MODELLING HYDROLOGICAL COMPONENTS AND IMPACT OF LAND USE/LAND COVER CHANGE ON HYDROLOGICAL REGIME

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ABSTRACT

Land and water are the two most vital natural resources of the world. Proper planning and management of these two most vital natural resources is, therefore, of utmost necessity. Watershed is considered to be the ideal unit for management of these natural resources. For proper planning and efficient utilization of the land and water resources it is necessary to understand the hydrological cycle and estimate the hydrological parameters. The reliable prediction of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. Use of mathematical models for hydrologic evaluation of watersheds is the current trend and extraction of watershed parameters using remote sensing and geographical information system (GIS) in high speed computers are the aiding tools and techniques for it. In the present study AVSWAT2000 (Soil and Water Assessment Tool), a physical based semi distributed hydrologic model having an interface with ArcView 3x GIS software was applied for Kulsi Basin, covering an area of 1593.27 sq.km in order to model the various hydrological components and to assess the impact of land use/land cover on the surface flow and sediment yield. The various input parameters like the meteorological data, discharge and sediment data were processed as per the requirement of the AVSWAT model. Various thematic maps like soil map, drainage map, digital elevation model, slope map, aspect map, land use/ land cover map were either acquired or prepared from satellite data and SOI toposheets using image processing and GIS softwares. Field soil samples were collected and analyzed for soil texture, field capacity, available water capacity, bulk density, organic carbon, rock fragment etc. required as input in SWAT model. Finally simulation was carried out on daily, weekly and monthly basis for the Kulsi basin.

The model was calibrated for the year 2001and validated with the observed runoff and sediment yield for the year 1991 and 2002. The performance of the model was evaluated using statistical and graphical methods to decide the capabililty of the model in simulating the runoff and sediment yield from the Kulsi basin. The calibration period reported an R^2 of 0.68, 0.75 and 0.82 for daily, weekly and monthly surface runoff results with Nash-Sutcliffe R^2_{NS} of 0.53,0.52 and 0.56. The model estimation result showed a

poor correlation during sediment calibration with an R^2 value of 0.36. Validation period reported an R^2 value of 0.43 and 0.72 for daily and monthly runoff values for 1991and 0.47 and 0.90 for 2002. Weekly comparison between simulated and observed values seemed to smoothen the graphs with R^2 values of 0.74 and 0.79 as compared to daily values for the year 1991 and 2002. The Nash-Sutcliffe R^2_{NS} was observed to be 0.57and 0.93. The model estimation result again showed a poor correlation during sediment validation for the year 2002 with an R^2 value of 0.19. Evapotranspiration simulated by the AVSWAT model using the Penman –Monteith method was observed to be maximum during the month of May (96.59 mm) and minimum in the month of December (13.85 mm).

In order to study the impact of land use/land cover on surface runoff and sediment yield monthly simulations were carried out for the year 1991 and 2002 using the same precipitation file. Results indicated that with a decrease in dense forest by 1.64% and increase in open forest and agricultural land by 0.9% and 0.74% during the period from 1991 to 2002 surface runoff and sediment yield increased by 17mm and 1.47t/ha showing that land use/ land cover has an impact on the hydrological regime.

(**Key Words**: Watershed, AVSWAT, Calibration, Validation, Image Processing, Remote Sensing, GIS, Nash-Sutcliffe, Evapotranspiration, Land use/land cover, Surface Runoff, Sediment Yield)

CHAPTER I

INTRODUCTION

Land and water are the two most vital natural resources of the world and these resources must be conserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite,non-renewable over the human time frame, and prone to degradation through misuse and mismanagement. In India, out of a total geographical area of 328 M ha, an estimated 175 M ha of land, constituting an area of 53% suffers from deleterious effect of soil erosion and other forms of land degradation and with the increasing population pressure, exploitation of natural resources, faulty land and water management practices, the problem of land degradation will further aggravate. Land use change within a region has not only an impact on various hydrologic landscape functions but also affects the habitat quality and thus the biodiversity of a landscape.

Water resources degradation is an issue of significant societal and environmental concern. Water pollution originates either from point or non-point source or from both. Non-point source pollution has been identified as a major reason for water quality problems. Also point source pollutions such as effluent from industries, feedlots and erosion from gully are also getting mixed with stream water causing pollution of water resources.

Proper planning and management of these two most vital natural resources is, therefore, of utmost necessity. Watershed is considered to be the ideal unit for management of these natural resources. Proper watershed management, which is a comprehensive term meaning the rational utilization of land and water resources for optimal production and minimum hazard to natural resources could be the solutions to all these problems. Watershed analysis provides a framework for ecosystem management, which is currently the best option for conservation and management of natural resources.

The North Eastern region of India dynamically rich in land and water resource. The region experiences a paradoxical hydro climatic environment and represents a typical hydrological entity in the world atlas. Endowed with huge water resources potential it has also the worst water resource problems rendering untold sufferings to millions every year. The region experiences excessive rainfall and high floods during monsoon months and also suffer from acute shortage of even drinking water in many areas due to lack of management. The basic issue under lying the water resources problems: one recurring floods, drainage congestion, soil erosion, human influence on environment and so on and calls for its integrated use for drinking, irrigation generation of hydropower, navigation, pisciculture, recreation etc. For proper planning and efficient utilization of the land and water resources in the region it is necessary to understand the hydrological cycle and estimate the hydrological parameters.

The reliable prediction of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that for hydrologic evaluation of watersheds, some suitable methods and techniques are to be used/ evolved for quantifying the hydrological parameters from all parts of the watersheds. Use of mathematical models for hydrologic evaluation of watersheds is the current trend and extraction of watershed parameters using remote sensing and geographical information system (GIS) in high speed computers are the aiding tools and techniques for it.

Hydrological modeling is a powerful technique of hydrologic system investigation involved in the planning and development of integrated approach management of natural resources. Models are important tools because they can be used to understand hydrologic processes, develop management practices, and evaluate the risks and benefits of land use over various periods of time (Spruill, C. A. et. al., 2000). The fundamental objective of hydrological modelling is to gain an understanding of the hydrological system in order to provide reliable information for managing water resources in a sustained manner to increase human welfare and protect the environment. A model aids in making decisions, particularly where data or information are scarce or there are numbers of options to choose from. It is not a replacement for field observations. Its value lies in its ability, when correctly chosen and adjusted, to extract the maximum amount of information from the available data, so as to aid in decision making process.

A number of simulation models have been developed to simulate the impact of land management on water , sediment, nutrient loss etc. at both field and watershed scale. Widely used field scale models include CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), and

GLEAMS (Groundwater Loading Effects of Agricultural Management System).Watershed scale models include storm event based AGNPS (Agricultural Non-Point Source Pollution) and continuous daily time step model SWRRB (Simulator for Water Resources in Rural Basins). These models were developed for their specific reasons with some limitations for modeling watersheds.

The SWAT (Soil and Water Assessment Tool) is one of the most recent models developed jointly by the United States Department of Agriculture (USDA), Agricultural Service and Agricultural Experiment Station in Temple, Texas. It is a physically based, continuous time, long-term simulation, lumped parameter, deterministic, and originated from agricultural models. The computational components of SWAT can be placed into eight major divisions: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The application of AVSWAT (ArcView SWAT) in the present study provides the capabilities to stream line GIS processes tailored towards hydrologic modeling and to automate data entry communication and editing environment between GIS and the hydrologic model. Thus, AVSWAT represents a preprocessor and as well as a user interface to SWAT model.

1.1 Role of Remote Sensing in Hydrological Modelling

A major problem in the hydrology is the inadequate field measured data to describe the hydrologic process. Remote Sensing has been identified as a tool to produce information in spatial and temporal domain, instead of point measurement, in digital form, with high resolution. The remotely sensed data acquired from space borne platforms, owing to its wide synoptivity and multi spectral acquisition provides spatial information about the various processes of the landphase of the hydrological cycle. These spatial informations can be used as input data for hydrological models and are extremely relevant as a means of estimating a number of key variables specifically in situation where distributed hydrological models are used. Remote Sensing techniques can produce high spatial coverage of important terms in water balance for large areas, but at the cost of a rather sparse temporal resolution. Hydrological model can produce all the terms of water balance at a high temporal, but low spatial resolution. The use of remote sensing data, in combination with distributed hydrological model, provides new possibilities for deriving spatially distributed time series of input variables, as well as new means for calibration and validation of the hydrological model.

Some of the main hydrological application fields of remote sensing are:

- Spatial rainfall patterns
- Evaporation and soil moisture
- Snow cover extent
- Groundwater
- Topography
- Water Bodies
- Vegetation

In the present study remote sensing data has been used to generate input data of thematic maps such as land use/land cover and geomorphology for a physically based fully distributed hydrological model.

1.2 Role of GIS in Hydrological Modelling

The use of remote sensing technology involves large amount of spatial data management and requires an efficient system to handle such data. Hence Geographic Information System makes it possible to store, analyze and retrieve data for large and complex problems.

Geographical Information System (GIS) is a computer based system designed tool applied to geographical data for integration, collection, storing, retrieving, transforming and displaying spatial data for solving complex planning and management problems. This tool focuses on proper integration of user and machine for providing spatial information to support operations, management, analysis and decision making. Since, GIS does not directly land itself to time varying studies, its features are utilised in hydrological studies by coupling it with hydrological models. Two types of approaches are possible for this purpose. In the model driven approach, a model or set of models is defined and thus the required spatial (GIS) input for the preparation of the input data and output maps. The other approach is the data driven approach. It limits the input spatial data to parameters which can be obtained from generally available maps, such as topographic maps, soil maps etc. The possibility of rapidly combining data of different types in a GIS has led to significant increase in its use in hydrological applications. It also provides the opportunities to combine a data from different sources and different types. One of the typical applications is use of a digital terrain model (DTM) for extraction of hydrologic catchment properties such as elevation matrix, flow direction matrix, ranked elevation matrix, and flow accumulation matrix. It also provides the ability to analyze spatial and non-spatial data simultaneously.

1.3 Rationale of the Study

The Kulsi basin as a whole, receives a good amount of rainfall throughout the year. Apart from the rolling hill topography, faulty cultivation practices and deforestation within the basin results in huge loss of productive soil and water as surface runoff. There is an urgent need for developing integrated watershed management based on hydrological simulation studies using suitable modeling approach. Since the time series data on rainfall, runoff and sediment yield are available at gauging station of the catchment, therefore, a research work was formulated to study the changes in the land use within the catchment using remote sensing data and to understand the effect of land use changes on the flow behaviour and sediment yield.

Considering hydrological behaviour of the study area and applicability of the existing models for the solutions of aforesaid problems , the current study was undertaken with the application of SWAT2000 in integration with Remote Sensing and GIS to estimate the surface runoff, sediment yield and other hydrological parameters of the Kulsi basin located in North Eastern India. The specific objectives of the present study are:

1) Extraction of watershed characteristics, and land use/ land cover information of the study area using Remote Sensing, GIS and collateral data.
2) Physical Based Semi Distributed Hydrological Modelling for Kulsi River Basin.
3) Sediment Yield Modelling for Kulsi River Basin.
4) To analyze the impact of land use/land cover on the surface runoff and sediment yield.

REVIEW OF LITERATURE

In order to model the hydrological processes in a multivegetated watershed it is necessary to update the information regarding the response of these processes to various watershed parameters and acquire an in depth knowledge about the suitability of different hydrologic models for the simulation of these hydrologic processes. As most hydrologic models requires the application of Remote Sensing and GIS, it is also necessary to update information regarding the information of remotely sensed watershed information and GIS techniques by different models. Keeping this in view the present chapter deals with the review of significant contributions made by researchers in the field of hydrologic models, use of remote sensing and GIS for runoff estimation. It also contains classification of models on watershed hydrology and their applications, comparative studies of the various models. Further, a brief review is presented for various studies dealing with the application of SWAT (Soil and Water Assessment Tool) in hydrological modeling of watersheds.

2.1 Models of Watershed Hydrology

Different types of hydrological models exists. These models have been developed to solve the different hydrological problems. They can be split into three broad groups: stochastic (chance dependent), deterministic (chance independent) and quasi-stochastic (elements of both) models. Stochastic models uses statistical properties of existing records and probability laws together with a random number generator to generate synthetic sequences which are used in solving hydrological problems. This type of models are more likely to be used where scales of space and time are large i.e in situations where a lot of averaging of heterogeneous time/space processes, and smoothing of the hydrograph has taken place. Deterministic models describes the behaviour of the hydrological cycle in terms of mathematical relationships which outline the interactions and linkages of the various processes and components of the spatially and temporally varying hydrological system in a known way, with individual submodels representing each particular hydrological process. Quasi-stochastic models are primarily planning tools; for instance, a deterministic model may be run with multiple artificial data sets stochastically generated with a Monte-Carlo simulation.

Deterministic models can be further classified into empirical, conceptual or physically based models depending on the attention paid to the fundamental physical laws operating in the catchment. Deterministic models can also be classified as point, lumped or distributed depending on the treatment of spatial variability. Point models are physically based and calculate hydrological properties for a single point or column. They are usually restricted to research applications. Lumped models use one set of parameters to define an area's physical and hydrological properties, whereas distributed hydrological models take heterogeneity into account. Distributed models is a playoff between advantages and limitations; the difficulty is in up or down scaling measured parameters, particularly as the governing physical equations are continuum equations requiring definable gradients in characteristics (Beven, 1993).

Song and James (1992) reviewed several models and described five scales (laboratory, hill slope, catchment, basin, and continental/global scale) used in hydrologic simulation. The catchment scale models add topography in simulation of surface runoff and geology in simulation of base flow, and often divide larger catchments into smaller homogeneous parts. Basin scale models employ storage and translatory routing schemes in combining runoff. Singh (1995) also classified hydrological models based on the basis of their intended use: planning models, management models and prediction models.

Hydrologic models are also grouped as field scale models, event based watershed scale and continuous watershed scale models. The scientific literature on the developments and application of hydrologic and NPS models as review articles have been presented by many researchers (Novotny, 1986; O'Connell,1991; Williams and Arnold, 1996).

2.2 Field Scale Models

NPS: The Non-Point Source model (Donigian and Crawford, 1976) is a field-scale, continuous model. It was developed to simulate NPS loads from urban and rural areas. It includes three major components: hydrology, erosion, and NPS pollutant loads. The model does not include channel routing, thus its use should be limited to areas less than 5 km2.

USLE: The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is a model that predicts soil erosion for a given cropping system, management practice, soil type, rainfall pattern, and topography. The model was empirically derived from experimental observations of approximately 10000 plot-years of basic runoff and soil loss data. The USLE is not an NPS model but an erosion model that computes long term soil losses from sheet and rill erosion under specific conditions, but it does not predict soil deposition or sediment yield from gullies or stream bank erosion. The model was intended to be used for conservation planning of farm fields or construction sites.

CREAMS: The Chemical, Runoff, and Erosion from Agricultural Management Systems (Knisel, 1980) is a physically based continuous model that estimates runoff, erosion/sediment transport, plant nutrient and pesticide yield from field sized areas (less than 100 ha). The CREAMS model consists of three major components: hydrology, erosion/sedimentation, and chemistry. The hydrology component estimates runoff volume and peak rate, infiltration, evapotranspiration (ET), and percolation. The CREAMS offers two options to determine runoff: the SCS-CN method when only daily rainfall data is available, and the Green-Ampt infiltration approach when breakpoint rainfall data is available. The erosion component is based on the modified USLE (MUSLE) and includes sediment transport capacity for overland flow. The nutrient sub model considers both sediment-bound and dissolved nutrients. CREAMS model, supported by USDAARS has been used extensively in NPS modeling.

GLEAMS: The Groundwater Loading Effects of Agricultural Management Systems (Leonard et al., 1987) is a field-scale model based on the CREAMS model. The original model was developed to predict pesticides losses; nutrient transport and transformations were later added. The hydrology and sediment subroutines in GLEAMS are same as for CREAMS model. The nutrient model is based on the EPIC model. The GLEAMS model was modified to represent water and solute movement in clay soil (Morari and Knisel, 1997). GLEAMS is widely used for NPS planning and is supported by the USDA-ARS.

EPIC: The Erosion Productivity Impact Calculator (Williams et al., 1983; Sharpley and Williams, 1990) is a field scale, continuous simulation model. It was developed to determine the effects of soil erosion on soil productivity throughout USA. The model includes hydrologic, erosion and sedimentation, plant growth and nutrient cycling components. Runoff is estimated using the SCS-CN method. Erosion is based on the MUSLE. Later it was modified as EPIC-PEST model by adopting the pesticide related subroutines from GLEAMS model, to simulate pesticides activities (Sabbagh et al., 1991). EPICPEST was evaluated for Ben Hur Research farm, near Baton. They concluded that GLEAMS pesticide related subroutine was successfully incorporated. Richardson and King (1995) applied EPIC model for estimating the nutrient and sediment losses for clay soil under conservation and zero tillage practices. EPIC is commonly used for NPS planning purposes.

RUSLE: The Revised Universal Soil Loss Equation (Renard et al., 1991, 1994) is a modern erosion prediction and conservation-planning tool based on the revised USLE. Changes have been made in all factors R, K, LS, C, and P. Modified R factor values are estimated based on hourly data. Soil erodibility factor K is modified based on seasonal variability. The model uses a new slope length and steepness (LS) algorithms and accommodates complex slopes. Values of crop management factor C have been divided into a series of sub-factors (reflecting prior land use, crop canopy, surface cover and roughness). New P factor values for the effect of terracing are developed by using CREAMS model. The model has been adopted by the USDA-SCS as its official erosion prediction and conservation-planning tool.

2.3 Watershed scale models

2.3.1 Event based models

FESHM: The Finite Element Storm Hydrograph Model (Ross et al., 1979) is a distributed parameter, event-oriented, watershed scale model. The model discretizes the watershed into homogeneous hydrologic response units (HRUs). The model was developed to predict flow from ungauged areas and then it was updated to include erosion and sediment transport processes. The model does not consider sedimentation in channels and the nutrient component. The model is neither supported nor widely used for NPS pollution modeling.

HEC-1: HEC-1 flood hydrograph model was developed by the Hydraulic Engineering Center (1981, 1990) to simulate the direct runoff hydrograph (DRH) due to precipitation. This model has been extended for determining discharge frequency relationships for

ungauged watersheds. The model allows several options for specifying precipitation, infiltration, base flow, runoff transformation,
and routing. The DRH is estimated using unit hydrograph and the kinematics wave methods. The optional model parameters are determined by a univariate search technique. It is perhaps the most comprehensive event based stream flow simulation model.

SCS TR-20 and TR-55: The US SCS Technical Release-20 is a single event rainfall-runoff model. The model uses the SCS-CN runoff equation and the SCS dimensionless unit hydrograph to estimate surface runoff resulting from any synthetic or natural rainfall. The runoff is then routed through stream channels using convex method and through reservoirs using storage indication method. The model was widely used by SCS Engineers in USA for urban and rural watershed planning, for flood hazards studies and for design of reservoirs and channel projects. TR-55 is a simplified version of this model and is applicable for a single watershed.

ANSWERS: The Areal Nonpoint Source Watershed Environmental Response Simulator (ANSWERS) (Beasley et al., 1980, 1982) is a watershed scale, distributed parameter, event-oriented, physically based model developed to simulate the impacts of watershed management practices on runoff and sediment loss. The original model included surface water hydrology only. Beasley et al. (1980) expanded the model to include erosion and sediment transport. The overall model structure consists of a hydrologic model, a sediment detachment and transport model, and several routing components necessary to describe the movement of water in overland, subsurface and channel flow phases. It requires rather large computer resources in order to simulate large watersheds. ANSWERS because of flexibility, could be applicable over the broad range of conditions, including ungauged watersheds for obtaining at least comparable results for various treatment and management strategies for erosion control. The sediment transport model was later updated to simulate sediment detachment and. transport of individual particle size classes in a sediment mixture during the overland flow processes. The erosion process was limited to theoverland flow regime and did not consider channel erosion (Dillaha and Beasley, 1983).

AGNPS: Agricultural Non-Point-Source Pollution Model (Young et al., 1987) is a distributed parameter, event based watershed scale model. AGNPS was developed to simulate runoff, erosion and sediment, nitrogen, phosphorus losses and chemical oxygen demand (COD) from agricultural watersheds in Minnesota. Runoff characteristics are simulated for each cell and routed to the outlet. Thus, flow, erosion, and the chemical at any point in the watershed can be studied. Upland sources contributing to a potential problem can be identified and locations can be prioritised for remedial measures to improve water quality most efficiently. Runoff is computed using the SCS-CN method. The upland erosion is computed using the MUSLE equation. The nutrient transport component is similar to that in CREAMS. The distributed parameter approach of this model preserves spatial characteristics and makes it appropriate to use a raster GIS system for storage, retrieval and manipulation of those spatial characteristics. The main advantage of AGNPS over older erosion prediction technologies, like the USLE, is its capability to estimate offside effects as well as on side effects.

EUROSEM: The European Soil Erosion Model (EUROSEM) (Smith et al., 1995) was developed by the European Union to address the particular conditions of European soils. EUROSEM is an event-based, distributed-parameter model that simulates soil erosion and produces hydrographs and sediment graphs on an event basis. EUROSEM's hydrology component is based on the KINEROS model (Smith et al., 1995).

RUNOFF: RUNOFF is an event based distributed parameter model that simulates time and space distributed rainfall excess, runoff, and sediment on a watershed. The model uses efficient algorithms to solve the continuity equation for sediment flow (Borah, 1989a, b). The model simulates the processes of interception, infiltration, runoff, soil detachment, transport, and deposition on both overland and channel flow units. Van Liew (1998) simulated sediment responses by applying modified version of RUNOFF model, suitable for agricultural areas and steep slopes, to Lan river watershed (1141.6 km2) in Shanshi Province, China. The study demonstrated capabilities of RUNOFF in sediment estimation for agricultural watersheds.

SmoRMod: Spatially distributed, a cell based Soil Moisture-based Runoff Model (SMoRMod) was developed and integrated with GRASS GIS for generation of input parameters (Zollweg et al., 1996). The overall model consists of soil moisture balance and runoff generation sub models and is called "hydrology" within the Unix file system. The model uses readily available watershed characteristics data e.g. soils; topography,

and land use and requires minimal calibration. The model was used to simulate stream flows for 77 rainstorms on the WD-38 watershed (68 ha) in east-central Pennsylvania using 10 m cell size. The simulated stream flows and peak flows compared favourably well with the
recorded values.

2.3.2 Continuous time step models

ARM: Agricultural Runoff Management (Donigian and Davis, 1978; Davis and Donigian, 1979) is a continuous lumped model that was developed to predict pollutant losses from agricultural areas. It includes four major components: hydrology, erosion, nutrient and pesticide transport. The model does not incorporate channel routing and is applicable on areas smaller than 5 km2.

HSPF: The Hydrological Simulation Program Fortran (Johanson et al., 1984) is a continuous, lumped, watershed scale model. It was developed to simulate the hydrology, erosion, sediment transport, nutrient, and pesticide movement, from both urban and rural areas. The model allows the division of watershed into land segments of uniform characteristics and uses a version of the Stanford Watershed
Model to simulate surface flow, subsurface flow and interflow. It takes into account snow accumulation and snowmelt. The chemical and erosion components are identical to those described in the ARM.

SWRRB: Simulator for Water Resources in Rural Basins (Williams and Nicks, 1985) was developed by USDA to determine the effect of various types of watershed management procedures on runoff and sediment yield in ungauged rural basins. SWRRB includes major processes of surface runoff, ET, transmission losses, pond and reservoir evaporation, sedimentation, and crop growth. The model has three major components: hydrology, weather and sediment yield. SWRRB was validated on basins up to 500 km^2 (Arnold and Williams, 1987).

MIKE SHE: The MIKE System Hydrologique Europeen (Abbott et al., 1986) developed by the Danish Hydraulic Institute (DIH) is a distributed parameter, physically based, deterministic, continuous catchment modeling system for the simulation of all major hydrological processes occurring in the land phase of the hydrological cycle. It simulates water flow, water levels, water quality and sediment transport. The model discretizes the watershed into an orthogonal grid network. The model consists of several individual modules, allowing user to add specific modules for various types of hydrologic simulation. The catchment and stream channel network system is modeled by the rainfall-runoff module. Runoff computations are based on a lumped-conceptual-type model. The model simulates snowmelt, canopy interception, ET, overland and channel flow, unsaturated and saturated subsurface flow. Overland and channel flow are simulated using a simplification of the St. Venant's equations. Unsaturated flow is simulated using Richards's equation, and the saturated flow is represented by a two-dimensional Boussinesq equation.

WEPP: The USDA-Water Erosion Prediction Project (WEPP) model (Laflen et al., 1991) represent a new erosion prediction technology based on fundamental hydrologic and erosion processes including major components for climate, infiltration, water balance, crop growth and residue decomposition, surface runoff, and erosion. WEPP is a simulation model with a daily time step. WEPP is having three versions: *profile or hill slope, watershed, and grid*. The profile version is the direct replacement of the USLE with the added ability to estimate sediment deposition on a slope. The model accommodates the spatial and temporal variability in topography, surface roughness, soil properties and land use conditions on hill slopes. The watershed version computes sediment transport, deposition and detachment in small channels and sediment deposition in small impoundments. The grid version deals with the sediment transport from element to element. The major limitations of all versions of WEPP include applicability to field size area (maximum 640 acres) and erosion processes are limited to sheet and rill erosion.

ROTO: Routing Output To Outlet (Arnold et al., 1995) model estimates water and sediment yields on large basins. ROTO is a continuous time model operating on a daily time step and allows management decisions to be evaluated. Model accepts input from continuous time step soil water balance model including SWRRB, EPIC and GLEAMS. ROTO uses a command structure to route and add
flows down the watershed through channels and reservoirs.

SWAT: Arnold et al. (1995a, 1996, 1998) and Neitsch et al. (2001) developed **S**oil and **W**ater **A**ssessment **T**ool (SWAT) model, which is a river basin, or watershed scale, continuous-time model developed in the USDA Agricultural Research Service (ARS).

SWAT was developed by merging SWRRB and ROTO into one basin scale model to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT allows basin division into grids or sub watersheds. SWAT incorporates better characteristics of lateral flow, ground water flow, channel transmission losses, and routing of sediment and chemicals through the watershed. The model uses a modified form of the SCS-CN technique (USDASCS, 1972) to calculate surface runoff. SWAT-GRASS interface was developed (Srinivasan and Arnold, 1994) using Geographic Resources Analysis Support System (GRASS) (Shapiro et al., 1992) to extract model input parameters.

ANSWER-2000: Non-point source pollution management model, ANSWERS-2000 was developed to simulate long term average annual runoff and sediment yield from agricultural watersheds (Bouraoui and Dillaha, 1996). The model is based on the event-based ANSWERS model. The physically based Green-Ampt infiltration equation was incorporated to improve estimates of infiltration. It maintains a daily water balance by computing percolation and ET on a daily basis. The model was validated without calibration using data from two field-sized watersheds in Watkinsville, and a larger watershed in Virginia and predicted cumulative sediment yields within 12 percent and 68 percent of observed values. Predicted cumulative runoff volumes ranged from 3 to 35 percent of observed values. The model predicted sediment yield and runoff for individual storms less accurately (within 200 percent of observed values). In a practical application, model was used to evaluate alternative management practice scenarios to minimize sediment loss from a watershed by targeting conservation tillage to potentially critical source areas identified by the model.

2.4 Application of Remote Sensing and GIS in Hydrological Modelling

The scope of hydrological applications has broadened dramatically with the advent of remote sensing and GIS. The remotely sensed data acquired from space borne platforms, owing to its wide synoptivity and multi-spectral acquisition offers unique opportunities for study of soils, land use/ land cover and other parameters required for hydrologic modeling of large areas (Schultz,1988). Remote Sensing and GIS are being widely used for solving environmental problems like degradation of land by water logging, soil erosion, contamination of surface and groundwater resources, deforestation, changes in ecological parameters and many more (Jasrotia et. al.,2002).

Tripathi, M.P. et. al. (2002) used remote sensing and GIS techniques for generation of land use, soil and contour map which were used for runoff modeling for a small watershed in Bihar.

Jasrotia, A.S. et. al. (2002) determined the rainfall-runoff relationship for the Tons watershed using SCS curve number technique by deriving the curve numbers through Remote Sensing and GIS techniques.

Several other studies have been conducted in different parts of the world (Gupta et. al., Sharma, et. al.,2001 Legesse, et. al.,2003) for modeling hydrological components integrated with Remote Sensing and GIS. Kaur and Dutta (2002) highlighted the advantages of GIS based digital delineation of watersheds over conventional methods which is a pre-requisite for proper planning and development of watershed.

2.5 Impact of Land use/ Land cover changes on hydrological response

In order to assess the impact of landuse changes on hydrological response a case study was carried out by Sharma. et. al. (2001) for an area of 89.16 km^2 in Jasdan taluka (district) of Rajkot in Gujarat, India. The Curve number (CN) model was used for estimating runoff from the watershed. Satellite and other collateral data were used to derive information on land use, hydrogeomorphology, soils and slope which were integrated to identify the problems and potential in the watershed and recommend measures for soil and water conservation. The impact of these conservation measures were assessed by computing runoff under alternative land use and management practices and it was observed that the runoff yield decreased by 42.88% of the pre-conservation value of the watershed.

Noorazuan (2003) evaluated the impact of urban land use- land cover change on hydrological regime for the period 1983 -1994 in Langat river basin, Malaysia, covering an area of 2271km^2.The study revealed that the landscape diversity of Langat significantly changed after 1980’s and as a result, the changes also altered the Langat’s streamflow response. Surface runoff increased from 20.35% in 1983-1988 to about

31.4% of the 1988-1994 events. Evidence from the research suggests that urbanization and changes in urban related landuse-landcover could affect the stream flow behaviour.

A study conducted by Ranjit Premlal De Silva et.al.(2002) to evaluate the impact land use/ land cover on hydrological regime revealed no obvious impacts of the changes of tree cover or any other landuse changes on the river flow during rainy season. However obvious deviations were observed in the dry weather flow for both the subcatchments. The increase of the dry weather flow could be related to the increase of the tree cover and the reduction in canopy cover could be attributed to the decrease in dry weather flow at Kotmale. The study provided conclusive evidence that the increase in tree cover would positively contribute to the water yield in the catchments in addition to its protective role of the environment

2.6 Application of SWAT in hydrological modeling

The development of SWAT model, its various components, operation, limitations have been described by Arnold. et. al. (1998) in his paper on "Large Area Hydrologic Modelling and Assessment Part-1: Model Development". In his paper an overview has been made on SWAT model development which was developed mainly to assist water resource managers in assessing water supplies and non point source pollution on watersheds and large river basins. The paper highlights the various components of the SWAT, methodology involved in simulating the various hydrological components, data requirement etc. The paper also gives an overview of the model limitations in simulating the various components of the hydrological cycle.

Singh et. al. made a comparative study for the Iroquois river watershed covering an area of 2137 sq. miles with the objectives to assess the suitability of two watershed scale hydrologic and water quality simulation model namely HSPF and AVSWAT2000. Based on the completeness of meteorological data, calibration and validation of the hydrological components were carried out for both the models. Time series plots as well as statistical measures such as Nash- Sutcliffe efficiency, coefficient of correlation and percent volume errors between observed and simulated streamflow values on both monthly and annual basis were used to verify the simulation abilities of the models. Calibration and validation results concluded that both the models could predict stream flow accurately.

Spruill et. al. (2000) evaluated the SWAT model and parameter sensitivities were determined while modeling daily streamflow in a small central Kentucky watershed comprising an area of 5.5 km^2 over a two year period. Streamflow data from 1996 were used to calibrate the model and streamflow data from 1995 were used for evaluation. The model accurately predicted the trends in daily streamflow during this period. The Nash-Sutcliffe R^2 for monthly total flow were 0.58 for 1995 and 0.89 for 1996 whereas for daily flows it was observed to be 0.04 and 0.19. The monthly total tends to smooth the data which in turn increases the R^2 value. Overall the results indicated that SWAT model can be an effective tool for describing monthly runoff from small watersheds.

Fohrer et. al.(2002) applied three GIS based models from the field of agricultural economy (ProLand), ecology (YELL) and hydrology (SWAT-G) in a mountainous mesoscale watershed of Aar, Germany covering an area of 59.8 km2 with the objective of developing a multidisciplinary approach for integrated river basin management. For the SWAT –G model daily stream flow were predicted. The model was calibrated and validated followed by model efficiency using Nash and Sutcliffe test. In general the predicted streamflow showed a satisfying correlation for the actual landuse with the observed data.

Francos et. al. (2001) applied the SWAT model to the Kerava watershed (South of Finland), covering an area of 400 km^2.Various spatial data were used for the study. The temporal series comprised temperature and precipitation records for a number of meteorological stations, water flows and nitrogen and phosphorus loads at the river outlets. The model was adapted to the specific conditions of the catchment by adding a weather generator and a snowmelt submodel calibrated for Finland. Calibration was made against water flows, nitrate and total phosphorus concentrations at the basin outlet. Simulations were carried out and simulated results were compared with daily measured series and monthly averages. In order to measure the accuracy obtained, Nash and Suttcliffe efficiency coefficient was employed which indicated a good agreement between measured and predicted values.

Eckhartd and Arnold (2001) outlined the strategy of imposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT. Subsequently an automatic calibration of the version SWAT-G of the SWAT model with a stochastic global optimization algorithm and Shuffled Complex Evolution algorithm is presented for a mesoscale catchment.

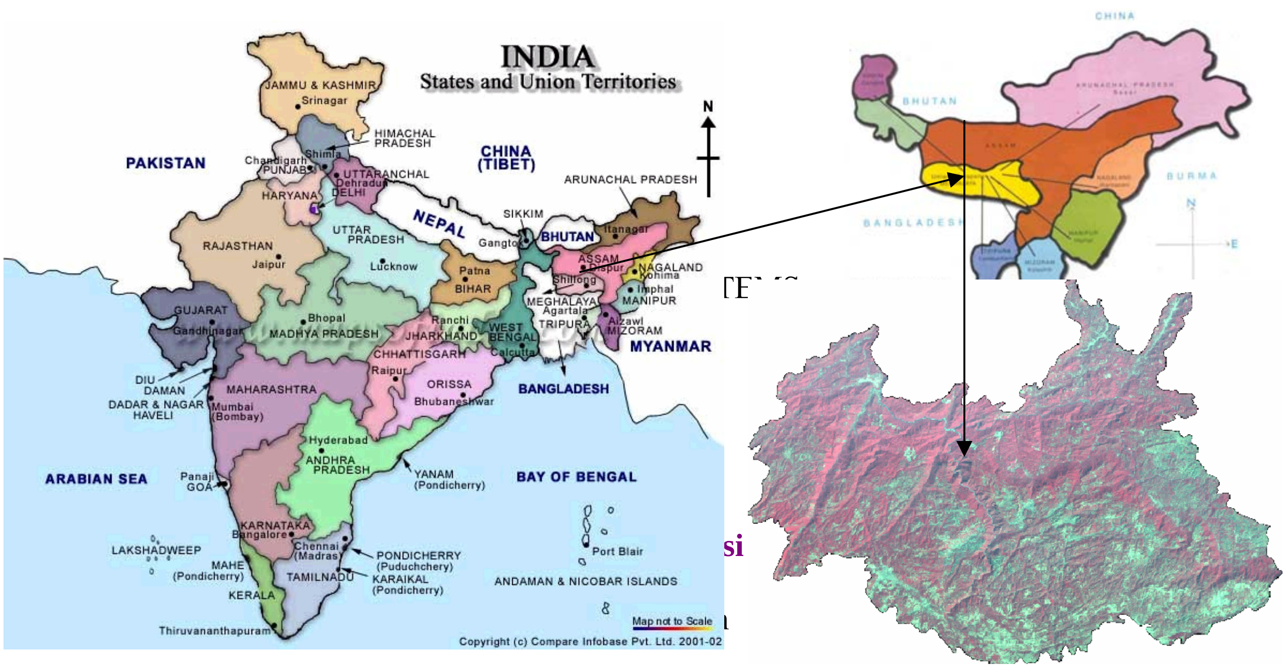
Tripathi et. al.(2003) applied the SWAT model for Nagwan watershed (92.46km^2) with the objective of identifying and prioritizing of critical sub-watersheds to develop an effective management plan. Daily rainfall, runoff and sediment yield data of 7 years (1992-1998) were used for the study. Apart from hydrometeorological data, topographical map, soil map, land resources and satellite imageries for the study area were also used. The model was verified for the monsoon season on daily basis for the year 1997 and monthly basis for the years 1992-1998 for both surface runoff and sediment yield. Critical sub-watersheds were identified on the basis of average annual sediment yield and nutrient losses during the period of 3 years (1996-1998) and priorities were fixed on the basis of ranks assigned to each critical sub-watershed according to ranges of standard soil erosion classes. The study confirmed that the model could accurately simulate runoff, sediment yield and nutrient losses from small agricultural watersheds and can be successfully used for identifying and prioritizing critical sub-watersheds for management purpose.

The review indicated that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged basin. However, it is evident from the review that not much work has been carried out in hilly areas to test the model applicability. Therefore to test the capability of model in determining the effect of spatial variability of the watershed on runoff and sediment yield AVSWAT2000 with arcview interface was selected for the present study.

3.1 Location

The Kulsi basin,a part of the Brahmaputra sub-basin is situated on the south bank of the mighty river Brahmaputra. This sub-basin spreads in the Kamrup District of Assam as well as west Khasi hills and Ribhoi district of Meghalaya. It is located between latitude $25^0$30’39”N – $25^0$58’03”N and longitude $91^0$11’52” E-$91^0$48‘ 09”E with an altitude between 100 m to 1900 m above msl and is covered by the Survey of India toposheets No.78 O/1, 78 O/5, 78 O/9, 78O/2, 78 O/10, 78 O/6 and 78 O/14.

The river Kulsi drains out a total area of 1593.27 sq. km. within the Kamrup District of Assam as well as west Khasi hills and Ri bhoi district of Meghalaya.



A) Kulsi: The Kulsi river is a north flowing river in the district of Kamrup, originating from the northern slopes of the west khasi hill ranges, wherein the elevation is from 1800 m-1900 m and flows down north. It is composed of three rivers, namely Khri, Krishniya and Umsiri, all of which originate from West Khasi Hill range and flow North and finally join the Brahmaputra. The river in its upper reach is known as Khri river and after being joined by two other tributaries namely Um Krishniya and Umsiri, within the khasi hills, it flows north-west and enters Assam at Ukium, and after that it flows north upto Kulsi village. All the three rivers are joined by innumerable number of small hilly streams and rivulets till they join together and flow down as Kulsi.

The river Um Krishniya is the centrally flowing river with Um Siri joining it on the left bank and Um Khri joining it on the right bank. Um Krishniya and Um Siri originate almost from the same place which is having the altitude around 1850 m and Um Khri originates from an area further east which has got elevation around 1600m.

The river Khri and Krishniya join together after flowing for a distance of about 79 Km. and 32 km. respectively. After joining, the combined river flows with the name of Khri for a distance of about 13 km, when it is joined by the Um Siri which flows for a distance of about 29 km. before meeting at Ukium. After this the river flows almost straight north for a distance of about 20 km. with the name Kulsi near the village Kulsi where it bifurcates into two branches. One branch flows by the western side of Kulsi reserve forest and the other by the eastern side of it, both are known as Kulsi, one as eastern Kulsi and the other as central Kulsi. The central Kulsi again bifurcates into two rivers near village Hatigarh and the left arm is known as Kharkhari and the right arm flows as original Kulsi. After this bifurcation the river Kulsi enters into the alluvial plain (flood plain of the Kulsi plain of the Kulsi and the Brahmaputra) and is comparatively shallow having meandering plan form. The eastern most channel (Kulsi) is joined by two small channels from its right before crossing the N.H. 37 near Kukurmara. In this reach the river is joined by another two small rivers Batha and Bahwa. After crossing national highway it takes a complete western turn and flows parallel to river Brahmaputra and then meets other branch of the Kulsi, i.e., the Kharkhari near the village Chamariya and flows west parallel to Brahmaputra with the name Jaljali till it joins the Brahmaputra. After the bifurcation of the river Kulsi, it takes a westerly swing and flows parallel to Brahmaputra.

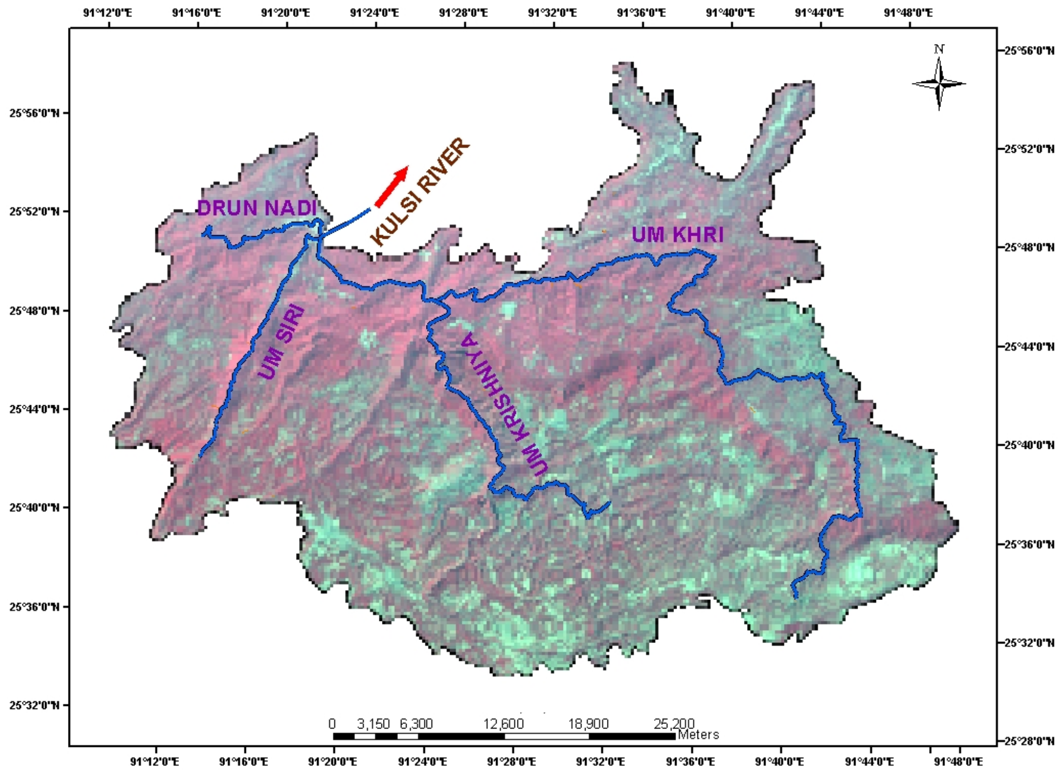


Fig.3.2: Map showing main river system of Kulsi Basin

3.3 Topographical features:

The area that the Kulsi river drains can broadly be divided into three reaches

i) The Upper Khasi hill reach

ii) The middle reserve forest reach

iii) The alluvial or flood plain reach

The Upper Khasi hill ranges of the catchment extend from the origin of the river Kulsi to Ukium (Assam Meghalaya border) and this reach lies entirely in the west khasi hill ranges, with the general altitude varying from 150 m to 1900 m. the whole area consists of series of hill range with intermittent plain areas. The whole of the reach is covered with evergreen forests.

The middle reserve forests reach consists of two reserve forests namely Borduar and Pantan reserve forest running parallely along the river from Ukium to Kulsi village with the Barduar reserve forest on eastern bank and Pantan reserve forest on the western bank. The eastern part of the Barduar reserve forest consists of comparatively plain areas with the famous Chandubi beel located therein. No tributary joins the river in this reach.

The alluvial or the plain reach consists of the plain areas along the southern bank of river Brahmaputra. Almost half of this reach is affected by the flood of the River Kulsi and the Brahmaputra

3.4 Climate

3.4.1 Precipitation

Within the Kulsi basin there are three number of raingauges out of which two are located at Ukiam, Mowdem which are at the lower reach of the basin and the third raingauge is located at Rambrai which is at the upper reach of the basin.Out of these three raingauge stations long term precipitation data is available only from raingauge installed at Ukiam. However long term precipitation data are available for other three nearest meteorological stations located at Guwahati, Shillong & Umiam which can provide an idea on the variation in the precipitation trend within the basin. Fig 3.3 shows the average monthly variation in precipitation for these four nearest raingauge station.

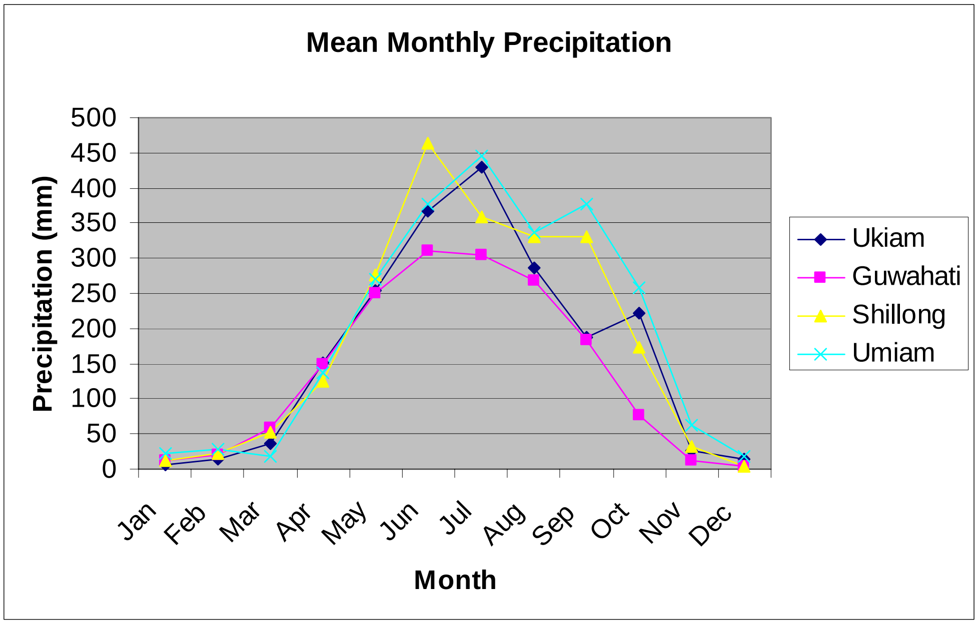


Fig.3.3: Mean Monthly Variation in Precipitation

3.4.2 Temperature

The climate of Kulsi basin, excluding the upper most reach is similar to that of the other districts in Central Assam. The winter is cold and foggy, while the summer is hot and humid. There is no meteorological centre within the catchment for observation of temperature. However the nearest observatories for the basin are at Guwahati, Umiam and Shillong. Based on long term data from these stations it has been observed that the average maximum temperature in this basin varies between 15^{0}C to 33^{0}C (fig 3.4)and average minimum temperature varies from 3^{0}C to 12^{0}C.(fig 3.5).

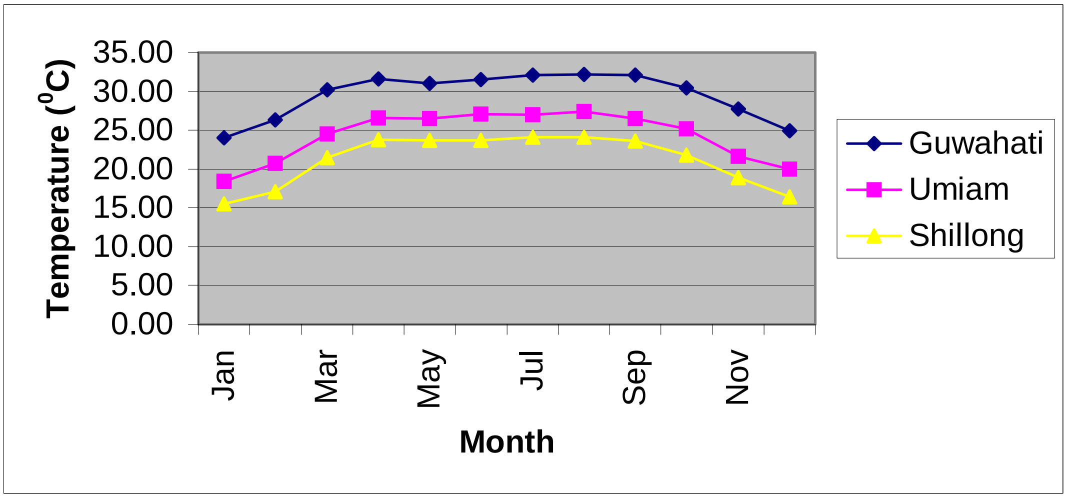


Fig.3.4: Mean Monthly Maximum Temperature

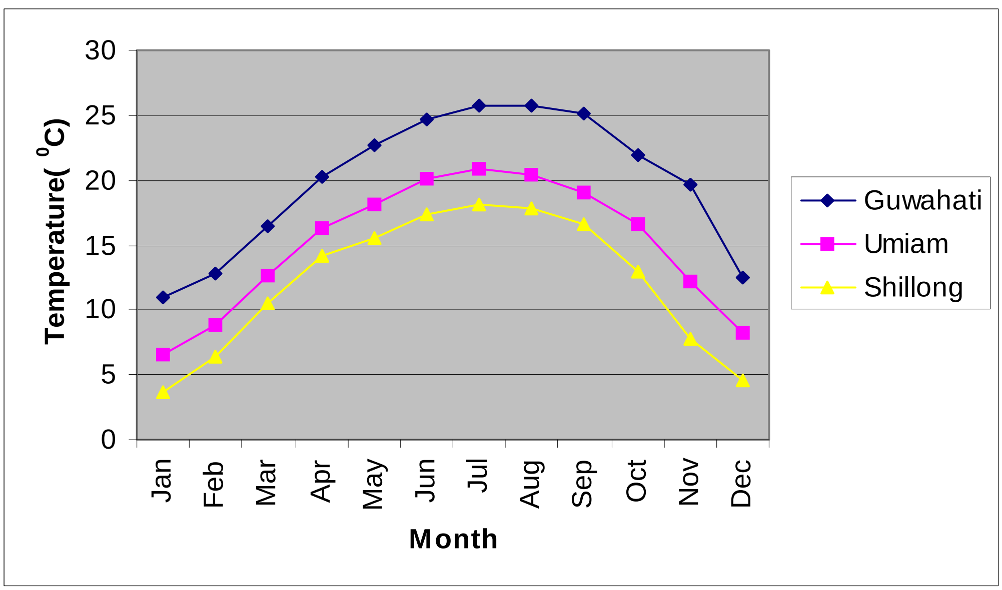


Fig.3.5: Mean Monthly Minimum temperature

3.4.3 Humidity

The climate of this sub-basin is generally very humid. There is no meteorological Centre in the sub-basin for observation of humidity. Humidity data is available only at Guwahati and Umiam station nearest to the sub-basin.

3.4.4 Wind Speed

There is no instrument within the Kulsi basin to measure the wind speed. However the nearest stations where wind speed is recorded are Guwahati, Umiam and Shillong. Based on the analysis of long term weather data the mean monthly normal variation in wind speed for these three stations are shown in figure 3.6.

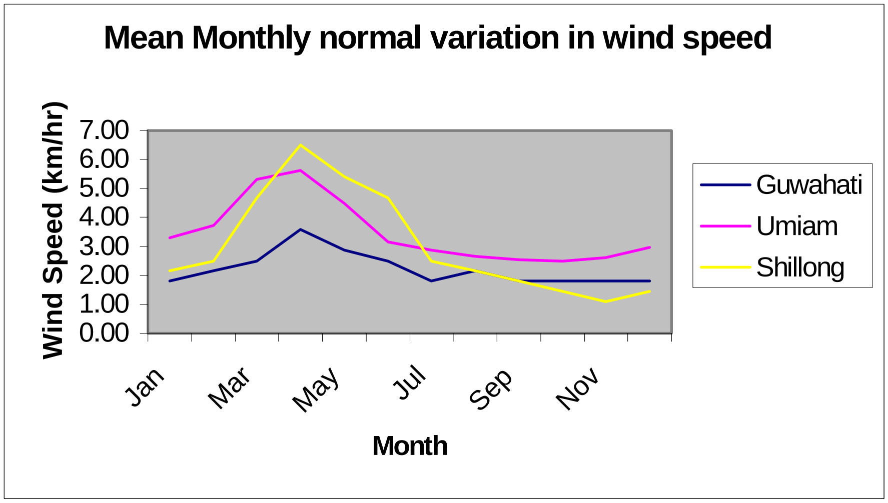


Fig.3.6: Mean Monthly Normal Variation in wind speed

3.4.5 Solar Radiation

Information about sunshine hours within the catchment is not available due to non availability of any measuring instruments. However , based on the analysis of long term data for the three nearest meteorological data at Guwahati, Umiam and Shillong it has been observed that the solar radiation is minimum in the month of January and maximum in the month of April for all the three places. The mean monthly normal deviation in the solar radiation is shown in figure3.7

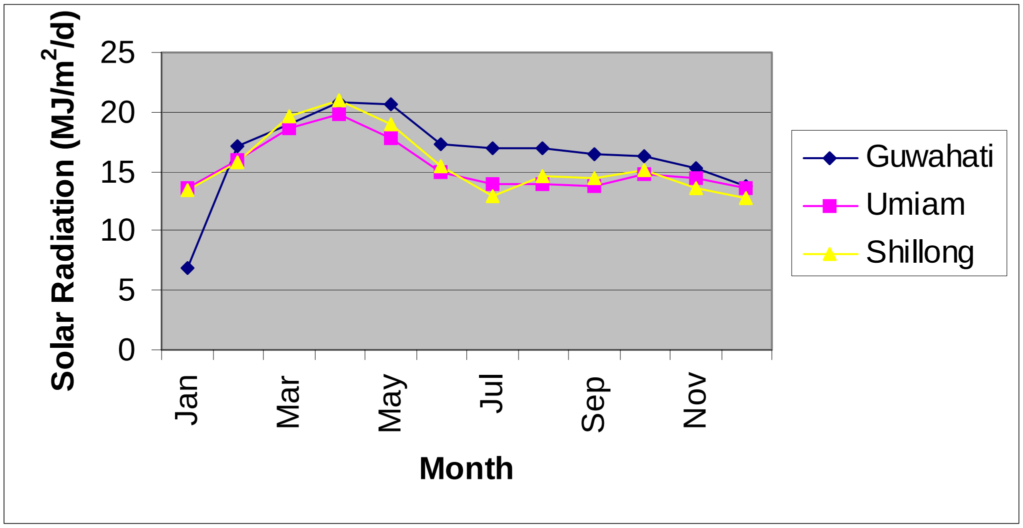


Fig.3.7: Mean Monthly Normal Variation in Solar Radiation

3.5 Socio Economic Status

The main occupation of the people of the sub-basin is agriculture. In the lower reach of the Kulsi basin paddy is the main agricultural crop. The most common variety of paddy is Sali, Ahu etc. The other products are pulses, maize, wheat, sugarcane, bananas, potatoes, onion, seasonal vegetables. In the hilly part of West Khasi hills and Ri bhoi district, paddy is the main product. The local plain people practice permanent cultivation in low lying and flat terrains using modern techniques of cultivation. But on the other hand the tribal people still depend on “Jhum Cultivation” or shifting cultivation along the hill slopes without adopting any kind of soil conversation measures. The supplementary employment is very limited due to the limitation in industrial growth.

3.5.1 Existing Farming System: Bun Method

In eastern Himalayan region, climatic condition is conducive for high biomass production that provides opportunities for utilizing these as organic manure for production of crops. Bun system of crop cultivation is very common in north eastern region particularly in khasi and jayantia hills of Meghalaya. In this system green vegetation is cut and put in strips along the slope at an interval of 1 to 1.5 m .The width of strips is kept 0.5 to 0.75 m. The soils between two strips are cut and turn down on the cutting materials of vegetation. In the second phase the soils between two strips are cut and kept on the strips of vegetation covered with soils in the first phase, and made a raised bed of 0.5 to 0.75m height, 0.75 to 1.25m width and 10 to 15 m length. The preparation of Bun is completed during the month of mid October. The crops such as Ginger, Turmeric, Paddy, Maize, Millets of local varieties as a sole crop or in combination with vegetable crops are sown in the month of March/ April. The seed is sown randomly by making small holes on the raised bed putting 50-100 gms, cowdung to each hole. The seed is kept on the cowdung (without mixing with the soil) and covered with the soil. The seed is not treated with the chemical and chemical fertilizers are also not used. After germination, generally two hand weeding is done to keep down the weeds. After harvesting, the other site is selected for bun cultivation. After 4-5 years the cycle is repeated.

Since bun is made along the slope and a big raised bed is made during the bun process. It permits high soil erosion with washing away of top soil (enrich in organic matter) and does not allow growing crops in the next 3-4 years.

The biomes is fully utilized for the production of crops, it does not depend on chemical fertilizers for the production of crops. The soil become porous during the process of bun making, allowing proper root development and good crop particularly rhizomes and tuber crops which require loose soil for proper growth. The incidence of insect and disease attack is also minimum.

3.5.2 Land tenure system

There is no land tenure system in Assam. So, most of the agriculture land in Assam are patta land and the remaining land are government land and reserved forest. However, land tenure system is prevailing in Meghalaya where District Councils are the sole authority regarding the administration of the land. Land ownership and land tenure system in the region is one of the important factors inhibiting agricultural development. There are three broad categories of land ownership within the Kulsi catchment,

(i) Land owned by villagers collectively
(ii) Land owned by the village headman
(iii) Land owned by individual farm families

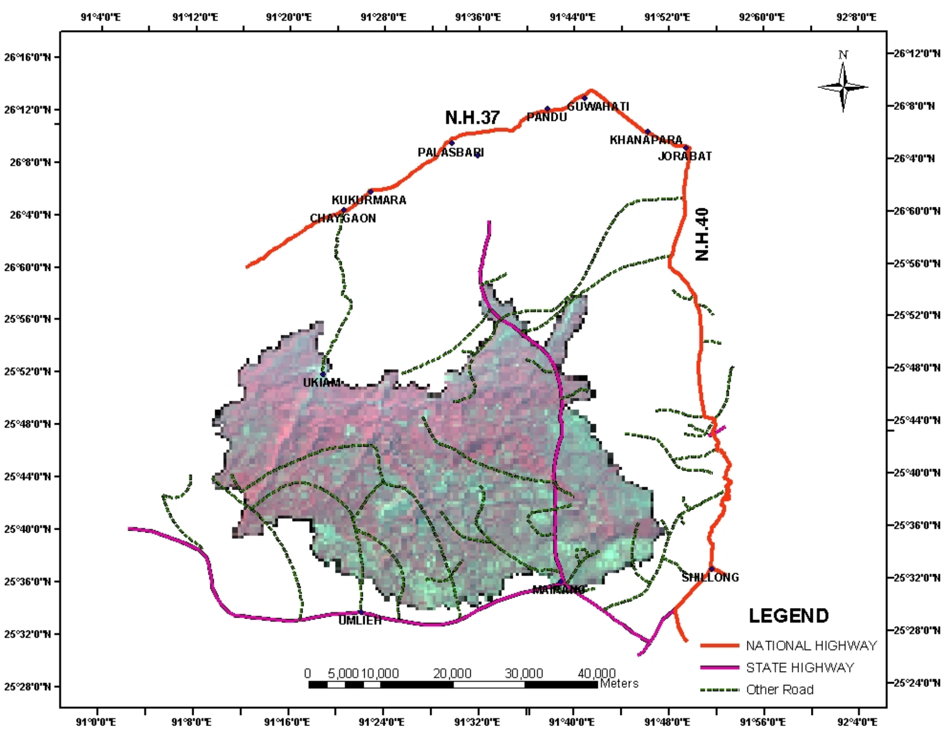
3.6 Roads and Infrastructure

There is no proper road network to reach the Kulsi Basin directly. The outlet on the lower reach of the basin is located at around 30km from the national highway N.H.37, connected by a kutcha road from a place called Chaygaon which is around 70km from Guwahati. In order to reach the middle and upper reach of the basin one has to go via

N.H.40 from Guwahati to Shillong. Figure 3.8 shows the road network map for the Kulsi basin.

3.7 Human Population

The total human population of the Kulsi basin is not available However, the population trend in the two state of Assam and Meghalaya for the 90 years i.e. 1990 to 1991 is shown in **Table 3.1**. From table it is seen that there has been sharp increase in population during the decade from 1961 while the increase in population in other decades are more or less uniform.



Source: Meghalaya PWD,2004

SOI toposheets

(1:250,000)

Fig 3.8: Road Network Map of Kulsi Basin

Table 3.1: Population trend in Assam and Meghalaya

State	Census years	Total Population (Nos.)	Density of population (nos./sq.m)		Total Population (Nos.)	Density of population (nos./sq.m)
Assam	1901	3290000	42	Meghalaya	340524	15
	1911	3849000	49		394005	18
	1921	4637000	59		422403	19
	1931	556000	71		480837	21
	1941	6695000	83		555820	25
	1951	8029000	102		605674	27
	1961	10837000	138		769380	34
	1971	14625000	186		011699	45
	1981	18041000	230		335819	60
	1991	22414000	286		774778	79
	2001	26638000	340		306069	103

Source: 1) Statistical Hand Book of Assam 2002.
2) Statistical Hand Book of Meghalaya, 2002

3.8 Geology

The rock types in the Kulsi basin varies from Precambrian stage to recent. The surface Geological formation is newer alluvium sand, gravel, clay and silt.

In Assam part of the basin falls in Kamrup District where two distinct groups of rock units i.e consolidated and unconsolidated formation of rocks are found. The unconsolidated formations represented by the alluvial deposits of recent age such as sand, gravel, pebble, silt and clay.

In the Meghalaya part of the basin, there are two, three types of formations like the Archaen complex, lower, cordovan rocks, and cretaceous tertiary sediments. The oldest formation of upper tertiary sediment occurs in Garo Hills.

3.9 Forest

Forest plays an important role in the climate, soil conditions, geological balance and flood of this sub-basin. As per the national forest policy (1988), 33% of the country's geographical area should be under forest cover. As per the State of Forest Report, 2001 Kamrup district of Assam has a forest cover area of 32.89% of the total geographical area of the district In Meghalaya total forest covered area is 15,584 sq. km. (69.48%) out of which Ri bhoi district and West Khasi hills district has a forest cover of 74.20% and 56.55% of the total geographical area of the district

The social forest department has planted economical species of vegetations in the sub-basin specially along the road side and river banks. The state wise forest cover assessment for the year 1991 & 2001 of Assam and Meghalaya are given in **Table3.2** and district wise forest-covered data of Kamrup , Ribhoi and West Khasi hills for the year 2001 are shown in **Table No. 3.3**

Table 3.2: State Wise Forest Cover Assessment for the year 1991 & 2002

(Area in km^2)

			Forest Cover				
Year	**State**	**Geographic Area**	**Dense Forest**	**Open Forest**	**Total**	**Percent**	**Scrub**
1991	Assam	78,438	-	-	24,751	31.55	-
	Meghalaya	22,429	-	-	15,875	70.77	-
2001	Assam	78,438	15,830	11,884	27,714	35.33	224
	Meghalaya	22,429	5,681	9,903	15,584	69.48	259

(Source: State of Forest Report, 2001)

Table3.3: District Wise Forest Cover Data of Kamrup, Ribhoi and West Khasi Hills

(Area in km^2)

		Forest Cover				
District	**Geographic Area**	**Dense Forest**	**Open Forest**	**Total**	**Percent**	**Scrub**
Kamrup	4,345	899	530	1,429	32.89	52
Ri bhoi	2,376	656	1,107	1,763	74.20	68
West Khasi	5,247	1,098	1,869	2,967	56.55	34

hills						

(Source: State of Forest Report,2001)

3.10 Hydrology

3.10.1 Meteorological Aspects

The Indian Meteorological Department describes the meteorological situation of the Brahmaputra Valley in their various reports published from time to time. From these reports the meteorological situation which govern the kulsi basin is summarized below.

There are four numbers of different seasons occurring in Kulsi- basin. These are (1) Winter Season(2) Pre-monsoon season (3) Monsoon season and (4) Post monsoon season.

1. Winter Season: The winter season starts from December and ends in February. This is the coldest season. During this season the catchment usually receives rains under the influence of east bound weather system. However, this season is devoid of flood in the valley due to meager rainfall.
2. Pre-monsoon season: This season begins in March and continues up to May. In this season most of the rainfall over the region is due to thunderstorm activities. Important synoptic situations over the basin responsible for precipitation are lopar/trough at the surface, wind discontinuity in the lower levels of the atmosphere, upper air trough and CYCIR in the different levels of the atmosphere. Further the high pressure cell over North Bay controls the moisture feed in the region. Also the rainfall activities enhance due to the approaching cyclones and depressions from North Bay and passage of western disturbances to the north across the basin. This seasons rainfall increases the water levels of the rivers. Major floods are not uncommon in this season specially towards the later half of the season.
3. Monsoon: The monsoon sets in the last week of May or in early June. This is the season which is more prone for devastating floods over the basin as major rainfall over the region takes place during this season. Important synoptic features responsible for heavy precipitation during this period are monsoon trough lying close to foot hills of Himalayas, Lopar or east west trough at the surface, CYCIR and upper air trough at various levels of atmosphere and approach of monsoon depressions and higher intense system from North Bay. Occasionally the rainfall activity increases due to the

passage of western disturbances in the north seen as westerly trough in the middle and upper levels of the troposphere.

4. Post Monsoon: This season starts in October and ends in December. During this season the catchment receives generally light to moderate rains, with rainfall decreasing as the monsoon marches. Floods are very rare in this season and occur mainly due to the approach of a cyclone from Bay of Bengal ands weakening over the region.

The seasonal distribution of rainfall for Ukium raingage is given in **Appendix I.**

3.10.2 Meteorological network

Rainfall is the most variable hydrological parameter. The design of a proper network of meteorological stations maintained for a sufficiently long time is necessary for various objectives like water resources assessment, flood forecasting, design storm estimations and water balance study. The number of raingauge in the Kulsi basin is three out of which two numbers are in plain areas at Ukiam and Mowdem. The third raingauge is installed at the boundary of the Upper reach of the catchment at a place called Rambrai. These many raingauges are insufficient to determine the spatial variability of rainfall for the entire catchment. The monthly rainfall data for these three stations are given in Appendix II.

3.10.3 Hydrological Aspects

3.10.3.1 Stream flow and river gauges

River gauges in the Kulsi river system were established from 1956 and first site as per record is Ukiam. Initially from 1956 to 1962, the records were maintained by C.W.C and since 1964 the records were maintained by B.F.C.C. This site was was subsequently taken over by Brahmaputra Board from 1983.

The gauge discharge data available at Ukium site is for 21 years. The discharge data at the outlet of the catchment is measured by area velocity method.

3.10.3.2 Sediment Load

The Kulsi river basin covers the northern slope of the west khasi hill ranges and the alluvial plains in the south bank of Brahmaputra in the Kamrup district. The Khasi hills range is covered with evergreen forest and gets copious rainfalls specially during the five monsoon months. Due to deforestation and faulty cultivation practices there has been a serious soil erosion problem within the catchment. In order to study the soil erosion status from the catchment a silt monitoring station has been set up at Ukium G.D. site.

CHAPTER IV
MODEL DESCRIPTION

This chapter deals with the theoretical consideration related to the SWAT2000 model. A brief description of various components and the mathematical relationships used to simulate the different processes and their interactions in the model as described by Neitsch et al. (2002) are considered.

4.1 Overview of SWAT

SWAT is a spatially distributed, continuous time scale watershed scale model developed by Dr. Jeff Arnold for the USDA-ARS. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, landuse and management conditions over long periods of time. Weather, soil properties, topography, vegetation and land management practices are the most important inputs for SWAT to model hydrologic and water quality in a watershed (Neitsch,2002)

SWAT allows a basin to be subdivided into sub-basins to evaluate hydrology, weather, sediment yield, nutrients and pesticides, soil temperature, crop growth, tillage and agricultural management practices.

The major components of the model are grouped under sub-basin and routing and are briefly discussed below

4.2 Sub-basin components

4.2.1 Hydrology

The hydrologic cycle as simulate by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \tag{4.1}$$

where, SW_t is the final soil water content (mmH_2O), SW_o is the initial soil water content (mmH_2O), t is time in days, R_{day} is amount of precipitation on day i(mmH_2O),Q_{surf} is the amount of surface runoff on day i(mmH_2O),E_a is the amount of evapotranspiration on day i(mmH_2O),w_{seep} is the amount of percolation and bypass exiting the soil profile bottom on day i (mmH_2O),Q_{gw} is the amount of return flow on day i (mmH_2O).

Since the model maintains a continuous water balance, the subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Thus runoff is predicted separately for each sub area and routed to obtain the total runoff for the basin. This increases the accuracy and gives a much better physical description of the water balance.

4.2.1.1Surface Runoff

Surface runoff component simulates the surface runoff volume and the peak runoff rates provided daily rainfall data are fed.

Surface runoff is computed using a modification of the SCS curve number (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration method (green and Ampt,1911). In the curve number method, the curve number varies non linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The Green & Ampt method requires sub-daily precipitation data and calculates infiltration as a function of the wetting front matric potential and effective hydraulic conductivity.

Surface runoff volume predicted in SWAT using SCS curve number method is given below

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} , \qquad R>0.2S \qquad (4.2)$$

where,Q_{surf} is the accumulated runoff or rainfall excess (mm),R_{day} is the rainfall depth for the day (mm),and S is retention parameter (mm).

Runoff will occur when $R_{day} > 0.2S$.The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as

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

where CN is the curve number for the day

4.2.1.2 Peak Runoff Rate

The model calculates the peak runoff rate with a modified rational method. The rational method is based on the assumption that if a rainfall of intensity *i* begins at time $t = 0$ and continues indefinitely, the rate of runoff will increase until the time of concentration, $t = t_{conc}$, when the entire sub-basin area is contributing to flow at the outlet. The rational formula is:

$$q_{peak} = \frac{C.i.Area}{3.6} \tag{4.4}$$

where, q_{peak} is the peak runoff rate (m^3s^{-1}), C is the runoff coefficient, i is the rainfall intensity (mm/hr), *Area* is the sub-basin area (km^2) and 3.6 is a unit conversion factor.

4.2.1.2.1Time of Concentration

The time of concentration is the amount of time from the beginning of a rainfall event until the entire sub-basin area is contributing to flow at the outlet. The time of concentration is calculated by summing the overland flow time and the channel flow time:

$$t_{conc} = t_{ov} + t_{ch} \tag{4.5}$$

where,, t_{conc} is the time of concentration for a sub-basin (hr), t_{ov} is the time of concentration for overland flow (hr), and t_{ch} is the time of concentration for channel flow (hr).

4.2.1.2.2 Overland flow time of concentration

The overland flow time of concentration, t_{ov}, is computed using the equation

$$t_{ov} = \frac{L_{slp}^{0.6}.n^{0.6}}{18.slp^{0.3}} \tag{4.6}$$

where, L_{slp} is the sub-basin slope length (m), n is the Mannings's roughness coefficient and slp is the average slope in the subbasin (mm^{-1})

4.2.1.2.3 Channel flow time of concentration

The channel flow time of concentration , t_{ch} is computed using the equation

$$t_{ch} = \frac{0.62.L.n^{0.75}}{Area^{0.125}.slp_{ch}^{0.375}} \tag{4.7}$$

where, t_{ch} is the time of concentration for channel flow (hr), L is the channel length from the most distant point to the subbasin outlet (km), n is the Manning's roughness coefficient for the channel, *Area* is the subbasin area (km^2) and slp_{ch} is the channel slope ($m\ m^{-1}$)

4.2.1.2.4 Runoff Coefficient

The runoff coefficient is the ratio of the inflow rate, i.*Area* , to the peak discharge rate, q_{peak}. The coefficient will vary from storm to storm and is calculated with the equation:

$$C = \frac{Q_{surf}}{R_{day}} \tag{4.8}$$

where Q_{surf} is the surface runoff (mm H_2O) and R_{day} is the rainfall for the day (mm H_2O).

4.2.1.2.5Rainfall Intensity

The rainfall intensity is the average rainfall rate during the time of concentration. Based on this definition, it is calculated with the equation:

$$i = \frac{R_{tc}}{t_{conc}} \tag{4.9}$$

where i is the rainfall intensity (mm/hr), R_{tc} is the amount of rain falling during the time of concentration (mm H2O), and t_{conc} is the time of concentration for the subbasin (hr).

4.2.1.2.6Modified Rational Formula

The modified rational formula used to estimate peak flow rate is presented as follows

$$q_{peak} = \frac{\alpha_{tc}.Q_{surf}.Area}{3.6.t_{conc}} \tag{4.10}$$

where, q_{peak} is the peak runoff rate (m^3s^{-1}) and α_{tc} is the fraction of daily rainfall that occurs during the time of concentration.

4.2.1.3 Percolation

Percolation is calculated for each soil layer in the profile. Water is allowed to percolate if the water content exceeds the field capacity for that layer. The volume of water available for percolation in the soil layer is calculated as:

$$SW_{ly,excess} = SW_{ly} - FC_{ly} \quad \text{if } SW_{ly} > FC_{ly} \tag{4.11}$$

$$SW_{ly,excess} = 0 \qquad \text{if } SW_{ly} \le FC_{ly} \tag{4.12}$$

where, $SW_{l,excess}$ and SW_{ly} are the drainable volume of water and water content in the soil layer, respectively on a given day (mm) and FC_{ly} is the water content of the soil layer at field capacity (mm).

The amount of water that moves from one layer to the underlying layer is calculated using storage routing methodology. The equation used to calculate the amount of water that percolates to the next layer is

$$w_{perc,ly} = SW_{ly,excess} \cdot \left(1 - \exp\left[\frac{-\Delta t}{TT_{perc}}\right]\right) \tag{4.13}$$

where, $w_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm), Δt is the length of the time step (hrs), and TT_{perc} is the travel time for percolation (hrs).

The travel time for percolation (TT_{perc}) is unique for each layer. It is calculated as:

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}} \tag{4.14}$$

where TT_{perc} is the travel time for percolation (hrs), SAT_{ly} is the amount of water in the soil layer when completely saturated (mm H_2O), FC_{ly} is the water content of the soil layer at field capacity (mm H_2O), and K_{sat} is the saturated hydraulic conductivity

4.2.1.4 Lateral Subsurface Flow

Lateral subsurface flow, or interflow in the soil profile is calculated using a kinematic storage model developed by Sloan and Moore (1984). The kinematic wave approximation of saturated subsurface or lateral flow assumes that the lines of flow in the saturated zone are parallel to the impermeable boundary and the hydraulic gradient equals the slope of the bed. The drainable volume of water stored in the saturated zone of the hill slope segment per unit area, $SW_{ly,excess}$, is

$$SW_{ly,excess} = (1000.H_o.\phi_d.Lhill)/2$$

(4.15)

where, $SW_{ly,excess}$ is the drainable volume of water stored in the saturated zone of the hill slope per unit area (mm), H_o is the saturated thickness normal to the hill slope at the outlet expressed as a fraction of the total thickness (mm/mm), ϕ_d is the drainable porosity of the soil (mm/mm), L_{hill} is the hill slope length (m), and 1000 is a factor needed to convert meters to millimeters.

4.2.1.5 Ground water flow

SWAT partitions groundwater into two acquifer systems: a shallow, unconfined acquifer which contributes return flow to streams within the watershed and a deep, confined acquifer which contributes return flow to stream outside the watershed.

The water balance for the shallow acquifer is

$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg} - Q_{gw} - w_{revap} - w_{deep} - w_{pump,sh} \qquad (4.16)$$

where, $aq_{sh,i}$ is the amount of water stored in the shallow aquifer on day i (mm), $aq_{sh,i-1}$ is the amount of water stored in the shallow aquifer on day i-1 (mm), w_{rchrg} is the amount of recharge entering the aquifer (mm), Q_{gw} is the groundwater flow, or base flow, into the main channel (mm), w_{revap} is the amount of water moving into the soil zone in response to water deficiencies (mm), w_{deep} is the amount of water percolating from the shallow aquifer into the deep aquifer (mm), and $w_{pump,sh}$ is the amount of water removed from the shallow aquifer by pumping (mm).

The water balance for the deep acquifer is

$$aq_{dpi} = aq_{dp,i-1} + w_{deep} - w_{pump,sh}$$

(4.17)

where, $aq_{dp,i}$ is the amount of water stored in the deep aquifer on day i (mm), $aq_{dp,i-1}$ is the amount of water stored in the deep aquifer on day i-1 (mm), and $w_{pump,dp}$ is the amount of water removed from the deep aquifer by pumping on day i (mm).

4.2.1.6 Evapotranspiration

Evapotranspiration is a collective term that includes all processes by which water at the earth's surface is converted to water vapor. It includes evaporation from the plant canopy, transpiration, sublimation and evaporation from the soil. Evapotranspiration is the primary mechanism by which water is removed from a watershed.

Numerous methods have been developed to estimate ET. Three of these methods have been incorporated into SWAT2000: the Penman-Monteith method (Monteith, 1965; Allen, 1986; Allen et al., 1989), the Priestley-Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves et al., 1985).

The Penman-Monteith equation combines components that account for energy needed to sustain evaporation, the strength of the mechanism required to remove the water vapor and aerodynamic and surface resistance terms. The Penman-Monteith equation is

$$\lambda E = \frac{\Delta.(H_{net} - G) + \rho_{air}.c_p.[e_z{}^o - e_z]/r_a}{\Delta + \gamma.(1 + r_c / r_a)} \tag{4.18}$$

where, λE is the latent heat flux density ($MJm^{-2}d^{-1}$), E is the depth rate evaporation (mmd^{-1}), D is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa^oC^{-1}), H_{net} is the net radiation ($MJm^{-2}\ d^{-1}$), G is the heat flux density to the ground ($MJ\ m^{-2}d^{-1}$), ρ_{air} is the air density (kgm^{-3}), c_p is the specific heat at constant pressure (MJ kg-1$^oC^{-1}$), e_z^o *is* the saturation vapor pressure of air at height z (kPa), e_z is the water vapor pressure of air at height z (kPa), γ is the psychrometric constant (kPa^oC^{-1}), r_c is the plant canopy resistance (sm^{-1}), and r_a is the diffusion resistance of the air layer (aerodynamic resistance) (sm^{-1}).

Priestley and Taylor (1972) developed a simplified version of the combination equation for use when surface areas are wet. The aerodynamic component was removed and the energy component was multiplied by a coefficient, α_{pet} = 1.28, when the general surroundings are wet or under humid conditions:

$$\lambda E_o = \alpha_{pet} \cdot \frac{\Delta}{\Delta + \gamma} .(H_{net} - G) \quad (4.19)$$

where, λ is the latent heat of vaporization (MJ kg^{-1}), *Eo* is the potential evapotranspiration (mm d^{-1}),α_{pet} is a coefficient, D is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa^{o}C^{-1}), γ is the psychometric constant (kPa^{o}C^{-1}), H_{net} is the net radiation (MJ m^{-2} d^{-1}), and *G* is the heat flux density to the ground (MJ m^{-2} d^{-1}).

The Priestley-Taylor equation provides potential evapotranspiration estimates for low advective conditions. In semiarid or arid areas where the advection component of the energy balance is significant, the Priestley-Taylor equation will underestimate potential evapotranspiration.

The Hargreaves method estimates potential evapotranspiration as a function of extraterrestrial radiation and air temperature. The modified equation used in theSWAT2000 is:

$$\lambda E_o = 0.0023.H_o.(T_{mx} - T_{mn})0.5.(T_{av} + 17.8) \quad (4.20)$$

where, λ is the latent heat of vaporization (MJ kg^{-1}), E_o is the potential evapotranspiration (mm d^{-1}), H_0 is the extraterrestrial radiation (MJ $m^{-2}d^{-1}$), T_{mx} is the maximum air temperature for a given day (^{o}C), T_{mn} is the minimum air temperature for a given day (^{o}C), and T_{av} is the mean air temperature for a given day (^{o}C).

4.2.1.7 Transmission loss

Transmission losses are losses of surface flow via leaching through the streambed.This type of loss occurs in ephemeral or intermittent streams where groundwater contribution occurs only at certain times of the year, or not at all. The abstractions, or transmission losses, reduces runoff volume as the flood waves travel downstream. Lane's method described in USDA SCS Hydrology Handbook (1983) is used to estimate transmission losses.Water losses from the channel are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when transmission losses occur in tributary channels.

4.2.2 Weather

SWAT uses precipitation, air temperature, solar radiation, relative humidity and wind speed in driving hydrological balance. The model can read these inputs directly from the file or generate the values using monthly average data analyzed for a number of years. It includes the WXGEN weather generator model (Sharpley and Williams,1990) to generate climate data or to fill in gaps in measured records. The weather generator first independently generates precipitation for the day, followed by generation of maximum and minimum temperature, solar radiation and relative humidity based on the presence or absence of rain for the day. Finally, wind speed is generated independently.

4.2.2.1 Precipitation

The precipitation generator is a Markov chain-skewed or Markov chain exponential model (Williams, 1995). A first-order Markov chain is used to define the day as wet or dry. When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount.

4.2.2.1.1Occurence of Wet or Dry Day

With the first-order Markov-chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. It is required to input the probability of a wet day on day i given a wet day on day $i-1$, $P_i(W/W)$, and the probability of a wet day on day i given a dry day on day i–1, $P_i(W/D)$, for each month of the year. From these inputs the remaining transition probabilities can be derived:

$$P_i(D/W) = 1-P_i(W/W) \tag{4.21}$$

$$P_i(D/D) = 1-P_i(W/D) \tag{4.22}$$

where, $P_i(D/W)$ is the probability of a dry day on day i given a wet day on day i–1 and $P_i(D/D)$ is the probability of a dry day on day i given a dry day on day i–1.

To define a day as wet or dry, model generates a random number between 0 and 1. This random number is compared to the appropriate wet-dry probability, $P_i(W/W)$ or $P_i(W/D)$. If the random number is equal to or less than the wet-dry probability, the day is defined as wet. If the random number is greater than the wet-dry probability, the day is defined as dry.

4.2.2.1.2 Amount of Precipitation

The model provides two options to describe the distribution of rainfall amounts: a skewed distribution and an exponential distribution. The equation used to calculate the amount of precipitation on a wet day is:

$$R_{day} = \mu_{mon} + 2.\sigma_{mon} \cdot \left(\frac{\left[(SND_{day} - \frac{g_{mon}}{6}).(\frac{g_{mon}}{6}) + 1 \right]^3 - 1}{g_{mon}} \right) \quad (4.23)$$

where, R_{day} is the amount of rainfall on a given day(mmH_2O), μ_{mon} and σ_{mon} are the mean and standard deviation of daily rainfall (mm), respectively for the month. SND_{day} is the standard normal deviate calculated for the day, and g_{mon} is the skew coefficient for daily precipitation in the month.

4.2.2.2 Solar Radiation and temperature

The procedure used to generate daily values for the maximum/minimum temperature and solar radiation is based on the weekly stationary generating process (Richardson and Wright, 1984). The temperature model requires monthly means of maximum and minimum temperatures and their standard deviations as inputs.

The solar radiation model uses the extreme approach extensively. Thus, only monthly means of daily solar radiation are required as inputs. The continuity equation relates average daily solar radiation adjusted for wet or dry conditions to the average daily solar radiation for the month.

$$\mu rad_{mon}.days = \mu Wrad_{mon}.days_{wet} + \mu Drad_{mon}.days_{dry} \quad (4.24)$$

where, μrad_{mon} is the average daily solar radiation for the month (MJm^{-2}), $days_{tot}$ are the total number of days in the month, $\mu Wrad_{mon}$ is the average daily solar radiation of the month on wet days (MJm^{-2}),$days_{wet}$ are the number of wet days in the month, $\mu Drad_{mon}$ is the average daily solar radiation of the month on dry days (MJm^{-2}), $days_{dry}$ arethe number of dry days in the month.

4.2.2.3 Relative Humidity

Daily average relative humidity values are calculated from a triangular distribution using average monthly relative humidity. The triangular distribution used to generate daily relative humidity values requires four inputs: mean monthly relative humidity, maximum relative humidity value allowed in month, minimum relative humidity value allowed in month, and a random number between 0.0 and 1.

4.2.2.4 Wind Speed

Wind Speed is required by SWAT when the Penman-Monteith equation is used to calculate potential evapotranspiration. Mean daily wind speed is generated in SWAT using a modified exponential equation :

$$\mu_{10m} = \mu wnd_{mon}.(-\ln(rnd_1))^{0.3} \quad (4.25)$$

where, μ_{10m} is the mean wind speed for the day (m $^{s-1}$), μwnd_{mon} is the average wind speed for the month (m $^{s-1}$), and rnd_1 is a random number between 0 and 1.

4.2.3 Erosion and Sediment Yield

The sediment yield for each sub-basin, in the SWAT model is computed by using the Modified Universal Soil Loss Equation (MUSLE) (Williams,1975)

$$sed = 11.8.(Q_{surf}.q_{peak}.area_{hru})^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}.LS_{USLE}.CFRG \quad (4.26)$$

where, *sed* is the sediment yield on a given day (metric tons), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor.

K_{USLE} is calculated using the following equation (Williams,1995)

$$K_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \quad (4.27)$$

where f_{csand} is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand, f_{cl-si} is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The factors are calculated:

$$f_{csand} = \left(0.2 + 0.3.\exp\left[-0.256.m_s.\left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (4.28)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3} \quad (4.29)$$

$$f_{orgc} = \left(1 - \frac{0.25.orgC}{orgC + \exp[3.72 - 2.95.orgC]} \right) \quad (4.30)$$

$$f_{hisand} = \left(1 - \frac{0.7.\left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9.\left(1 - \frac{m_s}{100}\right)\right]} \right) \quad (4.31)$$

where m_s is the percent sand content (0.05-2.00 mm diameter particles), m_{silt} is the percent silt content (0.002-0.05mm diameter particles), m_c is the percent clay content (<0.002 mm diameter particles), and orgC is the percent organic carbon content of the layer

C_{USLE} factor is estimated using the following equation:

$$C_{USLE} = \{\exp(\ln(0.8) - \ln(C_{USLE})).\exp(-0.00115.rsd_{surf}) + \ln(C_{USLE,mn})\} \quad (4.32)$$

where, $C_{USLE,mn}$ is the minimum value of the crop cover management factor for the land cover and rsd_{surf} is the amount of residue on the soil surface (kg/ha).

LS_{USLE} factor is estimated using the following equation:

$$LS_{USLE} = \left(\frac{L_{hill}}{22.1} \right)^m .(65.41.\sin^2(\alpha_{hill}) + 4.56.\sin\alpha_{hill} + 0.065) \quad (4.33)$$

where, L_{hill} is the slope length (m), m is the exponential term, and α_{hill} is the angle of the slope. The exponential m is calculated :

$$m = 0.6.(1 - \exp[-35.835.slp]) \quad (4.34)$$

where slp is the slope of the HRU expressed as rise over run(m/m). The relationship between α_{hill} and slp is:

$$slp = \tan\alpha_{hill} \quad (4.35)$$

The coarse fragment factor is calculated :

$$CFRG = \exp(-0.053.rock) \quad (4.36)$$

4.2.4 Nutrients and Pesticides

The SWAT models the complete nutrient cycle for nitrogen and phosphorus. Three forms of nitrogen in mineral soils are organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids, and mineral forms of nitrogen in solution. Nitrogen may added to the soil by fertilizer, manure, fixation by symbiotic or nonsymbiotic bacteria, and rain. Nitrogen is removed from the soil by plant uptake, leaching, volatilization, denitrification and erosion. SWAT monitors the five different pools of nitrogen in the soil.

Unlike nitrogen which is highly mobile, phosphorus solubility is limited in most environments. Phosphorus combines with other ions to form a number of insoluble compounds that precipitate out of solution. These characteristics contribute to a build-up of phosphorus near the soil surface that is readily available for transport in surface runoff. SWAT monitors six different pools of phosphorus in the soil. Three pools are inorganic forms of phosphorus while the other three pools are organic forms of phosphorus.

SWAT simulates pesticide movement into the stream network via surface runoff, and into the soil profile and acquifer by percolation. The equations used to model the movement of pesticide in the land phase of the hydrologic cycle were adopted from GLEAMS (Leonard et.al.,1987).

4.2.5 Soil Temperature

Daily average soil temperature is simulated at the center of each soil layer using daily maximum and minimum air temperature. Soil temperature for each layer is simulated using a function of damping depth, surface temperature and mean annual air temperature. Damping depth is dependent upon bulk density and soil water content.

4.2.6 Crop Growth

The plant growth component of SWAT is a simplified version of the EPIC plant growth model. As in EPIC, phenological plant development is based on daily accumulated heat units, potential biomass is based on a method developed by Monteith, a harvest index is used to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen or phosphorus stress.

4.2.7 Agricultural Management

SWAT allows the user to define management practices taking place in every HRU. The user may define the beginning and the ending of the growing season, specify timing and amounts of fertilizer, pesticide and irrigation applications as well as timing of tillage operations. At the end of the growing season, the biomass may be removed from the HRU as yield or placed on the surface as residue.

In addition to these basic management practices, operations such as grazing, automated fertilizer and water applications, and incorporation of every conceivable management option for water use are available. The latest improvement to land management is the incorporation of routines to calculate sediment and nutrient loadings from urban areas.

4.3 Components of channel routing

4.3.1 Channel Flood Routing

Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals.As water flows downstream, a portion may be lost due to evaporation and transmission through the bed of the channel. Another potential loss is removal of water from the channel for agricultural or human use.Flow may be supplemented by the fall of rain directly on the channel and/or addition of water from point source discharges. Flow is routed through the channel using a variable storage coefficient method developed by Williams (1969) or the Muskingum routing method. Users are required to define the width and depth of the channel when filled to the top of the bank as well as the channel length, slope along the channel length and Manning's 'n' value. Manning's equation for uniform flow in a channel is used to calculate the rate and velocity of flow in a reach segment for a given time step.

The variable storage routing method was developed by Williams (1969)and used in the HYMO (Williams and Hann, 1973) and ROTO (Arnold et al.,1995) models. For a given reach segment, storage routing is based on the continuity equation:

$$V_{in} - V_{out} = \Delta V_{stored} \qquad (4.37)$$

where V_{in} is the volume of inflow during the time step (m^3 H_2O), V_{out} is the volume of outflow during the time step (m^3 H_2O), and $\tilde{}V_{stored}$ is the change in volume of storage during the time step (m^3 H_2O).

This equation can be presented as :

$$\Delta t.\left(\frac{q_{in,1} + qi_{n,2}}{2}\right) - \Delta t.\left(\frac{q_{out,1} + q_{out,2}}{2}\right) = V_{stored,2} - V_{stored,1}$$

(4.38)

where, Δt is the length of the time step (s) and $q_{\text{in},1}$ and $q_{in,2}$ are the inflow rate at the beginning and end of the time step (m^3 /s), respectively. $q_{out,1}$ and $q_{out,2}$ are the outflow rate at the beginning and end of the time step (m^3/s). $V_{stored,1}$ and $V_{stored,2}$ are the storage volume at the beginning and end of the time step (m^3).

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

$$TT = \frac{V_{stored}}{q_{out}} = \frac{V_{stored,1}}{q_{out,1}} = \frac{V_{stored,2}}{q_{out,2}}$$

(4.39)

where, TT is the travel time (s), V_{stored} is the storage volume (m^3), and q_{out} is the discharge rate (m^3/s).

The relationship between travel time and storage coefficient is represented as:

$$q_{out,2} = \left(\frac{2.\Delta t}{2.TT + t}\right).qi_{n,av} + \left(1 - \frac{2.\Delta t}{2.TT + \Delta t}\right).q_{out,1}$$

(4.40)

The storage coefficient is calculated as:

$$SC = \frac{2.\Delta t}{2.TT + \Delta t}$$

(4.41)

Finally the volume of outflow is calculated as

$$V_{out,2} = SC.(V_{in} + V_{stored,1}) \qquad (4.42)$$

4.3.2 Transmission Loss

The transmission losses reduce runoff volumes and peak rates from the watersheds as flood waved travels down streams. Transmission losses are estimated with the equation:

$$tloss = K_{ch}.TT.P_{ch}.L_{ch} \tag{4.43}$$

where, $tloss$ are the channel transmission losses (m^3), K_{ch} is the effective hydraulic conductivity of the channel alluvium (mm/hr), P_{ch} is the wetted perimeter (m), and L_{ch} is the channel length (km).

Transmission losses from the main channel are assumed to enter bank storage or the deep aquifer.

4.3.3 Evaporation Loss

Evaporation losses from the reach are calculated as:

$$E_{ch} = coef_{ev}.E_o.L_{ch}.W.fr_{\Delta t} \tag{4.44}$$

where, E_{ch} is the evaporation from the reach for the day (m3), $coef_{ev}$ is an evaporation coefficient, E_o is potential evaporation (mm), W is the channel width at water level (m), and $fr_{\Delta t}$ is the fraction of the time step in which water is flowing in the channel (travel time/length of the time step).

4.3.4 Bank Storage

The amount of water entering bank storage on a given day is calculated:

$$bnk_{in} = tloss.(1 - fr_{trns}) \tag{4.45}$$

where, bnk_{in} is the amount of water entering bank storage (m^3) and fr_{trns} is the fraction of transmission losses partitioned to the deep aquifer.

4.3.5 Channel Water Balance

Water storage in the reach at the end of the time step is calculated:

$$V_{stored,2} = V_{stored,1} + V_m - V_{out} - tloss - E_{ch} + div + V_{bnk} \tag{4.46}$$

where, div is the volume of water added or removed from the reach for the day through diversions (m^3), and V_{bnk} is the volume of water added to the reach via return flow from bank storage (m^3).

4.4 Channel Sediment Routing

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach. SWAT computes these two processes using the same channel dimensions for the entire simulation. The model simulates down cutting and widening of the stream channel and update channel dimensions throughout the simulation. In SWAT2000, the equations are simplified and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. The peak channel velocity, $v_{ch,pk}$ is calculated

$$v_{ch,pk} = \frac{q_{ch,pk}}{A_{ch}} \tag{4.47}$$

where, $q_{ch,pk}$ is the peak flow rate (m^3/s) and A_{ch} is the cross-sectional area of flow in the channel (m^2).

The peak flow rate is defined as:

$$q_{ch,pk} = prf \cdot q_{ch} \tag{4.48}$$

where, prf is the peak rate adjustment factor and q_{ch} is the average rate of flow (m^3/s).

The maximum amount of sediment that can be transported from a reach segment is calculated as:

$$conc_{sed,ch,mx} = c_{sp} \cdot v_{ch,pk}{}^{sp\exp} \tag{4.49}$$

where, $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (ton/m^3), c_{sp} is a coefficient defined by the user, $v_{ch,pk}$ is the peak channel velocity (m/s), and $spexp$ is an exponent defined by the user. The exponent, $spexp$, normally varies between 1 and 2.

The net amount of sediment deposited is calculated:

$$sed_{dep} = (conc_{sed,ch,i} - conc_{sed,ch,mx}) \cdot V_{ch} \tag{4.50}$$

where, sed_{dep} is the amount of sediment deposited in the reach segment (metric tons), and V_{ch} is the volume of water in the reach segment (m^3).

If $conc_{sed,ch,i} < conc_{sed,ch,mx}$, degradation is the dominant process in the reach segment and the net amount of sediment reentrained is calculated as:

$$sed_{\deg} = (conc_{sed,ch,mx} - conc_{sed,ch,i}) \cdot V_{ch} \cdot K_{CH} \cdot C_{CH} \tag{4.51}$$

where sed_{deg} is the amount of sediment reentrained in the reach segment (metric tons), $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/L or ton/m^3), $conc_{sed,ch,i}$ is the initial sediment concentration in the reach (kg/L or ton/m^3), V_{ch} is the volume of water in the reach segment (m^3 H_2O), K_{CH} is the channel erodibility factor (cm/hr/Pa), and C_{CH} is the channel cover factor.

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

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{\deg} \tag{4.52}$$

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

The amount of sediment transported out of the reach is calculated as:

$$sed_{out} = sed_{ch} . \frac{V_{out}}{V_{ch}} \tag{4.53}$$

where, sed_{out} is the amount of sediment transported out of the reach (metric tons), sed_{ch} is the amount of suspended sediment in the reach (metric tons),V_{out} is the volume of outflow during the time step (m^3H_2O), and V_{ch} is the volume of water in the reach segment (m^3H_2O)

4.4.1 Channel downcutting and widening

While sediment transport calculations have traditionally been made with the same channel dimensions throughout a simulation, SWAT will model channel downcutting and widening. When channel downcutting and widening is simulated, channel dimensions are allowed to change during the simulation period.

Three channel dimensions are allowed to vary in channel downcutting and widening simulations: bankfull depth, $depth_{bnkfull}$, channel width, $W_{bnkfull}$, and channel slope, slp_{ch}. Channel dimensions are updated using the following equations when the volume of water in the reach exceeds 1.4×10^6 m^3.

The amount of downcutting is calculated (Allen et al., 1999):

$$depth_{dcut} = 358.depth.slp_{ch}.K_{CH} \tag{4.54}$$

where $depth_{dcut}$ is the amount of downcutting (m), $depth$ is the depth of water in channel (m), slp_{ch} is the channel slope (m/m), and K_{CH} is the channel erodibility coefficient (cm/h/Pa).

The new bankfull depth is calculated as:

$$depth_{bnkfull} = depth_{bnkfull,i} + depth_{dcut} \tag{4.55}$$

where $depth_{bnkfull}$ is the new bankfull depth (m), $depth_{bnkfull,i}$ is the previous bankfull depth, and $depth_{dcut}$ is the amount of downcutting (m).

The new bank width is calculated as:

$$W_{bnkfull} = ratio_{WD}.depth_{bnkfull} \tag{4.56}$$

where $W_{bnkfull}$ is the new width of the channel at the top of the bank (m), $ratio_{WD}$ is the channel width to depth ratio, and $dept_{hbnkfull}$ is the new bankfull depth (m).

The new channel slope is calculated as:

$$slp_{ch} = slp_{ch,i} - \frac{depth_{dcut}}{1000.L_{ch}} \tag{4.57}$$

where slp_{ch} is the new channel slope (m/m), $slp_{ch,i}$ is the previous channel slope (m/m), $depth_{bnkfull}$ is the new bankfull depth (m), and L_{ch} is the channel length (km).

CHAPTER V
MATERIALS AND METHODOLOGY

This chapter deals with the description of acquisition of various meteorological, hydrological, and remote sensing data used for data processing Procedures used for generation of different thematic layers using GIS are discussed. Methodologies for generation of input parameters for ArcView SWAT model using basic thematic layers is also described. Procedures used for calibration, validation and performance evaluation of the model is also described in this chapter.

5.1 Materials used in the study

5.1.1 Toposheet

The Survey of India toposheet number: 78 O/1, 78 O/5, 78 O/9, 78O/2, 78 O/10, 78 O/6 and 78 O/14 in the scale of 1:50000 were used for delineation of the study area and preparing the drainage network map.

5.1.2 Remote Sensing Data

Cloud free satellite data of Landsat TM dated 26-11-1991& Landsat ETM+ dated 17-2-2002 with spatial resolution of 30 m (Path:137, Row:42) for the year 1991and 2002 corresponding to the study area were downloaded from the global land cover facility (GLCF) website (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp) to quantify the changes in the land use/ land cover type of the area and to analyse its impact on surface runoff and sediment yield. The specification of both the sensors are given in **Table 5.1**and the satellite images for both the years are shown in fig 5.1 and fig 5.2.

5.1.3 Soil Map

The soil map of Assam and Meghalaya prepared by National Bureau of Soil Survey and Land Use Planning (NBSS Publ.66 and NBSS Publ.52) prepared in 1:250,000 scale and printed in 1: 500,000 scale was used for the study (fig 5.3).

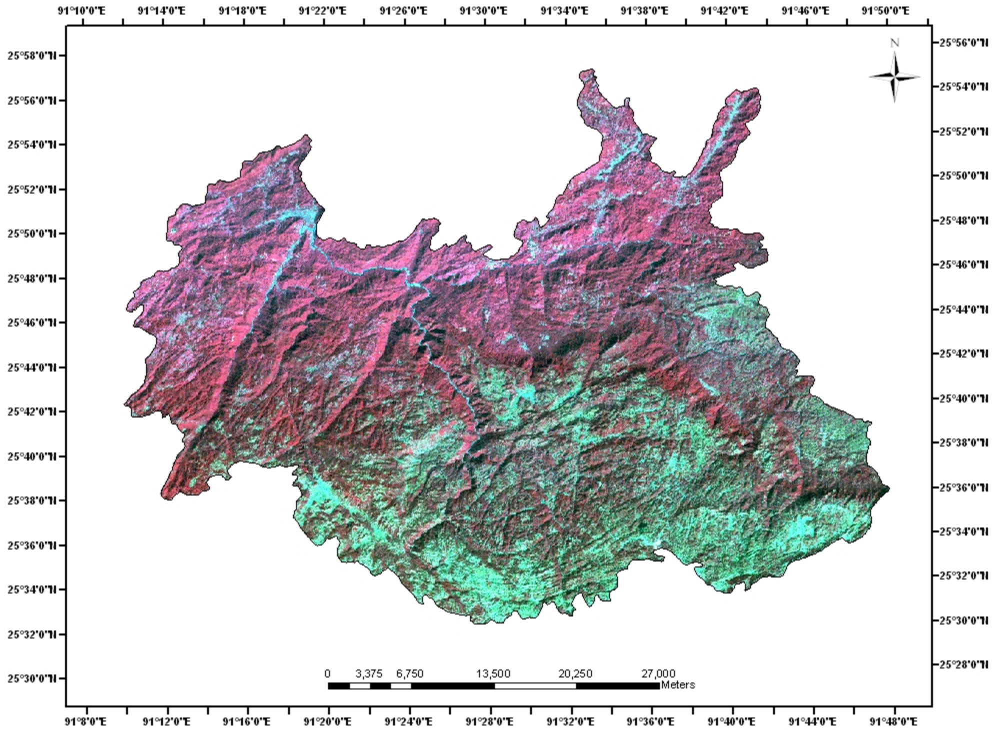


Fig.5.1: FCC of Landsat TM of Kulsi Basin dated 26-11-1991

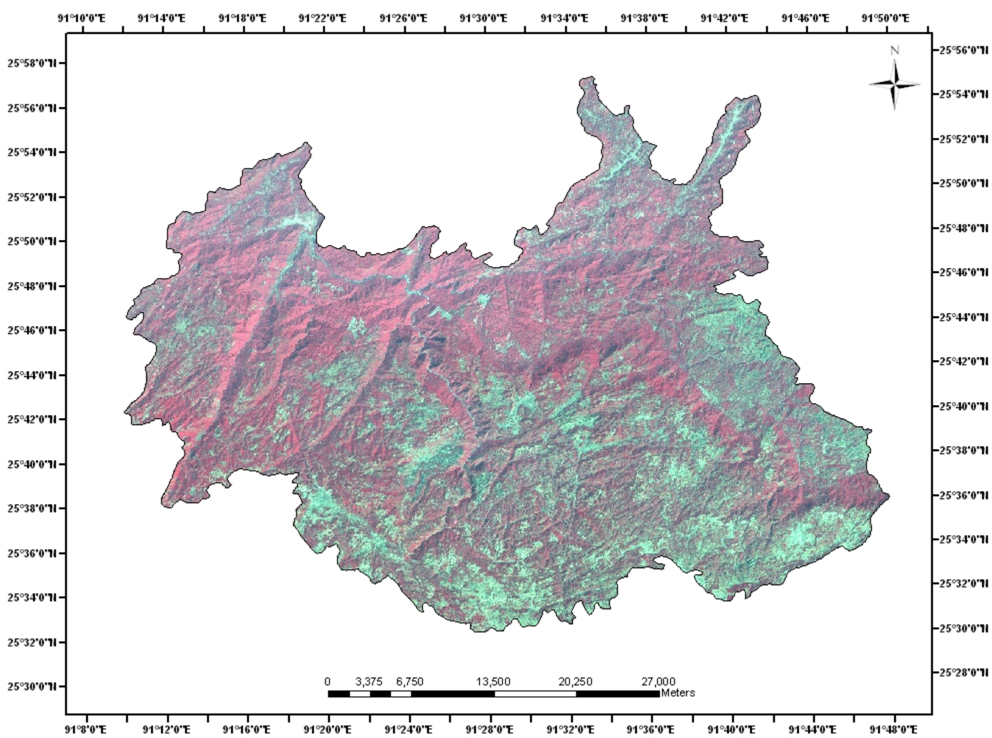


Fig.5.2: FCC of Landsat ETM of Kulsi Basin dated 17-02-2002

Table: 5.1 Specification of Landsat TM and Landsat ETM sensors

		Band Number	Wavelength Range (μm)	Spectral Location	Spatial Resolution (m)		
TM	**LANDSAT**	1	0.45-0.52	Blue-green	30 m	185 km	16 days
		2	0.52-0.60	Green	30 m	185 km	
		3	0.63-0.69	Red	30 m	185 km	
		4	0.76-0.90	Near IR	30 m	185 km	
		5	1.55-1.75	Mid IR	30 m	185 km	
		6	10.4-12.5	Thermal IR	120 m	185 km	
		7	2.08-2.35	Mid IR	30 m	185 km	16 days
ETM+	**LANDSAT**	1	0.45-0.515	Blue-Green	30 m	180 km	
		2	0.525-0.605	Green	30 m		
		3	0.63-0.69	Red	30 m		
		4	0.75-0.90	Near IR	30 m		
		5	1.55-1.75	Mid IR	30 m		
		6	10.40-12.50	Thermal IR	60 m		
		7	2.09-2.35	Mid IR	30 m		
		8	0.52-0.90	Panchromatic	15 m		

5.1.4 Meteorological Data

Historical daily rainfall data for 22 years (1977-1993 & 1998-2002) were collected from Brahmaputra Board, Guwahati, Assam. As there is no record of daily maximum and minimum temperature, wind speed and solar radiation for the study area, therefore 11years daily data (1994-2004) were downloaded for the nearest station i.e Guwahati from the National Climatic Data Centre site (NCDC). Long-term weather normals were also downloaded from FAO website for Guwahati and Shillong. Long-term meteorological data was also collected for another nearest station located at Umiam from ICAR Research Complex for NEH Region, Umiam.

5.1.5 Hydrological and Sediment Yield Data

The daily discharge data for the period between 1990-1993 and 1998-2002 and daily sediment yield data for the period 2001-2002 was also collected from Brahmaputra Board, Guwahati, Assam in order to validate and test the model performance.

5.2 Softwares used

5.2.1 ERDAS Imagine 8.6: The ERDAS (Earth Resources Data Analysis System) imagine, an image processing softwares having few capabilities of G.I.S. has been extensively used for importing and exporting of images from one format to another, rectification of imageries, subsetting of images and preparation of thematic maps.

5.2.2 ArcView3.2a: In the present study Arc View GIS software developed by ESRI (Environmental Systems Research Institute) has been used extensively for arranging all the layers in proper sequence (.shp format).

5.2.3 AVSWAT2000: SWAT2000 interfaced with ArcView has been used in the present study for simulating the various hydrological processes like runoff, ET, PET and sediment yield

5.2.4 Microsoft Office (MS Word, MS Excel & MS Power Point): For calculation purpose and producing charts MS Excel spreadsheet was used. Microsoft word and Microsoft Power Point were used for thesis typing and presentation purposes respectively.

5.3 Methodology

5.3.1Delineation of the Study Area, Scanning and Digitization

The Kulsi River Basin was delineated from seven Survey of India toposheets of 1:50000 scale based on the ridge line and drainage pattern. The delineated boundary was then traced over a tracing paper with the coordinates (tic points) of the toposheets being accurately marked on it. The stream network from the lowest order was also traced on the tracing paper. The traced map was then scanned in a A0 scanner at a resolution of 300 dpi. The scanned map was then geometrically corrected based on 16 control points in ERDAS Imagine software. The geometrically scanned map was then digitized onscreen to prepare the boundary and drainage map (fig 5.4) of the basin. Then all errors including dangles were removed from the coverages. The boundary was cleaned and built as polygon using the vector module of ERDAS Imagine to know the area and perimeter of the basin. Topology was also constructed for the drainage map in order to know the length of each stream. Attribute information about the stream order was entered in order to know the highest stream order within the basin and for morphometric analysis. Horton-Strahler's stream ordering classification system was followed while classifying the stream order.

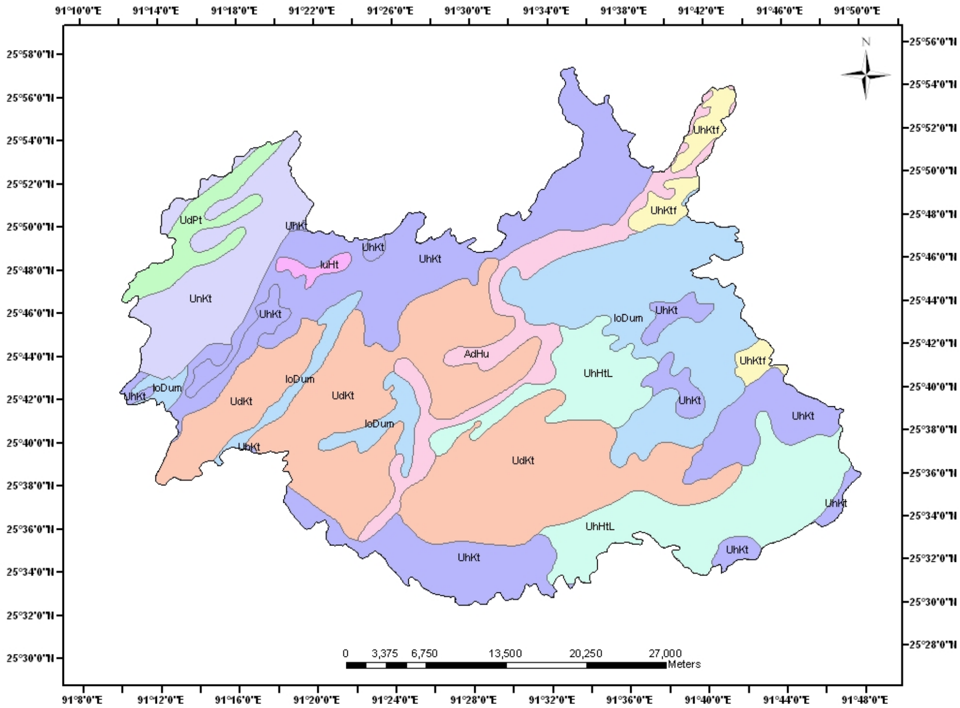


Fig.5.3: Soil Map of Kulsi Basin

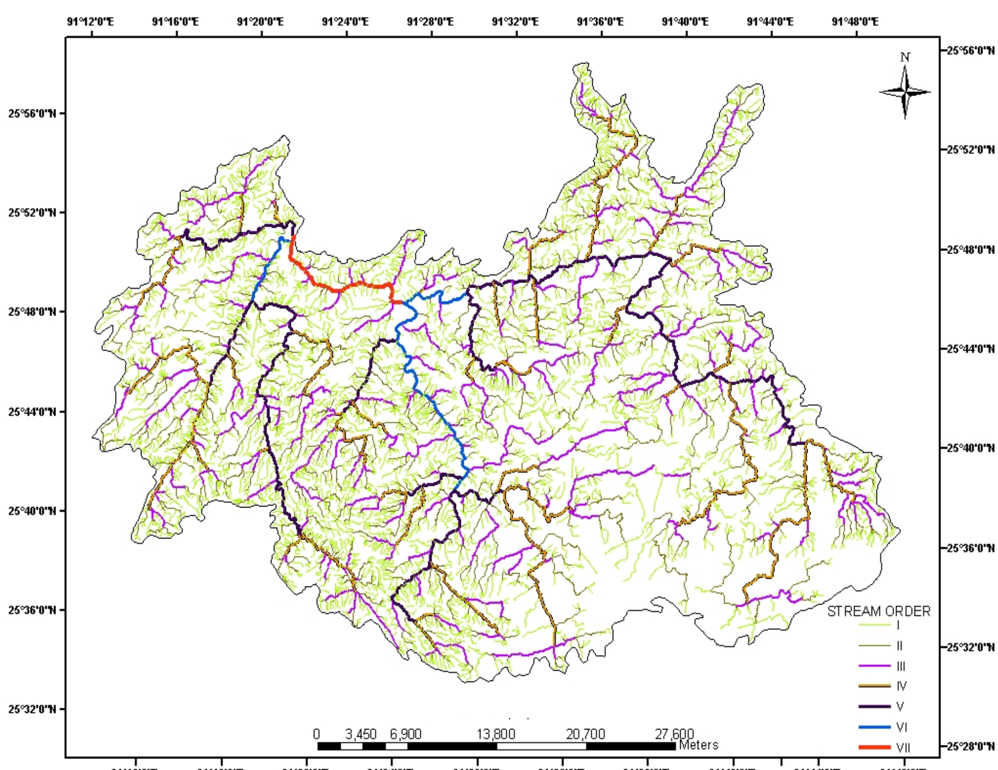


Fig.5.4: Drainage Map of Kulsi Basin

5.3.2 Extraction of Morphological Parameters

The morphological characteristics of a basin govern its hydrological response to a considerable extent (Singh et.al.,2003). The morphological characteristics of a basin represent its attributes, which may be employed in synthesizing its hydrological behaviour. Basin characteristics when measured and expressed in quantified morphometric parameters can be studied for their influence on runoff. Hence, linking of the morphological parameters with the hydrological characteristics of the basin can lead to useful procedures to simulate hydrological behaviour of various basins, particularly the ungauged ones.

In the present study a few of the important morphological parameters for Kulsi basin has been derived using ArcView GIS software and mathematical formula and are listed below

1)Basin Length (L_b): It is defined as the longest dimension of a basin parallel to the principal drainage line

$$L_b = 1.312A^{0.568} \tag{5.1}$$

where L_b is in km

2) Drainage Density (D_d): It is defined as the total length of the streams (L) of all the orders of a basin to the area (A) of the basin. The drainage density gives an idea of the physical properties of the underlying rocks. Low drainage density occurs in regions of highly resistant and permeable subsoil materials with dense vegetation and low relief, whereas high drainage density is prevalent in regions of weak, impermeable sub surface materials which are sparsely vegetated and have high relief (Strahler, 1964).

$$D_d = \frac{L}{A} \tag{5.2}$$

3) Shape Factor (B_s): It is the ratio of the square of the maximum length of the basin to the basin area (A)

$$B_s = \frac{L_b^2}{A} \tag{5.3}$$

4) Elongation Ratio (R_e): It is defined as the ratio between the diameter of a circle with the same area as that of the basin to the maximum length of the basin.

$$\mathrm{Re} = \frac{2}{Lb}\sqrt{\frac{A}{\Pi}} = 1.128A^{0.5}/Lb \tag{5.4}$$

The elongation ratio ranges from 0.6 to 1.0, over a wide range of climate and geological environments. Values nearing to 1.0 are typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

5) Circulatory Ratio (R_c): is a dimensionless parameter defined as the ratio of the basin area of a given order the area of a circle having a circumference equal to the basin perimeter. It is computed as

$$Rc = \frac{4\Pi A}{P^2} = \frac{12.57A}{P^2} \tag{5.5}$$

where, A and P are the area and perimeter of the basin . The value of Rc tends to approach 1 as the shape of the basin approaches a circle.

6) Length of overland flow (L_o) can be defined as the length of flow of water over the ground before it becomes concentrated in definite stream channels.

$$Lo = 0.5Dd \tag{5.6}$$

where D_d is the drainage density

5.3.3 Generation of Digital Elevation Models

Digital Elevation Models (DEM) is the digital cartographic representation of the elevation of the terrain at regularly spaced intervals in x and y directions, using z-values referenced to a common datum. DEM is a generic term for digital topographic, in all its various forms. It is called "model" because computers can use such data to model and automatically analyze the earth's topography in 3-dimensions, minimizing the need for labor intensive inhuman interpretation.DEM's can be prepared based on photogrammetrical techniques, or point interpolation techniques or through interpolation of contours. In the present study a DEM (fig 5.5) with a cell size of 30m x 30m spatial resolution, prepared under the ISRO GBP project has been used for the study area

5.3.4 Slope

Slope is a calculation of the maximum rate of change across the surface, either from cell to cell in a gridded surface or of a triangle in a TIN. Every cell in an output grid or triangle in a TIN has a slope value. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. Slope is often calculated as either percent slope or degree of slope. In the present study the slope map was prepared in ArcView software using spatial analyst tool. The slope map has been classified as per the IMSD guidelines and is shown in fig 5.6.

5.3.5 Aspect

Aspect identifies the steepest downslope across a surface. It can be thought of as a slope direction or the compass direction a hill faces. It is usually measured clockwise in degrees from 0 (due north) to 360 (again due north, coming full circle). The value of each location in an aspect dataset indicates the direction the surface slope faces. In the present study the aspect map has been prepared in the ArcView enviroment using spatial analyst and is shown in fig 5.7.

5.3.6 Flow Direction

The flow direction concept has been emphasized by Marks et. al. (1984), O'Callaghan and Mark (1984) and Jenson and Dominique (1988). The flow direction for a cell is the direction in which water flows out of the cell. There are eight output directions relating to the eight adjacent cells into which flow might occur. It was encoded according to the orientation of one of the eight cells that surrounded the cell (x) as below. Of the possible eight directions the one with the maximum downward slope is selected and stored in the flow direction matrix.

Maximum drop = change in 'z' value/distance

64	128	1		NW	N	NE	
32	X	2	=>	W	X	E	Clockwise direction
16	8	4		SW	S	SE	

For example, if cell 'x' flew to the left in matrix, its direction would be encoded as 32. Flow direction encoding was done in powers of two so that the surrounding conditions corresponded to unique values when the powers of two were summed.

The flow direction map of Kulsi Basin was prepared in the ArcView environment using the Hydrological Modelling extension and is shown in fig 5.8.

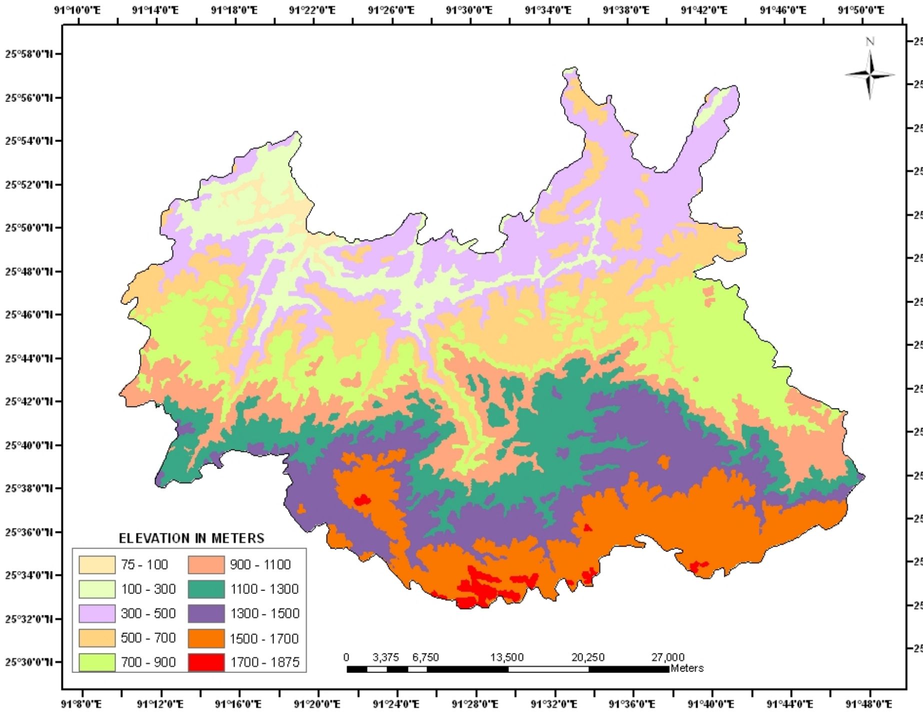


Fig.5.5: Digital Elevation Model of Kulsi Basin

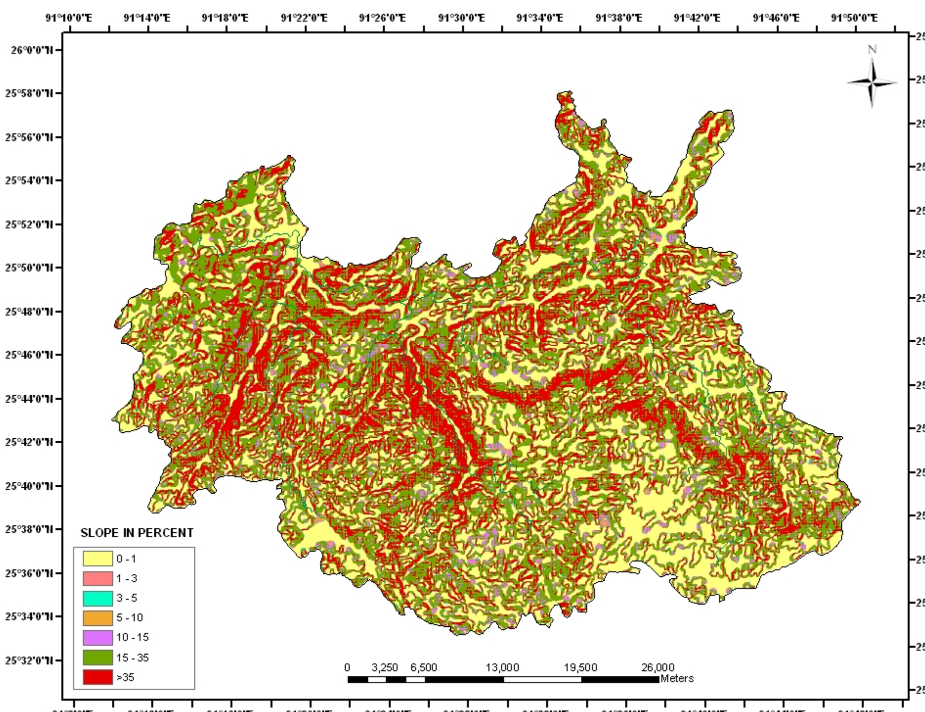


Fig.5.6: Slope Map of Kulsi Basin

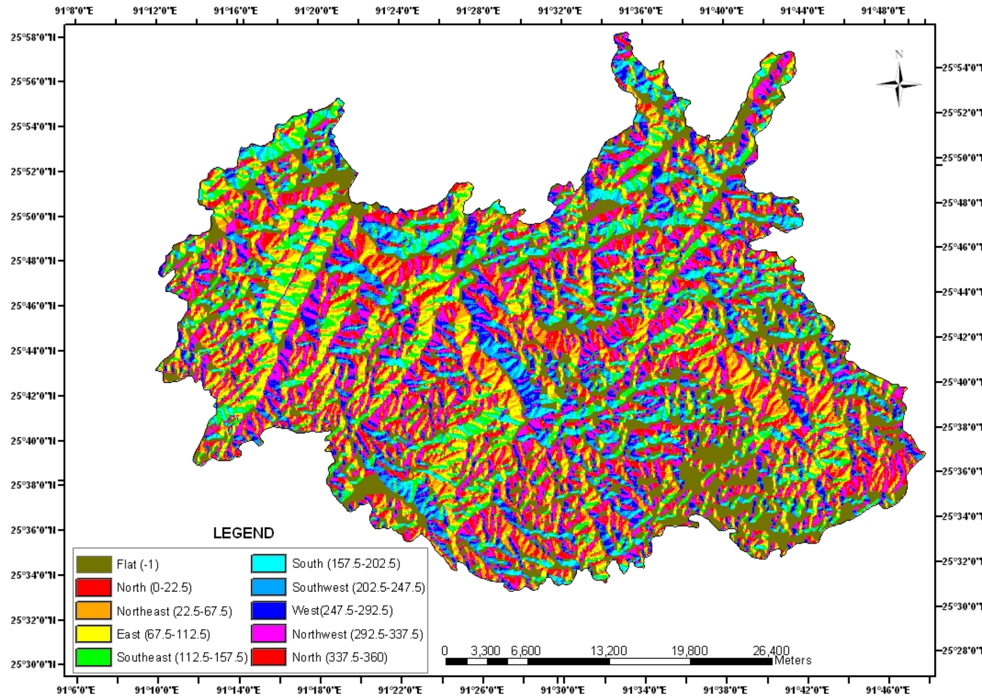


Fig.5.7: Aspect Map of Kulsi Basin

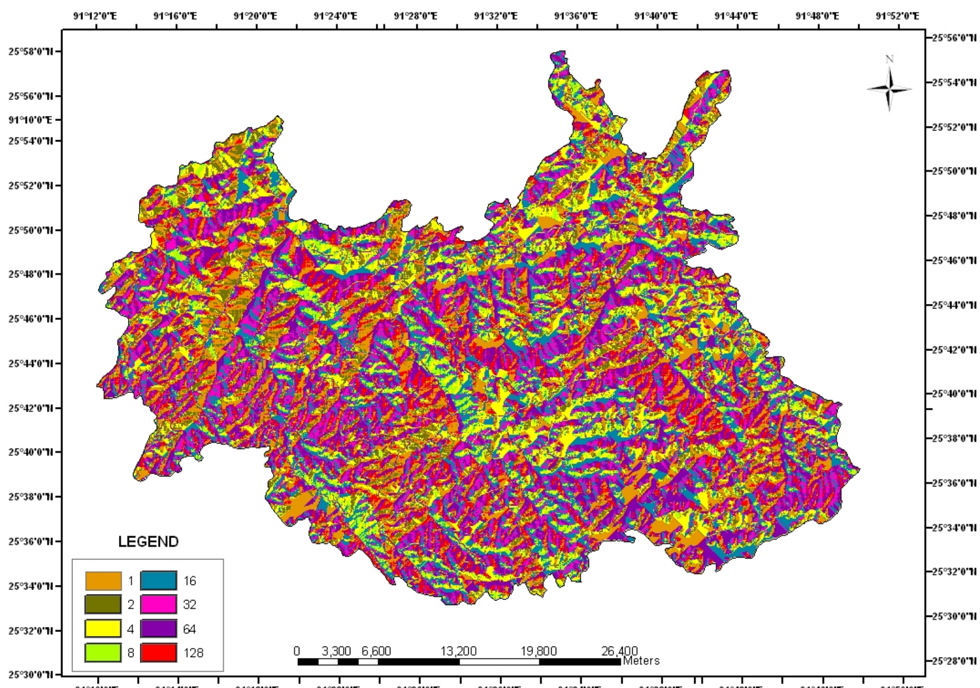


Fig.5.8: Flow Direction map of Kulsi Basin

5.3.7 Preparation of Land use/ Land cover Map

The classification of satellite data mainly follows two approaches i.e supervised and unsupervised classification. In the supervised approach to classification, the image analyst supervises the pixel categorization process by specifying to the computer algorithm numerical descriptors of the various land cover types present in the scene. To do this, representative training sites of known cover types are used to compile a numerical interpretation key that describes the spectral attributes for each type of interest. In case of unsupervised classification no training data is used for classification. Rather, this family of classifiers involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values.

In order to prepare the landuse/ land cover map for Kulsi Basin, the downloaded FCC of Landsat TM and Landsat ETM for the year 1991 and 2002 were subsetted to extract the area of interest. The subsetted areas were then geometrically rectified with reference to the topographic map coordinates marked on the tracing paper in the ERDAS Imagine software. As training samples were collected during field visit using hand held GPS (Garmin 72) and through interaction with local villagers supervised classification method using Maximum Likelihood classification algorithm was used for preparing the land use/ landcover map of the study area for both the years. The maximum likelihood decision rule assigns each pixel having pattern measurements. It quantitatively evaluates both the variance and co-variance of the category training data, which is normally distributed (Gaussian). The statistical probability of any pixel value to decide its particular land use class among the neighboring clusters is computed based on mean and co-variance matrices. The probability density functions are used to classify an unidentified pixel by computing the probability of the pixel value belonging to each pixel category. Altogether four classes i.e Dense Forest, Open Forest, Agricultural Land and River/ Streams were classified. In order to check the accuracy of the classified maps accuracy analysis was performed on the classified image with the accuracy assessment function of ERDAS. The land use/ land cover maps for both the years are shown in fig 5.9 and fig 5.10.

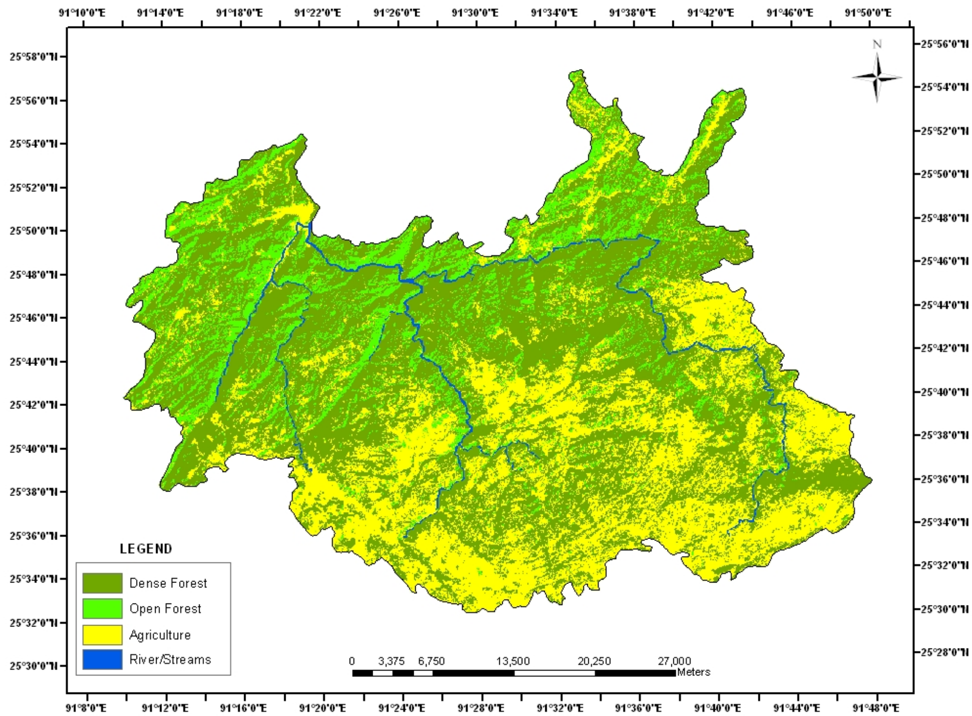


Fig.5.9: Land use/ Land cover map of Kulsi Basin for the year 1991

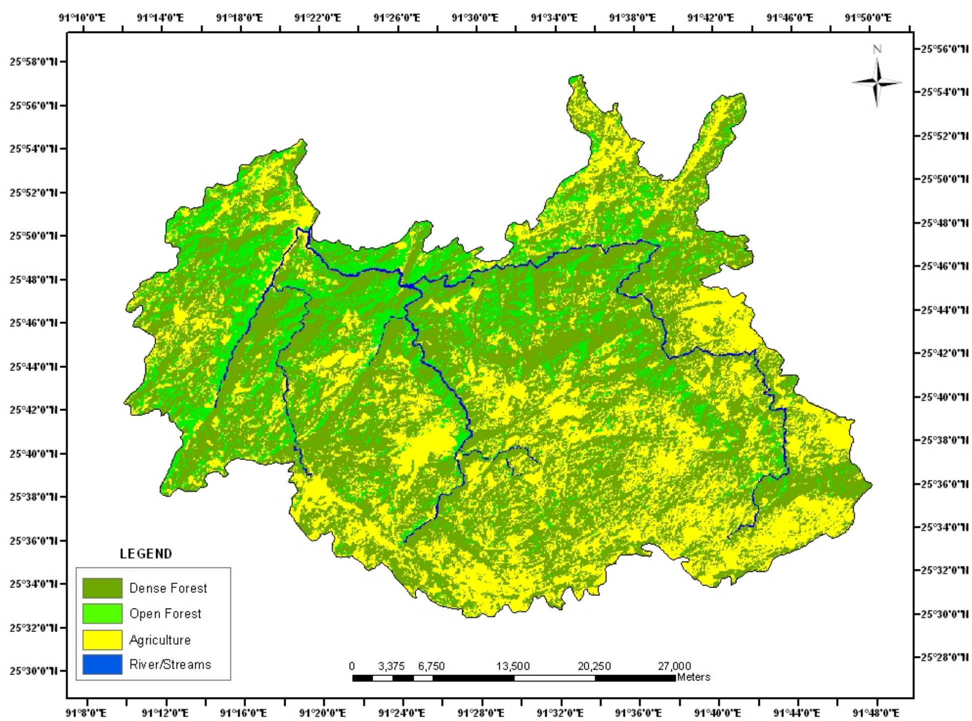


Fig.5.10: Land use/ Land cover map of Kulsi Basin for the year 2002

5.3.8 Data Processing for the Model

5.3.8.1 Meteorological data processing

The processing of meteorological data was done statistically. Daily and monthly observed meteorological data of Ukiam, Guwahati, Umiam and Shillong were used for the preparation of the weather generator file required in AVSWAT model. The meteorological data were analyzed to determine the various statistical parameters like mean monthly maximum and minimum temperature, average monthly wind speed, number of rainy days, average daily solar radiation, standard deviation for air temperature, precipitation, skewness for daily precipitation, and probabilities of wet day following a dry day or a wet day required as input by the weather generator file in SWAT. The analyzed data is presented in **Table 5.2** as mean monthly series.

5.3.8.2 Hydrological and Sediment Yield data processing

The daily observed discharge data (m^3/sec) for the study area at the outlet were converted to the depth (mm) of runoff by watershed area approach. For separating out the baseflow from the total runoff an automated baseflow filter program developed by J.G. Arnold was used. The observed sediment yield data (t/day) were converted into tons per hectare (t/ha) using the watershed area. The separated surface runoff and sediment yield values were later compared with the simulated values.

5.3.8.3 Soil analysis

Soil plays an important role in modeling the various hydrological processes. In the AVSWAT model various soil physico-chemical properties like soil texture, hydraulic conductivity, organic carbon content, bulk density, available water content are required to be analyzed to make as an input in the model for simulation purpose. In the present study 32 undisturbed soil samples were collected from a depth of 0-15 cm and 15-30 cm using core samplers at different locations of the basin for determination of the physico-chemical properties required by the model. While carrying out the soil sampling the soil map prepared by NBSSPUP was used as a base map. The collected soil samples were then analysed in a standard soil laboratory. Standard procedures like International Pipette Method for determination of soil texture, Tube Core method for bulk density, Constant Head method for Hydraulic conductivity and Titrimetric method for determination of carbon content were used for analysis of the soil samples. The available water content was calculated by subtracting the field capacity and wilting point which was determined using pressure plate apparatus. Based on the analysis it was observed that the soil texture for the study area was mostly clayey soil and falls in the hydrologic soil group D. The analysed soil physico-chemical properties for the Kulsi Basin is presented in **Table 5.3**.

5.4 AVSWAT model set-up and Simulation of Hydrological Processes

The following steps were followed to set-up the model and load the input databases

- Watershed Delineation
- Landuse and soil characterization
- Climate Data Definition
- Editing Input Information
- Automatic Calibration followed by validation

5.4.1 Watershed Delineation

AVSWAT automatically delineates a watershed into subwatersheds based on DEM and drainage network. The standard methodology, based on the eight –pour algorithm (Jensen and Domingue, 1988) is applied for automatic delineation. The DEM with a pixel size of 30m prepared under the ISRO GBP project was loaded to the AVSWAT model in a ArcInfo grid format.After the DEM was imported in the model a masking polygon of the study area was created in a ArcInfo grid format and was loaded in the model in order to extract out only the area of interest. Also the digitized stream network file in shape (.shp) format was imported in the model. The DEM was then preprocessed in order to determine the size and number of sub watersheds based on the threshold area or critical source area. The critical source area is the minimum drainage area required to form the origin of a stream. In the present study the minimum threshold area was taken to be 3000 ha which formed 29 sub watersheds. Once the watershed and sub-watersheds boundaries are delineated, all the geometric parameters of each sub-watersheds and stream reaches are calculated (**Appendix III**) and stored as vector themes (.shp format). The area delineated by the AVSWAT interface was found to be 1520.18 sq.km against the manually delineated area of 1593.17 sq.km. The error of calculation was found to be 4.58%. The automatically delineated watershed with its sub watershed is shown in fig 5.11. It can be observed that the automatically delineated watershed closely matches with the manually delineated except at few places, which might be due to the inaccuracy

Table 5.2: Monthly Weather Statistics of Kulsi Basin

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
TMPMX	19.30	21.37	25.40	27.33	27.07	27.43	27.73	27.90	27.40	25.83	22.73	20.43
TMPMN	7.03	9.37	13.23	16.90	18.77	20.73	21.57	21.33	20.30	17.17	13.17	8.40
TMPSTDMX	1.74	1.94	2.42	2.52	2.18	2.35	1.82	1.80	2.18	1.98	1.72	1.47
TMPSTDMN	1.70	1.73	2.22	1.78	1.54	1.13	0.90	0.88	1.00	1.54	1.96	1.63
PCPMM	6.33	13.70	36.18	151.93	253.34	367.66	428.83	285.50	187.41	221.32	25.93	14.47
PCPSTD	0.68	1.81	2.98	9.01	13.82	18.48	21.74	14.21	11.66	21.53	2.25	1.56
PCPSKW	1.15	2.37	2.54	2.34	1.96	1.84	1.91	1.68	2.19	2.62	2.74	2.3
PCPD	4	4	6	12	17	20	23	21	16	10	3	3
PR_W1	0.08	0.07	0.11	0.24	0.44	0.51	0.58	0.52	0.44	0.19	0.11	0.08
PR_W2	0.50	0.67	0.55	0.61	0.65	0.70	0.77	0.74	0.66	0.57	0.52	0.50
PCPD	4	4	6	12	17	20	23	21	16	10	3	3
WNDAV (m/s)	0.67	0.78	1.16	1.45	1.18	0.96	0.66	0.65	0.57	0.53	0.51	0.58
SOLARAV ($MJ/m^2/d$)	11.30	16.27	19.10	20.53	19.13	15.9	14.67	15.13	14.90	15.37	14.47	13.37
DEWPT(^0C)	12.70	13.43	15.23	19.82	23.07	25.30	25.87	25.89	24.98	22.89	19.04	14.73

Where,

TMPMX: Ave. maximum air temperature for month (^oC)

TMPMN: Ave. minimum air temperature for month (^oC)

TMPSTDMX: Standard deviation maximum air temperature for month (^oC)

TMPSTDMN: Standard deviation minimum air temperature for month (^oC)

PCPMM: Ave amount of precipitation falling in the month (mm)

PCPSTD: Standard deviation for daily precipitation in the month

PCPSKW: Skew coefficient for daily precipitation in the month

PCPD: Average number of days of precipitation in month

PR_W1: Probability of wet day following a dry day in month

PR_W2: Probability of wet day following a wet day in month

PCPD: Ave. number of days of precipitation in the month

SOLARAV: Ave daily solar radiation in the month ($MJ/m^2/d$)

DEWPT: Ave. dew point temperature in the month (^0C)

WNDAV: Ave. wind speed for the month (m/sec)

Table 5.3: Physico-Chemical Properties of Soil for Kulsi River Basin

Sl. No.	Sample No.	Organic Carbon(%)	BD (gm/cm^3)	AWC (mm water/mm soil)	Hydraulic Conductivity(mm/hr)	Rock fragment(%)	Clay(%)	Silt(%)	Sand(%)	Texture	K_usle
1	S1(a)	1.35	1.53	0.1151	1.39	23.71	48	15	37	C	0.11
	S1(b)	2.55	1.42	0.1148	1.36	13.35	50	14	36	C	0.09
2	S2(a)	1.39	1.5	0.1278	1.78	16.64	43	24	33	C	0.12
	S2(b)	2.75	1.19	0.1253	1.64	10.14	58	17	25	C	0.09
3	S3(a)	2.91	1.79	0.1192	1.68	22.42	42	20	38	C	0.10
	S3(b)	0.95	1.48	0.1204	1.45	34.33	50	17	33	C	0.12
4	S4(a)	2.55	1.3	0.1127	1.31	11.8	52	12	36	C	0.09
	S4(b)	2.31	1.3	0.1027	1.54	18.64	40	12	48	SC	0.09
5	S5(a)	2.47	1.69	0.1044	1.45	28.43	42	12	46	SC	0.09
	S5(b)	1.15	1.58	0.1132	1.36	23.77	48	12	38	C	0.11
6	S6(a)	3.59	1.38	0.1161	1.43	29.46	47	16	37	C	0.10
	S6(b)	2.43	1.17	0.1119	1.3	24.6	51	12	37	C	0.09
7	S7(a)	4.19	1.27	0.1089	1.46	17.76	44	13	43	C	0.09
	S7(b)	1.75	1.32	0.1028	1.69	29.99	38	13	49	SC	0.10
8	S8(a)	1.27	1.77	0.1123	1.37	26.89	47	14	39	C	0.11
	S8(b)	0.5	1.35	0.1208	1.45	22.89	53	16	31	C	0.12
9	S9(a)	2.79	1.51	0.1124	1.44	20.28	45	15	40	C	0.10
	S9(b)	1.59	1.75	0.1368	1.8	19.63	54	25	21	C	0.11
10	S10(a)	1.95	1.57	0.1148	1.36	16.61	50	14	36	C	0.09
	S10(b)	1.71	1.71	0.1089	1.46	24.91	43	14	43	C	0.10
11	S11(a)	2.43	1.63	0.1124	1.44	18.02	45	15	40	C	0.10
	S11(b)	2.39	1.62	0.1133	1.42	19.25	46	15	39	C	0.10
12	S12(a)	1.83	1.72	0.1098	1.43	15.98	44	14	42	C	0.10
	S12(b)	2.03	1.46	0.1078	1.41	25.5	44	13	43	C	0.09
13	S13(a)	2.47	1.5	0.1088	1.38	15.92	45	13	42	C	0.09
	S13(b)	2.11	1.43	0.129	1.83	12.19	60	19	21	C	0.10
14	S14(a)	1.91	1.54	0.1203	1.53	21.25	58	14	28	C	0.09
	S14(b)	2.91	1.69	0.1172	1.38	13.46	53	14	33	C	0.09
15	S15(a)	2.23	1.54	0.1159	1.39	28.98	49	15	36	C	0.09
	S15(b)	2.11	1.33	0.1114	1.39	29.27	46	14	40	C	0.09
16	S16(a)	1.82	1.48	0.1161	1.43	27.32	47	18	37	C	0.1

	S16(b)	1.55	1.52	0.1239	1.71	27.8	43	24	35	C	0.12

in the DEM or incapability of the model to exactly delineate the watershed.

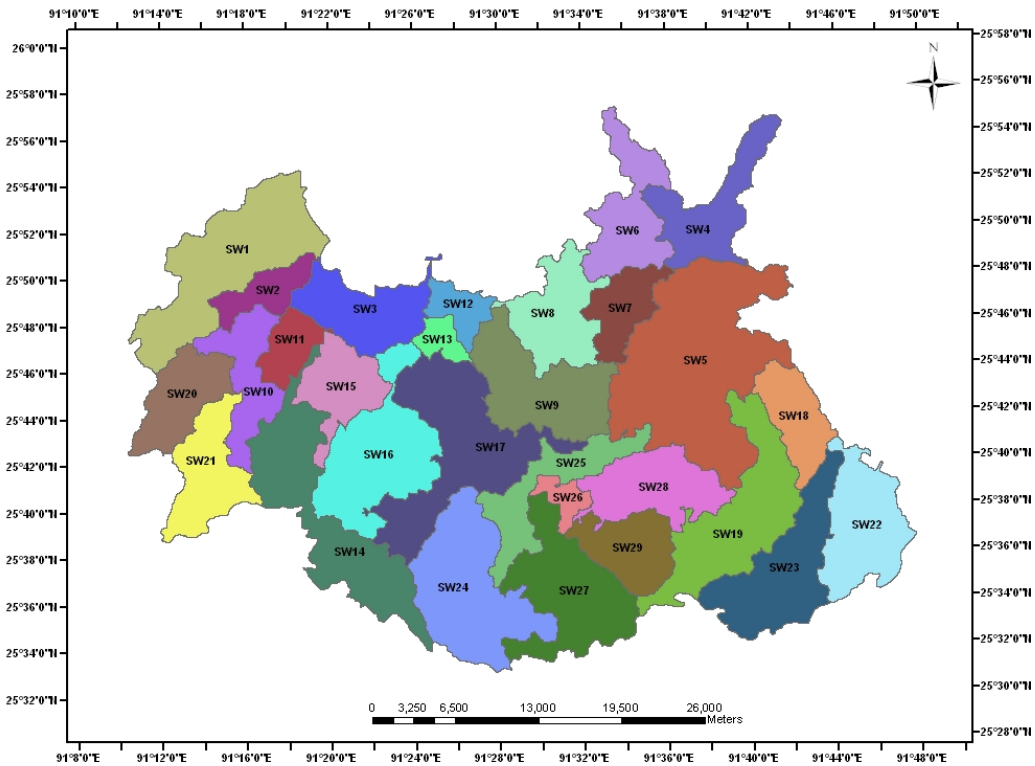


Fig.5.11: Map showing automatically delineated watershed along with its subwatersheds

5.4.2 Land use and Soil Characterization

Soil and Vegetation cover plays a significant role in the water movement process. Since the infiltration capacity of soil depends on the soil texture the highest infiltration rates are observed in sandy soils. This indicates that surface runoff is highest in clay or loamy soils which has low infiltration rates. Vegetation on the other hand acts as a barrier to flow of water. Dense vegetation covers the soil from raindrop impact and reduces the problems of erosion.

In the present study the prepared landuse and soil maps were converted into ArcInfo Grid format using ERDAS Imagine software and was imported in the AVSWAT model. Both the landuse and soil map were made to overlay and was then subdivided into hydrologic response units (HRU) based on the landuse and soil types. Subdividing the areas into areas into hydrologic response units enables the model to reflect the evapotranspiration and other hydrologic conditions for different landcover/crops and soils (Neitsch,2002).

5.4.3 Climate Data

One of the main sets of input for simulating the hydrological processes in SWAT is climate data. Climate data input consists of precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity and the weather generator file. The climate data for study periods were prepared in .dbf format and then imported in the SWAT model

5.4.4 Editing Input Information

After importing the climatic data, the next step is to set up a few additional inputs for running the SWAT model. These inputs were management data, soil data, soil chemical data, manning's roughness coefficient for overland flow and instream water quality parameters. These input files were set up and edited as per the requirement and objective of the project. In the management data file runoff curve numbers for Indian conditions (**Table 5.4**) as well as those prescribed in SWAT user manual were adopted for different landuse classes based on the landuse type and hydrologic soil group (HSG). Finally the SWAT model was run to simulate the various hydrological components.

Table 5.4: Runoff curve numbers for hydrologic soil cover complexes for the Indian conditions (AMC II)

Sl. No.	Land use	Treatment/ Practices	Hydrologic Condition	Hydrologic Soil Group			
				A	B	C	D
1.	Cultivated	Straight row	………..	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured & terraced	Poor	66	74	80	82
			Good	62	71	77	81
		Bunded	Poor	67	75	81	83
			Good	59	69	76	79
		Paddy (rice)	…………	95	95	95	95
2.	Orchards	With under stony cover	…………	39	53	67	71
		Without under stony cover	…………	41	55	69	73
3.		Dense	…………	26	40	58	61
		Open	…………	28	44	60	64
		Degraded forest/shrubs	…………	33	47	64	67
4.	Pasture		Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5.	Wasteland		…………	71	80	85	88

6.	Hard Surface		………..	77	86	91	93

(*Source: Handbook of Hydrology, Ministry of Agri. and Cooperation, Govt. of India (1972))*

5.5 Model Calibration

Calibration is the process whereby selected parameters and variables of the model are adjusted to make the model output match observations. Its main purpose, therefore, is to obtain an economical and reproducible method of identifying a parameter set for a particular catchment under particular conditions which gives the best possible fit between the simulated and observed streamflows for a particular calibration i.e. the calibrated parameter set aims at minimizing the difference between simulated and observed streamflows. Calibration is considered to be necessary because there may be uncertainties in the model input and because models give only simplified representations of the catchment's physical processes, which operate at a range of scales which are not always compatible with the catchment or grid scale.

In the present study the AVSWAT model was calibrated for the year 2001 based on the observed discharge and sediment data. While calibrating the model, parameters such as Manning's 'n' for overland flow, curve number, soil evaporation compensation factor (ESCO), available water capacity (AWC) and slope of sub-basin were taken into consideration within the prescribed limit of the model.

Parameters such as revap coefficient, specific yield and revap storage were also tried to calibrate the model. However, it was observed that the model performance is not significantly affected on variation of values for these parameters. Therefore, either model default values or range of values suggested by model developers were used. Several simulations were carried out after each parameter calibration till the simulated results were in good agreement with the observed results.

5.6 Model Validation

Model validation is the process of re-running the simulation, using a different time-series for input data, without changing any parameter values which may have been adjusted during calibration. In the present study, after proper calibration the model was validated for monthly and daily surface runoff for the year 2002 and 1991. For sediment yield the model was validated only for the year 2002 only due to non-availability of sediment data.

5.7 Performance Evaluation for Models

Evaluation of models is done in order to compare how the model simulated values fits with the observed values. Evaluations of hydrologic model performance utilize a number of statistics and techniques. Usually these tools include "*goodness of fit"* or relative error measures to assess the ability of a model to simulate reality. The following graphical and numerical performance criteria were used in the present study:

1) The coefficient of determination (R^2) describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0, with higher values indicating better agreement, and is given by,

$$R^2 = \left[\frac{\sum_{i=1}^{N} \left[O(i) - O_{avg} \right] \left[S(i) - S_{avg} \right]}{\left[\sum_{i=1}^{N} \left(O(i) - O_{avg} \right)^2 \right]^{0.5} \left[\sum_{I=1}^{N} \left(S(i) - S_{avg} \right)^2 \right]^{0.5}} \right] \tag{5.7}$$

where, O(i) is the i^{th} observed parameter, O_{avg} is the mean of the observed parameters, S(i) is the i^{th} simulated parameter, S_{avg} is the mean of model simulated parameter and N is the total number of events.

2) Coefficient of simulation efficiency (C_{OE}), also known as the Nash-Sutcliffe coefficient (Nash & Sutcliffe,1970) recommended by ASCE Task Committee (1993) is the second basic goodness-of-fit criterion used to evaluate the model performance. The equations is as follows:

$$C_{OE} = 1 - \frac{\sum_{i=1}^{n} \left(Q_i - Q'_i \right)^2}{\sum_{i=1}^{n} \left(Q_i - Q \right)^2} \tag{5.8}$$

where Q_i and Q'_i are the measured discharge and computed discharge, Q is the average measured discharge values. The values for C_{OE} can be varied from 0 to 1, with 1 indicating a perfect fit. A value for C_{OE} equal to zero indicates that the model was simulating no better than using the average of the observed data.

CHAPTER VI
RESULTS AND DISCUSSION

As per the objectives of the project, the Kulsi River basin was delineated from the SOI toposheets and various thematic maps were generated as per the requirement of the AVSWAT model. The database related to climate and soils were also prepared as per the input requirement of the model. Various hydrological components like surface runoff, sediment yield, ET, PET were simulated on daily, weekly and monthly basis. The predictions of the model for weekly and monthly surface runoff and sediment yield were compared with the measured counterparts. The performance of the model was also evaluated using statistical and graphical methods to decide the capabililty of the model in simulating the runoff and sediment yield from the Kulsi basin. The findings of land use/land cover changes and its impact on the hydrological regime is also presented and discussed in this chapter

6.1 Extraction of watershed characteristics and landuse/landcover informations using RS & GIS

The Kulsi basin was delineated from seven Survey of India toposheets at 1:50,000 scale. The total area and perimeter was found to be 1593.27 sq.km and 288.56 km. Drainage map was also prepared from toposheets upto the first order level. The drainage ordering map based after Strahler (1964), shows that Kulsi basin is 7th order stream. The GIS analysis shows that 1st order streams are 3598, 2nd order streams are 1828, 3rd order streams are 838, 4th order streams are 428, 5th order streams are 315, 6th order streams are 81 and 7th order streams are 34 in number. **Table 6.1** shows the total number of streams, total stream length for each order and percentage each stream order constitute in Kulsi Basin

Table 6.1: Statistics of Streams in Kulsi Basin

Stream Order	Number of Streams	Length (km)	% constitution of each order

I	3598	2155.49	56.54
II	1828	823.64	21.61
III	838	425.05	11.15
IV	428	224.70	5.89
V	315	138.13	3.62
VI	81	32.28	0.85
VII	34	12.89	0.34
Total	**7122**	**3812.18**	**100**

Based on the above statistics morphological parameters were calculated for the study area in GIS environment. The total relief of Kulsi basin was found to 1800m. The basin also shows a high drainage density (2.39 km km^{-1}) indicating more runoff than infiltration from precipitation which indicate the hilly terrain of consolidated materials. Stream frequency, a similar measure of the stream network of a drainage basin was found out to be 4.47 indicating the area to be consolidated. The computed morphometric parameters are presented in **Table 6.2**.

Table 6.2 Morphological parameters for Kulsi Basin

Sl. No.	Morphometric Parameters	Value
1	Basin Length (L_b)	86.46 km
2.	Drainage Density (D_d)	2.39
3.	Stream Frequency (F_u)	4.47
4.	Length of Overland Flow (L_o)	1.20
5.	Form Factor (R_f)	0.21
6.	Shape Factor (B_s)	4.69
7.	Elongation Ratio (R_e)	0.52
8.	Circulatory Ratio (R_c)	0.24

6.1.1 Land use/ land cover classification

Cloud free satellite data of Landsat TM for the year 1991as well as for the year 2002 (of dates 26-11-1991 & 17-02-2002) with specifications described in table 5.1 were classified with supervised classification method using maximum likelihood classifier as discussed in chapter V and presented in figure 5.7 and 5.8. In order to check the accuracy of the classified images accuracy analysis was also carried out using accuracy assessment classifier of ERDAS using ground truth informations collected from field. Overall accuracy for the classified land use/land cover maps for the years 1991 and 2002 were found to be 82.50% and 85% (Table 6.3 & 6.4) with overall kappa (K_{hat}) statistics of 0.73 and 0.77 respectively which is well within the acceptable limit. The trend in change in land use category for both the years was then analyzed. From the analysis it has been observed that there has been a drastic change in the landuse/ landcover pattern within a span of 11 years. Area under dense forest has reduced and either it is replaced by open forest/scrubs or by agriculture (shifting cultivation). In 1991 area under dense forest was 849.38 sq. km (53.22% of total area of watershed) and it decreased to 823.17 sq.km (51.6 %) in 2002 i.e. the net loss of around 26.21 sq. km (2621 ha) which is not a healthy sign of land cover change. Although agriculture area has increased from 490.44 sq.km (30.73% of total area of watershed) to 502.33 sq.km faulty cultivation practices in the study area (Bun cultivation) can create severe erosion problems in future. The land use statistics giving percentage of area under different classes of land use for both the study years are also presented in **Table 6.5.**

Table 6.3: Error Matrix of Image Classification (Landsat TM, 1991)

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy**	**Users Accuracy**
Dense Forest	17	21	16	94.12%	76.19%
Open Forest	9	6	6	66.67%	100.00%
Agriculture	14	12	11	78.57%	91.67%
Rivers/Streams	0	1	0	-	-
Total	40	40	33		
Overall Accuracy: 82.50% K_{hat} coefficient: 0.73					

Table 6.4: Error Matrix of Image Classification (Landsat ETM, 2002)

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy**	**Users Accuracy**
Dense Forest	19	21	17	89.47%	80.95%
Open Forest	5	6	4	80.00%	66.67%

Agriculture	15	12	12	80.00%	100.00%
Rivers/Streams	1	1	1	100.00%	100.00%
Total	40	40	34	-	-
Overall Accuracy: 85% K_{hat} coefficient: 0.77					

Table 6.5: Land use/ Land cover statistics for the year 1991 & 2002

LULC	1991		2002		Difference	% Difference
	Area (sq.km)	% Area	Area (sq.km)	%Area		
Dense Forest	849.38	53.22	823.17	51.58	-26.21	-1.64
Open Forest	235.09	14.72	249.17	15.62	14.08	0.9
Agriculture	490.44	30.73	502.23	31.47	11.79	0.74
River/Streams	21.32	1.33	21.32	1.33	-	-

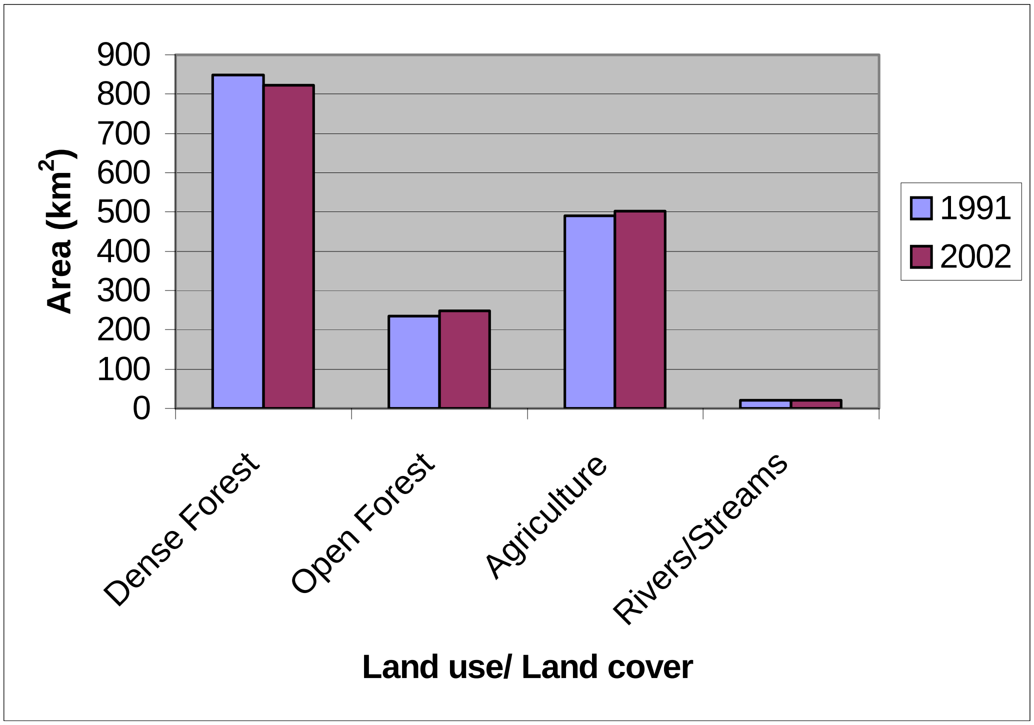


Fig.6.1: Graph showing Land use/ Land cover changes during the period 1991-2002

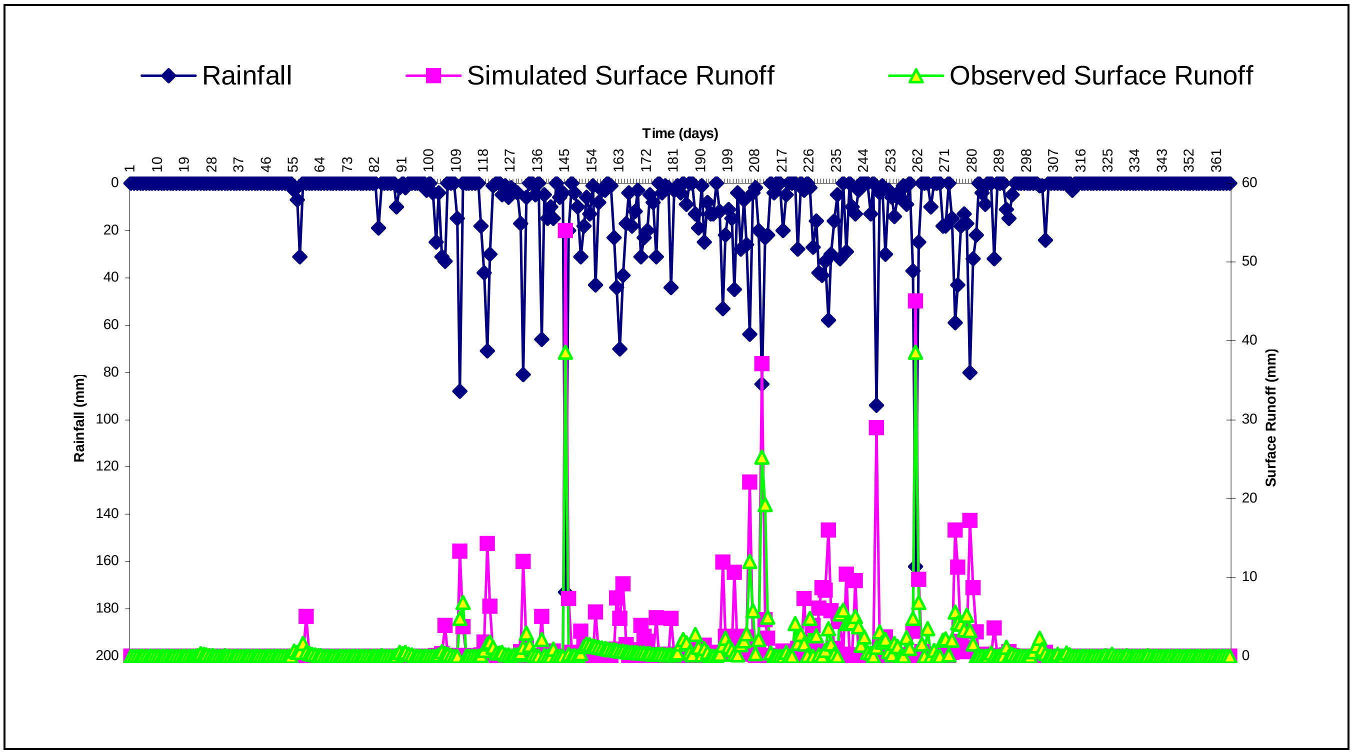
Modelling hydrological components

6.2.1Model Calibration

In the present study the AVSWAT model was calibrated for the year 2001 using the surface runoff and sediment yield data recorded at the outlet of the study area. The model was calibrated using different values of input parameters for available water content (AWC) and soil evaporation compensation factor (ESCO) within the prescribed range of the model. Though curve number is another very sensitive parameter the model was not calibrated by changing its values as standard curve numbers prescribed for Indian conditions were used for the present study. Several simulation runs were then applied until a goodness-of-fit between observed and simulated flow was obtained. In order to compare the simulated values with the observed values coefficient of determination (R^2) and Nash & Sutcliffe (R^2_{NS}) efficiency methods were applied. The calibrated parameter values for AWC and ESCO were found to be 0.025 and 0.250. respectively.

The time series of the simulated and observed surface runoff were compared graphically for daily, weekly and monthly basis. The calibration period reported an R^2 of 0.68, 0.75 and 0.82 for daily, weekly and monthly results. The Nash-Sutcliffe R^2_{NS} for daily, weekly and monthly results were found to be 0.53,0.52 and 0.56. Similar results have also been reported by Spruill et.al.,2000 during calibration process and were accepted for validation of the model. From the graphical analysis it was observed that the weekly comparison showed a better correlation then the daily values. The time series of the observed and simulated daily, weekly and monthly and surface runoff are shown in fig 6.2, fig 6.3 and fig 6.4 respectively.

An attempt was also made to calibrate for monthly sediment for the period July-December, 2001. For this calibration, the slope of the sub-basin, which is one of the most sensitive parameter for sediment load, was reduced by 22% as against the model prescribed range of -25% to +25%. The model estimation result showed a poor correlation during sediment calibration with an R^2 value of 0.36. One of the reasons may be due to the non-reliability of the observed sediment data. Another reason could be the number of delineated sub-basins as it has been observed that watershed subdivision has an effect on the sediment load (Jha et.al.,2004). The time series of observed and simulated sediment load is shown in fig 6.5.



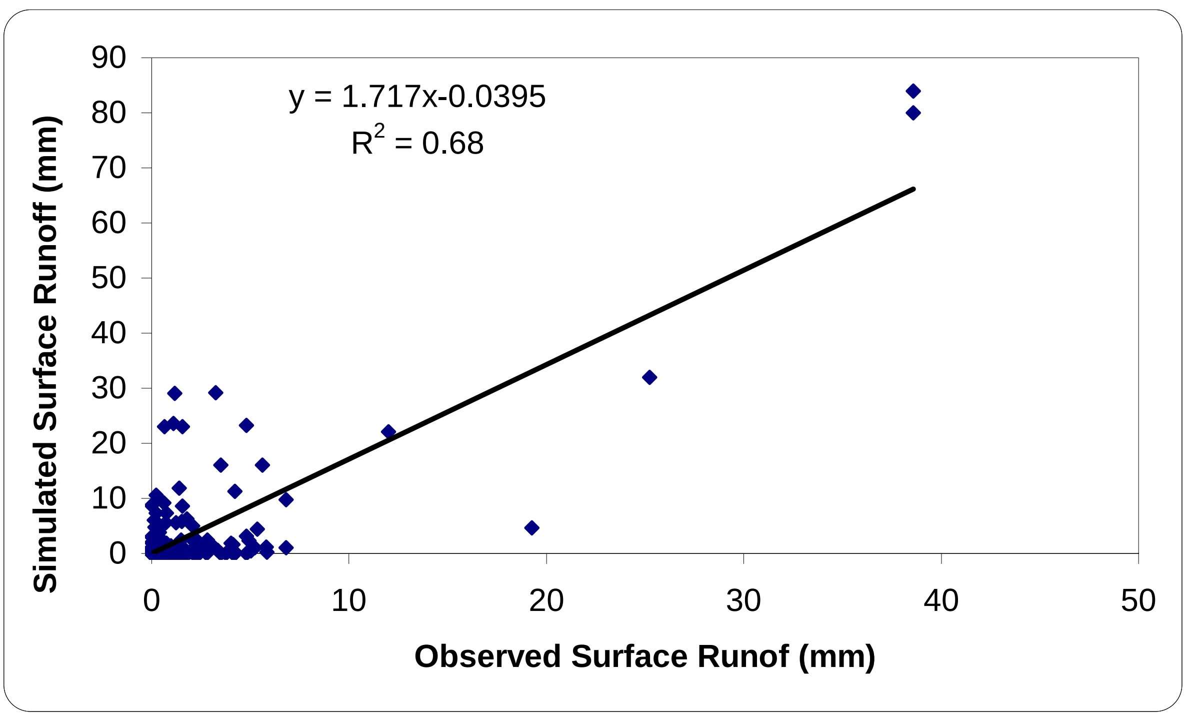
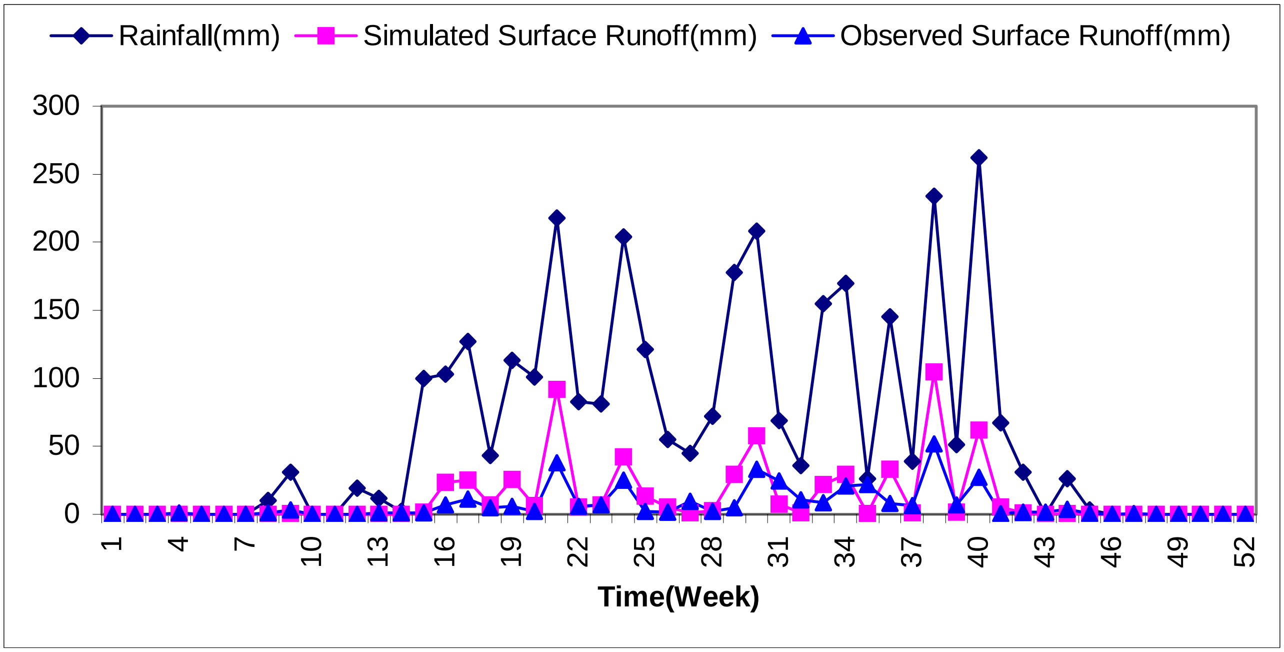


Fig.6.2: Comparison of daily observed and simulated runoff hydrograph during calibration (2001)



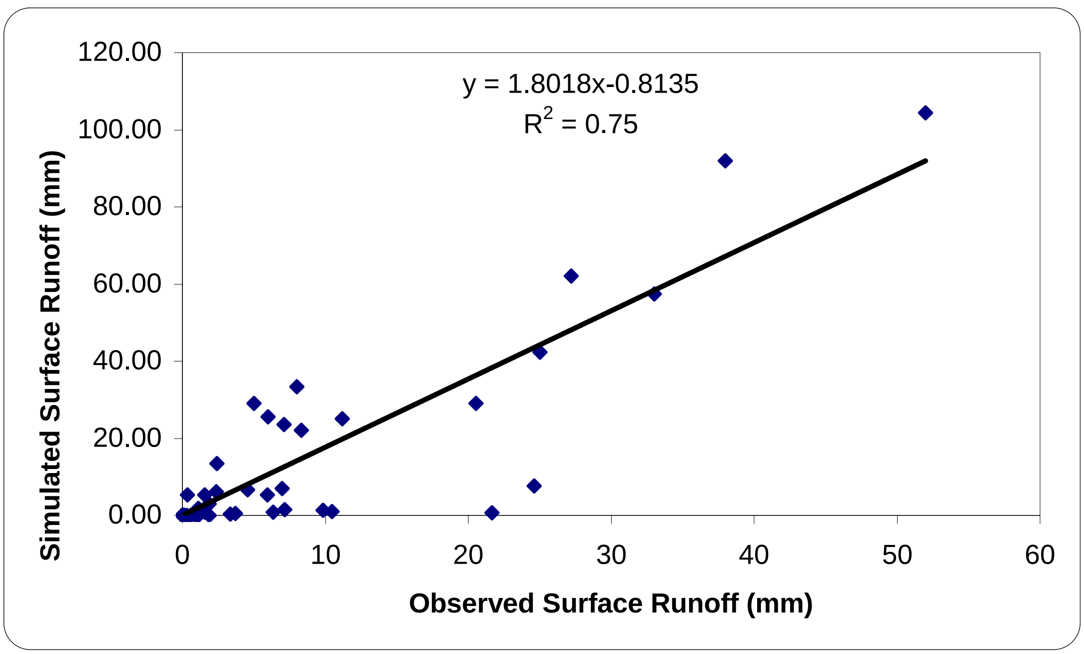
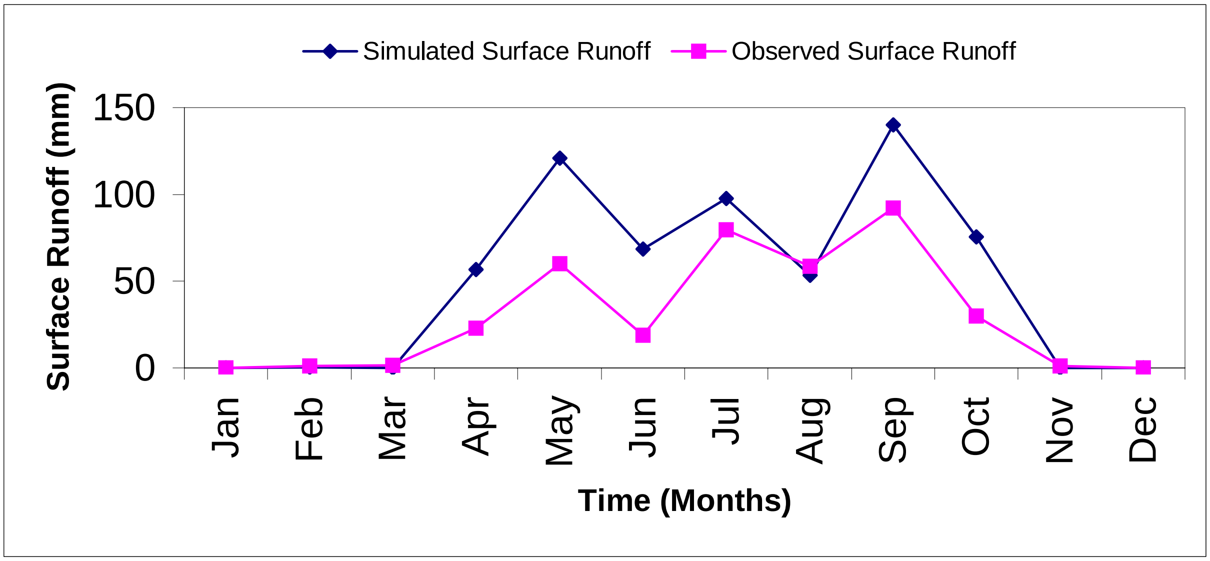


Fig. 6.3: Comparison of weekly observed and simulated runoff hydrograph during calibration (2001)



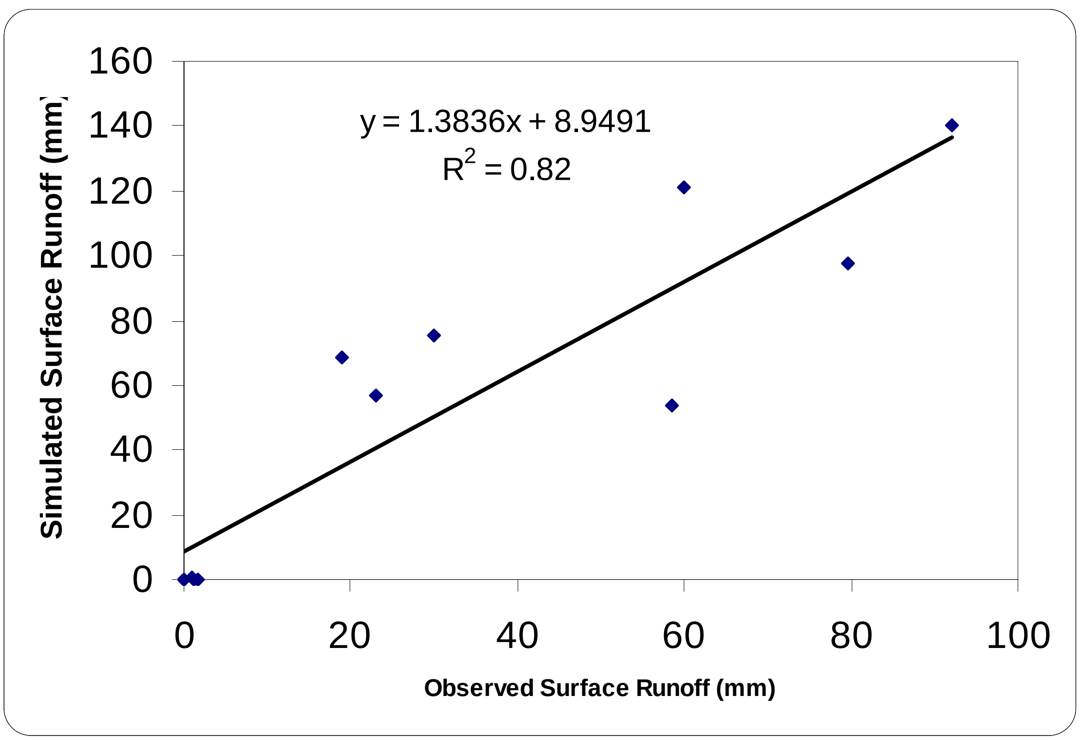
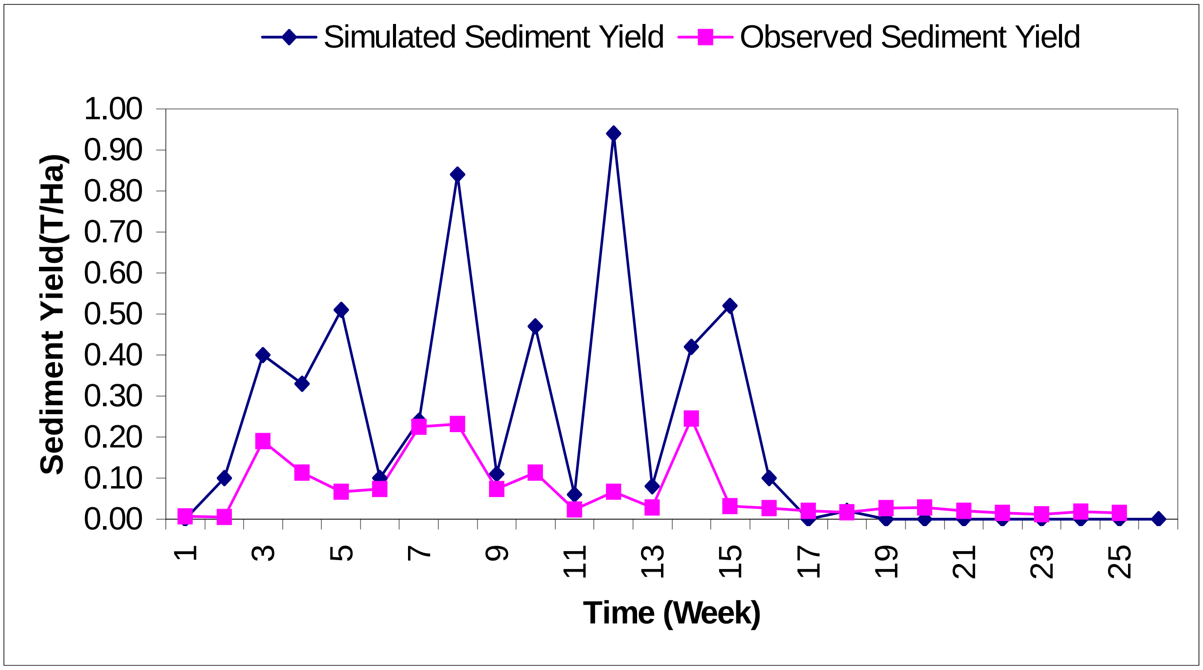


Fig.6.4: Comparison of monthly observed and simulated runoff hydrograph during calibration (2001)



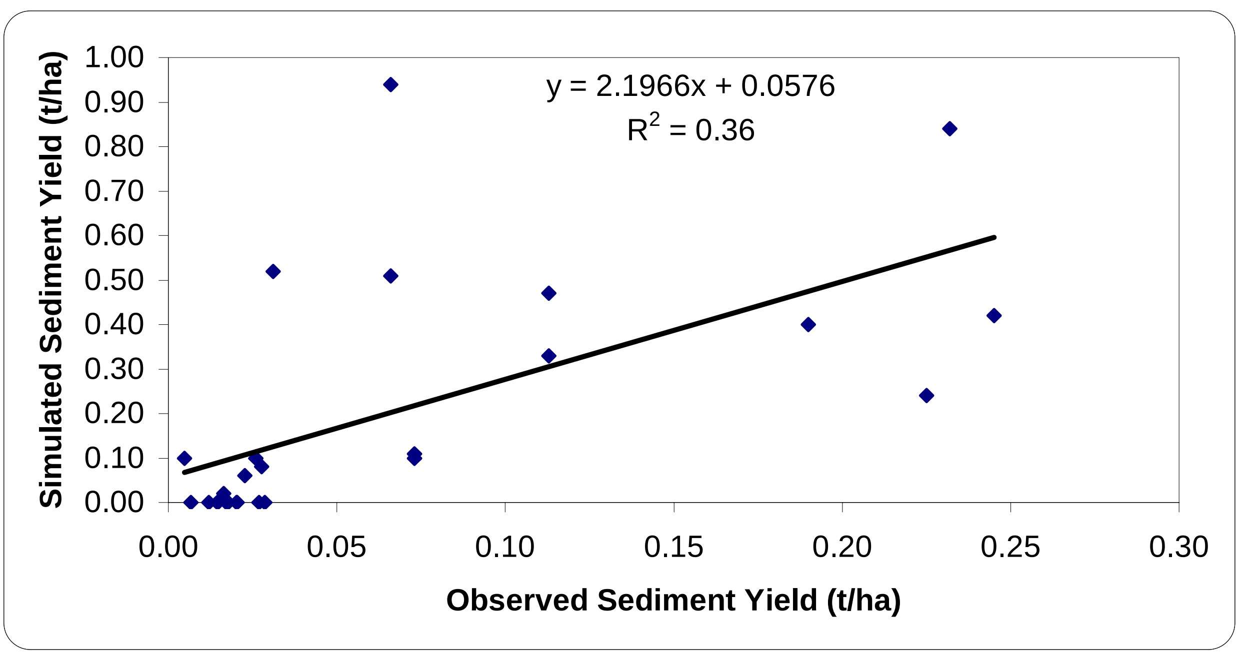


Fig.6.5: Comparison of weekly observed and simulated sediment yield during calibration (2001)

6.2.2 Model Validation

After calibration the model was validated for the daily, weekly and monthly surface runoff for the year 1991 and 2002 with the corresponding measured rainfall data.

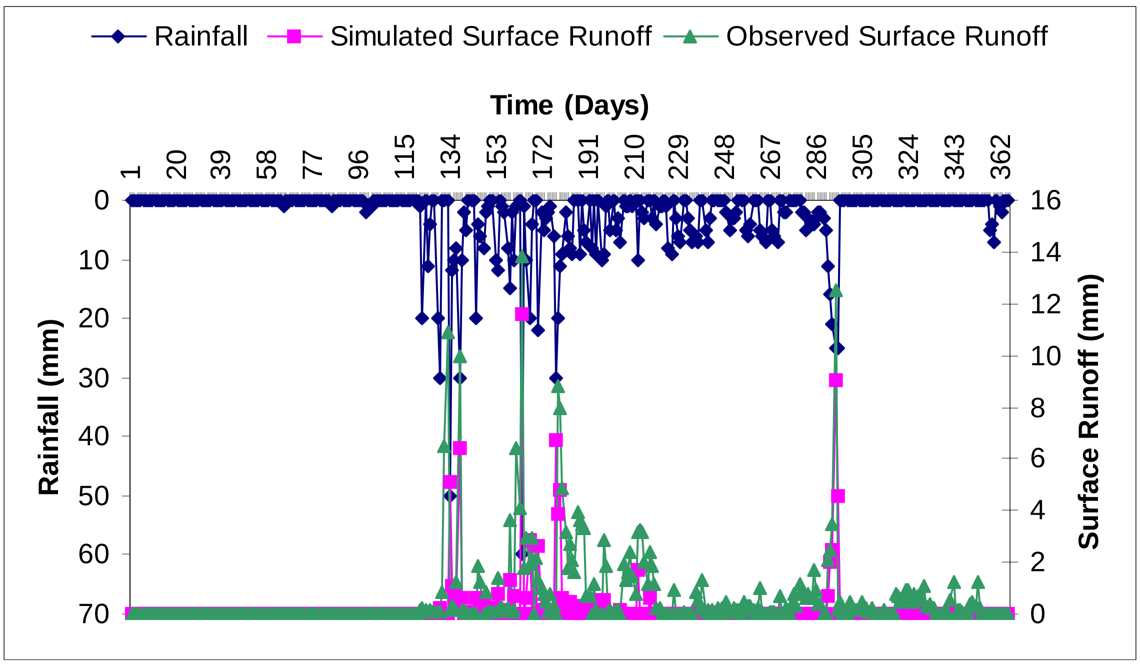
During the year 1991 the simulated runoff was 77.25mm as against the observed runoff of 224.10mm from a total rainfall of 957mm. The graphical analysis showed R^2 values of 0.43, 0.74 and 0.72 for daily, weekly and monthly runoff values for 1991 with NS values 0.57.The model mostly under predicted the daily observed values. This can be due to limited number of raingauge within the basin, as in the upper reach of the basin there is uncertainty about the rainfall data. The other reason could be the inaccuracy of the observed data as in few months surface runoff has been observed even in the absence of rainfall during a few months shown in Table 6.6.

For the year 2002 the simulated runoff was 505.61 mm as against the observed runoff of 397.95 mm out of a total rainfall of 2915.9mm. Daily comparison showed a correlation of R^2=0.47 between observed and simulated runoff as the model over predicted the daily observed values during most of the peak flows. However the model efficiency was reported to be very good (R^2_{NS}=0.93). It was however observed that the weekly and monthly comparison of observed and simulated values tends to smoothen the graph (R^2=0.79 & 0.90).

Validation was also done for weekly and monthly sediment yield for the year 2002. It was observed that the model over predicted the sediment load in most of the events. The R^2 was observed to be 0.35 and 0.19 respectively. The total simulated sediment yield was observed to be 3.88 t/ha/yr as against the observed sediment yield of 2.12 t/ha/yr.

Table 6.6: Discrepancy in Observed Surface Runoff during the year 1991

Month	Rainfall (mm)	Simulated Surface Runoff (mm)	Observed Surface Runoff (mm)
Jan	0	0	1.04
Feb	0	0	3.54
Mar	2	0	0.94
Apr	5	0	1.69
May	254	19.76	2.53
Jun	269	30.27	52.11
Jul	114	3.82	47.3
Aug	91	2.15	45.8
Sep	70	3.02	6.69
Oct	133	18.23	48.09
Nov	0	0	8.07
Dec	19	0	6.41
Total	**957**	**77.25**	**224.21**



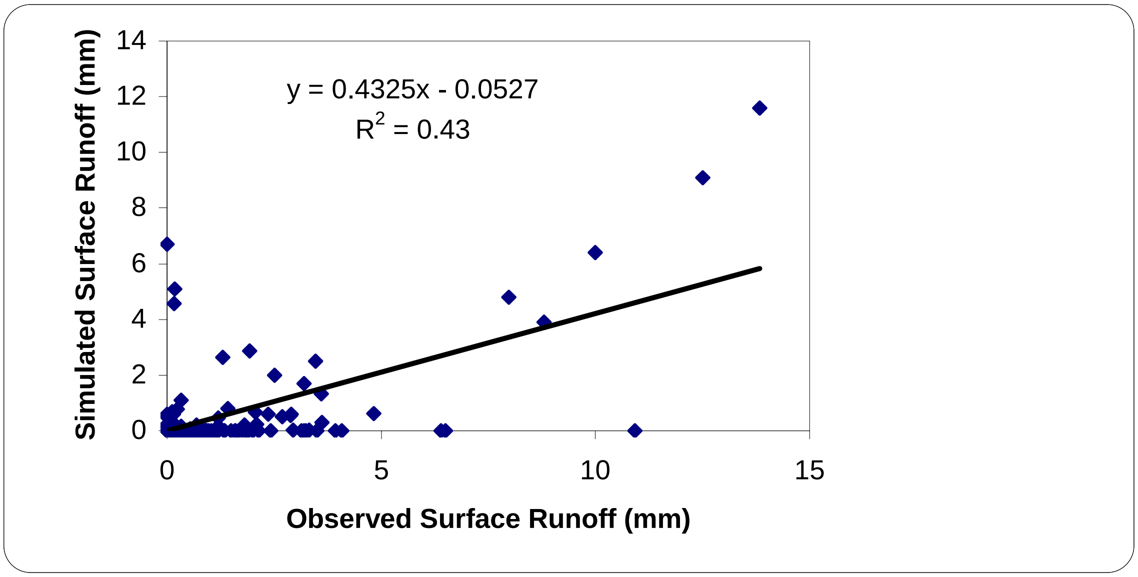
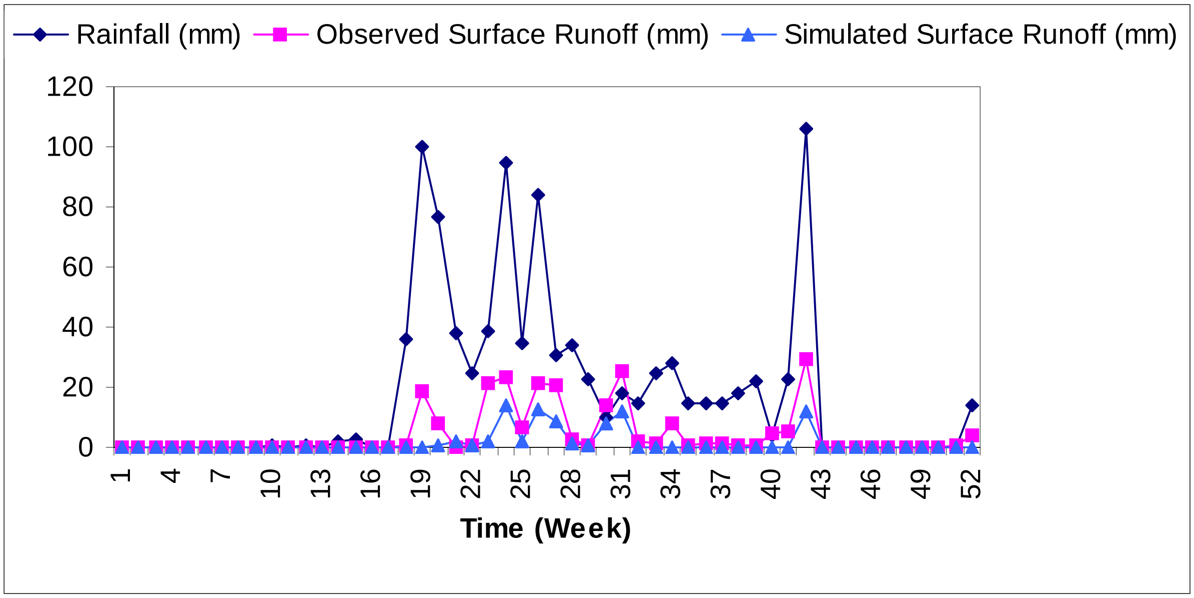


Fig. 6.6: Comparison of daily observed and simulated surface runoff hydrograph during validation (1991)



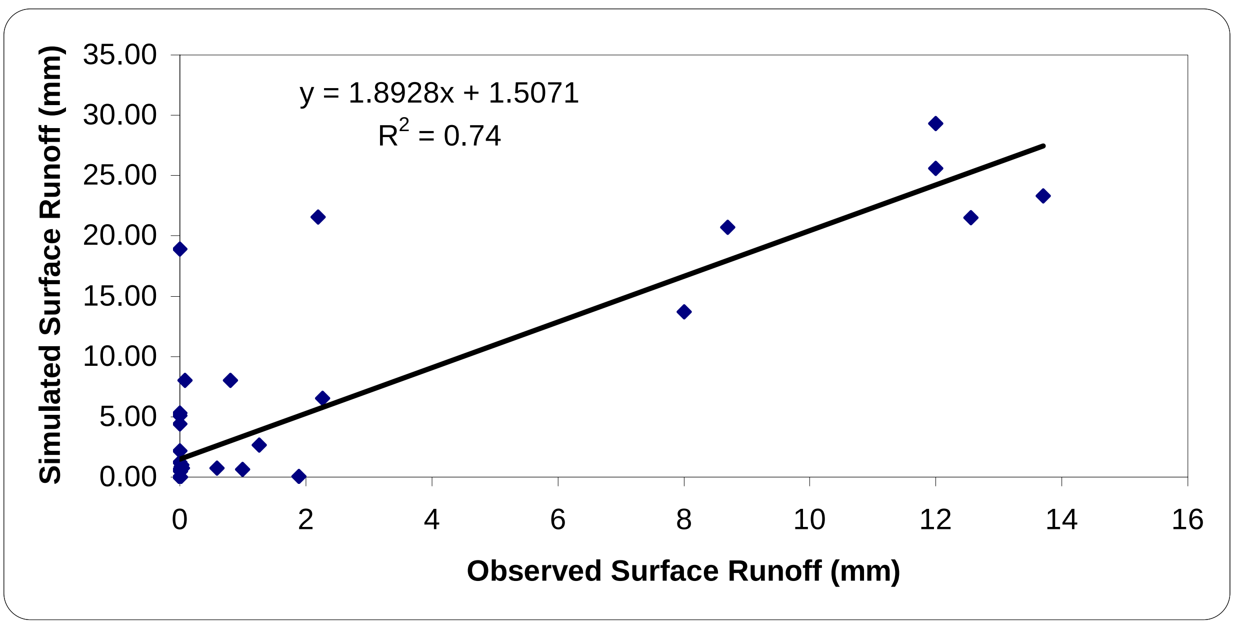
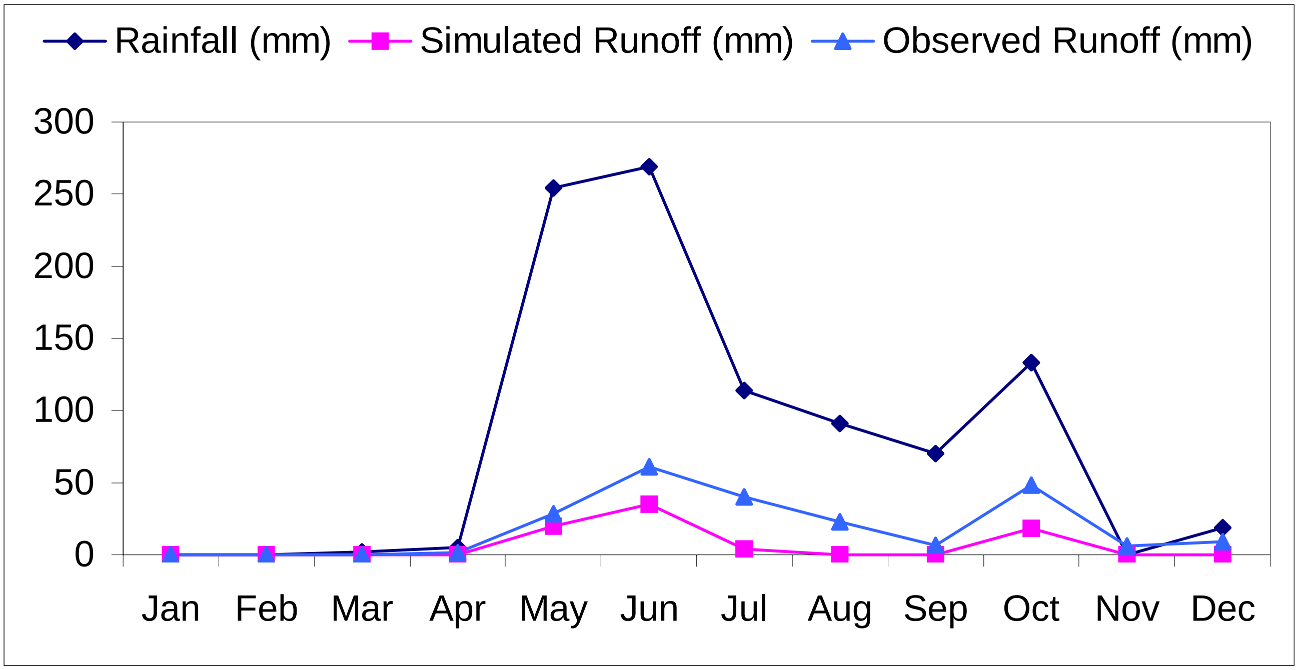


Fig. 6.7: Comparison of weekly observed and simulated surface runoff hydrograph during validation (1991)



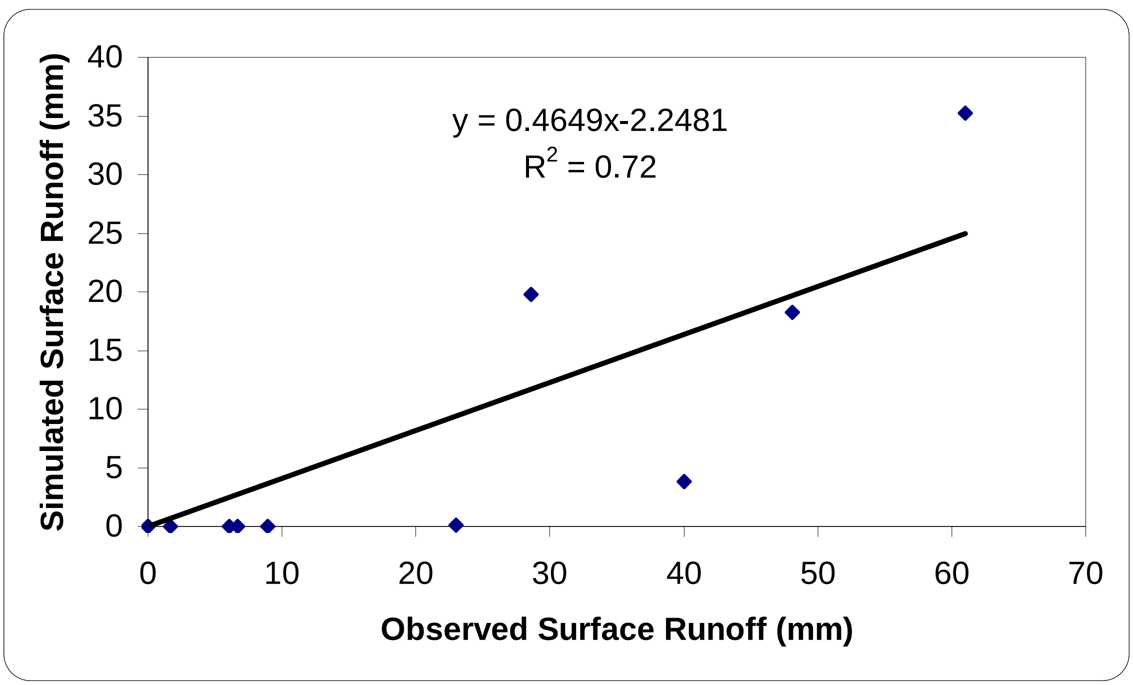
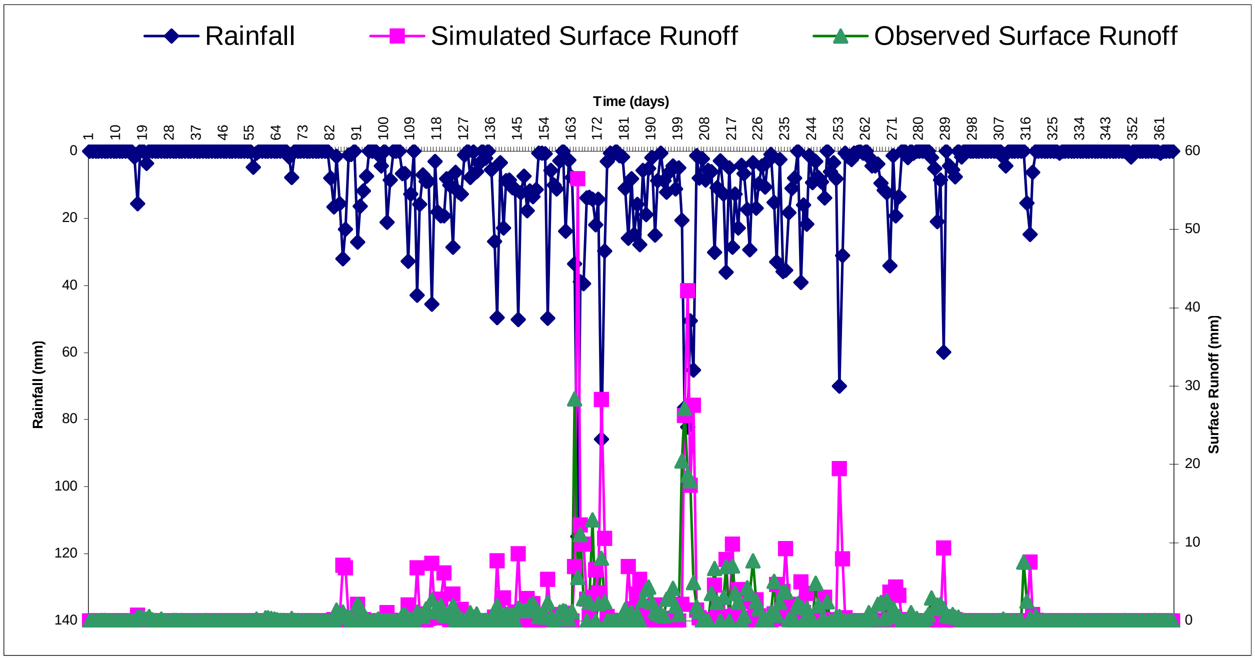


Fig. 6.8: Comparison of monthly observed and simulated surface runoff hydrograph during validation (1991)



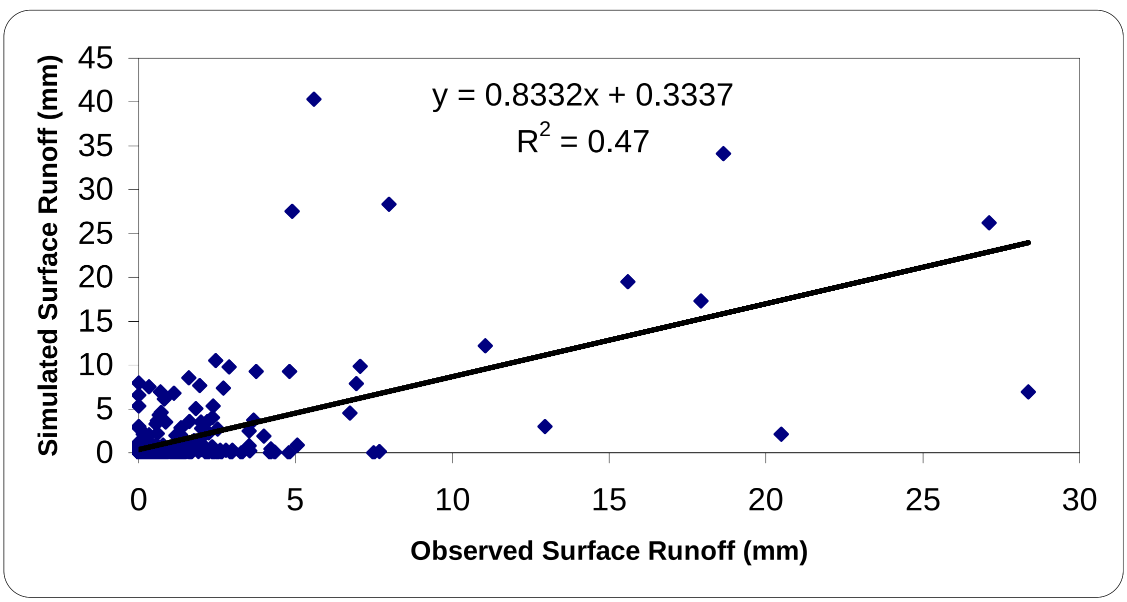
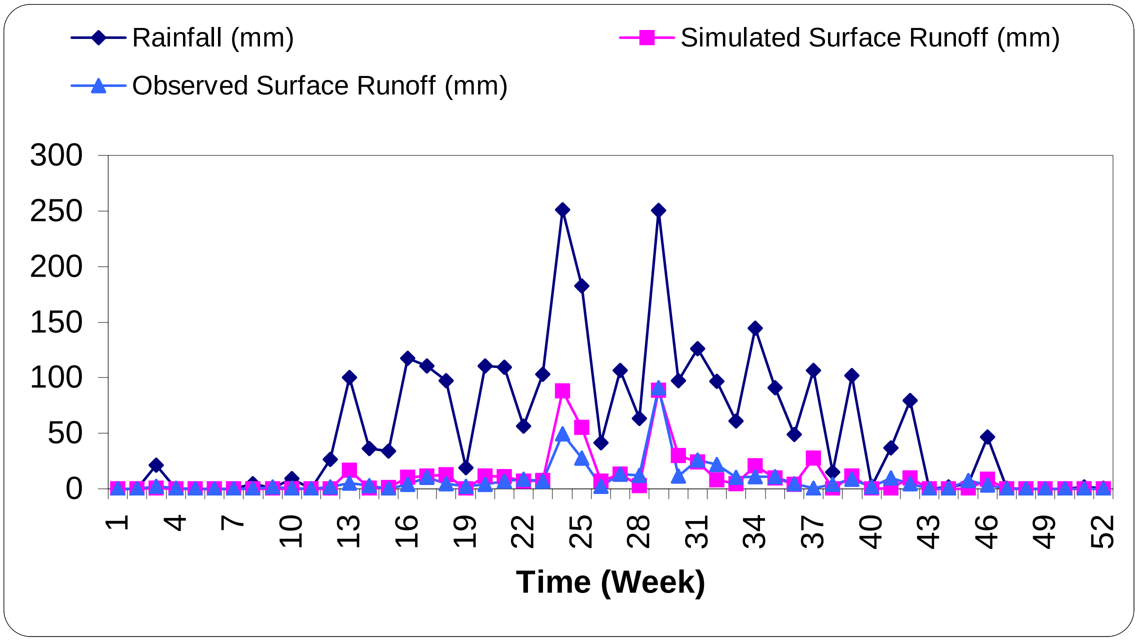


Fig.6.9: Comparison of daily observed and simulated runoff hydrographs during validation (2002)



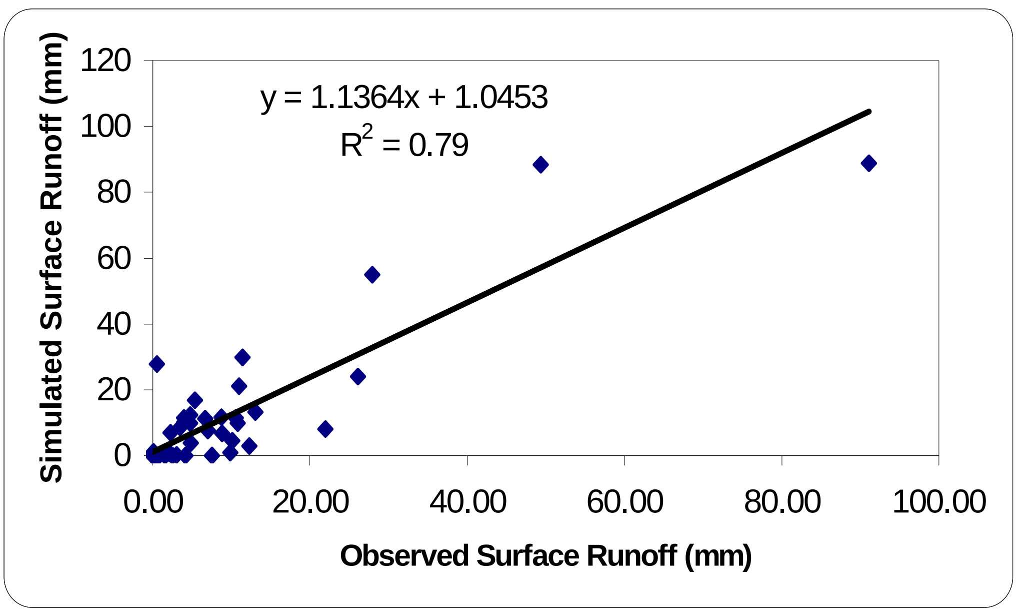
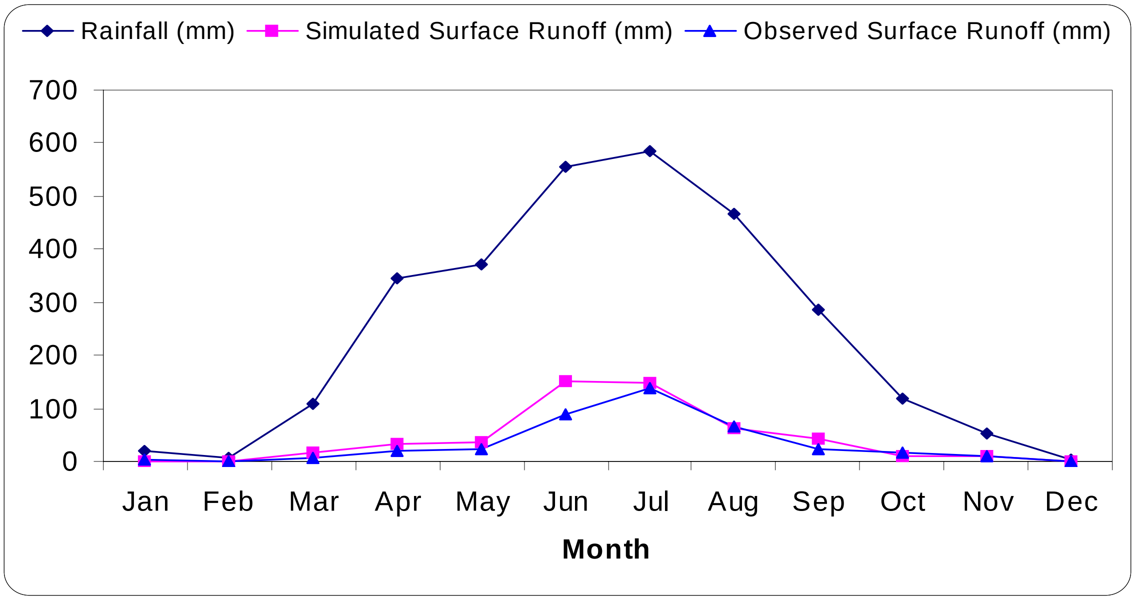


Fig.6.10: Comparison of weekly observed and simulated surface runoff hydrographs during validation (2002)



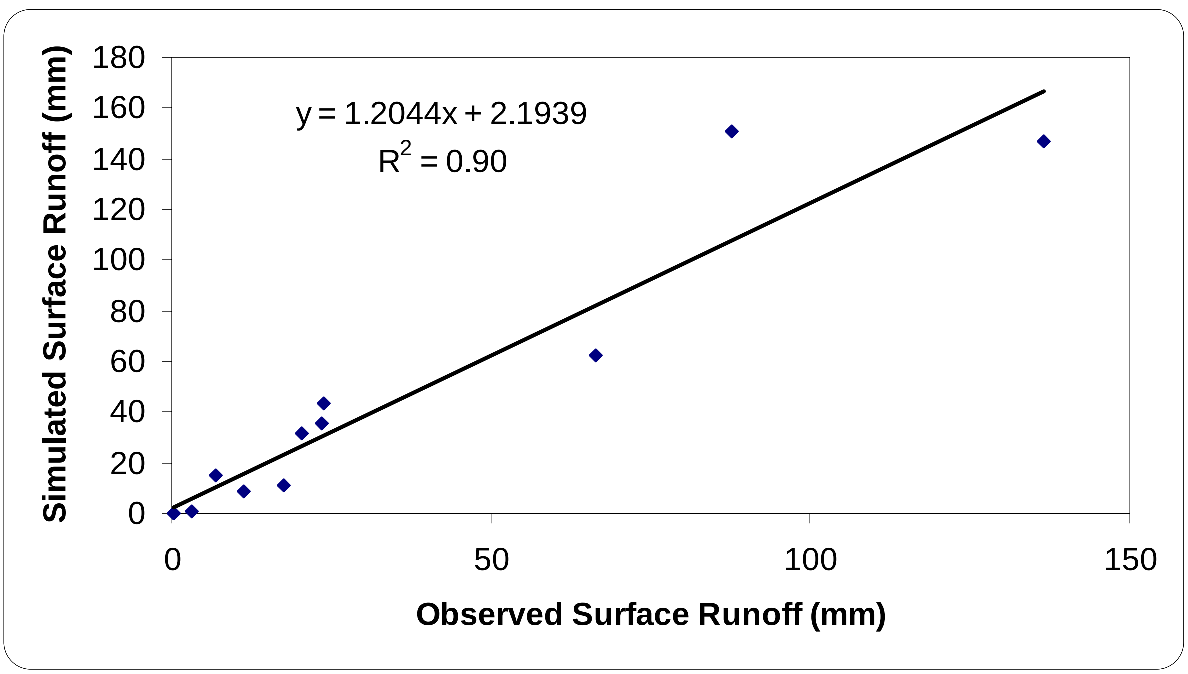
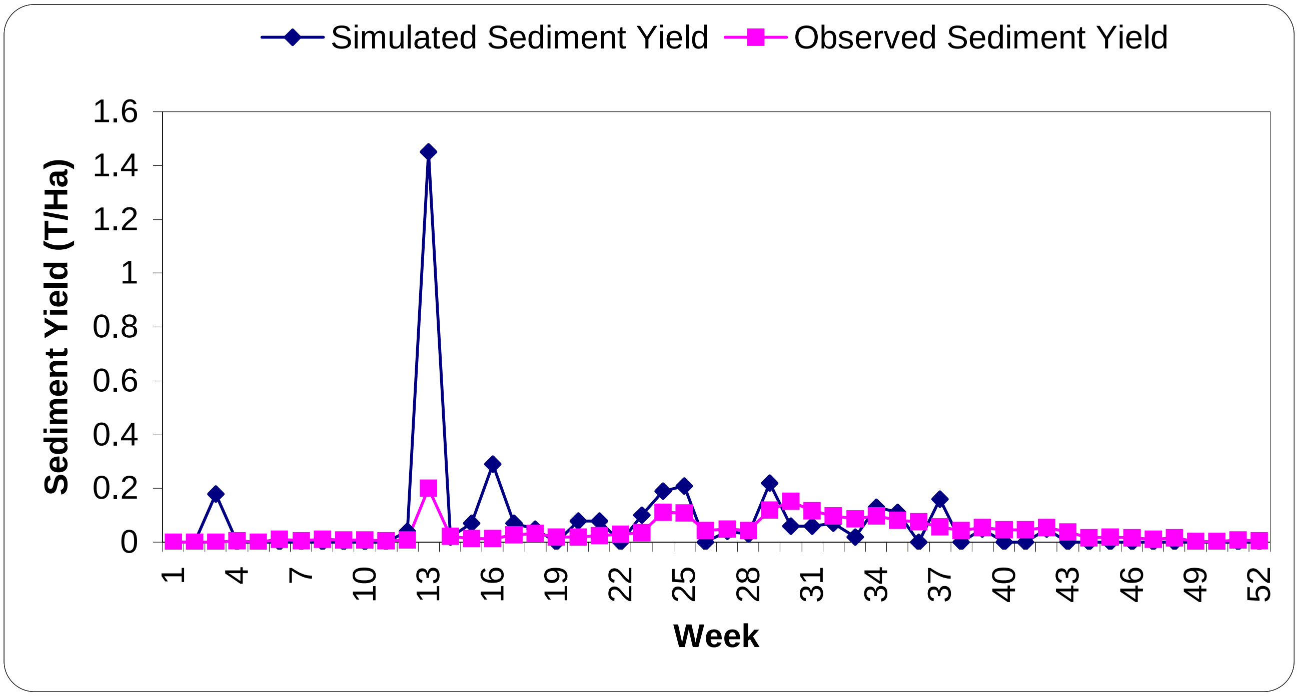


Fig.6.11: Comparison of monthly observed and simulated surface runoff hydrographs during validation (2002)



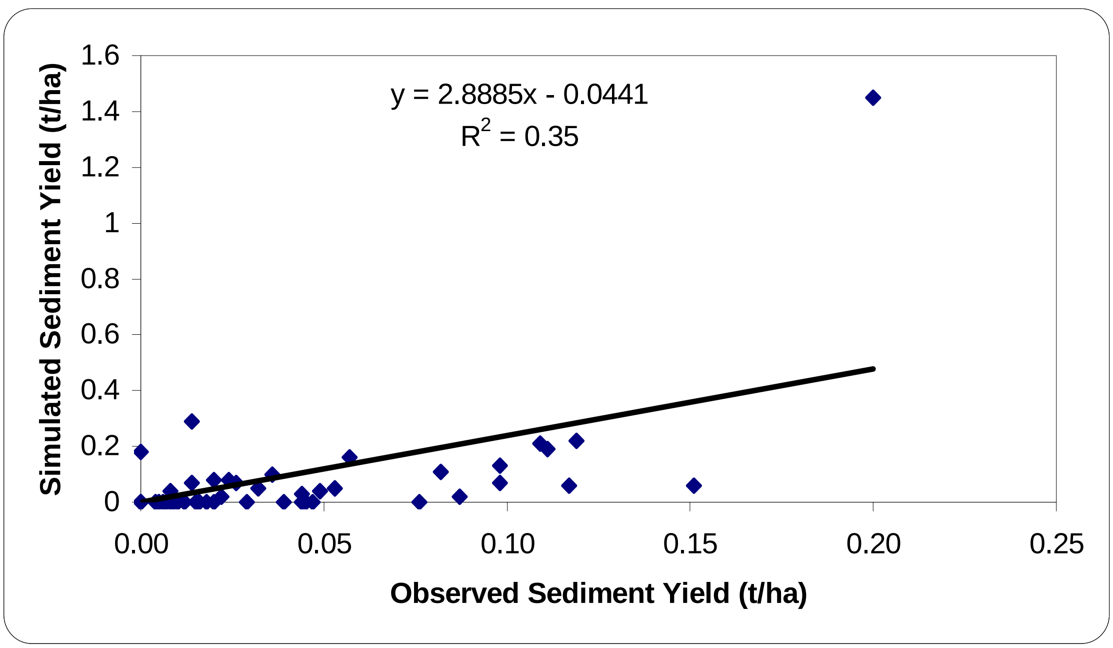
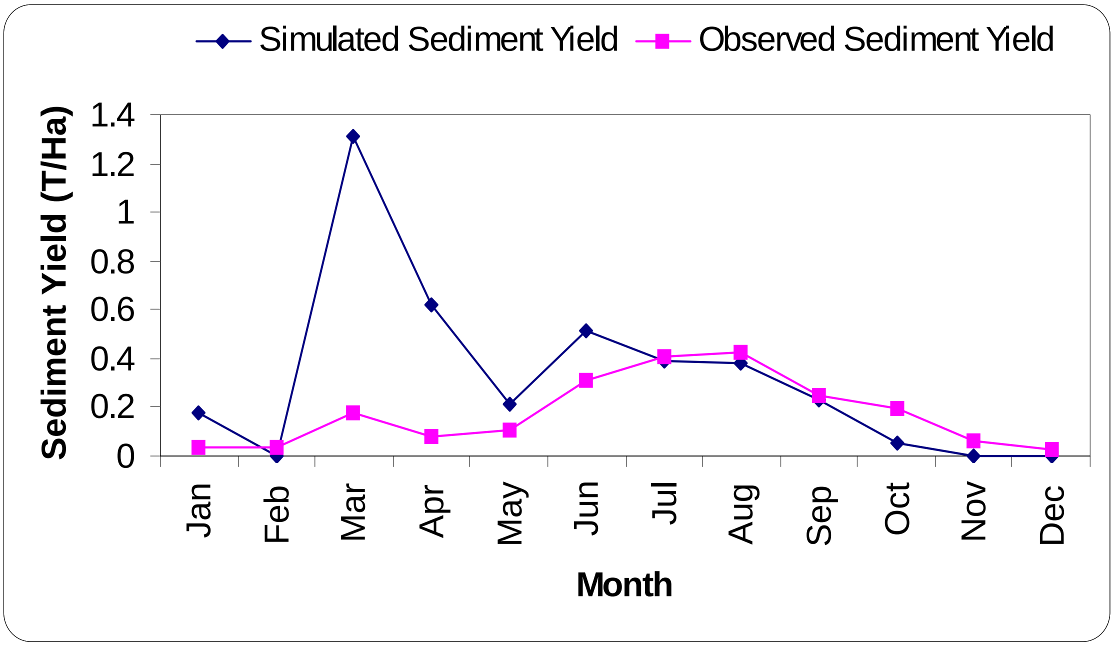


Fig.6.12: Comparison of weekly observed and simulated sediment yield during validation (2002)



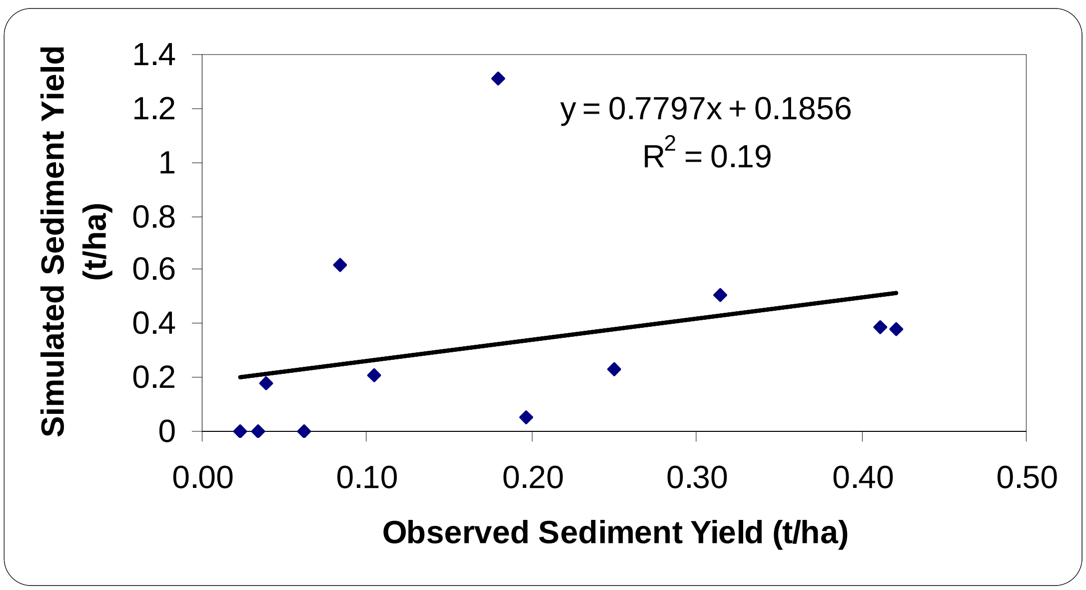


Fig.6.13: Comparison of monthly observed and simulated sediment yield during validation (2002)

Evapotranspiration was also simulated by the AVSWAT model using the Penman –Monteith method. The ET was observed to be maximum during the month of May (96.59 mm) and minimum in the month of December (13.85 mm).The weekly and monthly distribution of simulated ET and PET are presented in fig 6.15 & 6.16

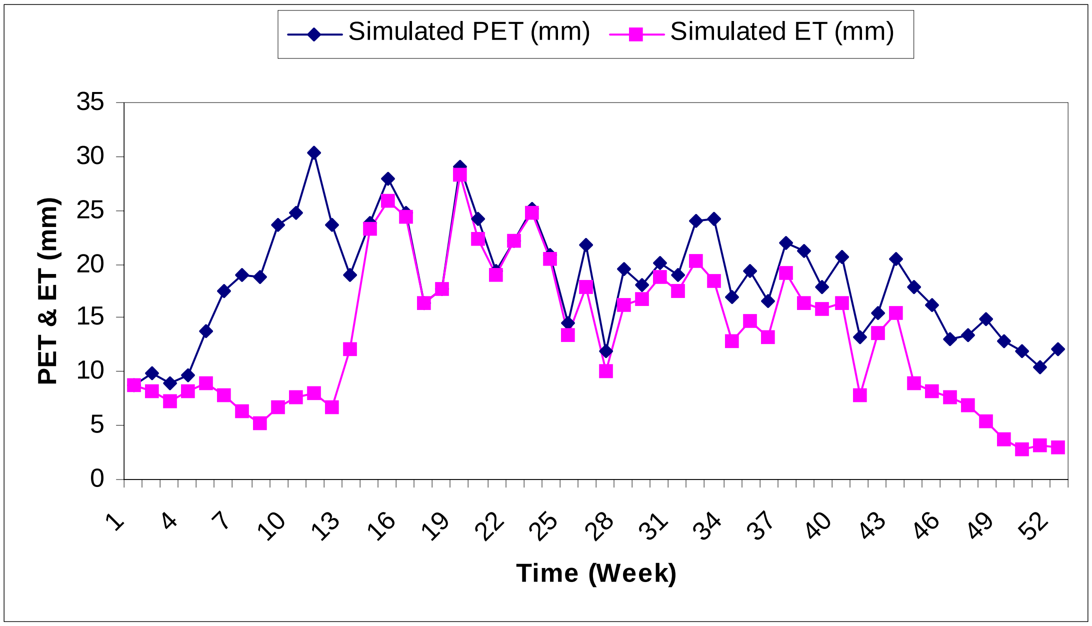


Fig.6.14: Graph showing weekly distribution of PET and ET

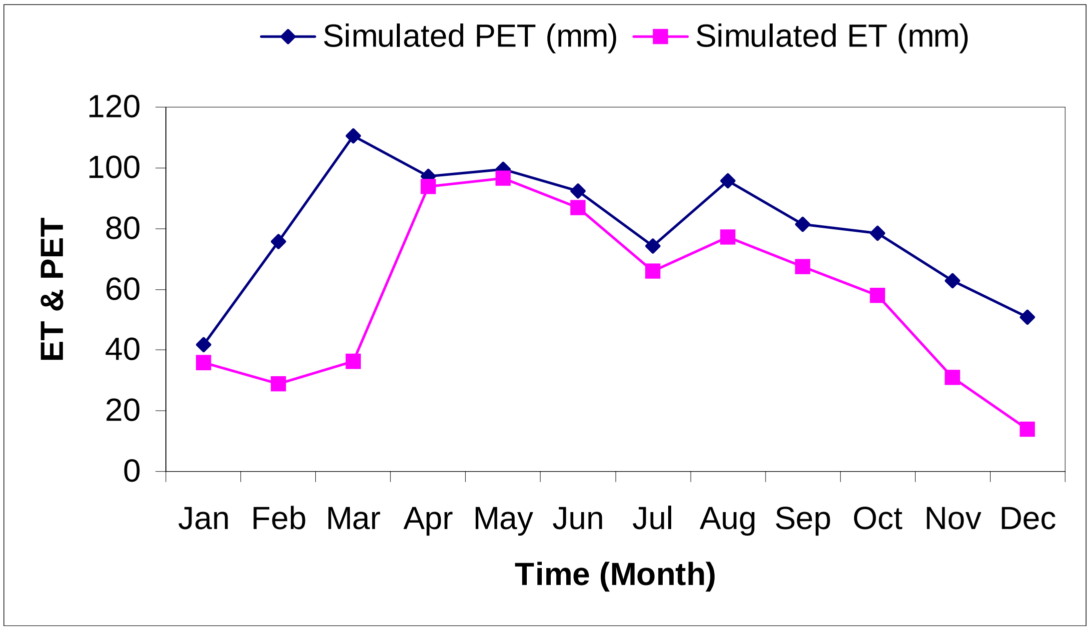


Fig.6.15: Graph showing monthly distribution of PET and ET

6.3 Impact of Land use/ Land cover on Surface Runoff and Sediment Yield

In order to study the impact of land use/landcover on surface runoff and sediment yield monthly simulated surface runoff and sediment load were compared with the observed values. During the year 1991 area under dense forest was 849.38 sq. km (53.22% of total area of watershed) and it decreased to 823.17 sq.km (51.58% of total area of watershed) in 2002 i.e. the net loss of around 26.21 sq. km (1.64% of total watershed area). The annual total runoff estimated was 75 mm for year 1991 from 957 mm of rain (a low rainfall year) and 505 mm for year 2002 from 2915 mm rain (a high rainfall year). It is clear from this that the two year comparison effect of forest is not discernible due to large variation in input i.e. rainfall. Thus, a simulation study, with 2002 rainfall that is around 45% higher than climatic mean (2000 mm) for kulsi basin was carried out for both the year. The result indicates that in 1991 the simulated runoff was 488mm and due to deforestation it has increased to505 mm. Similarly the simulated sediment yield was observed to be 3.88 t/ha in the year 2002 and 2.41 t/ha during the year 1991.Thus within a span of 11 years with a variation in the land use/ land cover a net difference of 17 mm and 1.47 t/ha/yr has been observed in surface runoff and sediment yield. From this we can conclude that change in the land use/ land cover statistics does has an impact on the hydrological behaviour of a catchment. The simulated surface runoff and sediment yield for the 1991 and 2002 are shown in figure 6.16 & 6.17.

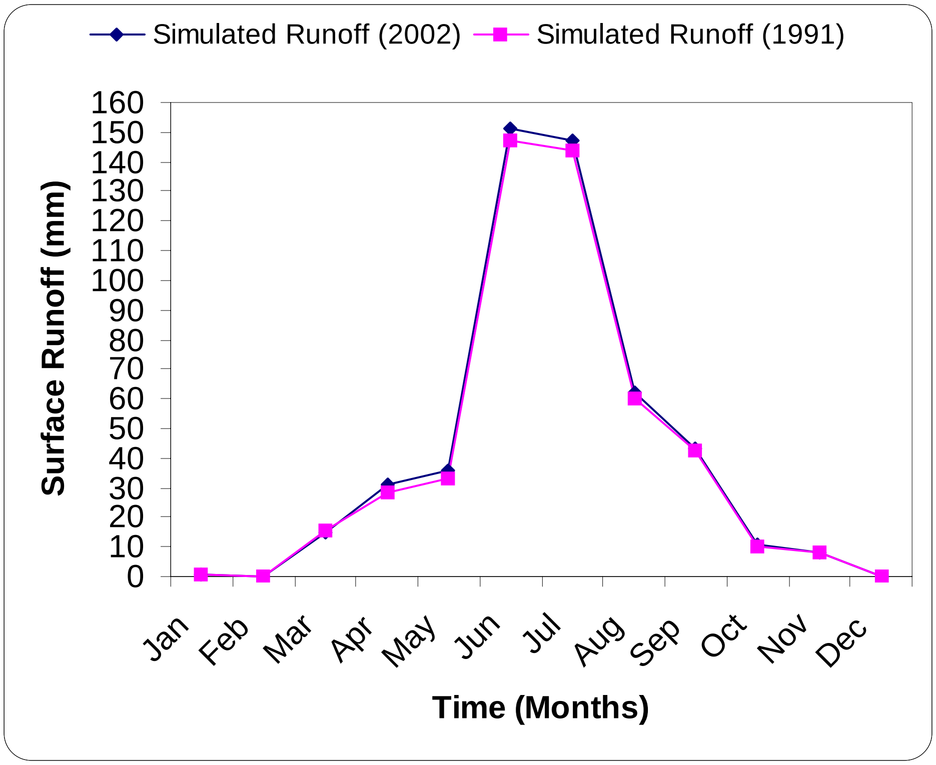


Fig.6.16: Graph showing impact of land use/ land cover on surface runoff for the year 1991 and 2002

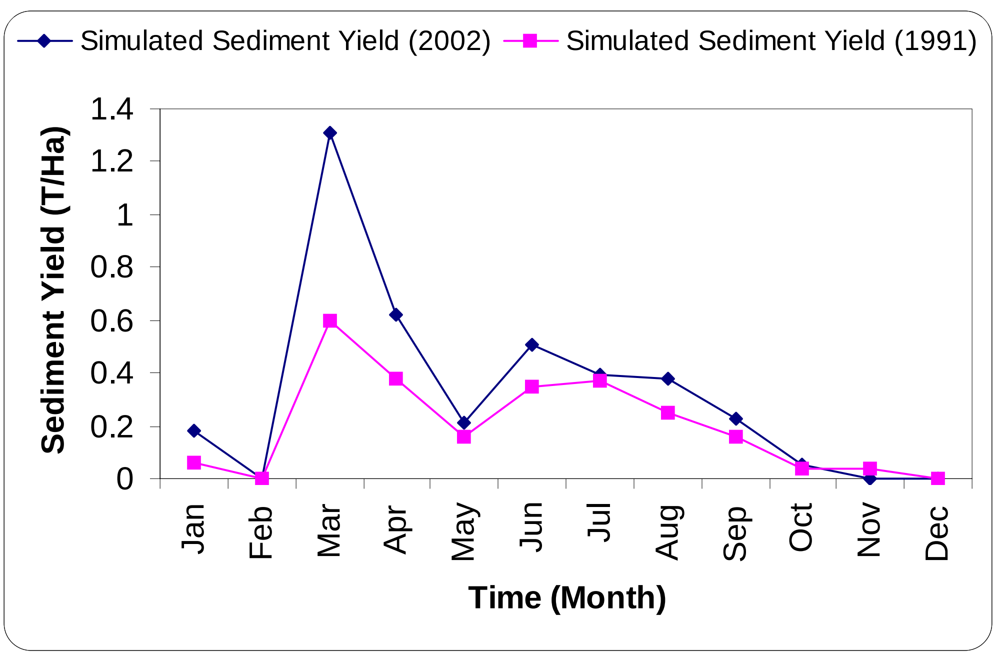


Fig.6.17: Graph showing impact of land use/ land cover on sediment yield for the year 1991 and 2002

SUMMARY AND CONCLUSION

In the present study Soil and Water Assessment Tool (SWAT2000), a physical based semi distributed hydrological model having an interface with ArcView GIS software was applied to Kulsi river basin for modeling the various hydrological components. The major objectives of the present study were

- Extraction of watershed characteristics, and land use/ land cover information of the study area using Remote Sensing, GIS and collateral data.
- Physical Based Semi Distributed Hydrological Modelling for Kulsi River Basin.
- Sediment Yield Modelling for Kulsi River Basin.
- To analyze the impact of land use/land cover on the surface runoff and sediment yield.

The study area covering an area of 1593.27 sq.km is located in the Kamrup district of Assam as well as West Khasi and Ri-Bhoi district of Meghalaya in North Eastern India. The area lies between latitude $25^0$30'39"N – $25^0$58'03"N and longitude $91^0$11'52" E-$91^0$48' 09"E with an altitude between 100 m to 1900 m above msl and is covered by the Survey of India toposheets No.78 O/1, 78 O/5, 78 O/9, 78O/2, 78 O/10, 78 O/6 and 78 O/14. The area is covered with rolling hill topography. The average annual rainfall in the area is around 2000 mm out of which more than 80% occurs during the pre monsoon and monsoon period.

Historical records on daily rainfall and runoff were collected from Brahmaputra Board, Guwahati, Assam. Daily sediment data measured at the outlet of the basin (Ukiam) were also collected for 2 years from the same organization. These collected data were then processed as per the objectives and requirement of the AVSWAT2000 model. Topographical maps at 1:50,000 scale prepared by Survey of India (SOI), soil map prepared at 1:250,000 and printed at 1:500,000 by National Bureau of Soil Survey and Land Use Planning (NBSSLUP) and Digital Elevation Model (DEM) of 30m x 30m prepared under the ISRO-GBP project were collected from Indian Institute of Remote Sensing (IIRS), Dehradun for delineation of study area and preparation of various thematic maps like drainage, slope, aspect and flow direction maps using GIS softwares.

SWAT2000 with its latest extension (avswat.avx) was downloaded from the FAO website (http://www.brc.tamus.edu/swat/soft_model.html).

Cloud free satellite data of Landsat TM dated 26-11-1991& Landsat ETM+ dated 17-2-2002 with spatial resolution of 30 m (Path:137, Row:42) for the year 1991and 2002 corresponding to the study area were downloaded from the global land cover facility (GLCF) website. Land use/ land cover maps were prepared from these satellite data using Maximum Likelihood classifier of supervised classification technique. The digital images were classified into four main categories i.e Dense Forest, Open Forest, Agriculture and River/ Streams. In the year 1991 area under dense forest, open forest and agriculture were observed to be 849.38 sq. km, 235.09 sq.km and 490.44 sq.km whereas in the year 2002 it was found to be 823.17 sq.km, 249.17 sq.km and 502.23 sq.km respectively. In order to check the classification accuracy, accuracy assessment was carried out for both the years using ERDAS Imagine software. The classification resulted an overall classification accuracy of 82.50% and 85.00% with kappa coefficient of 0.73 and 0.77 for the year 1991 and 2002.

After preparing all the thematic maps and database as per the format of AVSWATmodel, simulation was performed for daily and monthly values of surface runoff and sediment yield. Calibration was done for available water capacity (AWC), soil evaporation compensation factor and (ESCO) and slope of subbasin. Validation of the model was done for the year 1991 and 2002 using the climatic data for both the years. Model calibration and validation performance between the observed and simulated surface runoff and sediment data were evaluated using graphical and statistical methods.

Graphical and statistical methods revealed an R^2 value of 0.68, 0.75 and 0.82 for daily, weekly and monthly results for surface runoff and 0.36 for monthly sediment load during calibration period. The Nash-Sutcliffe R^2_{NS} for daily, weekly and monthly surface runoff were found to be 0.53,0.52 and 0.56. During the validation period R^2 values were observed to be 0.43,0.74 ,0.72 (1991) and 0.28,0.79 and 0.90 (2002) for daily, weekly and monthly results for surface runoff with Nash-Sutcliffe R^2_{NS} efficiency of 0.93. Simulated weekly and monthly sediment data showed a poor correlation (R^2=0.35 & 0.09) while compared with the observed sediment data.

The AVSWAT model using the Penman–Monteith method, also simulated Evapotranspiration. The ET was observed to be maximum during the month of May (96.59 mm) and minimum in the month of December (13.85 mm).

The impact of land use/ land cover on surface runoff and sediment yield was also studied based on the monthly simulated and observed values of 1991 and 2002. The annual total runoff estimated was 77 mm for year 1991 from 957 mm of rain (a low rainfall year) and 505 mm for year 2002 from 2915 mm rain (a high rainfall year). From the statistics of these two year it is clear that the two year comparison effect of forest is not discernible due to large variation in input i.e. rainfall. Thus, a simulation study, with 2002 rainfall that is around 45% higher than climatic mean (2000 mm) for kulsi basin was carried out for both the year. The result indicates that in 1991 the simulated runoff was 488mm and due to deforestation it has increased to505 mm. Similarly sediment yield increased from 2.41t/ha/yr 3.88t/ha/yr. From the analysis of these results we can conclude that land use/ land cover has got an impact on the surface runoff and sediment load.

Future Work

- Past studies reveals that watershed subdivision has an impact on predicted sediment yields mainly due to sensitivity of overland slope and slope length, channel slope and drainage density. Therefore, detailed study can be carried out to find its significance and suggest a threshold value beyond which watershed subdivision is not having an effect on sediment yield.
- In order to deeply study the impact of land use/ land cover on surface flow and sediment yield simulation studies can be carried out for 20 to 30 years with significant changes in land use/land cover and by using long term weather data (i.e around 30 years average rainfall).

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