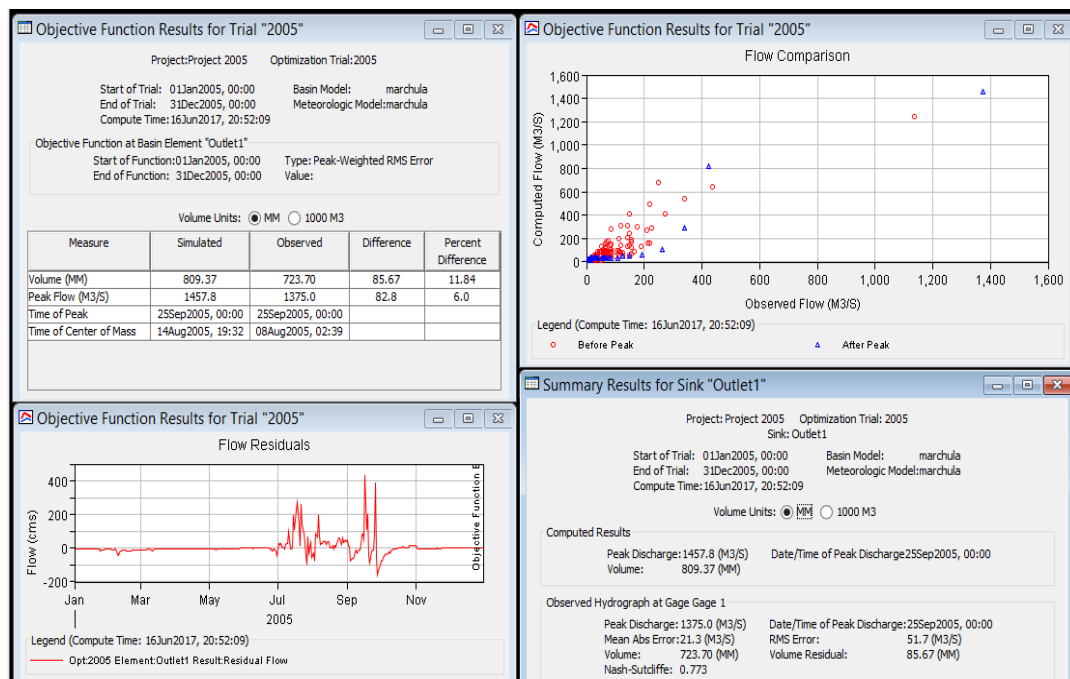


Table 4.13: Objective function and summary result for validation

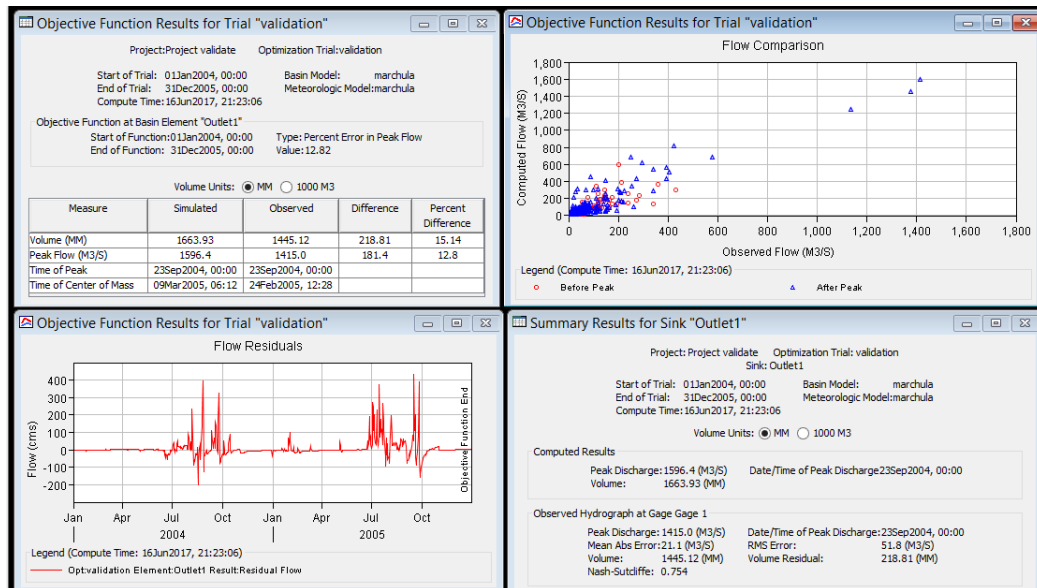
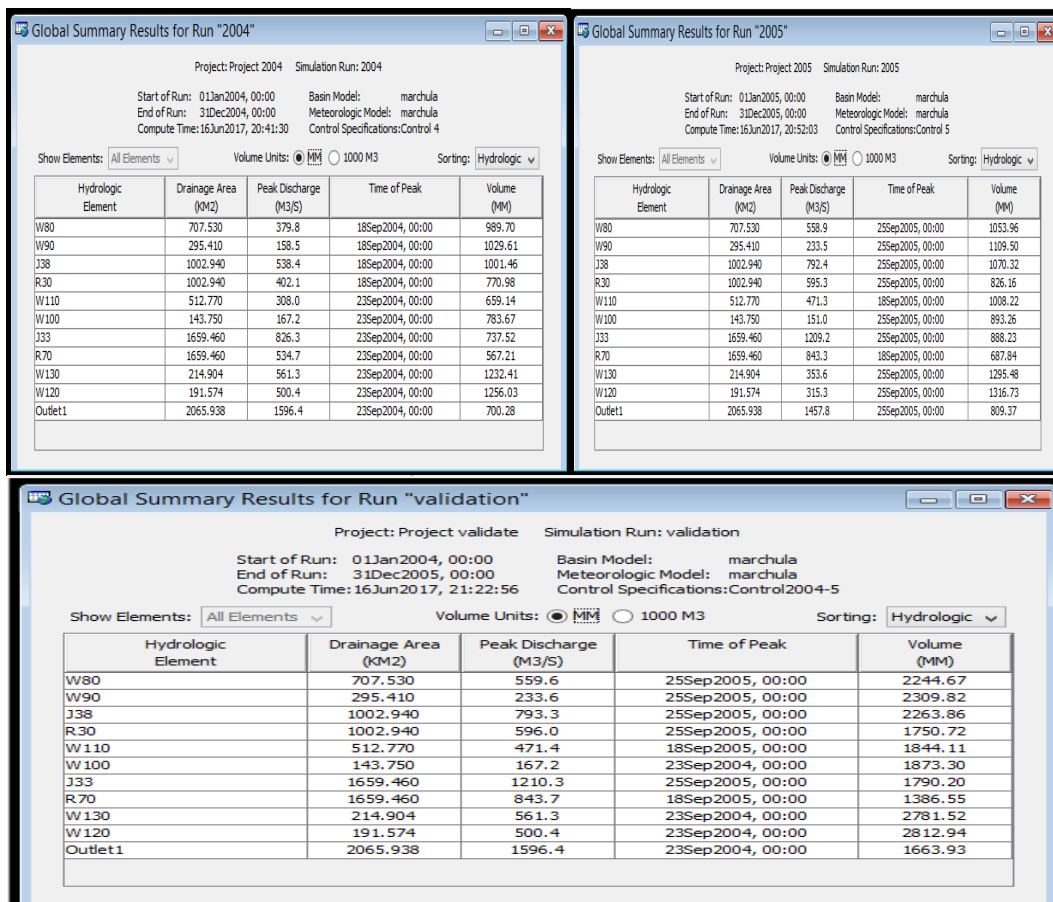


Table 4.14: Global summary for all, sub-watershed, reach and junction



4.5 Discussion on calibration and validation

From the overall observation there is difference in quantity and timing of observed and simulated discharge during the period of calibration and validation as seen in graphs, but the model performance is found satisfactory in terms of various efficiencies as mentioned in earlier sections. Thus we may conclude that model has been statistically calibrated and validated. Further the model can be used without much appreciable error.

Almost all the peaks are match with observed one but some peak were not well simulated as can be seen in figures above, the reason of difference in peak with observed peak is the contribution of improper rainfall input and technical capability of model. For example:

1. The rainfall was too little to produce excess rainfall.
2. Difference between lag time and discharge observation (take it in different time interval).
3. In actual situation rainfall varies with time and space. The rainfall observation at Symon's gauge does not reflect this, rainfall occurred in upstream and raingauge installed at downstream.
4. Actual field situation differ than the parameters used in model because of spatial and temporal variation in data at study area.
5. Evaluation of discharge of large watershed is preferably not suitable for this model.
6. According to previous researches, articles and observations, the model has more efficient for event modelling as compared to continuous modelling.

The calibration and validation results of the model indicate various factors which affect the runoff and peak flow. They are, for example- soil, land use land cover, rainfall pattern, topography, climate, and drainage density etc. These factors vary from watershed to watershed and Marchula watershed has its own characteristics. Some parameters which are more sensitive to runoff estimation are listed as

1. Curve number: as the study by model optimization shows the curve no. has significant affect to discharge from watershed area. If curve no. greater for model simulation then the runoff will occur more at outlet.
2. Initial abstraction: when rainfall occurs over the watershed area it must firstly fill up the all depression and interception loss before the flow over surface. Optimization results show that the significant effect of initial abstraction on calibration and validation result.
3. Lag time: it directly affects the peak of runoff hydrograph. If the all sub-watershed contribute the peak runoff at outlet in same time than the peak discharge from outlet is quiet high.

HEC-GeoHMS extracts topographic and hydrologic information from digital spatial data, and prepares an input file for the basin component of HEC-HMS, which opened automatically, creates a topologically correct schematic network of sub-basins and reaches, and attributes each element with selected hydrologic parameters. HEC-GeoHMS also generates an input file for the precipitation component of HEC-HMS. By using HEC-GeoHMS, the determination of physical parameters for HEC-HMS is a simple and automatic process that accelerates the setting up of a hydrologic model and leads to reproducible results. Precipitation and discharge data can be easy and clearly shown with graph, so that we can check the data easily.

The hydrological modelling using HEC-HMS includes three basic models namely basin model, meteorological model and control specification. Basin model is the most important input to run the model and simulate rainfall-runoff over entire watershed. For creating basin model for Marchula watershed, 6 Sub-basins and 2 routing reaches and 2 junctions were generated. The schematic drawing of Marchula watershed and its sub-basins, reaches are shown in Figure 3.7. The results of peak discharge and rainfall conversion to runoff in sub-watershed are presented in Table 4.8 and Table 4.13. In upper part of watershed contributing the less runoff as compared to nearest area of outlet because of more opportunity time to recharge ground water, initial loss and channel loss. Baseflow contribution in monsoon period is high as compared to summer season know as lean period of year. Meteorological model contain the rainfall gauge and evapotranspiration data for runoff compilation.

There is large variation in rainfall data of different gauges effect on the runoff volume and peak flow. Thus to minimise the variation of rainfall for evaluation of discharge with minimum error, weighted average rainfall using Thiessen polygon method have been used in the present study for the hydrological modelling.

The parameter calibration of HEC-HMS model was done with the option of optimization in HEC-HMS. Given initial estimates of the parameters, the models of HEC-HMS can be used with the observed boundary conditions (rainfall or upstream flow) to compute the output, either the watershed runoff hydrograph. The model evaluation indices include: Percentage error in peak, percentage error in volume and coefficient of determination

SUMMARY AND CONCLUSION

5.1 Summary

HEC-HMS is a semi distributed empirical watershed model that includes several methods which are used to simulate surface runoff and peak discharge over the Ramganga river at Marchula. The HEC-HMS model integrated with the ARC GIS has been set up for the Marchula watershed with an area of 2065 km² to simulate the rainfall-runoff at the daily time step. The hydrologic model, together with flood damage computation (include in HEC-HMS), provide an information about flood control management. The HEC-HMS hydrologic model was developed in 1976 by Leo R. Board and other members of the hydrologic engineering center with the U. S. Army Corps, to simulate the flood hydrograph in complex river basin (Singh 1982). After the model, time to time upgrade with new features. Different version of model with greatly extended capability have been released. In this study HEC-HMS version 4.2 were used

The combination of HEC Geo-HMS and HEC-HMS has been used for the better estimation of surface run-off from precipitation data of Marchula watershed. The model was calibrated using daily rainfall for a period of 2001-2003 and validation for period 2004-2005. The simulated and observed discharge curves are similar in nature. Though there is variation in quantity as well as timing of output in comparison to measured discharge, but the variations are within the acceptable limits. There are a lot of uncertainties in input variables in the model such as missing hydro-meteorological and climatic data, spatial distribution of rainfall event within the catchment, loss method selection, representation of base flow, selection of rainfall-runoff transformation method, representation of evapotranspiration etc. The hydrological model itself has some limitations such as not consideration of evapotranspiration during rainfall though precipitation is negligible. This result show that the simulated discharge close to observed

discharge with minimum error. Hence the model showed satisfactorily results and capability to model the hydrologic simulation in Marchula watershed. Simulated peak discharges available at

5.2 Conclusion

HEC-HMS model used for continuous simulation of rainfall runoff process for Marchula watershed. The initial values calculated for simulation is not suitable for model calibration. Optimized the parameters like curve no., lag time and initial storage which are directly affecting the runoff hydrograph. Summary table shows that the upper part of watershed that is more forest cover produced less runoff volume contribute to stream channels as compared to the sub-watershed near the outlet like sub-watershed, W80 and W90 is more sensitive to contribute the runoff to outlet. The maximum flood occurs in month of July to September within the watershed area. For calibration period (2001-2003) the maximum flood coming in 12 July 2003, about 1021cumec and the total volume of runoff contribute in year 2003 about 3338.265 Million Cubic Meter at Marchula watershed. The peak runoff occurs due to high intensity of rainfall and more available water content in soil of watershed area. The present study shows that the lag time affects the peak runoff of hydrograph. When the lag time greater for watershed area the peak of hydrograph become skewed toward to right side give broad base and low peak hydrograph. Reach 30 and reach 70 also effect on the runoff hydrograph and its component. Study flow of water through reach (prism storage) during the non-precipitation days due to the baseflow and induced the maximum flood during the high intensity rainfall.

Most parameters for methods included in sub-watershed and reach elements can be estimated automatically using optimization trials. Observed discharge must be available for at least one element before optimization can begin. Parameters at any element upstream of the observed flow location can be estimated. Six different objective functions are available to estimate the goodness-of-fit between the computed results and observed discharge.

Some conclusions that are drawn from the above study can be listed as;

- Nash Sutcliffe Efficiency for the calibration period is 0.71 and 0.75 for the validation period which is within the acceptable limit and the model is representing hydrological process in the catchment.
- The volumetric efficiencies of HEC-HMS model during calibration and validation process is within 20 percent which is acceptable but is fluctuating in upper side or lower side for different years due to non-uniform distribution of rainfall for entire catchment.
- Peak flood estimation efficiency is within 10 percent which is acceptable but somewhere peak discharge not match with observed peak due to non-uniform distribution of rainfall and non-availability of hydro-meteorological data of shorter duration than daily. But for the storm of relatively larger duration the observed and simulated values are near to each other.
- The coefficient of determination for the calibration period is 0.83 and for the validation period is 0.86, both the values are satisfactory.

5.3 Recommendations

The present study is limited to rainfall-runoff simulation for the Marchula watershed, Uttarakhand using available observed hydro-meteorological data of the four stations falling within the watershed. The assumed loss methods used in the study are SCS curve number, simple canopy and simple surface. The SCS unit hydrograph method has been used for rainfall runoff transformation. The results of this study are satisfactory. The model approach can be used in similar watershed of Uttarakhand for the accessing, development and management of water resources.

It is recommended that the future work should incorporate the use of satellite based precipitation data, use of higher resolution DEM, use of satellite images of higher resolutions for land use/land cover classifications, adoption of soil moisture accounting loss method, use of accurate method for base flow representation and use of different methods of rainfall-runoff transformations. etc. The modeling of the basin may be done at

grid level which represents the rainfall-runoff response in the basin more accurately without appreciable errors.

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