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ASSESSMENT OF WATER RESOURCE AND ENERGY POTENTIAL IN *KOPILI* RIVER BASIN USING MODELING TECHNIQUE

A thesis
submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

By
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Abstract

Land and water are two vital natural resources on the Earth. Management and utilization of these resources lead to development and prosperity of a region. Though precise assessment of these resources is prerequisite for development, these resources are not scientifically assessed in majority of the cases. There are several such examples and Kopili river basin is one of them where the water resources are not yet assessed. The Kopili is a major tributary of the mighty River Brahmaputra and it is expected that demonstration of a hydrological modeling tool in this river basin for water resource assessment will open up scope for its application in other parts of this inaccessible North eastern region of India. As in situ measurement is time consuming and also prone to error, simulation of the hydrologic process using modeling technique is becoming popular world wide for assessment and management of natural resources. In the present study attempt was made to assess the water resources in two selected watersheds *viz.*, Myntriang (267 sq km) and Umkhen (1204 sq km) in Kopili river basin using a physically based hydrological modeling tool. SWAT (Soil and Water Assessment Tool) model is a physically based distributed model and was found useful for the present study. The hydrological processes of Myntriang and Umkhen watershed could be adequately modeled by SWAT for desired output through calibration process. The SWAT model divides the whole watershed into Hydrological Response Units (HRUs) based on unique soil and land use features. The SWAT model was interfaced with a GIS tool (Arc View) to handle spatial input parameters of the watershed. Digital Elevation Model (DEM), stream network, soil maps, land use maps and meteorological data of Myntriang and Umkhen were the required model inputs. The maps were digitized through ILWIS GIS software.

The hydrologically delineated sub watersheds of Myntriang and Umkhen are an important output of this study and are expected to be useful for planners and decision makers. It is also anticipated that the characteristics of delineated sub watershed would assist in adopting appropriate management practices. Three sub watersheds for Myntriang and thirteen sub

watersheds for Umkhen were delineated in pre processing stage of the model run with a threshold of 50 sq km.

Calibration of seven model parameters assured good agreement between simulated and observed water yields for the period of 1988 to 1990. Validity of the model was tested through a set of data observed during 1991 to 1993 and which was not used for model calibration. The parameters where adjustments were made during calibration are: (a) SCS runoff curve number for moisture condition II; (b) Base flow recession alpha factor; (c) Soil evaporation compensation factor; (d) Available water capacity of the soil layer; (e) Threshold water depth in the shallow aquifer for flow; (f) Threshold water depth in the shallow aquifer for revap and (g) manning roughness coefficient. The validation criteria considered for the present study were coefficient of determination (R^2), model efficiency (E) and Index of agreement (d). The model was found validated based on these criteria evaluated for the entire period, the rainy period and non rainy period separately.

The model was used to assess the hydrological behaviors in terms of rainfall to water yield conversion, spatial and temporal distribution of water and sediment yields amongst the sub watersheds. The Myntriang watershed yielded 1126.3 mm of water as against an annual average rainfall of 1830.8 mm which comes to 61.5% conversion. The rainfall to runoff conversion for Umkhen was 51.9% for an average annual rainfall of 2674.6 mm. Distinct spatial variation were also observed with regards to water yields in both the watersheds. The range of variation of water yield amongst the sub watersheds of Myntriang was from 721.31 mm to 885.82 mm whereas for Umkhen it was from 379.26 mm to 3336.72 mm. The temporal variations of water yield during peak and lean seasons were also simulated and found to have a spatial variation as well. The maximum temporal variation of water availability was 90% between lean and peak season. Similarly, spatial variations were also observed for sediment yield amongst the sub watershed of Myntriang and Umkhen. The maximum modeled sediment yield was 1559 kg/ha in a sub watershed in Umkhen and warranted immediate attention.

Based on the modeled discharge at each selected reach and longitudinal profiles of the major streams theoretical hydropower potential was assessed. The theoretical potential indicated maximum availability at a given

location. The technically achievable hydro energy would be less than the theoretical hydropower potential due to competing demands by other sectors and other natural technical infeasibility. The criteria considered for selected site were, the sites should have a drop of 10 m and above and spaced at 500 m apart. Total of 45 sites for Myntriang and 107 sites for Umkhen were available for hydro power generation. The hydro power potential was determined at 50%, 75% and 90% dependability flow. The power potential for these three dependability flow for Myntriang watershed were 12.67 MW, 3.39 MW and 1.52 MW respectively. In Umkhen the power potentialities corresponding to three dependability flows were 144.85 MW, 21.51 MW and 11.40 MW respectively. Small and distributed power sites dominated both the study watersheds. Corresponding to 50% dependability flow, 106 sites amounting 21.34 MW were located in the entire study watershed. Remaining 123.51 MW was attributed to only 46 sites. Considering the present state of developmental affairs of the study region it seems decentralized hydro power production would be a suitable option.

Key words: SWAT, hydrological modeling, GIS, Water Yield, Watershed, potential hydro power

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Declaration

I, Sri B.C.Kusre, hereby give this undertaking to the extent that this thesis entitled "Assessment of Water Resource and Energy Potential in Kopili River Basin using modeling technique" submitted for award of Doctor of Philosophy in Energy under Department of Energy, School of Energy, Environment and Natural Resources is a record of work carried out by me. I declare that I have not submitted this work for the award of any other degree in this or any other University. I further declare that to the best of my knowledge no part of this work has been submitted by any one else for the award of any degree.

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This is to certify that the thesis titled **Assessment of Water Resource and Energy Potential in Kopili River Basin using modeling technique** submitted to the Tezpur University in the Department of Energy under the School of Energy, Environment and Natural Resources in partial fulfillment for the award of the degree of Doctor of Philosophy in Tezpur University is a record of research work carried out by Mr. *Bharat Chandra Kusre* under our personal supervision and guidance.

All help received by him for various sources have been duly acknowledged.

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LIST OF ABBREVIATIONS

AGNPS	Agricultural Non Point Sources
AMC	Antecedent Moisture Condition
ANSWERS	Areal Non point Source Watershed Environmental Response Simulation
APGCL	Assam Power Generation Company Limited
ARS	Agricultural Research Services
ARSAC	Assam Remote Sensing Application Center
AVSWAT	Arc View Soil and Water Assessment Tool
BCM	Billion cubic meter
°C	Degree centigrade
cm	Centimeter
CN	Curve number
CO_2	Carbon dioxide
CREAMS	Chemical Runoff and Erosion from Agricultural Management System
cumecs	Cubic meter per seconds
DEM	Digital Elevation Model
DTM	Digital Terrain Model
E	East
e.g.	Example
EU	European Union
FC	Field capacity
FDC	Flow Duration Curve
Feb	February
Fig	Figure
GIS	Geographical Information System
ha	Hectare
HEC-HMS	Hydrologic Engineering Center- Hydrological Modeling System
hr	Hour
HRU	Hydrological Response Unit
ICWE	International Council on Water and Environment
ILWIS	Integrated Land and Water Information System
IMD	Indian Meteorological Department
km	Kilometer
kW	Kilo Watt
kWh	Kilo Watt hour
LULC	Land use land cover
m	Meter
m^3	Cubic meter
ms^{-1}	Meter per second
m^3s^{-1}	Cubic meter per second
Mha	Million hectare meter
mm	Millimeter
mm^{-1}	Meter per meter
msl	Mean sea level
MSW	Myntriang sub watershed
MUSLE	Modified Universal Soil Loss Equation
MW	Mega Watt
N	North
NBSSLUP	National Bureau of Soil Survey and Land Use Planning

NC Hills	North Cachar Hills
NE	North Eastern
nos.	Numbers
NPS	Non Point Source
NRCS	Natural Resource Conservation Services
NWP	National Water Policy
S	South
SC	Scheduled Caste
SCS	Soil Conservation Service
SHE	System Hydrologique Europeen
SHP	Small Hydro Power
Sl	Serial
sq km	Square kilometer
ST	Schedule Tribe
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
t	Tonnes
US	United States
USA	United States of America
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
USW	Umkhen sub watersheds
UTM	Universal Transverse Mercator
viz.,	Namely
W	Watt
WXGEN	Weather generator model
US	United States

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Date: **BHARAT CHANDRA KUSRE**
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CHAPTER – 1

INTRODUCTION

CHAPTER-1
INTRODUCTION

Water and land are the most valuable natural resources. However, both of these resources are finite and non-creatable. The existence of the entire living world lies on the availability of these two precious resources on sustainable basis. Since time immemorial, exploitation of these resources for the development of mankind has been a common feature all over the world. There are many instances of over exploitation of these resources leading to serious problems to the environment. Increasing pressure of growing population and industrialization have been the major causes of excessive uses of these resources. On the other hand, cases are also there where these resources in general and water resources in particular, remains under utilized. Lack of location specific methods and tools for accurate assessment regarding availability of water resources over space and time seems to be a major cause of under-utilization in many regions despite of intense pressure on its demand.

The rationale of the present investigation in the background of (i) role of water resources development to meet the increasing demand and threat of scarcity (ii) global and regional concern for integrated water resource management, (iii) needs of water resource assessment using scientific advancement and (iv) use of computational tools (hydrological models) for assessment of water resource and hydro power are highlighted below.

As mentioned at the beginning, water resources occupy a special place among all natural resources due to their diverse and vital role in supporting human life and powering many natural processes shaping the earth. Throughout the world water is playing influencing role on food security, people's livelihoods, industrial growth, and ecological needs. However, the ever-increasing use of water by competing users leads to shortages of water. Supply of sufficient water at the right time at the right place and with the right quality is the basic issue of present time. The world water demand in 1995 was estimated as 3906 cubic kilometre which is projected to increase by 50% in the year 2025 mostly for uses other than irrigation (Rosegrant *et al.,* 2002).

This is expected to constrain developmental activities if the availability related issues are not properly addressed.

The seriousness of future imbalances of demand and availability of water has been widely realized. Thus, water has become an important issue of concern world wide and is appropriately raised through different forums. The need of preparedness to avoid a water crisis has also been stressed. The conference on Water organized at Mar del Plata in the year 1977 was probably the first to indicate such concern. The objective of the Mar del Plata Conference was to promote a level of preparedness, nationally and internationally, which would help the world to overcome water crisis by the end of the last century. However, even after the end of the century, the concern of this conference is still relevant. The concern for water was also expressed at International Conference on Water and Environment organized at Dublin (ICWE, 1992). The concluding statement of Dublin conference stated that "scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment, human health and welfare, food security, industrial development and the ecosystems on which they depend, are all at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in past". Further it stated "sustainable management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystem. Effective management links land and water across the whole of a river basin or groundwater aquifer". Similarly, the World Water Council (2000) viewed that the crisis for water availability might not arise due to insufficient water to satisfy the demands but due to ineffective water management that resulted in inadequate water availability. More or less similar concerns were also shown by Fresh Water Consultation (Berlin, 2001); World Water Forum (Hague, 2002) and Water for Human Survival (New Delhi, 2002).

Thus, the issues of water have drawn the global attention and it has become an accepted fact that human civilization might be under serious threats of scarcity of available water. Water resources need to be optimally managed for sustainable development of mankind. India is no exception in this regard which is also facing a problem of uneven spatial and temporal distribution of available water. There are several sectors where the available water can be used for developmental purpose and hydro power is one such sector. The development of water resources for generation of hydro energy can help in generating revenues through associated economic activities.

India occupies around 329 Mha of land mass that forms 2% of the worlds land area and supports about 17% of world population, 20% of world livestock with only 4% of the world water resources. As per international norms if per capita water availability is less than 1700 m^3 per year the country is categorized as water stressed and if the water availability per capita per year is less than 1000 m^3 the country is categorized as water scarce (Kumar *et al.,* 2005). According to an estimated analysis, the per capita water availability per annum in India reduced from 2309 m^3 in 1991 to 1902 m^3 in 2001. It has also been predicted that further reduction up to 1401 m^3 in 2025 and 1191 m^3 in 2050 would occur resulting serious hardship if appropriate steps are not taken.

Considering the threatening forecast and also due to existing pressure on water resources in India, the National Water Policy was revised in the year 2002 that recognized water as prime natural resource. The policy also prioritizes water allocation in the sequence of drinking, irrigation, hydro-power, navigation and industrial and other uses. The National Water Policy (2002) states that "Water is a scarce and precious natural resource, to be planned, developed conserved and managed as such, and on integrated and environmentally sound basis, keeping in view the socio-economic aspects and need of the states". Need of common approach and guidelines are also realized through the policy documents to address the issues such as environmental sustainability, and socio-economic consequence of water resource development including hydro-power generation. The research needs in all related areas focusing its conservation, utilization and management are also emphasized by the Government of India through its Policy documents (NWP, 2002).

Wide spatial variation of water resources with regards to source and availability exits in India. The country has arid (less than 100 mm average annual rainfall) to humid (more than 1000 mm average annual rainfall) region. Again, extreme seasonal variation of rainfall also exists. North eastern region of Indio is a high rainfall area and also considered rich in water resources.

The region (North East India) consists of eight states of India that occupy 27.22 Mha of land (8.11% of country's land mass). It is characterized by hills and valleys with 70% of the land falls under hilly terrain. It receives almost 30% of the country's rainfall resources with average rainfall varying from 2000 to 4000 mm annually in different parts of the region. Agriculture is the major activity in this region. The Planning Commission of India categorized this region as low productive but high potential zone of the country. Several unique features make this region distinguished form the remaining part of India. Existence of traditional cultivation practices (*jhum i.e.* shifting cultivation), diverse cultural norms and fabrics in the form of multiple tribes, community land holding pattern in the tribal areas and fragmented land holding in plain areas, high rainfall, inaccessible areas due to difficult terrain are some of the distinguishing features of this region. Economically, the states of this region including Assam are considered backward compared to other states of India (*IT*, 2005).

The region consists of two major river system *viz.,* Brahmaputra and Barak which carry total water resources to the tune of 5856 Billion Cubic Meters (BCM) and ground water resources constitutes around 35 BCM both stands highest in the country. However development of the water resources is at very nascent stage in the region. According to estimates the total irrigation development in Brahmaputra river basin is only 22% of the area which is less than other river basins of India (*e.g.*, 50% of the total area in Ganga basin and 78% of the area in Krishna basin are irrigated). Similarly, ground water development in this region has been estimated at only 3.5% of total ground water potential (MoWR, 1998).

Despite of having prospect for hydro power generation and also urgent requirements for such power, the existing scenario of hydro power generation is also not promising in this region. Major states in this region are deficient in power. The deficient power supply has seriously hampering the developmental activities in this region. According to estimate, the North eastern region of India has total hydro power potential of 33094 MW which is about 41% of India's hydro power potential. However, only 2% of the total hydro power potential has been utilised so far in this region. The enhancement of hydropower generation is expected to accelerate the developmental activities of this region.

It has been observed that massive deforestation have taken place for income generation in the north east India due to lack of other economic activities. Because, the lack of development and inaccessible terrain compel the inhabitants to excessively depend on the forest resources for fulfilling their energy and livelihood needs. Thus optimum utilization of water resources, particularly for the generation of hydro power in naturally available hilly areas of North eastern India is believed to release the undesirable pressure on forest resources. This has resulted in dwindling area under forest causing environmental constraint. The natural terrain and the abundant water resources may be useful for development of hydro power resources. This can provide energy to the remote villages and also a source for generation of income with least environmental hazards. The hydro power generation can also encourage people residing in remote places to take up other economic activities. The development of water resources can also add to availability of water at high altitude and also reduce flood damages in the valley portion of the region.

The importance of hydro power in general and small hydropower in particular was realized world wide due to its strength on several accounts (Leyland, 1995; Balsar, 2002; Ramchandran *et al.*, 2004). There have been many success stories to harness hydro-power from small and medium natural stream. As per the reported study out of the estimated small hydro power potential of 180,000 MW all over the world, only 26% have been realized so far (Naidu, 1998). Punys and Pelikan (2007) surveyed small hydro power systems (capacity less than 10 MW) installed in entire European Union and found that 17200 plants have been installed with a capacity of 11430 MW and concluded that small hydro power has the second largest share in all forms of renewable energy sources after large hydro in these countries. The technology is extremely robust and systems can last for 50 years or more with little maintenance. Small hydropower has a key role to play in meeting the challenges by reduction in carbon-dioxide (CO_2) emissions (Tondi and Chiaramonti, 1999). Even many countries have thought of making big business by establishing small hydropower projects (Moxon, 1999). There are many hilly or mountainous regions of the country where the grid will probably never reach, but which have sufficient hydro resources to meet basic domestic and cottage industry needs of the local populations.

Several indices of development, such as inadequate power supply, low per capita income, and poor industrialization (Table 1.1), warrant urgent needs of intensive exploitation of available natural resources of this region. As discussed earlier, amongst the natural resources, untapped water resources are considered vital for the development of this region. However, to avoid ill effects of improper utilisation of water resources, the accurate assessment is pre-requisite for planning and effective implementation of water resource projects.

Table 1.1: Some indices of development of North-eastern region compared to other region of India *(NEC, 2002)*

Parameters	North-eastern states,	Assam,	All India,
Per capita electricity consumption	106 kWh	123 kWh	338 kWh
Per capita net state domestic product at current prices in Rs. (as on 18th Feb, 2003)	41273	26273	1579573
No. of industrial units per 1000 sq km (as on 31st March, 1998)	45	79	268

Reliable assessments of water resources over space and time have been a challenging job due to several reasons. A number of interrelated spatially varying parameters pertaining to topography, climate and soil govern the complex mechanisms of water availability. Human intervention increases the complexity further. However, with the advent of modern computational facility coupled with development of hydrological models to mimic real world, the assessment of water resources are becoming easier. Hydrological modelling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practising water resources engineers. With the availability of GIS (Geographical Information System) and remote sensing technologies these models are becoming more physically based. Thus better simulation of physical world is possible. The hydrological models have been used world wide for assessing water resources, estimation of erosion, water quality, impact on environment including management practices (Metacalf and Eddy, 1971; Huber and Dickinson, 1988; Abbot and Refsgaard, 1996; Bingner, 1996; Jain and Soni, 1998; Seth *et al.*, 1999; Arnold *et al.*, 1999; Arwa, 2001; Mohan and Shrestha 2000; Bhuyan *et al.*, 2002; Pandey, 2002; Wurbs and James, 2002; Bruggeman and Meijden, 2003; Gossain *et al.*, 2003, Mishra, 2004; Mohammed *et al*, 2004; Sintondji, 2005; Knebl *et al.*, 2005; Gallart *et al.*, 2006; Abbaspour *et al.*, 2007, Jang *et al.*, 2007).

GIS is a system for capturing, storing, checking, integrating, manipulating, analysing and displaying data which are spatially referenced to the Earth, fall in to this category (DE, 1987). It produces intelligent data that supports analyses and allows display of tabular and spatial information to assist decision-makers (Kaijuka, 2007). GIS can provide a key set of components needed for planning in the form of georeferenced data. The GIS tool have been used by many researchers world wide for assessing the water resources and hydro power potential (Mustafa *et al.*, 2005; Das and Paul, 2006; Rao, *et al.*, 2006).

The GIS follows a database approach so as to represent features from real world and the relationship between them. The data in a computer database are managed and accessed through a database management system (DBMS). The GIS uses four types of database models for handling attribute data viz., hierarchical, network, relational and object oriented data model. Of these relational data models has been the most widely used, while object oriented model are emerging trends in GIS. The database is managed in relational DBMS through linking certain set of information such as parcel number or a set of coordinates by assigning primary key and secondary key (Konecny, 2003).

The predictions of hydrological behaviour have improved significantly after the development of physically based hydrological models supported by the advanced computing tools. The interfacing of these models with GIS tools have helped to describe the hydrological process more accurately and at spatial level thereby providing additional flexibility in decision making process for water resources management. Some of these physically based models that have been used world wide to simulate the hydrological processes for various purposes of water resources development, management and planning are AGNPS, HEC-HMS, SWMM, ANSWERS, TOPMODEL, MIKE SHE and SWAT. The application of such dynamic and process based hydrological models has several advantages. First, the predictions for a large extent of variations of input conditions become possible with minimum cost and time, if validated for the situations under consideration. Second, sensitivity analyses are possible with less effort under different levels of either management strategies or expected natural scenarios. Third and more important is for predicting hydrological behaviour for inaccessible regions. The application of spatial hydrological model for inaccessible region like North eastern region of India would harness this benefit.

Remote sensing technique, because of its capability of synoptic viewing and repetitive coverage provides useful information on land use dynamics. It can provide a measurement of many hydrological variables used in hydrological and environmental model applications compared to traditional forms of land use data collection. It is one of the most powerful and cost effective tool in natural resources assessment and development. Researchers have used the remote sensing tool for mapping of water resources, use in hydrological model for resources estimation, ground water exploitation, assessment of rural land use classification, estimation of soil erosion and hydro power assessment. (Rao and Mohan, 1988; Adinarayana and Krishna, 1996; Khudhairy *et al.,* 2002,; Mizukoshi and Aniya, 2002; Chen and Stow, 2003; Dudhani *et al.,* 2006; Dutta *et al.,* 2007).

However, use of these computational techniques requires certain input data that defines the study area. These data are related to topography, drainage network, land use land cover, soil and climate. Even after collecting these data, all the processes in the nature cannot be described mathematically and therefore some components need to be lumped through calibration processes. Once the model is calibrated, it needs to be validated for another set of conditions for which model was calibrated. This is required to ascertain its applicability in unforeseen situations. As nature is very dynamic, certain assumptions are to be made during the model development for certain region. These assumptions may be to ignore extreme values, prevalence of uniform land use land cover during the study period.

In spite of strength of such modeling technique and wide scope for utilization for assessment of water resource in the north-eastern region, its application has been limited till now in India in general (Behra and Panda, 2006) and North eastern region in particular. If the success stories of model application elsewhere could be repeated here in this region then assessment of water resources would be easier. This will promote planning and development, hence prosperity of NE region. Several utilities of the model applications are anticipated. First the model results would be in the form of delineated watershed. The decentralized planning would be easier which would benefit remotely located people. Second, based on the water assessment, developmental projects including hydropower could be planned. Output of the model will be in a spatial form. Therefore, integration of social elements as well as available infrastructural facilities would also be easier. Above all, traditionally adopted trial and error plan could be avoided.

Amongst the other expected uses, hydro power generation are considered a major one because of vast untapped water resources flowing through natural undulating topography. Hydroelectricity represents a large-scale alternative to fossil fuel generation, contributing only very small amount to green house gas emissions. Hydropower is a renewable and sustainable energy source to meet global challenges (Frey and Linke, 2002). However, developing the hydroelectric potential in a sustainable way offers many challenges (Balsar, 2002). These challenges include creation of hydrological database and assessment of the resources on spatial and temporal scale. The conventional investigation techniques are time consuming and also lead to cost escalation (Agarwal, 1996) and the information created in this process become inadequate and unreliable at the time of actual implementation of the project (Yogendra Prasad, 2000). Thus, the hydrological model could overcome such constraint and provide reliable and reasonably accurate source of information in a very short time.

From the above discussion it can be summarized that there has been world wide concern for the water resources which are going to be scarce in the coming future if not appropriately managed. Historically water induced economic developments are common as it contributes in farming and industrialization besides supporting lives. However, proper management of water resources could only bring sustainable development. Assessment of water resources is a pre-requisite for planning and implementation of management strategy. North-eastern region of India though economically backward, endowed with sufficient water resources. Inadequate assessment seems to be the biggest hurdles for initiating any development oriented water management programme. As the region is lagging behind the country in developmental fonts, the water resources can be utilized for overall development of the region.

The Kopili is one the major tributaries of river Brahmaputra having a catchment area of 14760 sq km. The water resources in the catchment provide a scope for development if proper assessment is done. It is anticipated that the rising population coupled with degradation of the catchment area of the river is affecting the available water resources. There have been several examples of successful applications of advanced computing tools and modeling techniques for assessment of the resources elsewhere. There are large number versatile physically based spatial model capable of integrating hydrological processes at watershed levels. Selection of a suitable models and related computational tools and techniques for mimicking hydrological phenomena in selected watersheds in Kopili river basin are expected to provide spatial information required for water resource planning. It is expected that besides, such spatial information, hydropower assessment will also be possible from model application.

Keeping in view of the above the present study is taken up on two watersheds *viz.*, Umkhen and Myntriang of Kopili River basin in North Eastern region of India were considered. Umkhen river starts at an altitude of 1829 m near Shillong in the state of Meghalaya in India. The catchment area of the watershed is 2228 sq km. the modelling was done based on the observed data the catchment area till that point is 1204 sq km. The Myntriang is a sub watershed of Umkhen. The entire catchment area of Myntriang falls in the state of Assam in India. The total catchment area of the watershed is 267 sq km. The present study was taken up with the following objectives:

(i) To identify suitable GIS based model for assessment of water resources and calibrate as well validate the model for Myntriang and Umkhen watersheds of Kopili river basin

(ii) To estimate water resource potential and sediment yield of the study watersheds using calibrated model

(iii) To assess the hydro energy potential on spatial and temporal basis based on model output.

CHAPTER- 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

In order to assess water resources on spatial and temporal scale in two watersheds located in the Kopili river basin, attempts were made to use hydrological modeling tool and techniques. In addition to assess water resources, the potential utilization hydropower generation was also investigated. The hydrological processes are inherently complex as these processes interact with heterogeneous soil and climate distributed over space and time. The modeling technique, supported by good hydrological data made job easier for prediction of such complex processes. Available literature citing research works on hydrological processes (rainfall–runoff) study, hydrological modeling efforts, application of hydrological modeling, and assessment of hydro power potentiality have been reviewed and presented in this chapter under the following sections:

1. Hydrological (Rainfall-runoff) processes
2. Hydrology modeling
3. Application of hydrological model
4. Assessment of model performance
5. Assessment of potential hydro power.

2.1 Rainfall-Runoff processes

Runoff has been utilized by mankind for various purposes. With the advancement of different sections of sciences hydrology also progressed. Simultaneously investigation on rainfall-runoff processes drew attention of many researchers world wide. Scientists and engineers recognized the importance of estimating water availability from the available hydrologic data for the purposes of planning water resource projects even in nineteenth century. However, paucity of adequate data perhaps forced to adopt simple correlation for the estimation of runoff. One of the most common methods is to correlate runoff with rainfall and fit a linear or exponential regression line for very rough estimation. Numbers of similar literature are available covering varied aspects on it. Literatures of a few such works relevant to present study are presented below.

Rational formula for estimating runoff from rainfall is tracked back to mid nineteenth century (Mulvany, 1850). This is still most widely used method in small watersheds. Although valid criticisms have been raised about the adequacy of this method, it continues to be used for storm design for land use planning because of its simplicity. The idea behind the rational method is that if a rainfall of intensity *i* begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration t_c, *i.e.*, when all of the watershed is contributing to flow at the outlet. The product of rainfall intensity and watershed area is the inflow rate for the system, and the ratio of this rate to the rate of peak discharge Q (which occurs at time, t_c) is termed as runoff coefficient C ($0 \leq C \leq 1$).

The ways to derive discharge hydrographs from rainfall events have been studied extensively since early 1930s (Mutreja, 1990). One method that is receiving considerable attention is called the unit hydrograph method. Sherman (1932) advanced the theory of the unit hydrograph related to the surface runoff phenomenon. The theory is considered even today as one of the most important contribution to hydrology. A unit hydrograph is a discharge hydrograph resulting from 1 cm of rainfall excess generated uniformly over the watershed area at a uniform rate during a specified period of time.

The fundamental Green and Ampt infiltration model which was developed about 100 years ago using Darcy's law is still applied in various situations including watersheds modeling. The Green and Ampt equation was developed to predict infiltration assuming excess water at the surface at all times. The equation assumes that the soil profile is homogenous and antecedent moisture is uniformly distributed in the profile. As water infiltrates into the soil, the model assumes the soil above the wetting front is completely saturated and there is a sharp break in moisture content at the wetting front. Some users claim that Green and Ampt equation is advantageous being theoretically derived with physically based parameters (Neitsch *et al.*, 2002).

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Soil Conservation services Curve Number (SCS-CN) model has been considered most appropriate model to study hydrologic response (Wurbs and James 2002, Mishra and Singh 2002). The curve number is an integer value varying between zero and hundred. From empirical analyses of rainfall-runoff data on small watersheds and hill-slope areas, the National Resource Conservation Service (NRCS) proposed a table of CN values with four defining parameters *viz.*, Land Use Land Cover, hydrologic condition, hydrologic soil group and Antecedent Moisture Conditions (AMC) (NRCS, 1985). Accordingly curve number is generated relating the abstraction of rainfall for generating runoff. The Soil Conservation services Curve Number has been widely used in many hydrological assessment studies extending many regions of the world (Svoboda, 1991; Mishra and Singh, 1999; Yu *et al.*, 1997; Beven, 2000; Mishra *et al.*, 2003; Dutta *et al.*, 2006). The usefulness and application of the curve number technique have been further increased with the introduction of hydrological process modeling.

2.2 Hydrological modeling

The rational method, unit hydrograph method, Green and Ampt infiltration method and SCS-CN method were the landmark contribution to the science of hydrology. However, each one of them has limitation and cannot represent entire spectrum of hydrology. Hydrology is a combination of several phenomenons all of which can be conceptualized by scientific principles and thus can be modeled. The use of above concepts in isolation or in combination could be seen in the development of hydrological modeling.

The term model may be defined as mathematical representation of a real world system. A "watershed hydrology model" is an assemblage of component models mimicking hydrological processes involving soil, climate and geography. As mentioned earlier there has been growing need for development of physically based watershed hydrological model all over the world. A number of physically based hydrological models have been developed over the years for many hydrologic applications at the watershed scale. Reviews of some of these models are discussed below.

Storm Water Management Model (SWMM)

In an effort of analyzing quantity and quality of urban runoff, the Storm Water Management Model (SWMM) was developed in 1971 by Metacalf and Eddy Inc., Water Resources Engineer Inc., and the University of Florida (Metacalf and Eddy, 1971, Huber and Dickinson, 1988). Basically the model was developed for Environmental Protection Agency, USA. Both single-event and continuous simulation could be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, and pollutant concentrations. It is claimed that this model was useful for accurate simulation of backwater, looped connections, surcharging, and pressure flow. Further, it is stated that it could simulate all aspects of the urban hydrologic cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analysis could be performed on long-term precipitation data and also on output from continuous simulation. The model also incorporated planning module for an overall assessment of urban runoff problem or evaluating proposed abatement options. The application of the model for evaluation of urban development strategies is seen by many workers. Recently Jang *et al.,* (2007) used SWMM for hydrological impact assessment in four urban watersheds in Korea.

Hydrologic Modeling System (HEC-HMS)

HEC-HMS and its predecessor, the HEC-1 Flood Hydrograph package (Wurbs and James, 2002), are one of the popular watershed computer models. The model has been applied to watersheds ranging from small urban areas of less than 1sq km to large river basins of several hundred thousand sq km. HEC-HMS, first released in 1997, is an object oriented, menu driven update of HEC-1 that has evolved through various versions dating back to 1968. The model computes discharge hydrographs at pertinent locations from observed precipitation events or synthetic design storms. Rainfall depths for each time increment of a storm are inputs. Snowfall and snowmelt are simulated using either degree-day or energy budget methods. A unit hydrograph can be either input or synthesized by the model using the NRCS dimensionless, Snyder, Clark or Modified Clark method. The storage- outflow method is used for reservoir routing. An optimization routine facilitates parameter calibration in HEC-HMS. In an recent effort Knebl *et al.,* (2005) demonstrated the application of HEC-HMS model in San Antonio river basin (10000 sq km) in USA and commented that the model is useful for flood forecasting on a regional scale that causes severe flash flooding.

Agricultural Non-Point Sources (AGNPS)

Agricultural Non Point Source (AGNPS) is a distributed parameter model developed by Agricultural Research Service (ARS) scientist and engineers. It predicts soil erosion and nutrient transport loadings from agricultural watersheds for real or hypothetical storms (Young *et al.,* 1994). As such AGNPS is an event based model. Erosion modeling is built upon the Universal Soil Loss Equation applied on a storm basis. Its hydrology is based on the SCS technique. AGNPS incorporates another model (CREAMS: Chemical Runoff and Erosion form Agricultural Management System) to predict nutrient and pesticides and soil particle size generation and interaction. The delineation of study watershed into uniform grids is required. The simulation of models requires 22 parameters for each grid pertaining to its antecedent conditions, physical characteristics (e.g. soil type and slope steepness), management practices and rainfall. Amongst the several AGNPS users, Bhuyan *et al.,* (2002) applied AGNPS model in a watershed in Cheney reservoir in Kansas, USA for estimating nutrient loading of different sub watersheds. They calibrated and validated the model in each sub watersheds and concluded that the model was more effective in smaller watershed with adequate rainfall data. In another attempt, Mohammed *et.al,* (2004) tested and validated AGNPS model in Kori watershed in Ethiopia to simulate surface runoff, peak runoff and sediment yield and obtained high degree of agreement. The model could identify the erosion prone areas needing treatment.

Areal Non Point Source Watershed Environmental Response Simulation (ANSWERS)

ANSWERS is a hydrological model (Areal Nonpoint Source Watershed Environmental Response Simulation) developed by Department of Biological Systems Engineering, Virginia Tech, Blacksburg, Virginia, USA (Beasley *et al.*, 1980). It is a distributed model designed to simulate the processes of flow, erosion and transport of the sediments form agricultural catchments. The interception of the rain by the vegetation, the infiltration and surface detention are modeled successively by modules of ANSWERS. The detachment of the sediments by the rain and their transport, their deposit or their recoveries were also simultaneously simulated in ANSWERS.

TOPMODEL

TOPMODEL is a simple but physically based hydrological model that aims to represent the effects of catchment heterogeneity and, particularly, topography on the dynamics of hydrological response (Beven and Kirby, 1979). It is a topography based watershed hydrology model that has been used to study a range of features, including spatial scale effects on hydrological process, topographic effects on water quality, topographic effects on stream flow, climate change effects on hydrological processes, the geo-morphological evolution of basins, and the identification of hydrological flow paths. The TOPMODEL is a variable contribution area conceptual model in which the predominant factors determining the formation of runoff are represented by the topography of the basin and a negative exponential law linking the transmissivity of the soil with the vertical distance from the ground level. In this model the total flow is calculated as the sum of two terms, surface runoff and the flow in the saturated zone. According to model developer, though TOPMODEL is a conceptual model, it can be described as "physically based" in the sense that its parameters are measured directly in situ. Jain and Soni (1998) observed the TOPMODEL as one of the few conceptual models that accounts explicitly for the saturation excess overland flow mechanism and integrates the variable contributing area concept, both of which are essential to model the catchment accurately. While testing TOPMODEL (Gallart *et al.*, 2006) with data from the Can Vila research basin (Vallcebre, Spain) to verify its adequacy for simulating runoff and the relative contributions from saturated overland flow and groundwater flow, satisfactory agreement was obtained for overland flow simulation. However, the uncertainty of prediction of the contribution from groundwater was extremely large. The conditioning on water table records and the distribution of parameters obtained from point observations strongly reduced such uncertainty of predictions.

MIKE SHE Model

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

Soil Water Assessment Tool (SWAT)

The Soil Water Assessment Tool (SWAT) is a distributed parameter, continuous time hydrologic model (Arnold, *et al.*, 1993, 1998). It is the continuation of a long-term effort of non-point source pollution modeling with the USDA - Agricultural Research Services (ARS). SWAT allows division of basin into grids or sub watersheds. It is claimed that SWAT incorporates better characteristics of lateral flow, ground water flow channel transmission losses and routing of sediment and chemical through the watershed (Arnold, *et al.*, 1993, 1998). The model uses a modified form of SCS-CN technique (USDA-SCS, 1972) to calculate surface runoff.

2.3 Application of hydrological model (SWAT)

The seven major hydrological models and some of their specific uses are discussed above. The present investigation used SWAT for water resources assessment of two hilly watersheds located in northeastern regions of India. The consultation of earlier review indicated wide range of application of SWAT for water resources planning and management world wide. Some of the relevant applications of SWAT in hydrological studies are reviewed below:

Bingner (1996) simulated runoff for a watershed in northern Mississippi using SWAT model for ten years period. Reasonably acceptable agreement in the simulation of runoff on daily and annual basis were obtained in all the delineated sub basins with area varying from 0.05 to 21.3 sq km , variation in land cover was found to influence the prediction as the simulated runoff in sub basin covered with forest cover was in disagreement with observed results.

In another use of SWAT, Arnold *et al.,* (1999) evaluated stream flow and sediment yield data in Texas Gulf Basin with drainage area ranging from 2253 to 304260 sq km. They used data of 1000 stream monitoring gauges during a period of 1969 to 1989 to calibrate and validate the model. Their results indicated that predicted average monthly flows for three basins were 5% higher than the measured flow with standard deviation between measured and predicted flow within 2%.

While using SWAT for analyzing hydrology in small watersheds in North Syria, Bruggeman and Meijden (2003) obtained 225 mm average annual precipitation from the weather generation module of SWAT. The module considers 100 years of simulation period. Additionally, the model predicted 11% recharge of ground water resources.

Another notable application of SWAT has been watershed prioritization. Pandey *et al.,* (2002) prioritized sub watersheds in Banikdih watershed of Gowai river system in two states (Jharkhand and West Bengal) of India on the basis of sediment yield characteristics using SWAT2000. The close agreement between observed and modeled sediment yield at the outlet of the watershed for the year 1998 and 2000 were found.

Similarly Tripathi (2003) applied SWAT model to prioritize sub watershed in Jharkhand (India). Simulated water yield and sediment yield in a small watershed (92.46 sq km) were used for prioritization after successfully validating the simulated results. The weather generator module of SWAT (Markov chain model) was also used for simulating precipitation which was successfully validated.

Mishra (2004) used SWAT model to a small multi-vegetated Banha watershed in Jharkhand (India) to simulate the hydrologic processes and associated transport of non point source of pollutant (NPS). The calibration and validation of the model revealed satisfactory predictability for daily, monthly and season runoff, sediment yield and NPS pollutant. The sensitivity analysis conducted in the watershed indicated that runoff was most sensitive to initial soil moisture whereas sediment yield was sensitive to mannings 'n' for tributary channel flow. The prediction of SWAT also indicated that small multi-vegetated watershed were more prone to channel than field erosion.

Thus SWAT has been used to model hydrological processes of watershed to obtain runoff, sediment yield, ground water and non point source of pollution. Apart from conventional uses of water resource and sediment assessment, SWAT has also been used for other purposes. In such a varied approach, Gossain *et al.,* (2003) studied the impact of climate change on water availability of 12 river basins of India. They observed that impact of climate change is varying across the river basins and sub basins. Their study revealed that future scenarios may deteriorate in terms of severe drought or severe floods and there is general perception of reduction of available runoff in future. SWAT also predicted flood scenario of Mahanadi basin (India) with the peak discharge increasing from the present level of 20000 cumecs to 37000 cumecs.

Similarly Sintondji (2005) conducted a study in Terou-Igbomakoro basin (2336 sq km) in West Africa dominated by wood lands in the form of tree and shrub savannah, followed by deciduous forest and crop land. The aim of the study was to adapt a regional model for the rainfall-runoff system and sediment yields, taking into account climate and land cover dynamics and socio-economic practices using SWAT model. High goodness of fit was observed between simulated and modeled results. The goodness of fit on monthly time were obtained through coefficient of determination (R^2= 0.7), Nash and Suctcliffe efficiency (E= 0.7) and Index of agreement (*d* greater than 0.9). Shallow aquifer flow was identified as an important component of the total discharge within the study area by the SWAT. While evaluating some futuristic scenario, the impact of future land use and climate change on hydrology indicated reduction of discharge from 241 mm to 106 mm in 25 years (2000-2025). However, the scenario for erosion predicted unchanged with the year 2000 probably because of decrease in rainfall and changes in land surface.

From the literature it could also been seen that SWAT has been used to model the transport processes of agricultural chemical for identifying suitable management option. One such study was conducted by Tolson and Shoemaker (2007) for simulating hydrologic process in Cannonsville reservoir watershed (1178 sq km) in US which is the major source of water for New York City. According to the investigators, the reservoir was subjected to water quality problems particularly phosphorus loading and thus attempted to model the hydrologic processes for identifying management options. They used seven years data for calibration and 4 years data for validation. Model performance was assessed using R^2 (coefficient of determination) and E (Nash and Sutcliffe) criteria and found satisfactory.

In a recently completed related study, Abbaspour *et al.,* (2007) used SWAT to model hydrologic processes and transport processes for Thur river basin (1700 sq km) in Switzerland. They calibrated discharge using the data from the year 1991 to 1995 and validated for the years 1996 to 2001. The SWAT simulated discharge and nitrate to a good agreement and sediment and phosphorus loading to a reasonable extent. In this study the degree of uncertainty (*d* factor) was considered. The value of calculated *d* factor for calibration period and validation period were 1.0 and 0.95, respectively, whereas a value of less than 1 is considered to be desirable measure.

Gossain and Rao, (2005) demonstrated the use of SWAT model for selection of hydro power sites in hilly state of Nagaland located in the North Eastern region of India. SWAT model was used to identify locations of adequate discharge. GIS tool was then used to extract the longitudinal profile of the drainage system and hence drops along the profile. From the discharge available through SWAT simulation, flow duration curves were generated for hydro power assessment.

Thus it can be seen that SWAT has been used world wide for various purposes. The various fields where the model has been applied were for assessment of water resources, simulating sediment yield, prioritization of watershed for planning treatment measures, studying the impact of climate on the water resources, to model loading of agricultural chemicals in the water bodies and also to assess hydro power potential.

2.4 Efficiency criteria for assessment of model performance

Usefulness of a model depends upon its performance *i.e.* accuracy of prediction of required events for the situation under study. The variability and uncertainty at different levels *viz.*, model development, data collection, calibration and simulation may accumulate to negatively affect the end results. The situation would vary from case to case. Therefore, it is inevitable to test the performance of hydrological model for each case. There have been lots of studies on performance assessment of hydrological modeling. Comparative assessment studies based on multi-criteria were also being found. The reviews of these works are presented below:

Abbot and Refsgaard (1996) reviewed several hydrological models as part of assigned studies for Commission for the European Communities (SAST, 1992). The evaluation was made on the basis of five criteria *viz.*, adequacy of scientific basis, level of scientific test, validation status, practical applicability and constraints for practical application. A number of practical field problems such as water resources assessment, irrigation, soil erosion, pollution transport, effect of management practices, climate change, aquatic ecology and on line forecasting were incorporated for evaluation of several models. A number of models have been developed for each of the above uses. They analyzed and found that most of these models have limitations as far as set of criteria are concerned. However, performance of some models could pass their evaluation test including hydrological modeling for surface water resources assessment. According to the study, models with adequate scientific basis, scientifically well tested and validated were available for water resources assessment.

The necessity of evaluating model performance based on calculated efficiency criteria and identifying the areas of where model improvement is required were emphasized by Krause *et al.*, (2005). Some selected efficiency criteria *viz.*, coefficient of determination (R^2), Nash and Sutcliffe efficiency (E) and index of agreement (d) in isolation or in combination were commonly used in hydrological studies. These criteria were applied on Wilde Gera (13 sq km) watershed in Germany for the period of November, 90 to April, 91. The results indicated that each of the criteria had some limitations and therefore, suggested to judge their merit during model calibration and evaluation.

Gassman *et al.*, (2007) reviewed 113 case of SWAT applications all over the world and observed that R^2 and E were the most widely used statistics for hydrologic calibration and validation for daily, monthly and annual hydrological events. The range for R^2 is from 0 to 1 (0 means no correlation and 1 indicates perfect fit) and E ranges from $-\infty$ to 1 (the values of 1 shows perfect fit and values equal to or lower than 0 indicates mean of the observed data is better predictor than the predicted value). While compiling the results of 113 modeled cases it was observed that values of R^2 varied from 0.01 to 1 and E varied from - 35.7 to 0.9 for both calibration and validation.

2.5 Assessment of hydro power potential

One of the objectives of the present study was to estimate the hydro power potential of Myntriang and Umkhen watershed from the simulated water resources. Some of the aspects related to assessment of hydro power potential were reviewed and are presented below.

Punys and Pelikan (2007) reviewed various technical aspects related to the status of small hydropower (SHP) in the enlarged European Union (EU) and countries wishing to join EU. They found that in fifteen member countries of European Union there are about 14000 SHP with a total capacity of 10000 MW with average size of each plant of about 0.7 MW. In almost all analyzed countries hydropower is a dominant source of energy in renewable electricity production and SHP occupies the second contributor (after large hydro). The survey also indicated that in most of surveyed countries more than a half of total SHP plants are low head power plants (gross head < 5 m). This fact is especially common in Central and Eastern European countries. The countries located mostly in Southern Europe (Slovenia, Bulgaria, Romania and Turkey) have the highest share of high head (>15 m) SHP plants.

In another study conducted in Uganda for planning rural electricity using GIS technology, Kaijuka (2007) mentioned that small-scale hydro installations in rural areas could offer considerable financial benefits to the beneficiary communities, particularly where careful planning identifies income-generating uses for power. The study also stated that small-hydro schemes not only provide renewable energy, but are also cheaper to maintain, given basic training to the users. The main advantage of small-hydro schemes has been attributed to simpler construction and absence of dam and storage facility. It simply diverts water from the river, channels into a valley and 'drops' into a turbine via 'penstock' (pipeline). This type of hydro generating would thus avoid the damaging environmental and social effects that larger hydroelectric systems can cause.

An effort was made by Dudhani *et al.*, (2006) to demonstrate a methodology to extract information through remote sensing technologies for identification and assessment of water resources and its associates such as inhabitation and settlement pattern, forest and vegetation coverage, snow coverage and selection of probable sites for small hydropower projects. They expected that use of technology would save manpower and time required for surveying and updating the information of the potential and will result into significant impact on the cost.

A study was conducted by Nunes and Genta (1996) to assess mini and micro hydro power in Uruguay for the power above 1 MW and up to 5 MW (small hydropower utilization). The generating potential was assessed all around the country, featuring sites according to the length and height of the dam and volume of water to turbinate, by means of a coefficient which relates the volume of the lake to the power to be installed. They started with mapping from 1:500,000 hypsographic charts with contour lines every 50 meters. Altogether 107 points were identified to locate micro dams. Further they commented that if power lower than 1 MW or lower than 100 KW was considered , the information available on the maps with contour lines, including in those of a 1:500000 scale is not enough to identify the most adequate places. Instead the knowledge of the place is indispensable in these cases.

Das and Paul (2006) in their study attempted identification of suitable sites for setting small hydel power plant in Himalayan region in India using GIS tools. Distributed curve number method was used to calculate the average monthly runoff for the identified site. The base flow was measured at an accessible point in different watersheds/sub-watersheds having similar characteristics. As all the streams were ungauged so regression analysis was done to arrive at an equation for calculation of the base flow on the basis of number of pixels draining at the point of measurement and the average slope of the watershed/sub watershed. The base flow at the site in the sub watershed was ascertained on relational basis. Knowing the total flow and the head the power generating capacity at the site was ascertained.

The information of the research work related to hydrological processes, hydrological modeling, application of hydrological model, assessment of model performance and assessment of potential hydro power as discussed above will be useful for the present investigation.

2.6 Summary

In this chapter literature was reviewed on hydrological processes, hydrological modeling, application of hydrological model, assessment of model performance and assessment of potential hydro power. The review identified various methods for modeling runoff processes, its advantages and associated constraints. It was found that SCS-CN method was suitable for the present study areas and the method was adopted in the thesis. Number of hydrological models were also reviewed and its application world wide was also studied. The advantages, availability and applicability was also studied and SWAT was found to be suitable in the present context. The criteria for evaluation of hydrological model as suggested by Krause *et al.*, (2005) helped in adopting the methodology and was further strengthened by Gassaman *et al.*, (2007) where they reviewed 113 SWAT application world wide using the selected criteria as suggested by Krause *et al.*, (2005). The methods used by Nunes and Genta (1996) and Das and Paul (2006) was adopted in the present study for assessment of hydro power potential.

CHAPTER- 3

HYDROLOGICAL MODELING

The identification and selection of hydrological model is key to simulate the natural process as close possible to the real world situation. Therefore it is necessary to select a suitable model and to understand the processes going on within the model to simulate the real world process. In this chapter an attempt was made to select a suitable model and the methods used and are presented in the chapter under the following sections

1. Model selection
2. Description of the selected model (SWAT2000)
3. Different component and sub component of SWAT2000 such as runoff modeling, peak rate of runoff, evapotranspiration, soil water modeling, weather component modeling and soil erosion.

3.1 Model selection

A number of physically based distributed models have been developed which can be used to simulate watershed hydrology. Each of these models has distinguishing features and suitability is situation specific. It is often seen to select a specific model based on situation specific criteria. Six criteria (Table 3.1) were set to select model for assessment of water resources in Myntriang and Umkhen watershed.

Number of physically based models such as SWMM, HEC-HMS, AGNPS, ANSWERS, TOPMODEL, MIKE-SHE and SWAT were studied and their world wide applications were also reviewed. After critically reviewing these physically based models, SWAT was selected to simulate the hydrologic process of Myntriang and Umkhen watershed as it could fulfill all the set criteria.

Some of the salient features in support of the SWAT are discussed below.

Table 3.1 Criteria for model selection

Sl No	Criteria	Justification	Decision
1	The model should be capable to handle large watersheds (>100 sq km)	The areas of the study watersheds are 267 sq km for Myntriang and 1204 sq km for Umkhen.	Number of physically based models such as SWMM, HEC-HMS, AGNPS, ANSWERS, TOPMODEL, MIKE-SHE and SWAT were studied and their world wide applications were also reviewed. After critically reviewing these physically based models, SWAT was selected to simulate the hydrologic process of Myntriang and Umkhen watershed as it could fulfill all the set criteria.
2	It should have a capability to interface with Geographic Information System tools	This will enable to handle all relevant spatial parameters	
3	The model should be able to physically represent the hydrological processes of the study watershed	This will enable to meet the set objectives	
4	Available data should be sufficient to run the selected model.	Availability of observed data is limited in a study region. However, availability of some specific data could be confirmed. Therefore compatibility with regards to such data has been a major criterion.	
5	The model that can be easily available as a part of a freely accessible package	This is due to institutional constraint with respect to cost involved and wider use of research result by prospective users.	
6	There should be a continuous technical back up support from the developer or users	To overcome any run time difficulty.	

The SWAT model is readily available and user friendly. It is claimed that the model uses readily available inputs (elevation, land use land cover, and soil), computationally efficient and operates on large basins in reasonable time. Further, SWAT is a physically based model capable of simulating long periods. It is a distributed model that allows a watershed to be divided into smaller watersheds to incorporate spatial details. More detailed Modeling can be achieved in SWAT with the concept of Hydrologic Response Units (HRUs), which divides a sub basin into units with unique land use and soil types. The derivation of HRUs captures the variability within the sub basin. Processes in each individual HRU are calculated independently, and thus output for a basin reflects the behavior of all HRUs it contains. Interfacing with Arc-View software, allows easy pre and post processing of the spatially distributed input data and generating rainfall-runoff process. The model is well documented, transparent and source code could be downloaded from the web page at no cost. Finally, a continuous support was also available from the developer and other users by means of an e-mailing list server and a discussion forum on the web page (Arnold, *et al.,* 1998; Neitsch *et al.,* 2002; Pandey *et al.,* 2002, Gossain *et al.,* 2003, Chen and Mackay, 2004; Mishra, 2004 Goassain and Rao, 2005; Romanowicz, *et al.,* 2005; Rao, *et.al,* 2006; Barlund *et al.,* 2007; Kannan, *et al.,* 2007).

Neitsch *et al.,* (2002) has described various sub components of the model showing the mathematical relationships. The theoretical background of using these sub components for modeling Myntriang and Umkhen are discussed in this chapter. The sub-basin components that include hydrology, weather, sediment yield, soil, temperature, and agricultural management are described followed by the description of channel routing components of the model.

3.2 Soil and Water Assessment Tool (SWAT2000)

SWAT2000 is a long term, physically based, continuous simulation watershed model. It has capabilities of simulating surface runoff, sediment yield agricultural chemicals and nutrient losses from small, medium and large watersheds. It can be applied to a large un-gauged rural watershed with more than 100 numbers of small sub-watersheds. The physical processes associated with water and sediment movement, crop growth, and nutrient cycling are modelled by SWAT. There are three main components in the model *viz.,* (i) sub basin (ii) reservoir routing and (iii) channel routing. In the present study no reservoirs exist within the watershed, therefore, only sub basin and channel routing components of the model are considered. The sub basin components consist of eight major divisions. These are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides. The present study requires only four components *viz.,* hydrology, weather, sedimentation and agricultural management practices.

The present study uses the SWAT2000 to asses the hydrologic processes in Myntriang and Umkhen watershed. In particular this study investigates spatial and temporal variation of water and sediment availability.

SWAT model divides a watershed into sub basins which allows accounting of land uses and soil properties impact on hydrology. Then, the model subdivides these sub basins into smaller homogenous units known as Hydrologic Response Units (HRU). The HRUs are lumped land areas within the sub basin comprising of unique features of land cover, soil and its management.

3.3 SWAT Hydrology Component

Simulations of the hydrology of a watershed are separated in two major components: (i) the land phase and (ii) the routing phase (movement through the channel network) of the hydrologic cycle.

The hydrology model is based on the fundamental water balance equation considering a finite volume of soil within each HRU of the watershed

$$SW_t(j) = SW_0 + \sum_{i=1}^{n} \{R(i,j) - Q_{surf}(i,j) - E_a(i,j) - W_{seep}(i,j) - Q_{gw}(i,j)\} \qquad (3.1)$$

Where SW_t (j) is the soil water content at the j^{th} HRU at the end of period under study; SW_0 is the initial soil water content; n is the number of days, $R(i,j)$ is the amount of precipitation, $Q_{surf}(i,j)$ is the amount of surface runoff, $E_a(i,j)$ is the amount of eapotranspiration, $W_{seep}(i,j)$ is the amount of water entering the vadose zone from soil profile, and $Q_{gw}(i,j)$ is the amount of return flow. All measured in *mm* at j^{th} HRU on i^{th} day.

SWAT model sub divides the watershed into sub watershed and further into HRUs. This sub division enables the model to reflect differences in evapotarnspiration for different crops and soils. Runoff is also predicted separately for each HRU and routed to obtain the total runoff for the watershed. This process increases accuracy and gives a much better physical description of the water balance.

Traditionally hydrologic cycle are divided into six distinct phases *viz.* (i) precipitation, (ii) interception, (iii) surface runoff, (iv) soil and root zone infiltration, (v) evapotranspiration and (vi) ground water flow (Fig 3.1).

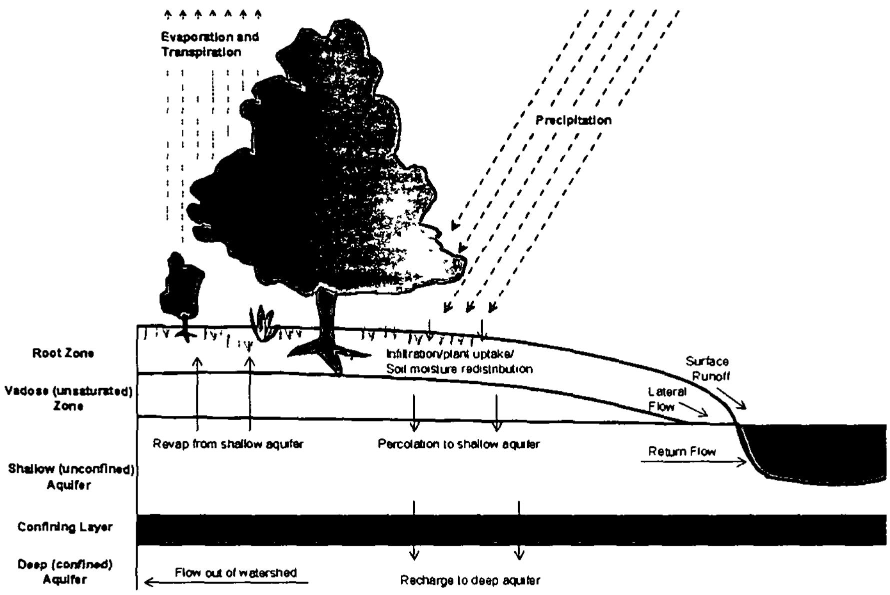

Fig 3.1 Conceptual model of the hydrologic cycle
(Source Neitsch et al., 2002)

The theoretical consideration and the assumptions made for modeling of individual components *viz.,* (i) surface runoff (ii) peak rate of runoff (iii) surface runoff lag (iv) evapotranspiration (v) soil water (vi) ground water (vii) weather and (vii) soil erosion of water balance equation are described below:

3.3.1 Surface Runoff Modeling

SWAT provides two methods for estimating surface runoff. They are (i) the *SCS (Soil Conservation Service) curve number procedure* (SCS, 1972) and (ii) the *Green and Ampt infiltration method* (Green and Ampt, 1911).

The SCS runoff equation is an empirical model developed in 1950s. The model was outcome of studies involving rainfall runoff relationships from small watersheds across the United States (US). The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981).

The *Green and Ampt* equation was developed to predict infiltration assuming excess water at the surface at all times. The equation assumes that the soil profile is homogenous and antecedent moisture is uniformly distributed in the profile. As water infiltrates into the soil, the model assumes the soil above the wetting front is completely saturated and there is a sharp break in moisture content at the wetting front.

Green and Ampt equation is theoretically derived with physically based parameters. Both *SCS curve number* method and *Green and Ampt* method requires model parameters. However, estimating model parameters for un-gauged watersheds by the *Green and Ampt* equation is more difficult than estimating CN values. Also, the *Green and Ampt* equation considers infiltration only; whereas the CN method includes other abstractions as well that includes surface storage, interception and infiltration prior to runoff. Fontaine, *et al.* (2002) mentioned the intensive data requirements of the *Green-Ampt* method and the advantage of simpler and less data intensive method such as SCS curve number method over the *Green- Ampt* method.

In the present study daily rainfall data were available for the Myntriang and Umkhen watershed. The use of readily available daily rainfall data is particularly important attribute of the *curve number* technique. Therefore, *SCS curve number* method for estimating surface runoff was chosen. It is widely used method. Some of the recent users of SCS curve number methods are

Dingman (1994); Arnold *et al.,* (1998); Lukman (2003); Van Liew and Garbrecht (2003); Dutta *et,al,* (2006); Kannan *et al.,* (2007), Tolson and Shoemaker (2007); and Abbaspour *et al.*, (2007).

In the following section the details of curve number method and its use for modeling of surface runoff is described.

3.3.1.1 Runoff - *Curve Number* Relation

SCS curve number method for estimating surface runoff is defined by a single parameter, namely the curve number that is an integer value varying between 0 and 100. From empirical analyses of rainfall-runoff data on small watersheds and hill slope areas, the National Resource Conservation Service (NRCS) proposed a table of CN values with four defining parameters (NRCS, 1985): (i) Land use and land cover (LULC); (ii) hydrologic condition, (iii) hydrologic soil group and (iv) Antecedent Moisture Conditions (AMC). For a watershed of complex combinations of land use and hydrological soil groups, an effective CN of the watershed is computed by linear combination of CN of all combinations, weighted by their respective area (Beven, 2000).

NRCS (1986) defined three Antecedent Moisture Conditions *viz.,* AMC I, AMC II and AMCIII. Moisture condition at wilting point is referred as AMC I, field capacity as AMC III and average of these extreme conditions is referred as AMC II. Typical curve number for antecedent moisture condition II are listed by SCS, Engineering Division, for various land cover and soil types.

The spatial and temporal form of surface runoff is expressed in terms of rainfall and *curve number* by the following functional relationship

$$Q_{surf}(i,j) = \{R(i,j); CN(i,j)\} \quad (3.2)$$

Where, Q_{surf} *(i,j)* is the surface runoff in mm at j^{th} HRU on i^{th} day; *R(i,j)* is the rainfall in mm at j^{th} HRU on i^{th} day and *CN(i,j)* is the curve number at j^{th} HRU on i^{th} day.

According to SCS (1972), the *SCS curve number* functional relationship can be modelled as

$$Q_{surf}(i,j) = \frac{\{R(i,j)\ -I_a(i,j)\}^2}{\{R(i,j) - I_a(i,j) + S(i,j)\}} \qquad (3.3)$$

The runoff will occur if

$R(i,j)_y > I_a(i,j)$ (3.3a)

Where $Q_{surf}(i,j)$ is the accumulated runoff or rainfall excess (mm), $R(i,j)$ is the amount of rainfall (mm), $I_a(i,j)$ is the initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm), and $S(i,j)$ is the retention parameter (mm). All parameters referred on i^{th} day and at j^{th} HRU. 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 given by the following empirical equation

$$S(i.j) = 25.4 \times \left(\frac{1000}{CN(i,j)} - 10) \right) \qquad (3.4)$$

Where $CN(i,j)$ is the curve number for the i^{th} day on j^{th} HRU. The model uses Eq (3.4) to obtain the maximum retention that may take place in a watershed using *CN* value corresponding AMC I.

The initial abstraction, $I_a(i,j)$ is a function of retention parameter approximated by the following relationship

$$I_a = 0.2S \qquad (3.5)$$

Incorporating equation (3.5) in equation (3.3) the following relationship is obtained

$$Q_{surf}(i,j) = \frac{\{R(i,j)\ -0.2S(i,j)\}^2}{\{R(i,j)\ +0.8S(i,j)\}} \qquad (3.6)$$

The retention parameter $S\ (i,\ j)$ which is a function of curve number $CN(i,\ j)$ is dependent on the soil hydrologic characteristics. Based on the soil hydrologic characteristics the soils are classified into various soil hydrologic groups. The characterization of soil hydrologic groups are described below.

3.3.1.2 Soil Hydrologic Groups

Soil hydrologic group is defined as a group of soils having similar runoff potential under similar storm and cover conditions (NRCS, 1996). Soil characteristics that influence the infiltration rate are (i) depth of water table, (ii) saturated hydraulic conductivity and (iii) depth to impermeable layer. Based on these characteristics NRCS (1996) has classified soil into following groups:

Soil group A: (soils with low runoff potential). The soils have a high infiltration rate even when thoroughly wetted. It chiefly consists of deep, well drained to excessively drained sands or gravels. They have high rate of water transmission.

Soil group B: The soils have moderate infiltration rate when thoroughly wetted. These coils are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse texture. They have a moderate rate of water transmission.

Soil group C: The soils have a slow infiltration rate when thoroughly wetted. These soils have a layer that impedes downward movement of water or have moderately fine to fine texture. They have slow rate of water transmission.

Soil group D: The soils have a very slow infiltration rate when thoroughly wetted. These soils consists of clay soils that have a high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have slow rate of water transmission.

The properties of each soil hydrologic groups are shown in Appendix-6.

The curve number that is a function of soil hydrologic groups varies with change in antecedent moisture condition. The various moisture conditions that may exists in a watershed is described below.

3.3.1.3 Antecedent Soil Moisture Condition

As discussed in section 3.3.1.1, SCS defines three antecedent moisture conditions: AMC I dry (wilting point), AMC II (average moisture), and AMC III (Field Capacity). The curve numbers for moisture condition I and III are calculated with the following empirical equations:

$$CN1(i,j) = CN2(i,j) - \frac{20 \times (100 - CN2(i,j))}{(100 - CN2(i,j) + \exp[2.533 - 0.636 \times (100 - CN2(i,j))]} \quad (3.7)$$

$$CN3(i,j) = CN2(i,j) \times \exp[0.00673(100 - CN2(i,j)] \quad (3.8)$$

Where *CN1(i,j)* curve number corresponding to AMC I, *CN2(i,j)*is the curve number corresponding to AMC II, and *CN3(i,j)* is curve number corresponding to AMC III for i^{th} day and j^{th} HRU.

The retention parameter varies with soil profile water content according to following equation

$$S(i,j) = S_{\max}(i,j)\left(1 - \frac{SW(i,j)}{[SW(i,j) + \exp(w_1 - w_2 \times SW(i,j)]}\right) \quad (3.9)$$

Where *S(i,j)* is the retention parameter for a given moisture content (mm), $S_{max}(i,j)$ is the maximum value the retention parameter can achieve on i^{th} day (mm), *SW(i,j)* is the soil water content of the entire profile excluding the amount of water held in profile at wilting point (mm), and w_1 and w_2 are shape coefficients respectively for i^{th} day and j^{th} HRU. The maximum retention parameter value $S_{max}(i,j)$ is calculated using Equation (3.4) for *CN1(i,j)*.

The shape coefficients are determined by solving equation 3.9 assuming that

(i) the retention parameter for AMC I curve number corresponds to wilting point soil profile water content,

(ii) the retention parameter for AMC III curve number corresponds to field capacity soil profile water content, and

(iii) the soil has a curve number of 99 (S = 2.54) when completely saturated.

$$w_1 = In\left[\frac{FC(i,j)}{1 - S3(i,j) \times S_{max}^{-1}(i,j)} - FC(i,j)\right] + w_2 \times FC(i,j) \qquad (3.10)$$

$$w_2 = \frac{\left(In\left[\frac{FC(i,j)}{1 - S_3(i,j) \times S_{max}^{-1}(i,j)} - FC(i,j)\right] - In\left[\frac{SAT(i,j)}{1 - 2.54 \times S_{max}^{-1}(i,j)} - SAT(i,j)\right]\right)}{(SAT(i,j) - FC(i,j))} \qquad (3.11)$$

where, *FC(i,j)* is the amount of water in the soil profile at field capacity (mm), $S_3(i,j)$ is the retention parameter for the moisture condition III curve number, $S_{max}(i,j)$ is the retention parameter for the AMC I curve number, and *SAT(i,j)* is the amount of water in the soil profile when completely saturated (mm) on i^{th} day at j^{th} HRU.

The daily curve number value adjusted for moisture content is calculated by rearranging Equation (3.4) and inserting the retention parameter calculated for that moisture content as given below

$$CN(i,j) = \frac{25400}{S(i,j) + 254} \qquad (3.12)$$

Where *CN(I,j)* is the curve number on the i^{th} day at j^{th} HRU and *S(I,j)* is the retention parameter calculated for the moisture content of the soil on the corresponding day and HRU.

3.3.1.4 Slope Adjustments

The *CN2* provided by NRCS are assumed to be appropriate for 5% slope. Williams (1995) proposed the following equation to adjust the curve number to a different slope:

$$CN2S(i,j) = \frac{(CN3(i,j) - CN2(i,j))}{3} \times [1 - 2 \times \exp(-13.86 \times slp)] + CN2(i,j) \quad (3.13)$$

Where *CN2S(i,j)* is the curve number at AMC II adjusted for slope, *CN3(i,j)* is the curve number at AMC III for 5% slope, *CN2(i,j)* is the curve number at AMC II for 5% slope on i^{th} day at j^{th} HRU, and *slp* is the average percent slope of the basin.

The rainfall, soil profile, land use and terrain data available for the watershed were used the model to estimate the surface runoff for Myntriang and Umkhen watersheds.

3.3.2 Peak Rate of Runoff Modeling

The peak runoff rate is the maximum runoff flow rate that occurs within a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT 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

$$q_{peak} = \frac{C \times i \times Area}{3.6} \quad (3.14)$$

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 (sq km) and 3.6 is a unit conversion factor.

For the estimation of peak rate of runoff the values of time of concentration, runoff coefficient and rainfall intensity are to be determined. The methods for estimation of each parameter are described in the following sections.

3.3.2.1 Time of concentration

The time of concentration (t_{conc}) is the amount of time (hour) 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 in hr (t_{ov}) and the channel flow time t_{ch} (the time it takes for flow in the upstream channels to reach the outlet in hr) and is given by the following relationship

$$t_{conc} = t_{ov} + t_{ch} \quad (3.15)$$

The methods for determination of overland flow time of concentration and channel flow time are described in the subsequent sections.

3.3.2.2 Modeling Overland Flow time of concentration

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

$$t_{ov} = \frac{L_{slp}}{3600\ v_{ov}} \quad (3.16)$$

Where L_{slp} is the sub basin slope length (m), v_{ov} is the overland flow velocity (ms^{-1}) and 3600 is for unit conversion.

The overland flow velocity is estimated from *Mannings* equation by considering a strip of 1 m width down the sloping surface as

$$v_{ov} = \frac{q_{ov}^{0.4} \times slp^{0.3}}{n^{0.6}} \quad (3.17)$$

where q_{ov} is the average overland flow rate (m^3s^{-1}), *slp* is the average slope in the sub basin ($m\ m^{-1}$), and *n* is the *Manning's* roughness coefficient for the basin. The model assumes the average flow rate of 6.35 mm/hr which is also considered to be applicable to the Myntrinag and Umkhen watershed. After converting the units the equation (3.17) becomes

$$v_{ov} = \frac{0.005 \times L_{slp}^{0.4} \times slp^{0.3}}{n^{0.6}} \tag{3.18}$$

By substituting equation (3.18) in (3.16), t_{ov} becomes

$$t_{ov} = \frac{L_{slp}^{0.6} \times n^{0.6}}{18 \times slp^{0.3}} \tag{3.19}$$

3.3.2.3 Modeling Channel Flow time of concentration

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

$$t_{ch} = \frac{L_c}{3.6 \times v_c} \tag{3.20}$$

where L_c is the average flow channel length for the sub basin (km), v_c is the average channel velocity (m s^{-1}), and 3.6 is for unit conversion. The average channel flow can be estimated using the following equation

$$L_c = \sqrt{L \times L_{cen}} \tag{3.21}$$

where L is the channel length from the most distant point to the basin outlet (km), and L_{cen} is the distance along the channel to the sub basin centroid (km).

Assuming $L_{cen}=0.5L$, the average channel flow length is

$$L_c = 0.71L \tag{3.22}$$

The average velocity is estimated from *Manning's* equation assuming a trapezoidal channel with 2:1 side slopes and a 10:1 bottom width - depth ratio,

$$v_c = \frac{0.489 \times q_{ch}^{0.25} \times Slp_{ch}^{0.375}}{n^{0.75}} \tag{3.23}$$

Where v_c is the average channel velocity (m s^{-1}), q_{ch} is the average channel flow rate (m^3 s^{-1}), slp_{ch} is the channel slope (m m^{-1}), and n is the *Manning*'s roughness coefficient for the channel.

By expressing the average channel flow rates in mm/hr and assuming the unit source area flow rate as 6.35 mm/hr, average channel velocity becomes

$$v_c = \frac{0.317 Area^{0.125} Slp_{ch}^{0.375}}{n^{0.75}} \tag{3.24}$$

Substituting Equation (3.21) and (3.24) into (3.20) gives

$$t_{ch} = \frac{0.62 \times L \times n^{0.75}}{Area^{0.125} \times Slp_{ch}^{0.375}} \tag{3.25}$$

Where t_{ch} is the time of concentration for channel flow (hr), L is the channel length from the most distant point to the sub basin outlet (km), n is Manning's roughness coefficient for the channel, Area is the sub basin area (sq km), and Slp_{ch} is the channel slope (m m^{-1}).

Finally, time of concentration T_c is obtained as the sum of Eq (3.19) and (3.25).

The topographical parameters of the study watersheds *viz.*, area, channel slope, channel length used in the equations will be generated from the digital elevation model which is the input to the model. The values of n are obtained from the values provided by Chow (1959) for channel flow and Engman (1983) for overland flow.

It is argued since the mathematical relationships for time of concentrations (Equations 3.19 and 3.25) are based on hydraulic considerations, they are more reliable than purely empirical equations (Neitsch *et al.,* 2002).

3.3.2.4 Modeling Runoff Coefficient

The runoff coefficient is the ratio of the inflow rate,($i \times Area$) to the peak discharge rate, q_{peak}. The runoff coefficient will vary from storm to storm and is calculated as

$$C = \frac{Q_{surf}(i,j)}{R(i,j)} \qquad (3.26)$$

Where Q_{surf} (i,j) is the surface runoff (mm) on i^{th} day and at j^{th} HRU and R_{day} (i,j) is the rainfall on i^{th} day and at j^{th} HRU (mm).

3.3.2.5 Rainfall Intensity

The rainfall intensity is the average rainfall rate during the time of concentration. Based on this definition rainfall intensity is calculated as

$$i_r = \frac{R_{tc}}{t_{conc}} \qquad (3.27)$$

Where, i_r is the rainfall intensity (mm/hr) and R_{tc} is the amount of rain falling during the time of concentration (mm).

An analysis of rainfall data collected by Herschfield (1961) for different durations and frequencies showed that the amount of rain falling during the time of concentration was proportional to the amount of rain falling during the 24 hour period. Using this conception following relationship is written

$$R_{tc} = \alpha_{tc} \times R_{day} \qquad (3.28)$$

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

The rational formula used to estimate peak flow rate was modified by substituting Eqs 3.26, 3.27 and 3.28 into Eq 3.14. Thus, the resulting expression becomes

$$q_{peak} = \frac{\alpha_{tc} \times Q_{surf} \times Area}{3.6 \times t_{conc}} \qquad (3.29)$$

where q_{peak} is the peak rate of runoff (m^3 s^{-1}), Q_{surf} is the surface runoff (mm), *Area is the sub-basin area* (sq km), t_{conc} *is the time of concentration for* the basin (hr) and 3.6 is for unit conversion.

3.3.3 Modeling Surface Runoff Lag

In large basins with time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the i^{th} day. SWAT incorporates a surface runoff storage feature to lag a portion of the surface runoff release to the main channel.

Once surface runoff is calculated the amount of surface runoff released to the main channel is calculated

$$Q_{surf}(i,j) = (Q'_{surf}(i,j) + Q_{stor,i-1}(i,j))\left(1 - \exp\left[\frac{-surlag}{t_{conc}}\right]\right) \qquad (3.30)$$

Where $Q_{surf}(i,j)$ is the amount of surface runoff discharged to the main channel (mm), Q'_{surf} is the amount of surface runoff generated in the sub basin (mm) on i^{th} day and j^{th} HRU, $Q_{stor,i-1}$ is the surface runoff stored or lagged from the previous day (mm) from the j^{th} HRU, *surlag* is the surface runoff lag coefficient, and t_{conc} is the time of concentration for the sub basin (hrs).

The surface runoff lag is determined during the process of calibration of the model.

3.3.4 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 soil.

An accurate estimation of evapotranspiration is critical in the assessment of water resources and the impact of climate and land use on those resources (Neitsch *et al.,* 2002).

The SWAT model incorporates three methods for estimation of evapotranspiration: the Penman-Monteith method (Monteith, 1965; Allen, 1986; Allen *et al.,* 1989), the Priestley-Taylor method (Priestley & Taylor, 1972) and Hargreaves method (Hargreaves *et al.,* 1985). The model also provides option to reads in daily PET values if the users prefer to apply a different potential evapotranspiration method.

Input requirements differs in all the three methods. The Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestly- Taylor method requires solar radiation, temperature and relative humidity. The Hargreaves method requires air temperature only and this method was used for the present study.

The Hargreaves method was originally derived from eight years of cool-season Alta fescue grass lysimeter data from Davis, California (Hargreaves, 1975). Several improvements were made to the original equation (Hargreaves and Samani, 1982 and 1985) and the form used in SWAT was published in 1985 (Hargreaves *et al.,* 1985):

$$\lambda E_0 = 0.0023 H_0 (T_{mx} - T_{mn})^{0.5} (\bar{T}_{av} + 17.8) \qquad (3.31)$$

Where λ is the latent heat of vaporization (MJ kg^{-1}), E_o is the potential evapotranspiration (mmd^{-1}), H_0 is the extra terrestrial radiation ($MJm^{-2}d^{-1}$), T_{mx} is the maximum air temperature for a given day (°C), T_{mn} is the minimum air temperature for a given day (°C), and $\bar{T}_{av}$ is the average temperature for a given day (°C).

Due to availability of maximum and minimum temperature data for the Myntriang and Umkhen watershed Hargreaves method was used for estimating evapotranspiration.

Once total potential evapotranspiration is determined, actual evaporation must be calculated. SWAT first evaporates any rainfall intercepted by the plant canopy. Next, SWAT calculates the maximum amount of transpiration and the maximum amount of sublimation/soil evaporation using an approach similar to that of Richtie (1972). The actual amount of sublimation and evaporation from the soil is then calculated.

3.3.5 Soil Water Modeling

Water maintained in the soil profile after infiltration can flow under saturated or unsaturated conditions. In saturated soils, flow is driven by gravity and usually occurs in the downward direction. Unsaturated flow caused by gradients arising due to adjacent areas of high and low water content. Unsaturated flow may occur in any direction.

SWAT directly simulates saturated flow if the water content is superior to the field capacity. The model records the water contents of the different soil layers (minimum 1 layer of soil and maximum 10 layers) but assumes that the water is uniformly distributed within a given layer. This assumption eliminates the need to model unsaturated flow in horizontal direction. Unsaturated flow between layers is indirectly modelled with the depth distribution of plant water uptake and depth distribution of soil water evaporation.

Percolation and lateral flow are modelled separately as given below.

3.3.5.1 Percolation

Percolation is the volume of water that seeps into the soil. Water is allowed to percolate from one layer if the water content exceeds the field capacity water content for this layer. Percolation is dependent on many factors major being soil water, soil structure and texture.

The volume of water available for percolation in the soil layer is

$$SW_{ly,excess}(i,j) = SW_{ly}(i,j) - FC_{ly}(j), \quad \text{if } SW_{ly} > Fc_{ly} \qquad (3.32)$$

$$SW_{ly}(I,j) = 0, \quad \text{if } SW_{ly} \leq Fc_{ly} \qquad (3.33)$$

Where $SW_{ly,\ excess}$ (i,j) is the drainable volume of water in the soil layer on i^{th} day and at j^{th} HRU day (mm), SW_{ly} $(i,j)$is the water content of the soil layer on i^{th} day and at j^{th} HRU (mm) and Fc_{ly} is the water content of the soil layer at field capacity (mm) at j^{th} HRU.

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

$$w_{perc,ly}(i,j) = SW_{ly,excess}(i,j)\left[1-\exp^{\left(\frac{-\Delta t}{TT_{perc}}\right)}\right] \tag{3.34}$$

Where $w_{perc,ly}$ $(i,j)$is the amount of water percolating to the underlying soil layer on i^{th} day and at j^{th} HRU (mm), $SW_{ly,\ excess}$ $(i,j)$is the drainable volume of water in the soil layer on i^{th} day and at j^{th} HRU (mm), Δt is the length of time step (hr), and TT_{perc} is the travel time for percolation (hr).

The travel time for percolation is unique for each layer. It is calculated

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}} \tag{3.35}$$

where TT_{perc} is the travel time for percolation (hr), SAT_{ly} is the amount of water in the soil layer when completely saturated (mm), FC_{ly} is the water content of the soil layer at field capacity (mm) and K_{sat} is the saturated hydraulic conductivity (mm h^{-1}).

The soil profile characteristics viz., saturated hydraulic conductivity and available water and the texture of the study watershed was used by the model to estimate the percolation.

3.3.5.2 Lateral Flow

The model incorporates a kinematic storage model for subsurface flow 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 (Fig 3.2). The drainable volume of water stored in the saturated zone of the hill slope segment per unit area, $SW_{ly,\,excess}$ is

$$SW_{ly,excess} = \frac{1000 \times H_0 \times \phi_d \times L_{hill}}{2} \tag{3.36}$$

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) and L_{hill} is the hill slope length (m).

In large sub basins with a time of concentration greater than 1 day, only a portion of the lateral flow will reach the main channel on the day it is generated. SWAT incorporates a lateral flow storage feature to lag a portion of lateral flow release to the main channel and calculated a total lateral flow by summing the two fractions contributing from a given day and the previous day.

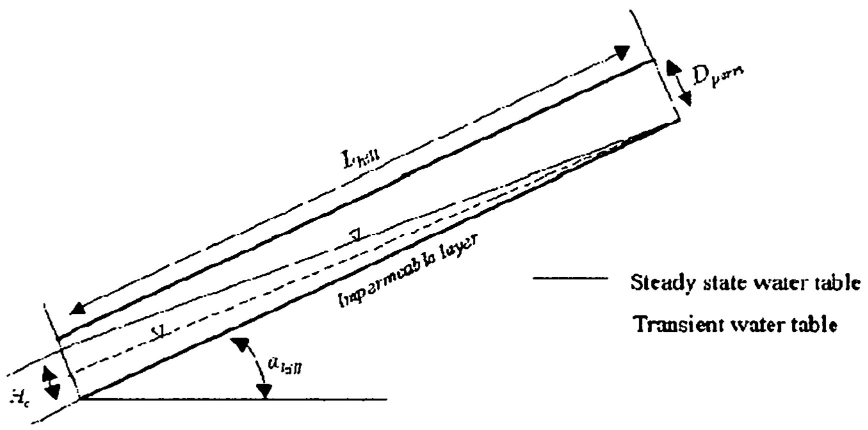

Fig 3.2: Behaviour of water table as assumed in kinetic storage model. (Source Neitsch et.al, 2002)

In the present study the soil characteristics viz., the drainable porosity and the land slope derived from the DEM of Myntriang and Umkhen watershed were used to estimate the percolation and lateral flow process.

3.3.6 Modeling Groundwater

SWAT simulates two aquifers in each sub basin. The shallow aquifer is an unconfined aquifer that contributes to flow in the main channel or reach of the subbsain. The deep aquifer is a confined aquifer. The water that enters the deep aquifer is assumed to contribute to stream flow somewhere outside of the watershed (Arnold *et.al, 1993*).

Water leaves groundwater storage either by discharge into rivers / lakes or by upward movement from the water table into the capillary fringe. It can also leave by seepage to the deep aquifer. The contribution of ground water to stream flow is simulated by creating a shallow aquifer storage which is recharged by percolation from the unsaturated zone, and discharges to the reach of the sub basin. The water balance for the shallow aquifer is:

$$aq_{sh}(i,j) = aq_{sh}(i-1,j) + w_{rchrg}(i,j) - Q_{gw}(i,j) - w_{revap}(i,j) - w_{deep}(i,j) - wu_{sa}(i,j) \quad (3.37)$$

Where $aq_{sh}(i,j)$ is the shallow aquifer storage on i^{th} day and at j^{th} HRU (mm), $aq_{shi,}(i-1)$ is the shallow aquifer storage on *(i-1)* day *at j^{th} HRU* (mm), $w_{rchrg}(i,j)$ is the recharge entering the aquifer on i^{th} day and at j^{th} HRU (mm), Q_{gw} is the groundwater flow or base flow, into the main channel on i^{th} day and at j^{th} HRU (mm), W_{revap} is the amount of water moving into the soil zone in response to water deficiencies on i^{th} day and at j^{th} HRU (mm), w_{deep} is the amount of water percolating from the shallow aquifer into the deep aquifer on i^{th} day and at j^{th} HRU (mm) and wu_{sa} is the water use from the shallow aquifer (mm).

Ground water flow into the main channel on day "*i*" and j^{th} HRU is calculated using the following equation

$$Q_{gw}(i,j) = Q_{gw}(i-1,j) * e^{-\alpha\Delta t} + w_{rchrg}(1 - e^{-\alpha\Delta t}) \quad (3.38)$$

Where α is the recession constant which describes the lag flow from the aquifer and Δt is the time step. α can be best estimated by analyzing measured stream flow during the period of no recharge in the watershed.

The soil characteristics of the watersheds were used to model the ground water flow in the hydrologic process.

3.3.7 Modeling Weather Component

Water management and catchment hydrologic processes modeling require long term weather data obtained at specific sites on daily and even sub daily basis. Several models require long term daily values of rainfall, solar radiation as well as maximum and minimum temperature (Soltani, 2000). The SWAT model requires daily data on the above mentioned parameters for the simulations. However, many areas do not have sufficient available weather data due to a lack of regular follow-up of chronological data acquisition for many stations. In case of applying SWAT the user may choose to read these inputs from a file or generate the values using monthly average data summarized over a number of years.

SWAT includes the weather generator model (WXGEN) (Sharpley and Williams, 1990) to generate climatic data or to generate missing data. Initially the weather generator independently generates precipitation for the day, followed by generate maximum/minimum temperature, solar radiation and relative humidity based on the presence or absence of rain. Finally, wind speed is generated independently.

3.3.7.1 Precipitation generation with stochastic weather generators

Stochastic weather generators are used in a wide range of studies, such as hydrological applications, environmental management and agricultural risk assessments. Such studies often require long series of daily weather data for risk assessment and weather generators can produce time series of synthetic daily weather data of any length. Weather generators are also used to interpolate observed data to produce synthetic weather data at new sites, and they have recently been employed in the construction of climate change scenarios (Semenov *et al.,* 1998). Any generator should be tested to ensure that the data that it produces is satisfactory for the purposes for which it is to be used.

3.3.7.2 Precipitation generation

To define the day as wet or dry, SWAT precipitation generator (WXGEN) used the first order Markov chain model (Nicks, 1974). When a wet day is generated, a skewed distribution or exponential distribution is used to generate the precipitation amount. With this model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.1 mm of rain or more. Given the wet-dry probabilities, the model stochastically determines the occurrence of rainfall in a particular day.

The model requires two state transition probabilities input. These are *Pi*(*W/W*), the probability of a wet day on day *i* given a wet day on day *i* – 1, and *Pi*(*W/D*), the probability of a wet day on day *i* given a dry day on day *i* – 1 for each month of the year. From these inputs the remaining transition probabilities can be derived

$$P_i(D/W) = 1 - P_i(W/W) \quad (3.39)$$

$$P_i(D/D) = 1 - P_i(W/D) \quad (3.40)$$

Where *Pi(D/W)*, the probability of a dry day on day *i* given a wet day on day *i* – 1, *Pi(D/D)*, 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, SWAT generates a random number between 0.0 and 1.0. This random number is compared to the appropriate wet-dry probability, *Pi*(*W/W*) or *Pi*(*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.

Then, the skewed distribution proposed by Nicks (1974) is used to calculate the rainfall amount by using the following equation:

$$R_{day} = \mu_{month} + 2.\sigma_{month}.\left\{ \frac{\left[\left(SND_{day} - \frac{g_{month}}{6}\right)\left(\frac{g_{month}}{6}\right) + 1\right]^3 - 1]}{g_{month}} \right\} \quad (3.41)$$

Where: R_{day} is the amount of precipitation on a given day (mm) ; μ_{month} is the mean daily precipitation (mm) for the month; σ_{month} is the standard deviation of daily precipitation (mm) for the month; SND_{day} is the standard normal deviation calculated for the day; g_{month} is coefficient of skewness for daily precipitation in the month.

The mean daily precipitation (mm) for the month is obtained as:

$$\mu_{month} = \frac{PCPMM}{PCPD} \quad (3.42)$$

Where:

PCPMM = average amount of precipitation falling in a month (mm)

PCPD = average number of days of precipitation in a month.

The standard normal deviate (SDN) for the day is calculated:

$$SND = \cos(6.283P \times rnd_2) \times \sqrt{-2In(rnd_1)} \quad (3.43)$$

Where md_1 and md_2 are random numbers between 0.0 and 1.0

The exponential distribution is provided as an alternative to the skewed distribution. This distribution requires fewer inputs and is most commonly used in areas where limited data on precipitation events is available. As the rainfall data were available for the study area, the first method has been used.

SWAT generates rainfall using the WXGEN model based on historical statistics. It requires the long term monthly statistics such as mean rainfall and standard deviations. The model uses the same set of monthly statistics for generating long time series. That may introduce some errors for the daily values. Another plausible source of errors is the aggregated lower level generated data (daily) which could be inconsistent with higher level (monthly) observed data. Some authors (Wallis & Griffiths, 1995; Hayhoe & Stewart, 1996) discussed the unrealistic estimates of WXGEN model and its incapability of generating statistics such as mean and standard deviation consistent with the observed statistics. Then, as daily measured data were available for several gauged stations in our catchment, observed daily rainfall data were used instead of simulated. However, the days with data gaps were filled by the model. In this way, the consistency between generated daily data and the observed monthly data can be maintained for the months which have a few days of missing data.

The historical rainfall data of Shillong, Haflong and Chaparmukh stations were collected from Indian Meteorological Department (IMD). These data were used in the precipitation generator model.

3.3.7.3 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 the 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:

$$\mu rad_{mon} \times days_{tot} = \mu Wrad_{mon} \times days_{wet} + \mu Drad_{mon} \times days_{dray} \qquad (3.44)$$

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

The historical temperature data of Shillong, Haflong and Chaparmukh stations were collected from Indian Meteorological Department (IMD).

3.3.7.4 Relative Humidity

Daily average relative humidity values are calculated from a triangular distribution using average monthly relative humidity. The maximum daily relative humidity value is calculated from the mean monthly relative humidity with the equation:

$$R_{hUmon} = R_{hmon} + (1 - R_{hmon}) \times \exp(R_{hmon} - 1) \qquad (3.45)$$

where, R_{hUmon} is the largest relative humidity value that can be generated on a given day in the month, and R_{hmon} is the average relative humidity for the month. The minimum relative humidity value is calculated from the mean monthly relative humidity with the equation:

$$R_{hLmon} = R_{hmon} \times (1 - \exp(-R_{hmon})) \qquad (3.46)$$

where, R_{hLmon} is the smallest relative humidity value that can be generated on a given day in the month.

The continuity equation relates average relative humidity adjusted for wet or dry conditions to the average relative humidity for the month:

$$R_{hmon}.days_{tot} = R_{hWmon}.days_{wet} + R_{hDmon}.days_{dry} \qquad (3.47)$$

where, R_{hWmon} is the average relative humidity for the month on wet days and R_{hDmon} is the average relative humidity of the month on dry days.

The input of monthly average of relative humidity for Shillong, Haflong and Chaparmukh stations were collected from Indian Meteorological Department (IMD).

3.3.7.5 Wind speed

Mean daily wind speed is one of the input parameter of the weather generator model used by SWAT2000. The available mean wind speed for Shillong, Haflong and Chaparmukh were used to generate average wind speed for Myntriang and Umkhen watershed. Mean daily wind speed is generated using a modified exponential equation:

$$\mu_{10m} = \mu wnd_{mon}.(-In(rnd_1))^{0.3} \quad (3.48)$$

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 md_1 is a random number between 0 and 1.

The input of monthly average of wind speed for Shillong, Haflong and Chaparmukh stations were collected from Indian Meteorological Department (IMD).

3.4 Soil Erosion

Erosion caused by rainfall and runoff is computed with modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeir and Smith (1965, 1978).

The USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condiction as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

3.4.1 Modified Universal Loss Equation (MUSLE)

The modified universal soil loss equation (Williams, 1995) is:

$$Sed(i,j) = 11.8 * (Q_{surf}(i,j) \times q_{peak} \times area_{hru})^{0.56} K_{USLE} C_{USLE} P_{USLE} LS_{USLE} CFRG \quad (3.49)$$

Where *Sed* is the sediment yield on i^{th} day at j^{th} HRU (metric tonnes), Q_{surf} is the surface runoff volume (mm)/ ha) on i^{th} day at j^{th} HRU, q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil eroibility factor (0.013 metric ton m^2 hr/m^3-metric ton cm), 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. Each of the sub components are described below:

3.4.1.1 Soil Erodibility Factor

Some soils erode more easily than others even when all other factors are the same. The difference is termed as soil erodibility and is caused by the property of the soil itself. Wischmier and Smith (1978) define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.1 m (72.6 ft) long, with a uniform length wise slope of 9 percent, in continious fallow tilled up and down the slope. Continuous fallow is defined as land that has been tilled and kept free of vegetation for more than 2 years. The units for the USLE soil erodibility factor in MUSLE are numerically equivalent to the traditionally English unit of 0.01 (ton acre hr)/(acre ft-ton inch).

Direct measurement of the erodibility factor is time consuming and costly. D Wischmier et al. (1971) and Williams (1995) proposed different methods to estimate erodibility factor based on the soil texture and organic carbon. The Williams method was adopted in the present study due to availability of all the parameters of soil for Myntriang and Umkhen watershed. Williams (1995) equation is presented as

$$K_{USLE} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \quad (3.50)$$

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 organic carbon content, and f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The factors are calculated:

$$f_{csan} = \left(0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left\{1 - \frac{m_{silt}}{100}\right\}\right]\right) \quad (3.51)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (3.52)$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgC}{orgC + \exp[3.72 - 2.95 \times orgC]}\right) \quad (3.53)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \left[1 - \frac{m_s}{100}\right]}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (3.54)$$

where m_S is the sand content (0.05-2.00 mm diameter particles), m_{silt} is the percent silt content (0.002-0.05 mm 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 (%).

3.4.1.2 Cover and Management Factor

The USLE cover and management factor, C_{usle}, is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeir &Smith, 1978). C_{USLE} is estimated using the following equation:

$$C_{USLE} = \exp(\lfloor In(0.8) - In(C_{USLE,mn}) \rfloor \exp\lfloor -0.00115 \times rsd_{surf} \rfloor + In\lfloor C_{USLE,mn} \rfloor) \quad (3.55)$$

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

The minimum C factor can be estimated from a known average annual C factor using the following equation (Arnold & Williams, 1995):

$$C_{USLE,mn} = 1.463 \times In\left[C_{USLE,aa}\right] + 0.1034 \quad (3.56)$$

Where $C_{USLE,mn}$ is the minimum C factor for the land cover and $C_{USLE,aa}$ is the average annual C factor for the land cover.

3.4.1.3 Support practice factor

The support practice factor, PUSLE is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip cropping on the contour, and terrace systems. Stabilized waterways for the disposal of excess rainfall are a necessary part of each of these practices.

Contour tillage and planting provides almost complete protection against erosion from storms of low to moderate intensity, but little or no protection against occasional severe storms that cause extensive breakovers of contours rows. Contouring is most effective on slopes of 3 to 8%.

3.4.4.4 Topographic Factors

The topographic factor, LS_{USLE}, is the expected ratio of soil loss per unit area from a field slope to that from a 22.1 m length of 9% slope under otherwise identical conditions. The topographic factor is calculated:

$$LS_{USLE} = \left(\frac{L_{hill}}{22.1}\right)^m \times \left(65.41 \times Sin^2(\alpha_{hill})\right) + 4.56 \times \sin(\alpha_{hill}) + 0.065 \quad (3.57)$$

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

$$m = 0.6 \times \left(1 - \exp\left[-35.835 \times slp\right]\right) \tag{3.58}$$

where *slp* is the slope of the HRU expressed rise over run (m/m). The relationship between α_{hill} and *slp* is $slp = \tan\alpha_{hill}$. The topographic parameters of the study watershed were obtained from the DEM.

Thus in the present study the theoretical considerations that were adopted for estimation of surface runoff, peak rate of runoff, surface runoff lag, evapotranspiration, soil water movement, ground water movement, generation of weather data for missing values and soil erosion rate. The input data for Modeling these components included the terrain data, soil profile data, land use data and weather data for the Myntriang and Umkhen watershed.

3.5 Summary

This chapter deals with the hydrological model. SWAT2000 was selected as it could cater to the criteria set for the selection of model. To model the surface runoff component SCS CN method was selected, rational method was used for modeling the peak rate of runoff, different methods for estimating evapotranspiration were discussed and Hargreaves method was selected for the present study, model component for soil water, percolation and ground water movement were also discussed. The weather generator model WXGEN was also discussed to moderate the long term data for areas where sufficient data is lacking. The MUSLE model was used for modeling soil erosion. Integrating these components for modeling hydrological processes of the two watersheds (Myntriang and Umkhen) were discussed in this chapter.

CHAPTER- 4

MATERIALS AND METHOD

The present study aims to investigate hydrological behavior of two watersheds of Kopili river basin situated in the hilly region on North Eastern India. The study is taken up in order to assess water resources hence hydro-power potential in these watersheds. Hydrology is a complex phenomenon influenced by a number of region specific spatial parameters. Development of a reliable computational tool (physically based distributed model) capable of integrating relevant spatial input parameters and generating realistic outputs have been the primary need of the this investigation. The procedure of this study includes:

(i) Investigation of the study area with reference to location, topography, geology, geomorphology, physiography and climate,

(ii) Application of SWAT-Arc View interfacing for assessment of water resources on spatial and temporal basis.

(iii) Collection of input data.

(iv) Processing of input data as per requirement of spatial model.

(v) Generating output data.

(vi) Calibration of model and validating its outputs.

(vii) Investigation of hydrological behavior of watersheds and

(viii) Assessment of hydro-power potential.

4.1 Investigation of the Study Area

4.1.1. The North Eastern (NE) region and The River Brahmaputra

The NE region of India covers an area of 272200 sq km consisting of eight states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland, Sikkim and Tripura of India. The region lies within 22°N and 30°N latitude and 90°E and 97°E longitude. The area is characterized by hills and valleys and about 70% of the areas are hills. It constitutes about 8.11% of the geographical area of the country and receives almost 30% of the country's rainfall. Rainfall varies with an average ranging between 2000-4000 mm within the different parts. The region forms the part of catchment of mighty river Brahmaputra which flows from East to West dividing the entire region into North and South parts. The entire region drains into the Brahmaputra which forms the major drainage line of the region.

The river Brahmaputra and its tributaries are the major source of water resources in the region. The Brahmaputra is an international river and it has a catchment area of 293000 sq km in Tibet (China), 195000 sq km in India, 45000 sq km in Bhutan and 47000 sq km in Bangladesh (NEC, 1993). The length of the river Brahmaputra in the respective countries are 1625 km in Tibet (China), 918 km in India and 337 km in Bangladesh before joining river Ganga in Bangladesh.

The river Brahmaputra divides the NE region into South and North. The South and North parts of the river differ substantially due to its geological formation. The North bank is characterized by the Himalayas and the Southern part consists of Shillong Plateau and Naga-Patkai ranges. The Southern side which consists of Shillong Plateau is made up of high grade metamorphites, gneisses and granites. These are overlain by low grade metasediments of Shillong group with granite and emplacements (NEC, 1993).

Whereas on the northern side of Brahmaputra valley, the formations generally comprise alluvial plain abutting against the Siwalik ranges of the Himalayas. In the Lohit area on extreme eastern side, the Siwalik belts are not exposed and the alluvial deposits are by and large directly abutting against the metasediments followed by rock outcrops of different characters. It is however; felt that the basement of the entire basin is made up of the type of metamorphites of Shillong Plateau and Mikir Hills (NEC, 1993). Due to these reason the characteristics of the Northern region differs from the Southern region in terms of silt carrying nature and changing of river course and number of rivers.

4.1.2 Tributaries of the Brahmaputra

The river Brahmaputra is contributed by total of 38 major tributaries within India. Out of these 38 tributaries, 20 rivers join on North bank and 13 in South bank within India (Fig 4.1). However, remaining 5 rivers though originates in India meet the mighty Brahmaputra inside Bangladesh territory. The tributaries and the location of confluence with reference to Indo-Bangladesh border is presented (Table 4.1).

Kopili is one such major tributary joining river Brahmaputra on South bank at a distance of 220 km from Indo-Bangladesh border. The Kopili river basin occupies 2.44% catchment area of The River Brahmaputra.

4.1.3 The Kopili River Basin and its Major Tributaries

The Kopili, the principal river and axis of the basin originates from the Barail ranges near Jowai in Jaintia hills District of Meghalaya (India) at altitude of 1800 m above mean sea level (msl). The catchment area of the basin falls in the states of Meghalaya and Assam in India (Fig 4.2). The river flowing through the entire District of Jaintia hills enters North Cachar Hills District of Assam. The Kopili river basin consists of four major left bank tributaries viz. Umiam (also known as Killing); Umkhen (also known as Borpani); Myntang and Kharkar and three right bank tributaries *viz.*, Diyung, Jamuna and Nonoi. The Kopili river basin occupies 14760 sq km covering Karbi Anglong, North Cachar Hills and Nagaon Districts of Assam and Khasi hills and Jaintia hills District of Meghalaya in India , (Fig 4.3).

Kopili river has already been studied with respect to terrain, geology, geomorphology etc (Saikia, 1990). The Kopili river flows due North in its initial phase through a deep gorge, passing over numerous rapids and water falls till it comes down to the Kopili plains. The river drops to about 580 m in the first 110 km from the source. But in the next 16 km, the drop is about 189 m. Again the tributaries of Kopili river in its first 70 km are small streams and *nallas* (drains). The first major tributary to fall in Kopili is *Kharkar*. The approximate length of *Kharkar* River is 45 km and confluences at an altitude

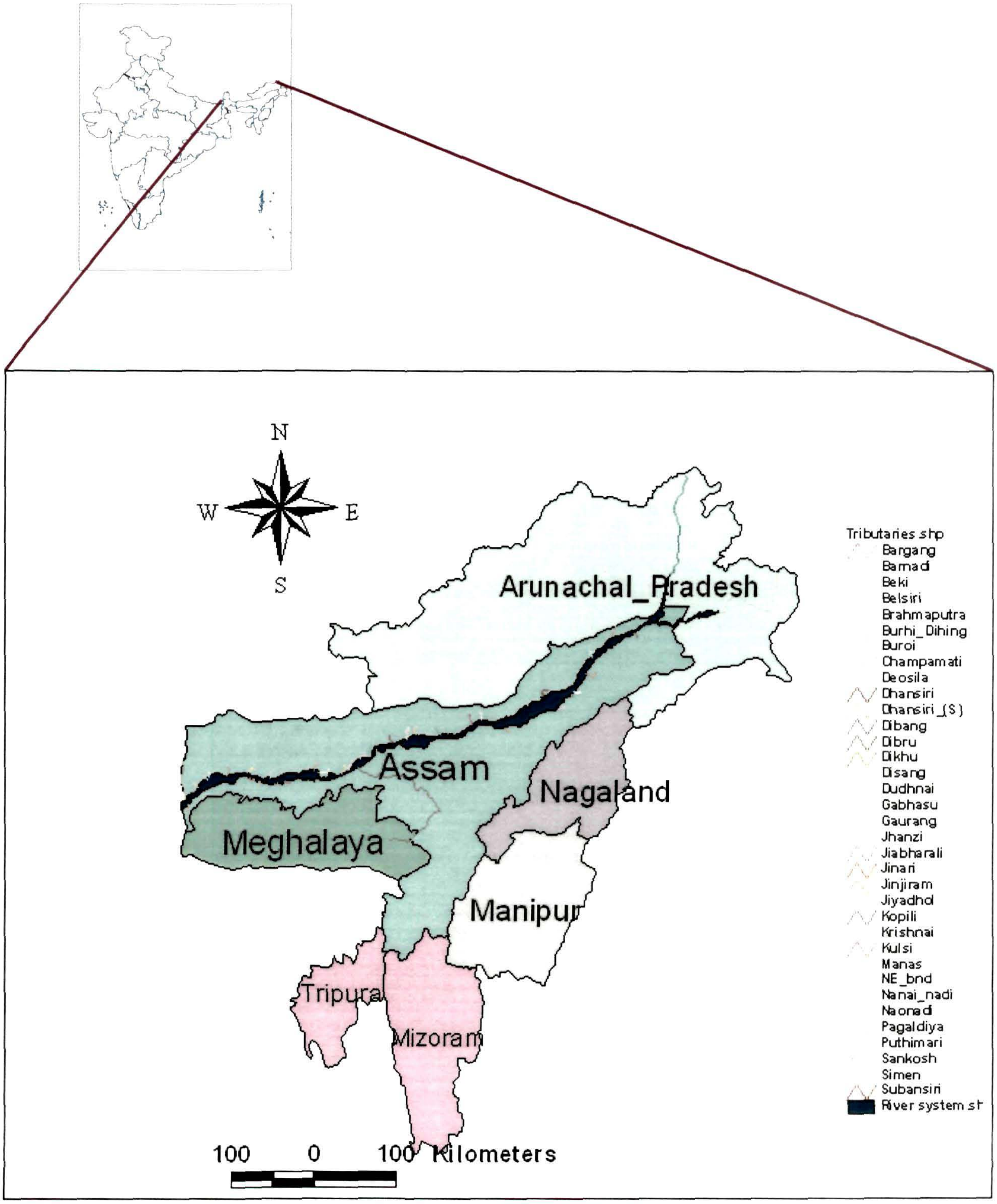

Fig 4.1: The Brahmaputra and its major tributaries

Table 4.1: List of major tributaries and its chainage (km) of confluence from Indo Bangladesh border

Sl No	North Bank Tributaries	Chainage	South bank tributaries	Chainage
1	Simen	580	Dibru	592
2	Jiya dhol	540	Burhi Dihing	540
3	Subansiri	430	Disang	515
4	Burai	392	Dikhu	505
5	Bargang	382	Jhanzi	495
6	Jia Bhoroli	338	Dhansiri (S)	420
7	Gabhasu	300	Kopili	220
8	Belsiri	280	Kulsi	140
9	Dhansiri	270	Deosila	130
10	Noa Nadi	230	Dudhnai	108
11	Nanai nadi	215	Krishnai	107
12	Bar Nadi	205	Jinari	100
13	Puthimari	172	Jinjiram	0
14	Pagladiya	170		
15	Beki	115		
16	Manas	85		
17	Champamati	63		
18	Gaurang	43		
19	Tipkai	40		
20	Sankosh	0		

(Source, NEC, 1993)

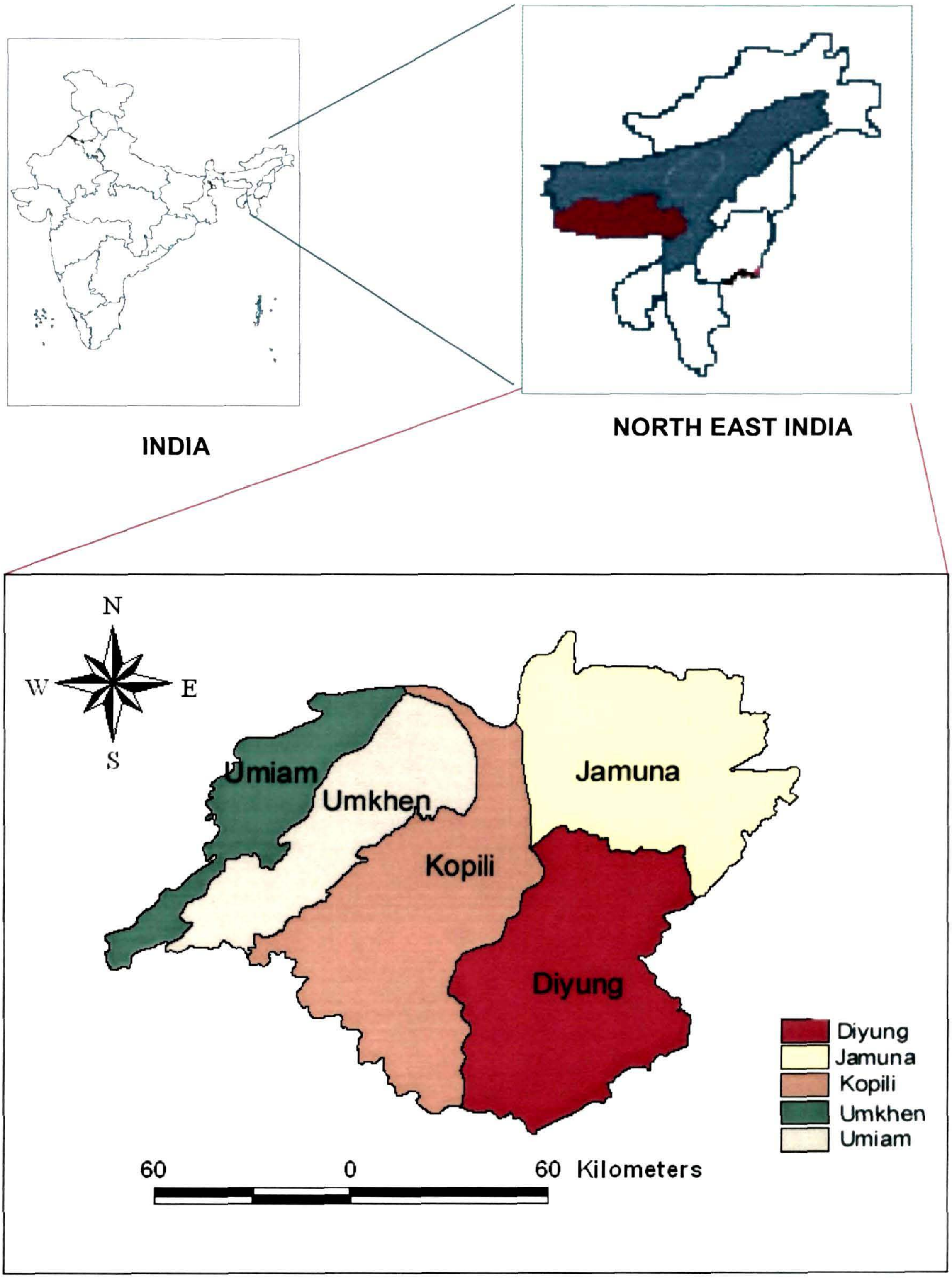

Fig 4.2: Location map of Kopili Catchment

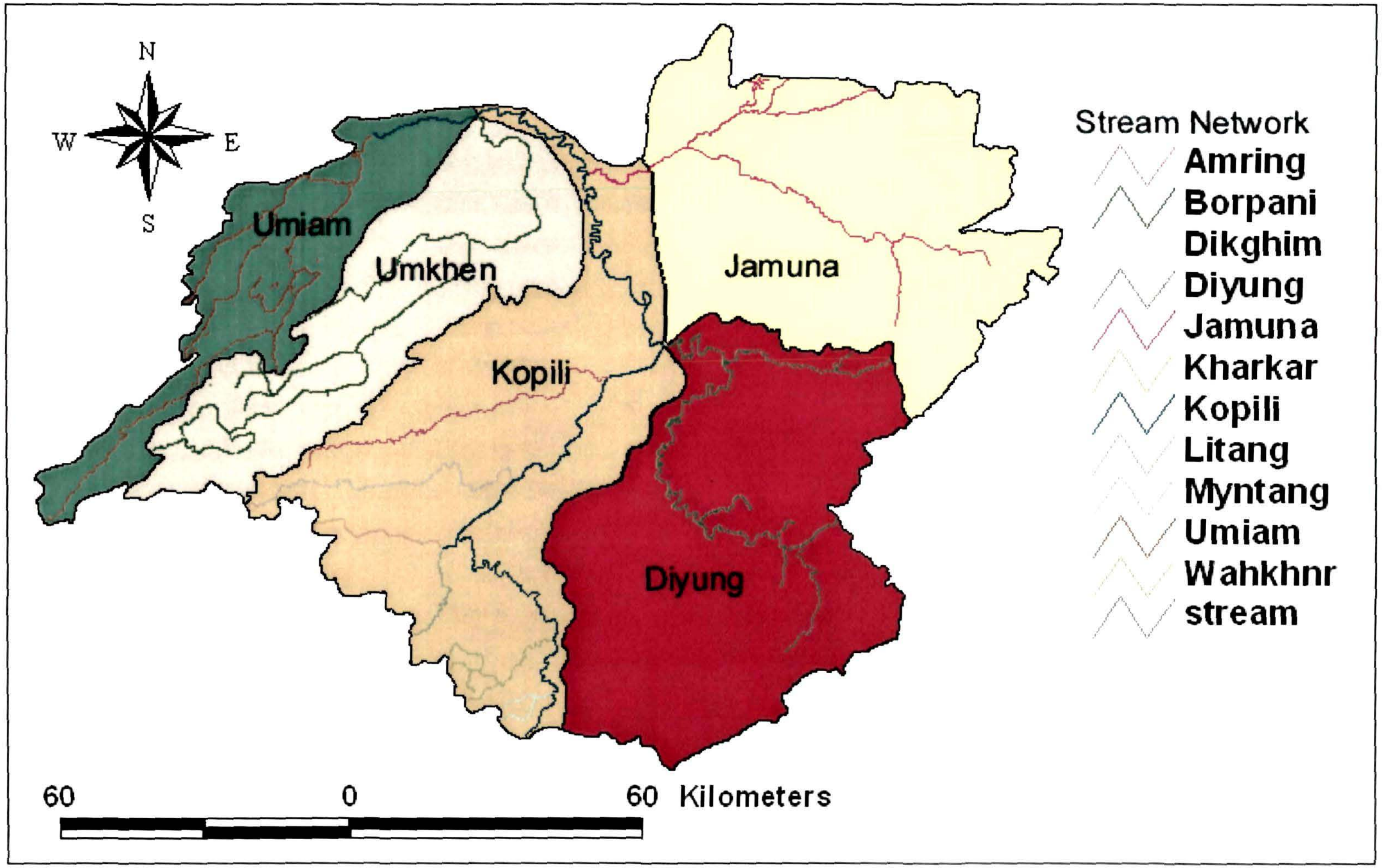

Fig 4.3: Schematic description of the tributaries of Kopili River

of 714 m. After the confluence of the river, the Kopili flows rapidly over a water fall known as Wallie with a height of 20 m. Then it passes through a narrow gorge with meandering channel for about 5 km, dropping by about 28 m. The next tributary of the Kopili River at 86th km is *Myntang* with a catchment area of 512 sq km. The Kopili then continues to flow in the north eastern direction over a series of rapids and water falls. Further down, it is fed by a number of drains, namely Dinar, Amreng from west and *Umrong, Longyen, Lumkindong* from east. The Kopili River comes down from the hilly tracts of the basin at Panimur to enter Nagaon districts of Assam which is a plain area till it confluence the main stream of Brahmaputra.

From Panimur, river forms the boundary between North Cachar Hills and Nagaon District up to its confluence with *Diyung* at 135th km of its run. After this confluence, Kopili flows in the north westerly direction with a meandering channel over the Nagaon plain up to the confluence of the *Jamuna* River at 206th km near Jamunamukh. The river then flows westerly direction and meets the other two major tributaries, *Umkhen* and *Umiam* from the left bank. The catchment area of Umkhen basin is 2228 sq km and confluences the Kopili river at 254th km of the main river Kopili. The Umiam with a catchment area of 1843 sq km drains into Kopili at 280th km chainage from the origin. The Kopili River then joins the river Kollong at 290th km near Dharamtul in Morigaon District of Assam. Kollong is a spill channel of river Brahmaputra which origins near village Hatimukh in Nagaon District of Assam. Figure 4.3 shows the location of the tributaries of Kopili River.

The Umkhen is a major watershed occupying 15.09% of catchment area of Kopili river basin. In the present study the Umkhen watershed and a sub watershed Myntriang were considered.

4.1.4 Description of Umkhen watershed

The Umkhen River starts at an altitude of 1829 m near Shillong in the state of Meghalaya in India. The river then enters Assam in Karbi-Anglong District and then joins the main Kopili River near Kampur in Assam. The river Myntriang is a tributary of Umkhen River with a catchment area of 267 sq km.

The entire catchment area of Myntriang River falls in the state of Assam in India. The location of the river falls between the latitude 25°30′ and 26°00′ longitude 91°50′ and 92°35′. The Umkhen watershed showing its neighboring tributaries and catchment areas are presented through Fig 4.3 and 4.4 respectively.

The Umkhen River with basin area of 2228 sq km originates near the South Western slope of the Shillong Peak, flows almost parallel to Umiam River in the south-west and north eastern direction, which confirms with the flow direction of flow of the Umiam River and general structural trend of the western Kopili basin. The upper reaches of the Umkhen River have a steeper slope between 15th and 78th km, when the river passes over the granite gneissic structures. Then the slope along the longitudinal section increases at the point of emergence from the plateau tracts to the Nagaon plains between 78th to 97th km the river in its plain course have gentle gradient of 1: 04.8 m in between 97th to the confluence with the Kopili. The slope characteristics of the river at different points are shown in Table 4.2.

Table 4.2: Channel slope characteristics of Umkhen River

(*Source: Saikia, 1990*)

Distance in Kilometers	Gradient in meters
0-5	1:304.80
5-10	1: 133.40
10-15	1:76.20
15-29	1:14.00
29-60	1:6
60-78	1:8.20
78-87	1:1.17
87-97	1:16
97-145	1:0.48

The Umkhen river, while passing through the rugged terrain of the Shillong plateau passes through deep gorge with numerous rapids and a 30.7 m high water fall at 9 km known as 'Sweet fall'. The river in its run from the source to mouth receives many tributaries from its right and left bank. Of these the Washung, Umud of the right and Umland, Myntriang, Sunani river on the left are note worthy.

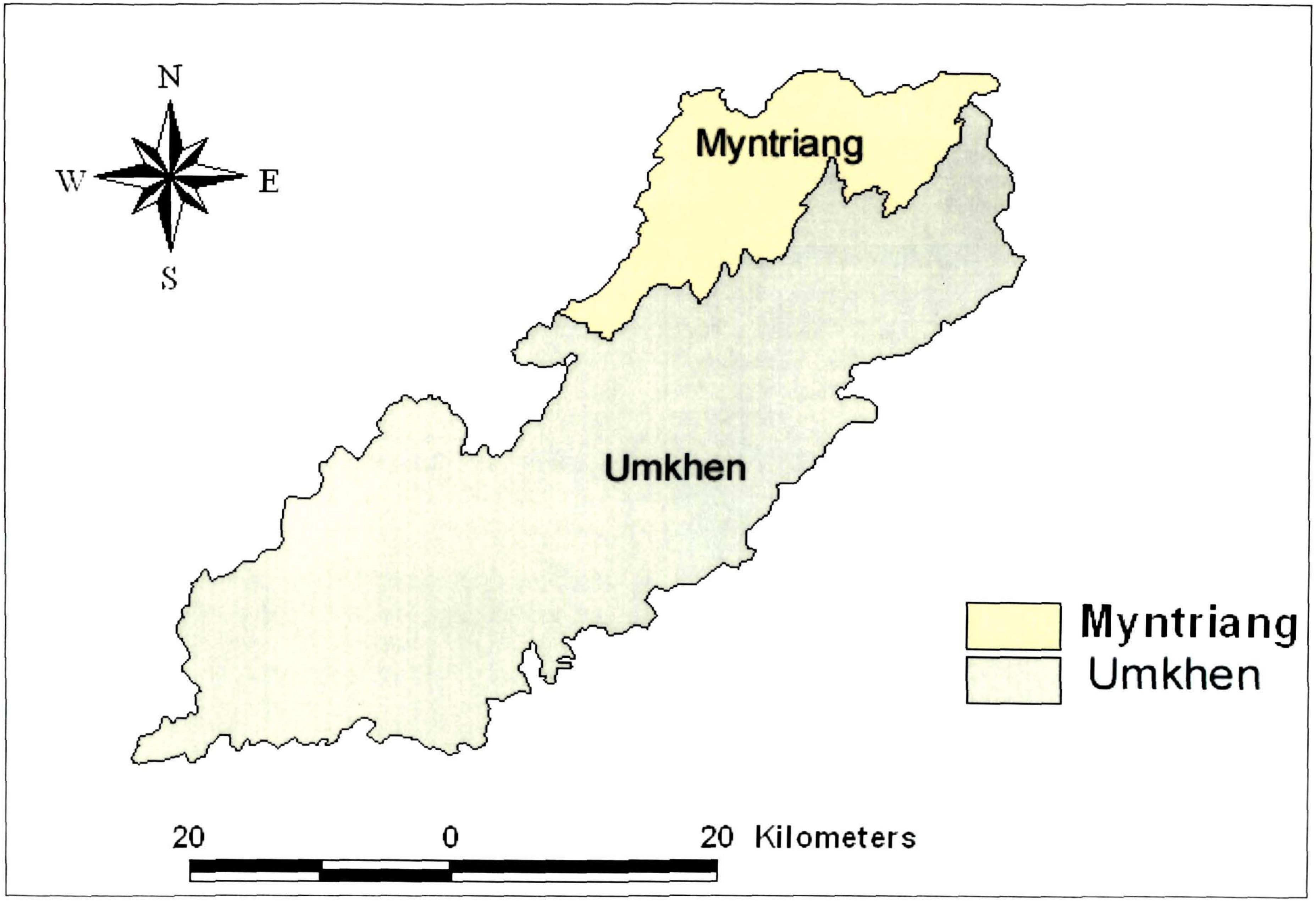

Fig 4.4 Catchment area map of Umkhen watershed

In this study, the available data for Umkhen river at a 102 km run of the river including Myntriang river were considered. The catchment areas of both the rivers up to its outlets are 1204 sq km and 267 sq km respectively. The river Umkhen has catchment in the state of Meghalaya and Assam. Out of the total catchment area of 1204 sq km of Umkhen river, the catchment area in Meghalaya is 677 sq km in East Khasi hills District and 527 sq km in Karbi Anglong District of Assam.

The major feature which affects the hydrology includes geology, geomorphology, physiography and climate. Descriptions about those features are available for the entire Kopili river basin. The river Umkhen and Myntriang being the part of the Kopili basin will have identical characteristics features as that of Kopili. The features are discussed below.

4.1.5 Geology

The occurrence of water in the sub surface is broadly governed by the geological framework. Earth's crust consists of layers of strata of rocks of various kinds resting upon another and the massive or foliated rocks that underlie or intersect the stratified series (Karanth, 1989). Thus effort was made to understand the geological characteristics of the Kopili basin to understand the processes going within the catchment and its effect on the ground water condition.

The geological formation of the earth have been divided, according to age, into Groups and Systems (Appendix 1) which have further been sub divided into Series. The grouping of the rocks in the chronological order of their age of formation forms the basis of stratigraphy. As the occurrence and availability of groundwater in a region is mainly controlled by its geology, the grouping of rocks according to their age provides a basis for an orderly discussion of ground water conditions (Meinzer, 1923).

Geologically, the Kopili Basin comprises of Archaean Granito- Gneissic complex to quaternary alluvium. The Archaean Grianito-Gneissic complex is exposed in the central, south and south western part of the Kopili basin. These rocks are believed to be the northeastern extension of the Indian Peninsula. The geological set up of the region covering Kopili basin along with the Hydrogeology map are presented in Appendix 2 (a) and 2 (b) respectively.

As per age group (Appendix 1) the Archean groups rocks are the oldest formation and ground water movement is slow as compared to the younger alluvium formation. Early study indicates that except Nagaon District with alluvial plains having aquifer materials the availability of aquifer is limited in major parts of the basin is limited.

4.1.6. Geomorphology

Geomorphology is a science which deals with the systematic description, analysis and understanding of landscapes and the processes that changes them (Bloom, 1992). Land surface form has important effect on construction, trafficability, erosion hazard, farming and irrigation and drainage. In most of these applications general geomorphometry is the relevant approach (Goudie *et al.*, 1990). Geomorphology of the basin has been described to understand the nature of changes that have taken place in the catchment since its formation.

The Kopili River Basin, geomporphologically forms part of Shillong plateau, Karbi Anglong and North Cachar hills and Nagaon or Kopili plains. The geomorphic evolution of the basin was in progress in about two thousand million years. Based on (i) geological structures, (ii) geomorphologic processes, (iii) relief and slope and (iv) drainage pattern, the Kopili basin is divided into four geomorphologic units (Chetry and Saikia, 2002). They are

(i) North west-south west and North Eastern Zone represented by a complex Archaean structure composed of gneiss, granite, schist, quartzite. Moderate to steep, moderate to high relief and drainage pattern controlled by geological structure.

(ii) East and southeastern zone represented by tertiary sedimentary rocks, moderate to high slope, moderate to high relief, and dendritic drainage pattern.

(iii) Central and Northern zone represented by new alluvium and a narrow belt of older alluvium, low slope, low relief, meandering river flowing over the extensive alluvial plain.

(iv) Piedmont zone between Shillong plateau and Karbi Anglong, NC hills and Kopili plains.

Further in a study conducted by Chakrabarti *et al.* (1987) it was reported that the dissected plateau which covers central part of Meghalaya and in some parts of Mikir hills, lineaments controlled drainage pattern with patches of sub-dendritic drainage are the major characteristics. In the Shillong plateau region deep gorges have been carved out of the structural plateau giving rise to very conspicuous canyon topography. However, in the eastern and north-eastern parts (*i.e.* south and east of Karbi-Anglong hills and east of Shillong plateau) the dissection is low to moderate and without much deep incision. These areas exhibit fine dendritic drainage which forms the major part of Kopili basin.

4.1.7. Physiography

Physically the Kopili basin is made up of lofty hill range, plateau, old and new alluvial plains. The topography of the basin is by and large uneven with about 61% of the total catchment area covered by highlands of Shillong plateau, Karbi-Anglong and hill ranges of North Cachar. The elevation of the basin varies between below 60 m to 2000 m (msl). These high lands are dissected by numerous tributaries and sub tributaries of Kopili river system. The varying altitude of the basin gradually increases towards west, south and northeast. (Chetry and Saikia, 2002).

4.1.8. Climate

The hydrological phenomenon in a watershed starts with precipitation on lands and ends with its disposal as surface and sub-surface flow and as evaporation and transpiration. The precipitation is affected due to many factors which are collectively termed as climate (Mutreja 1990). The climatic factor *viz.*, rainfall pattern and its distribution affect the hydrology of any area. The understanding of climate of study area plays an important role in describing the hydrological process in the river system. Thus an effort was made to understand the climate of the Kopili river basin.

The climate of the basin is extremely variable with reference to distribution of rainfall, temperature and humidity. Average annual rainfall in the area is ranging from around 2000 mm in the lower parts of the basin to 3000 mm, in the upper parts of the basin near Shillong. More than 80% of rainfall occurs during the monsoon months (June to September). Daily mean temperature ranges from a maximum of 44°C (May) to a minimum of 4°C (January). The daily mean relative humidity varies from a minimum of 40% (April) to a maximum of 95% (July).The rainfall and temperature pattern of some stations covering Kopili basin are shown pictorially in Fig 4.5 and Fig 4.6.

4.1.9 Land use and Land Cover in Kopili River Basin

Land use and land cover are important factors after precipitation which affects the water resources in a catchment. The knowledge of the land use and land cover therefore plays an important role in hydrological studies.

The catchment of Kopili river basin is forest dominated. How ever agriculture is also practiced in limited areas. In the agricultural area most of land is under shifting cultivation practices. Shifting cultivation is a traditional practice of agriculture, essentially an agro-forestery system organized both in space and time (Ramakrishnan, 1992). The practice involves clearing the hill slope by slash and burning of the vegetation and cultivating on it. After the completion of the process the land is left fallow for regeneration.

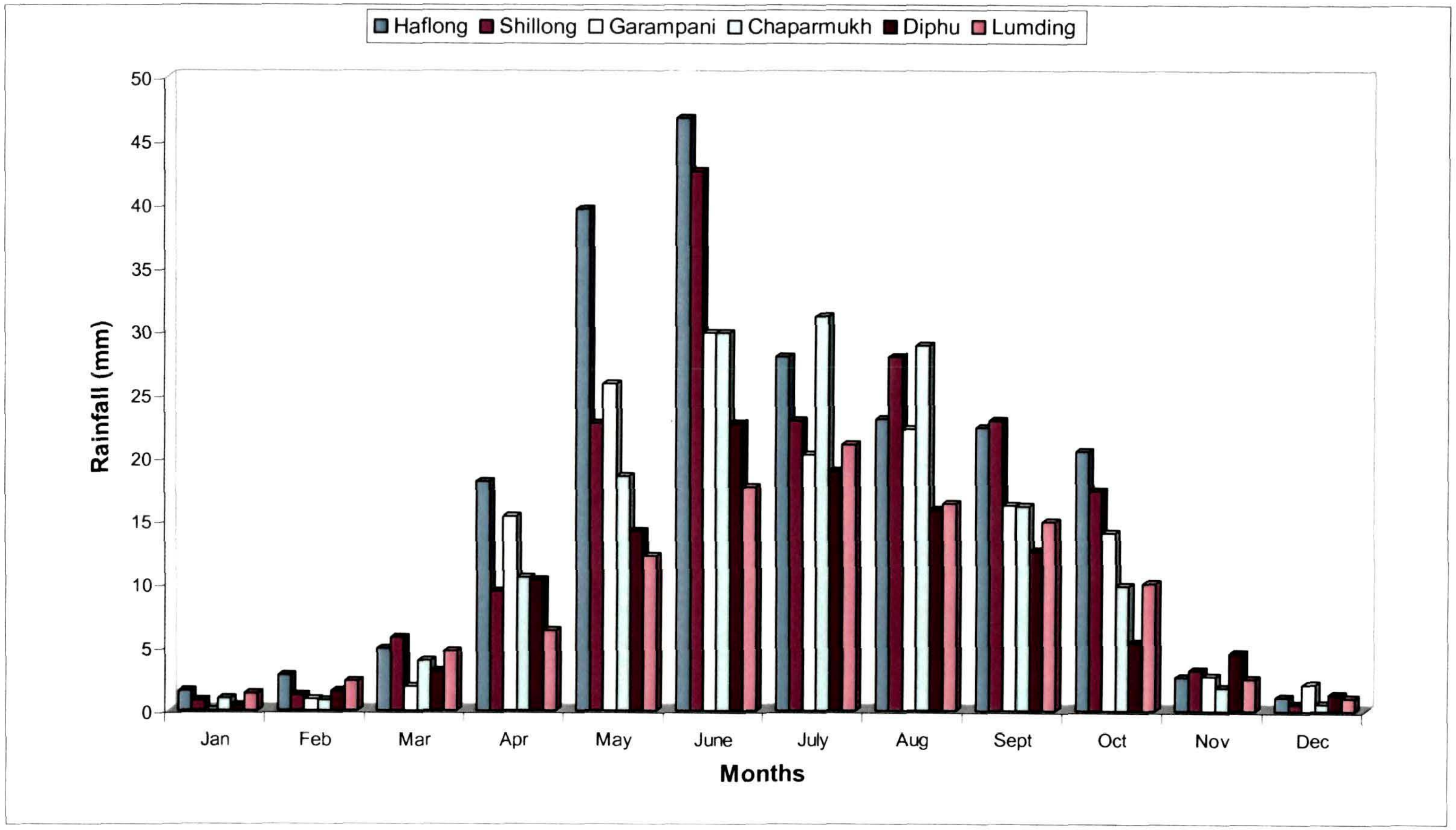

Fig 4.5: Monthly rainfall pattern of the selected station within Kopili River basin (*Source: IMD, Kolkata)*

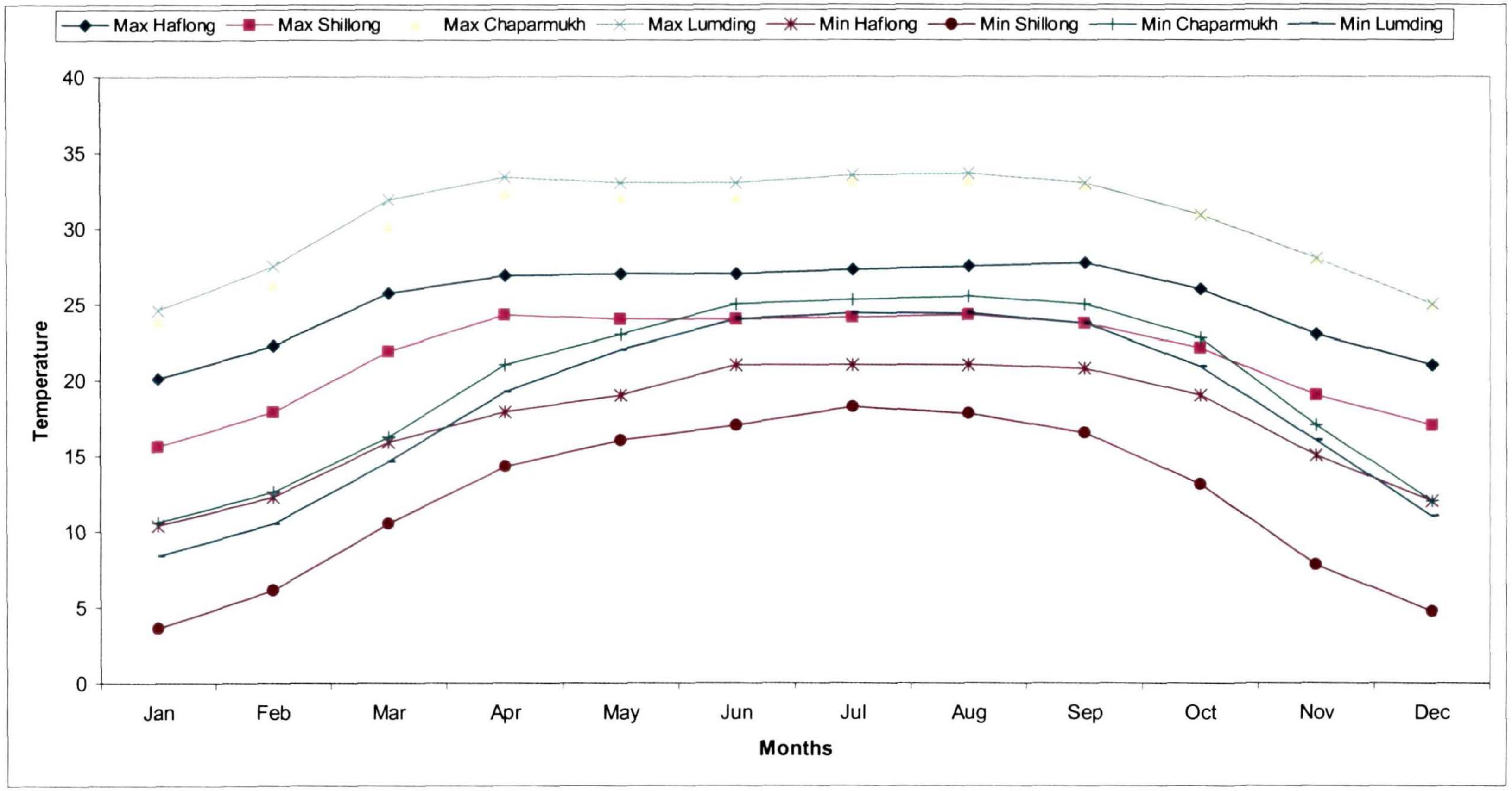

Fig 4.6: Monthly temperature (°C) pattern at select stations within Kopili river basin (*Source: IMD, 1999)*

The basin due to its physiography, climate, geology and soil is rich in its abundant species of flora. The natural vegetation of the basin can be classified into evergreen and semi ever green forest; deciduous forest, riverine forest, mixed deciduous bamboo and evergreen coniferous pine forest in the higher altitudes in Shillong plateau (NBSSLUP, 1999b; Chetry and Saikia, 2002). The important flora in the Meghalaya portion of the basin are Bamboo species (*Bambusa plymorpha, Bambusa tulda, Dendrocalmas spp, Musa spp*); sal (*Shores robusta*); Teak (*Tectona grandis*) etc (NBSSLUP, 1999a). In the Assam portion common trees in evergreen forest are Titasopa (*Michelea champesa*), Lali (*Amara wallichil*), Sam (*Artocarpus chaplasha*), Badam (*Mensonia Dipicia*) and Simul (*Bombax cadea*) and in deciduous forest major species are Sal (*Shorea robusta*), Sagun (*Tectona grandis*) and Sida (*Legemotronia pemiflora*) (ARSAC, 1990).

4.1.10 Socio-economic status

The success of a soil conservation or land reclamation and even water resources planning and management depends upon the socio-economic factors of the particular region (Singh, 1990).

The area under Kopili river basin is mainly dominated by tribal with other communities being in minority. Most of the families are farmers with poor economic status. The demographic condition as per 2001 census is given in Table 4.3. Agriculture is major occupation in the basin. Prevalence of shifting cultivation and customary laws which govern the land tenure system are wide spread among the tribes.

Table 4.3: Demographic patterns of five Districts under Kopili River Basin (*CI, 2001*)

Sl No	Name of the district	Population					Literacy Rate	Main Worker (%)	Cultivators (%)
		Total (nos.)	Rural (%)	Urban (%)	SC (%)	ST (%)			
1	2	3	4	5	6	7	8	9	10
1	East Khasi Hills	660923	58	42	0.4	77.5	76.1	33.2	23.5

2	Jaintia Hills	299108	91.6	8.4	0.2	96	51.9	32	47.1
3	Karbi Anglon g	813311	88.7	11.3	3.6	55.7	57.7	28.5	58.7
4	North Cachar Hills	188079	68.4	31.6	1.8	68.3	67.6	29.3	48.9
5	Nagaon	2314629	88	12	9.3	3.9	61.7	24.5	38.4

4.2 SWAT-Arc View Interface: The Modeling Technique

For the present study SWAT 2000 and Arc View 3.3 are used. Arc View is integrated with SWAT2000 to have AVSWAT extension. Some features of AVSWAT including system requirements are presented in Appendix 3.

AVSWAT2000 is a complete pre-processor, interface and post-processor for the watershed scale assessment and controls of non-point source pollution. It improves the efficiency of analysis and control on watershed scale. The watershed-modeling framework is delineated starting from the digital description of the landscape (DEM, land use and soil data sets) using Arc View Spatial Analyst with geomorphological assessment procedures. It is a unique and single modeling environment based on several user interface tools. The present model performs the intended job in a sequential order as:

(i) The delineation and codification of watershed upon the topography
(ii) Automatic stream delineation
(iii) Sub division of watersheds
(iv) Overlaying land use and soil layers
(v) Analysis i.e. integrating inputs through requisite hydrological laws,
(vi) Calibration of the hydrologic simulations and repeat step (v) to ensure desired outputs.

The entire watershed is delineated into distinct homogenous regions. Such smallest spatial region is called hydrologic response unit (HRU). Watershed delineation component is an automated sequence of steps by which some options are interactively activated to improve the results and define the desired configuration. Land use and soil definition component encompasses a set of tools to load and clip the grid or vector layers carrying the land use and soil information on the watershed area. The layers are created based on land use and soil types that are defined within the model databases for the region under study. The overlay of the land use and soil layers within the watershed defines the composition of land use and soil variations within each sub-watershed.

The model has provision of defining weather stations in terms of locations and data sets and it is used accordingly.

The operation flow chart for running SWAT model using Arc View interface is shown in Fig 4.7.

4.2.1 AVSWAT Input requirements

To create a SWAT dataset, the interface requires to access Arc View map themes and database files, which provides spatial and non-spatial information about the watershed. The necessary Arc View maps and the tables/ text files that need to be prepared prior to running the interface are given in Appendix 4 (a) and (b).

4.3 Data Collection and Processing

The Kopili is characterized by high altitude, forest cover and undulating topography. The required data for model was taken from available sources within the region considering it to be representative for the entire basin and applicable to Myntriang and Umkhen watersheds. The data stations considered for this study are shown in Fig 4.8.

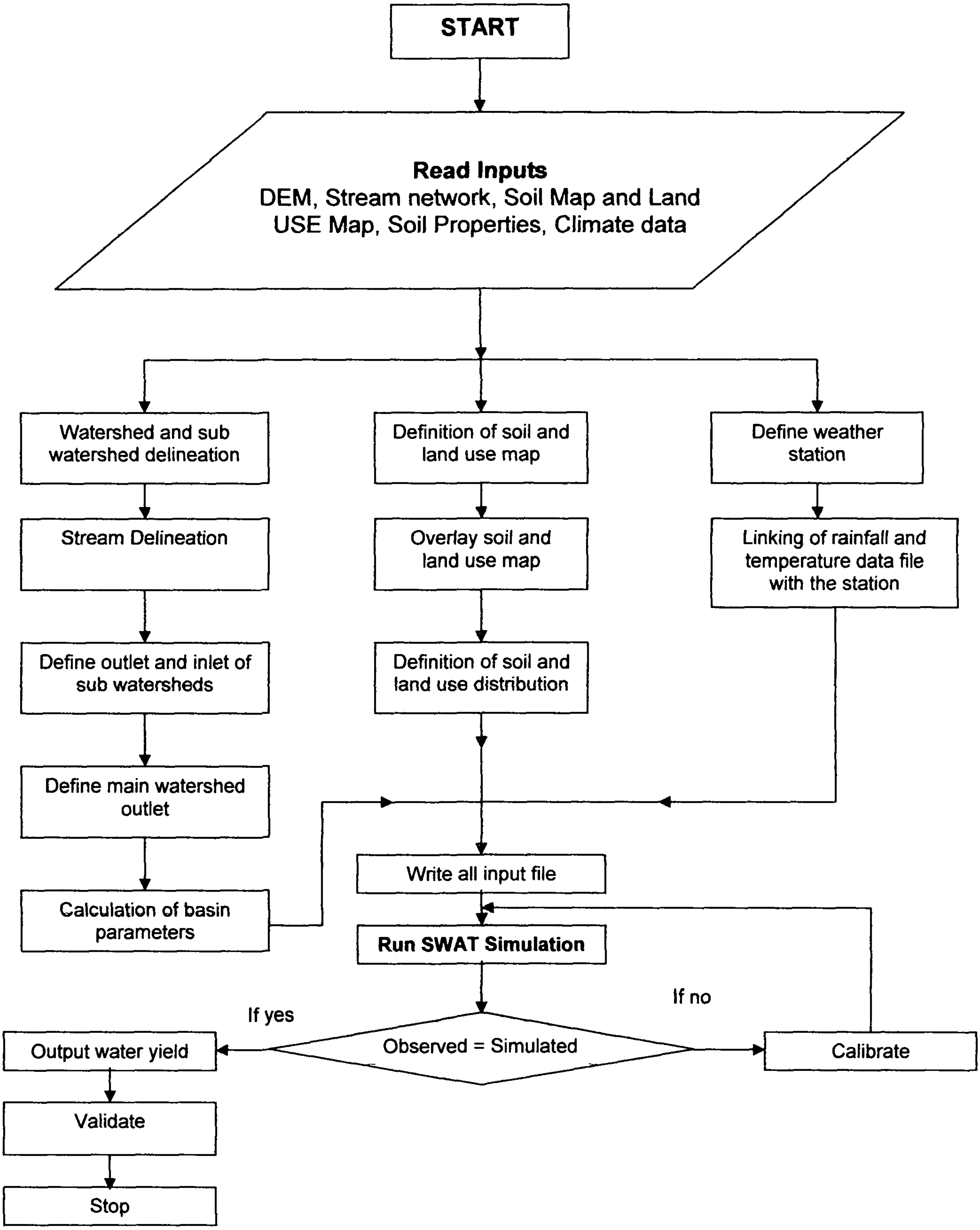

Fig 4.7: Flow chart for operation of SWAT model

4.3.1. Data Source

The data requirements of model for simulation run are meteorology, discharge, terrain, soil, land use and stream network. Data sources and its use are:

(i) **Meteorological data:** The model requires meteorological data of watershed and location of data stations from where the data is collected. The five recognized meteorological stations within and nearby the study area are considered as data station as per requirement of the model. The stations are Shillong, Jowai, Haflong, Chaparmukh and Baithalangso (Table 4.4). Further, the model requires long term average of selected weather parameters such as rainfall, temperature, wind speed, solar radiation and dew point temperature. The values are processed by a weather generator model incorporated within SWAT model to generate the missing values. The values were obtained from the Indian Meteorological Department (IMD, 1999). The stations considered are Shillong, Chaparmukh and Haflong. The values are shown in Appendices 5 (a), (b) and (c).

(ii) **Discharge Data:** The daily discharge data of the Myntriang and Umkhen watersheds were collected from the discharge site maintained by the Karbi-Langpi project authorities under Assam Power Generation Company Limited (APGCL). The period for which the daily data is available is from the year 1984 to1993. The data have been used to calibrate the model for improving the agreement between observed and simulated values and also for validation.

(iii) **Terrain:** Information on the terrain is one of the important input for any physically based model. The terrain information is generated from the contour data available in the toposheet prepared by the Survey of India at 1: 50000 scale. The contour data available in the toposheet are at 20 m interval. The Myntriang and Umkhen watershed are available on toposheet number 83C2, 83C5, 83C6, 83C9 and 78O14.

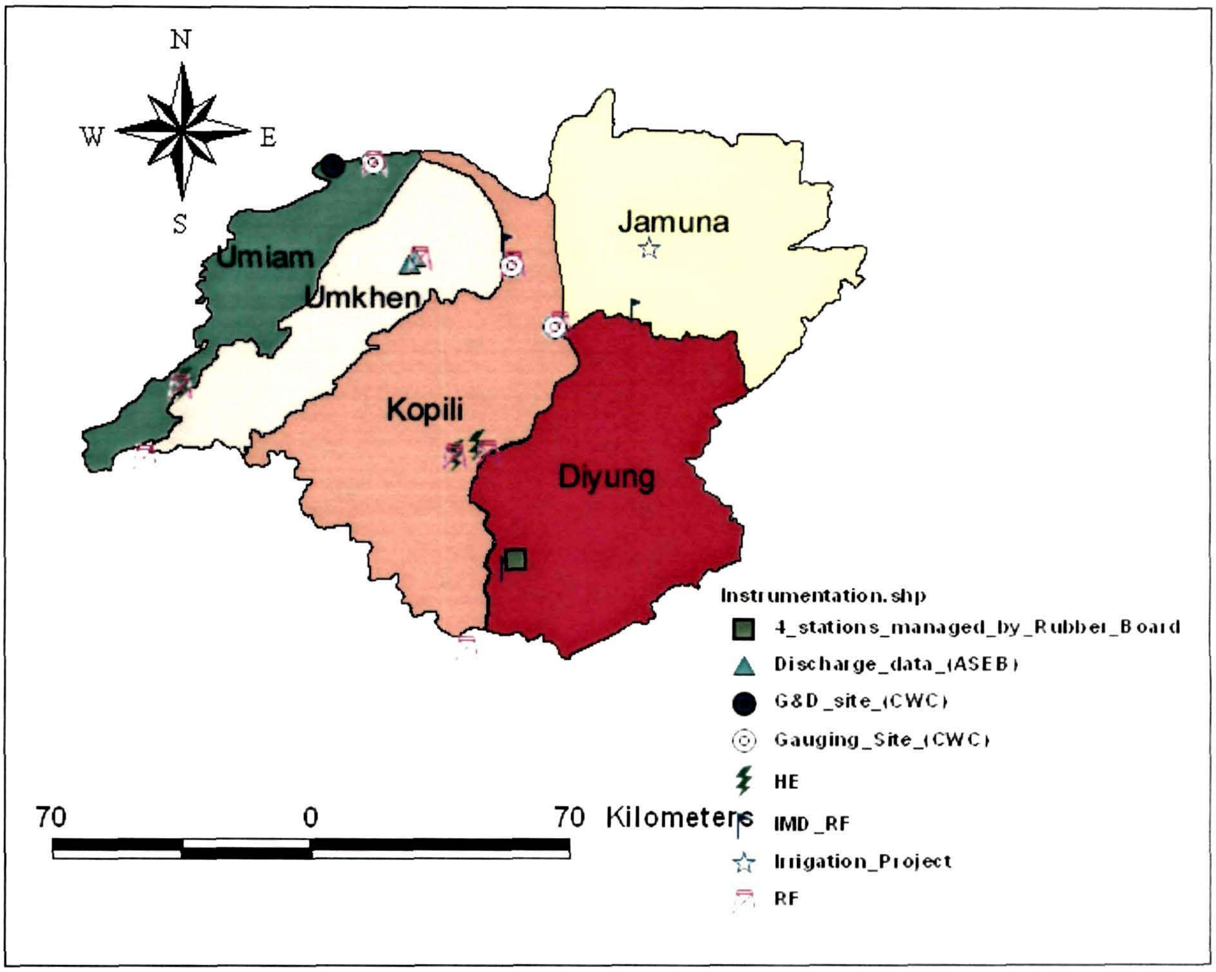

Fig 4.8: Location of Hydrological data stations in Kopili River basin

Table 4.4: Data station and the period of data used

Sl No	Station (Longitude and latitude)	Period	Source
1	Haflong (25°100′5.25″ N; 93°00′56.23″ E)	1969-1978 for rainfall 1969-1978 for temperature	Indian Meteorological Department
2	Chaparmukh (26°01′27.17″ N 92°47′11.25″ E)	1969-1992 for rainfall 1969-1992 for temperature	
3	Shillong (25°30′30.09″ N 91°49′30.02″ E)	1969-2000 for rainfall 1969-2000 for temperature	
4	Baithalangso (25°59′32.83″ N 92°33′02.57″ E)	1984-1993 for rainfall 1984- 1993 for temperature	Assam Power Generation Company Limited
5	Jowai (25°02′47.86″ N 92°40′41.94″ E)	1983-2005 for rainfall 1990 –2005 for temperature	Department of Agriculture, Government of Meghalaya

(iv) **Stream data**: Stream network data for the Myntriang and Umkhen watershed is collected from the toposheets prepared by Survey of India at 1: 50000 scale. The toposheet numbers are 83C2, 83C5, 83C6, 83C9 and 78O14.

(v) **Soil data:** The hydrologic processes are related to the soils physical properties that govern the movement of water and air through the profile and have a major impact on the cycling of water within the HRU.

For modeling the runoff and sediment yield the SWAT requires various data regarding the soil. The Table 4.5 describes the various soil input data required by the model.

The values adopted for the soil profiles in the Myntriang and Umkhen watersheds are shown in Appendices- 11(a) and (b).

Table 4.5: Soil physical properties required by SWAT

Sl No	Description of data requirements	Data Source
1	Number of layers in the soil	Soil profile data from NBSSLUP
2	Maximum rooting depth of soil profile	
3	Depth from soil surface to bottom of layer	
4	Organic carbon content	
5	Clay content	
6	Silt content	
7	Sand content	
8	Rock fragment content	
9	Soil hydrologic group (A, B, C, D)	Details given in Appendix 6
10	Fraction of porosity from which anions are excluded	Details given in Appendix 7
11	Moist bulk density	
12	Available water capacity of the soil layer	Details given in Appendix 8
13	Saturated hydraulic conductivity	Details given in Appendix 9
14	Moist soil albedo	Details given in Appendix 10
15	Soil erodibility factor	Method proposed by William (1995) described in section 3.3.1.1

(vi) **Land use data:** The Umkhen basin have a catchment area in Assam and Meghalaya and for Myntriang watershed lies entirely within the state of Assam. The land use data for Assam was collected from the Assam Remote Sensing Application Center (ARSAC), Guwahati. The land use data for the Meghalaya portion was collected from the map prepared by Department of Geography, Cotton College prepared under a project sponsored by Department of Science and Technology, Government of India.

Ideally the data of all the selected stations should be of the same period. However, due to absence of long term data for the same period in all the station, the available data was used with the assumption that the weather trend has not changed in the weather generator model. In the study watershed the data of the input variables viz., rainfall, temperature and discharge for the period 1988 to 1990 was used for calibration of the model and the data for the period of 1991 to 1993 was used for validation.

4.3.2 Data Processing

4.3.2.1 Registration and transformation of Topographic Maps of Myntriang and Umkhen watershed

The topographic maps were taken as input. For creating the contour and stream network the input maps were registered through (ILWIS 3.3) GIS software. The registration of the topographic maps for Myntriang and Umkhen watersheds were carried out as per the procedure described below:

(i) Creation of a coordinate system:

A coordinate system was created for defining the minimum and maximum X's and Y's. In the present study the coordinate system was created using Universal Transverse Mercator (UTM) system. The predefined ellipsoid Everest (India, 1956) and datum (India, Nepal) was used. The study area falls under Zone 46 of the UTM projection system.

(ii) Creation of Geo-reference:

A geo-reference was created for each individual topographic map. The input maps were geo-referenced by using intersection of latitude and longitude as control point. The toposheet at 1: 50000 scale are available with latitude and longitude at an angular interval 5 minutes. The intersection of the latitude and longitudes in spherical coordinates are transformed to the rectangular coordinates (i.e., as eastings and northings) using transform coordinate command in ILWIS 3.3. The individual maps were displayed and rectangular coordinates were entered in place of spherical co-ordinates. Then these were geometrically transformed to the appropriate location on the blank database.

4.3.2.2 Digitization of contour and stream map

(i) Digitization of contour:

The contour map is the input for creation of digital elevation model (DEM) which specifies the terrain condition of any watershed. After defining co-ordinate system and geo-reference, with reference to selected location (Myntriang and Umkhen watershed), the contour was digitized through an operation called *create segment layer* in ILWIS 3.3. For digitization a domain was created for specifying contour values. The 'value domain' was used to specify values of each contour segment in terms of its altitude in meters.

(ii) Digitization of stream network:

The stream network map provides information about the location of streams of various orders and their density in the Myntriang and Umkhen watershed. For digitizing the stream network a 'class domain' was created to identify the stream. In the present study, the streams have been identified as stream order based on Strahler's method (Strahler, 1958).

4.3.2.3 Creation of thematic maps (Soil and Land use maps):

The thematic maps are polygon maps. Two such polygon maps for Myntriang and Umkhen watersheds were required. One for soil types and another for land use. The available maps of both the categories were used to create the polygon map. Each polygon were assigned labels corresponding to soil types and land use of Myntriang and Umkhen watersheds. The form polygon command was used to create the final theme maps.

For using the DEM and stream network in Arc View 3.3, the data need to be imported in appropriate format. The Arc-view can read the vector layer (segment and polygon layer) in *Shape* format and the raster layer (DEM) in *Grid* format. The stream layer, theme layer (soil map, land use) and DEM created in ILWIS 3.3 were exported to shape and grid format respectively using export command.

Soil maps (1: 250,000 scale) of the state of Assam and Meghalaya were obtained from National Bureau of Soil Survey and Land Use Planning (NBSSLUP). The soil resources mapping was undertaken using the technology as detailed in Field Manual (Sehgal *et al.* 1987) and Laboratory Manual (Sarma *et al.*, 1987).

The soil maps were digitized in the coordinate system as mentioned earlier. After the creation of the soil map of the selected district in which the catchment area lies, overlay operation was performed to extract the soil layers within the Myntriang and Umkhen watershed.

The land use/ land cover map for the Assam portion of the catchment was obtained from the map prepared by Assam Remote Sensing Application Center (ARSAC). The map for the Meghalaya portion was obtained from the map prepared by Department of Geography, Cotton College under Department of Science and Technology sponsored project. The maps were digitized through ILWIS 3.3 and the portion covering Myntriang and Umkhen watershed was extracted by applying overlay operation.

4.3.2.4 Digital Elevation Model of Myntriang and Umkhen watershed

Digital Elevation Models (*DEM's*) store continuously varying variables such as elevation, groundwater depth or soil thickness at specific spatial resolution in digital format. *Digital Terrain Models* (*DTM's*) are digital representations of altitude and are frequently used in hydrological, erosion and engineering geological studies.

The Digital Elevation Model was created from the digitized contour map in ILWIS 3.3 software with the Contour interpolation technique. The operation of creating DEM is carried by converting segment map (contour lines) into raster format and then conducting contour interpolation. The steps are described as follows:

I. *Segment to raster conversion:* First the segment (contour) map was converted to raster, using a georeference in which the pixel size, the number of lines and columns, and the minimum and maximum X and Y coordinates of the map are defined. In the present study the $X_{minimum}$ and $Y_{minimum}$ were defined as 25°28′16.43″ N, 91°48′12.59″E and $X_{maximum}$ and $Y_{maximum}$ were defined as 26°00′00″, 91°52′24.39″E respectively . The raster map resulting from the segment to raster conversion contained values for those pixels covered by a contour line. At this stage all other pixels in the map remain undefined.

II. *Contour interpolation:* A linear interpolation is made between the pixels with altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The output of the contour interpolation is a raster map in which every pixel has a value. The interpolation method is based on the *Borgefors distance* method. The operation calculates, for each undefined pixel in between two rasterized segments (outcome of the first step), the shortest distance towards the two nearest isolines. The elevation value *(Zp)* for a pixel *(p)*, between two contour lines is calculated as:

$$Z_p = Z_2 + \left(\frac{d_2}{(d_1 + d_2) \times (Z_1 - Z_2)} \right) \tag{4.1}$$

where *Zp* is the calculated elevation value for an output pixel, Z_1 and Z_2 are the elevation values of the higher and lower contour lines and d_1 and d_2 are the distances from the pixel to the higher and lower contour lines.

4.3.2.5 Processing of spatial parameters using DEM of Myntriang and Umkhen watershed

The spatial analyst module of the AVSWAT has a function to generate flow direction, flow accumulation, slope and aspect features of a watershed from the DEM. These features were used by the model to delineate the Myntriang and Umkhen watershed into sub watershed. The functions are described below:

(i) *Flow direction*: Flow direction function takes a surface as input. It provides outputs as a grid showing the direction of flow out of each cell. There are eight valid output directions, relating to the eight adjacent cells into which flow could occur. The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell.

(ii) *Flow accumulation*: Flow accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into down slope cell in the output grid. Cells with a high flow accumulation are areas of concentrated flow and were used to identify as stream channels. Cells with zero flow accumulation are used to identify ridges.

(iii) *Slope:* Slope identifies the maximum rate of change in elevation value from each cell to its neighbors. Conceptually, the slope function fits a plane to the 'z' values of a 3 x 3 cell neighborhood around the processing or center cell. The slope direction of the plane faces is the aspect for the processing cell. The slope for the cell is calculated from the 3 x 3 neighborhood using the average maximum technique.

(iv) *Aspect:* Aspect is a slope direction expressed in positive degrees from 0 to 360, measured clockwise from the north. Cells in the input grid of zero slope (flat) was assigned an aspect of 1. Aspect identifies the down-slope direction of the maximum rate of change in value from each cell to its neighbors.

4.3.2.6 Delineation of streams and watershed in Myntriang and Umkhen watershed

The standard methodology, based on the eight-pour point algorithm (Jenson and Domingue, 1988) for delineating streams from a raster digital elevation model (DEM) is applied for watershed delineation. Cells, which are potentially part of a stream network, have a larger flow accumulation value, whereas cells near watershed boundaries and where overland flow dominates have a low flow accumulation value. The stream branches are controlled by the user specified threshold on contributing number of grid cells, which creates the stream branches. The default definition of the sub-watershed outlets is accomplished in locating the down stream edge of each stream branch. Once the sub-watersheds outlet locations are specified, the main watershed outlet can be defined using customized selection tool. The sub-watershed delineation is performed by a process tracing the flow direction from each grid cell until either an outlet cell or the edge of the DEM grid extent is encountered. The interface is provided with two additional setting tools i.e. DEM properties and threshold area in hectares, used for the calculation of geomorphic parameters. As the threshold is increased, drainage density decreases and vice versa.

Once the watershed and sub-watersheds boundaries are delineated, all the geometric parameters of each sub-watersheds and stream reaches are calculated by raster-grid functions and stored as attributes of derived vector themes.

For this study the threshold value is taken as 5000 ha in line with existing government policy of implementing watershed management programme (MoA, 2000).

4.4 Generation of Output

4.4.1 Curve Number Determination

Curve number is a continuous spatial function and is generated by the model. This is the result of the processing of

(i) Delineated watershed map,

(ii) Soil map and

(iii) Land use map

Curve number is a function of the soil permeability, land use and antecedent moisture conditions. The model uses to curve number to calculate the water retention within the watershed and thus generates the water yield after subtracting initial abstractions after any rainfall event.

The AVSWAT model performed the characterization of land use and soil themes of Umkhen and Myntriang watersheds. After importing and linking the land use and soil themes in to the SWAT databases, hydrologic response units (HRU) distribution was determined by assigning threshold values to the land use and soil themes. Threshold values of land use and soil are assigned to each HRU based on their extent of coverage. The HRUs are the portions of a sub watershed that possess unique land use, management and soil attributes. The spatial analyst of the interface computed and cross-tabulated areas between land use and soil data sets. The process completed in various steps i.e. defining and classifying the land use theme and soil of the soil theme, and overlay of land use and soil themes. Land use and soil themes were then processed and clipped to the sub watershed boundaries. The land use and soil attributes were entered manually in to respective data bases. Total 13 sub watersheds in Umkhen and 3 sub watersheds were created in Myntriang with 5000 ha as threshold value.

The hydrologic soil groups based on soil properties and antecedent moisture conditions (AMC-II) as described by Neitsch *et al.*, (2002) were taken for calculation of curve number for individual HRUs. A hydrologic group classification is presented in Appendix 6. The CN values are provided by the tables by (SCS Engineering Division, 1986) taking into account of soil infiltration rate when thoroughly wetted (Ks) and slope adjustments (Williams, 1995). Finally, weighted curve number values for each sub-watershed of Myntriang and Umkhen watersheds were worked out and used for calibration and validation of the model.

4.4.2 SWAT Database files

The SWAT2000 creates input and output files that contains information that are used by the model during simulation. The model input files are classified under watershed and sub watershed level. The number of output files are generated at every model simulation. The details of the files are described in Appendix 12.

4.5 Model Calibration

Model calibration is the adjustment of model parameters, within recommended ranges, to optimize the agreement between measured data and model simulation results.

The SWAT model was built with state-of-art components to simulate the processes physically and realistically. Most of the model inputs are physically based. The successful application of a hydrologic watershed model depends on how well the model is calibrated. The observed climatic parameters of rainy and non rainy season of the year 1988-1990 were used for the calibration of the model. The model has a calibration tool which allows global adjustments of model parameters (Appendix 13) through user intervention. There are 27 parameters in SWAT2000 where the adjustments are to be made within the prescribed range. Many researchers have applied the SWAT model by adjusting the variables within the range specified for each parameter in the calibration tool (Romanowicz *et al.*, 2005; Kannan *et al.*, 2007, Abbaspour *et al.*, 2007; Tolson and Shoemaker 2007,). The flow chart of the model calibration is shown in Fig: 4.9.

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The parameters where adjustments were made during calibration are (i) SCS runoff curve number for moisture condition II; (ii) Base flow recession alpha factor; (iii) Soil evaporation compensation factor; (iv) Available water capacity of the soil layer (mm/mm of soil); (v) Threshold water depth in the

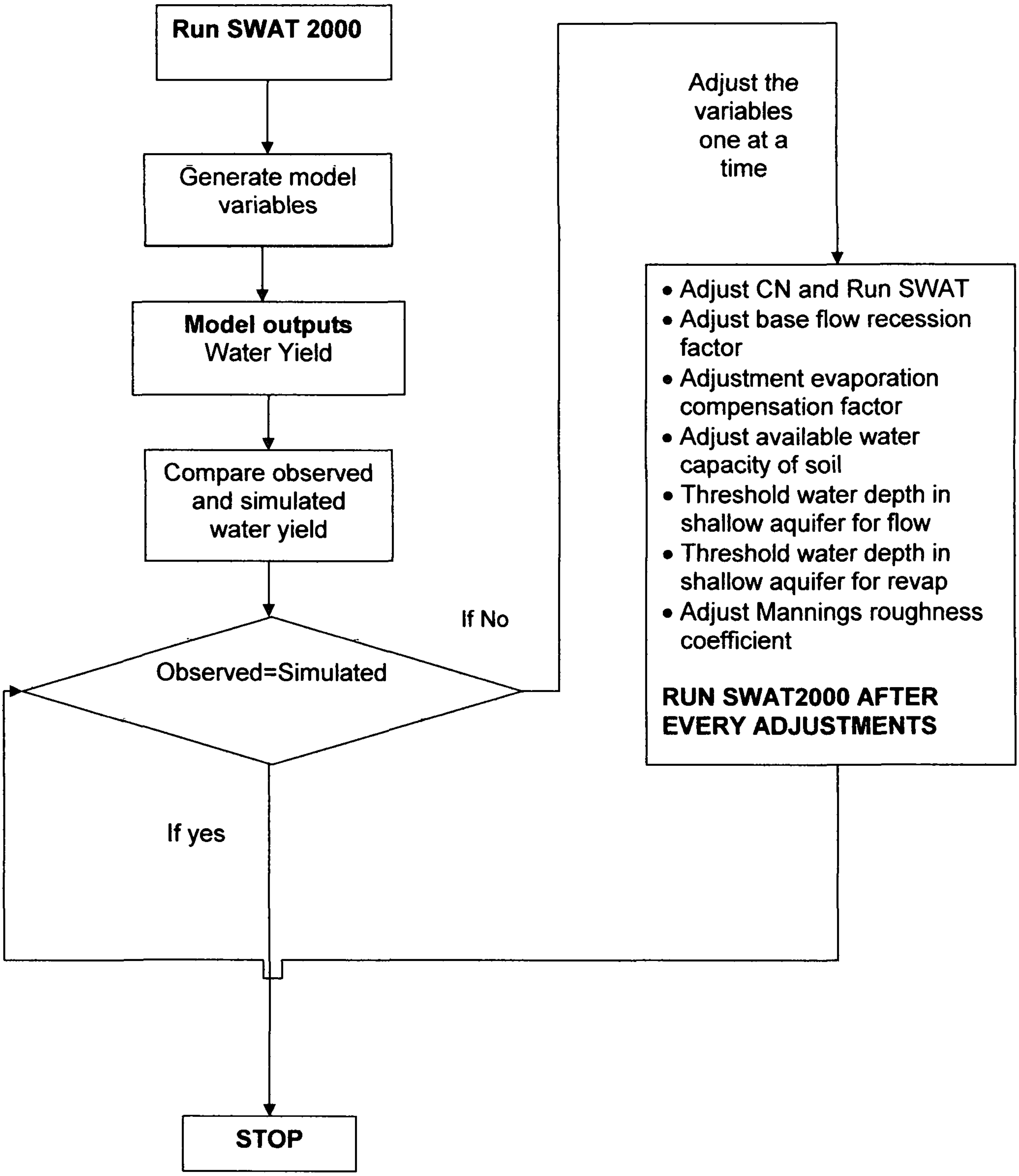


Figure 4.9: Flow Chart for Model Calibration

shallow aquifer for flow (mm); (vi) Threshold water depth in the shallow aquifer for revap (mm) and (vii) manning roughness coefficient.

4.5.1 Model validation

Proper validation of the calibrated model is essential to understand its simulation performance. After calibration, simulation run was made using for the climatic data prevailing in Myntriang and Umkhen watersheds during the period of1991 to 1993. The simulated values were obtained on daily basis which were converted into 10 daily values. The simulated water yield was compared with the observed water yield for validation of the model. Further comparison was also made for the rainy and non rainy season during the same period to understand the model behavior. The criteria for validation and its procedure are given below.

4.5.2 Criteria for validation

The acceptability of a model is judged by the goodness of fit between observed values and values estimated by a model. For quantitative comparison between observed and estimated values, the following statistical measures have been employed in the study.

(i) Coefficient of Determination (*R^2*)

The coefficient of determination R^2 is defined as the squared value of the coefficient of correlation. It is calculated as:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2} \times \sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2 \quad (4.2)$$

Where *O* and *P* are observed and simulated values corresponding to i^{th} observation, *n* is the number of observation. $\bar{O}$ and $\bar{P}$ are mean of the observed and predicted values. The method is used by many researchers viz., Krause *et al.* (2005), Sintondji (2005), Tolson and Shoemaker (2007).

(ii) Nash-Sutcliffe efficiency (*E*)

The efficiency E proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (4.3)$$

Where E is the Nash and Sutcliffe efficiency, O_i and P_i are observed and simulated values for i^{th} observation and $\bar{O}$ is the average observed value.

(iii) Index of Agreement (*d*)

The index of agreement (d) was proposed by Willmot (1981). The index of agreement represents the ratio of the mean square error and the potential error (Willmot, 1984) and is defined as :

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(\left|P_i - \bar{O}\right| + \left|O - \bar{O}\right|\right)^2} \qquad (4.4)$$

Where O_i and P_i are observed and simulated values corresponding to i^{th} observation and n is the number of observation, $\bar{O}$ and $\bar{P}$ are mean of the observed and simulated values

The index of agreement (*d*) is used by many researchers such as Krause (2005) and Sintondji, (2005).

The model results will be considered validated for a set value of the validation criteria.

4.6 Investigation of hydrological behavior of watersheds

As discussed earlier, the entire study area comprises of two major watersheds *viz.* Myntriang and Umkhen. In this study, comparison is made between Myntriang and Umkhen watersheds in terms of percentage of rainfall events. The water yield per unit area of the two watersheds was obtained to describe the percentage of rainfall that is converted into water yield.

Similar comparison was made between the sub watersheds of Myntriang and Umkhen watersheds. The comparison was made for the capability of the sub watersheds to produce water yield and sediment yield on annual basis.

4.7 Assessment of hydro-power potential

One of the objectives of the present study is to assess the hydro power potential in the selected river basins. For the assessment of hydro-power potential it is necessary to obtain the information regarding the discharge and drop at the selected site. The principle of estimation of hydro-power potential and the methodology adopted is discussed below.

In natural circumstances, when water flows down a river course by gravitation, the hydro energy is lost in overcoming the resistance and scouring of the river bed. The energy lost can be established by the Bernoulli's equation and the energy loss (expressed by the head H_{1-2}) of the unit water volume can be obtained:

$$H_{1-2} = (Z_1 - Z_2) + \frac{P_1 - P_2}{\gamma} + \frac{\alpha_1 V_1^2 - \alpha_2 V_2^2}{2g} \qquad (4.5)$$

Where, Z_1, Z_2 are the elevation of the water surface of up stream and downstream section respectively; P_1, P_2 are the atmospheric pressure of the two sections; V_1, V_2 are the water flow velocities of the two sections; α_1, α_2 are the uneven distribution of V_1 and V_2; γ is the unit weight of water and g is the gravitational acceleration.

Since the term $[(P_1-P_2)/\ \gamma]$ and $[(\alpha_1 V_1^2 - \alpha_2 V_2^2)/2g]$ are so small, they can be ignored. Thus Z_1-Z_2= $H_{1\text{-}2}$, so the hydro energy (hydraulic potential) of the unit water volume can be expressed simply by the elevation differences.

When a discharge Q is flowing through a stream during t seconds without head losses, taking γ = 1000 kg /m^3 (N/m^3) the hydro energy delivered during t seconds is

$$P_{1-2} = 9.81\alpha Q H_{1-2} \text{ (kW)} \qquad (4.6)$$

Where α is the efficiency of the system. In this study the efficiency was considered as 0.5 as stated by Maher and Smith (2001) for small hydro project, In this study the power potential was assessed on 10 daily average basis. As the 10 daily average basis is generally accepted basis for power. The power potentiality has been estimated based on the Equation 4.6. The method of obtaining drop and construction of flow duration curve is discussed below. The methodology for assessment of hydro-power potential is shown as flow chart (Fig 4.10) and a conceptual layout of a hydro-power generation unit is shown in Fig 4.11

4.7.1 Drop Identification and Flow Assessment

Extraction of profiles along the identified streams was carried out to locate the specified drops along the streams. For selection of the appropriate locations the following criteria were considered,

- Availability of drop of at least 10 m (and above) and located 500m apart.
- The location should have considerable contributing area. To satisfy the condition the stream with stream order 4 and higher were considered.

Generally selection of site also consider the population pattern. However, the study area is very sparsely populated, therefore the criteria was not given due consideration.

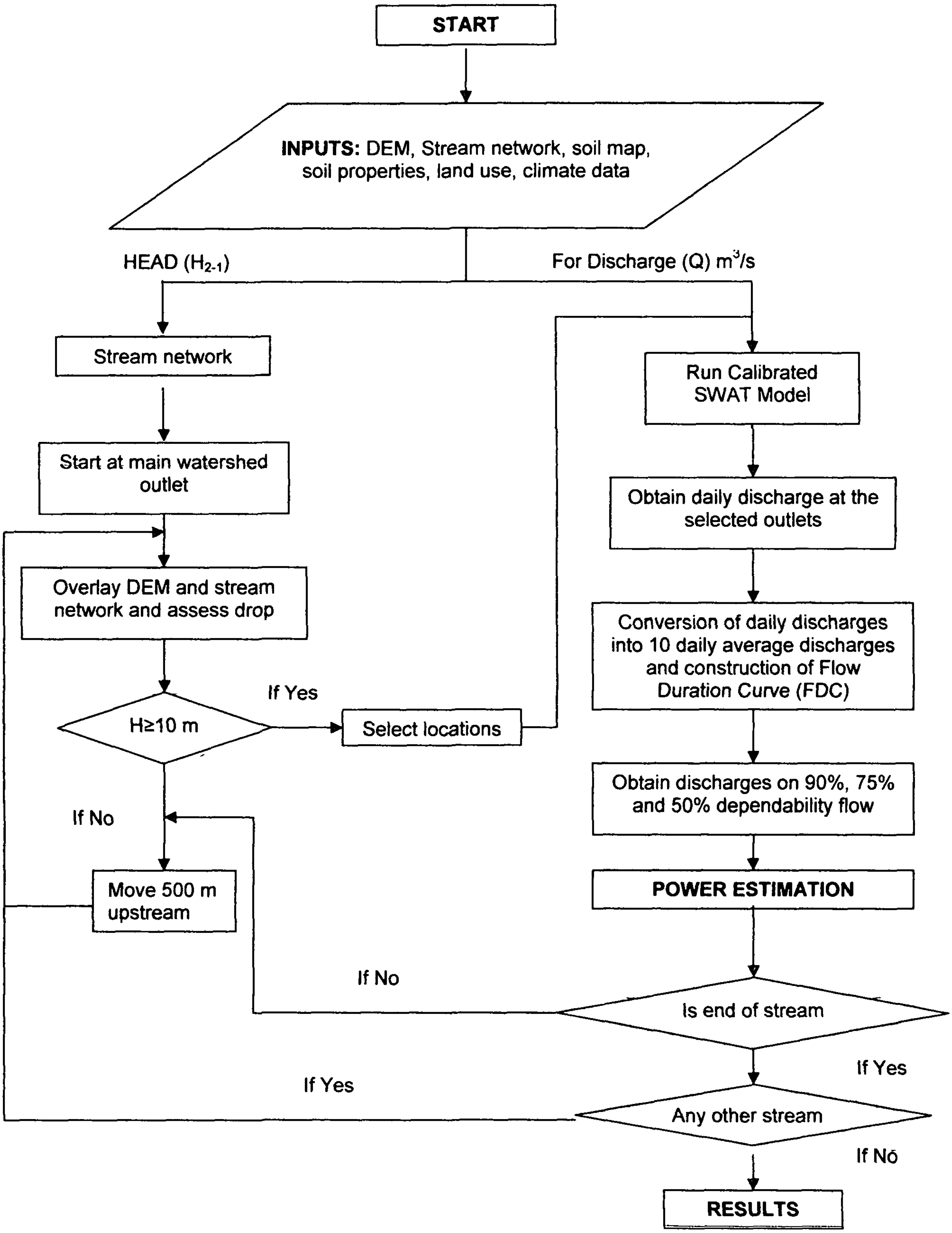


Fig 4.10: Flow chart for assessment of hydro-power potential

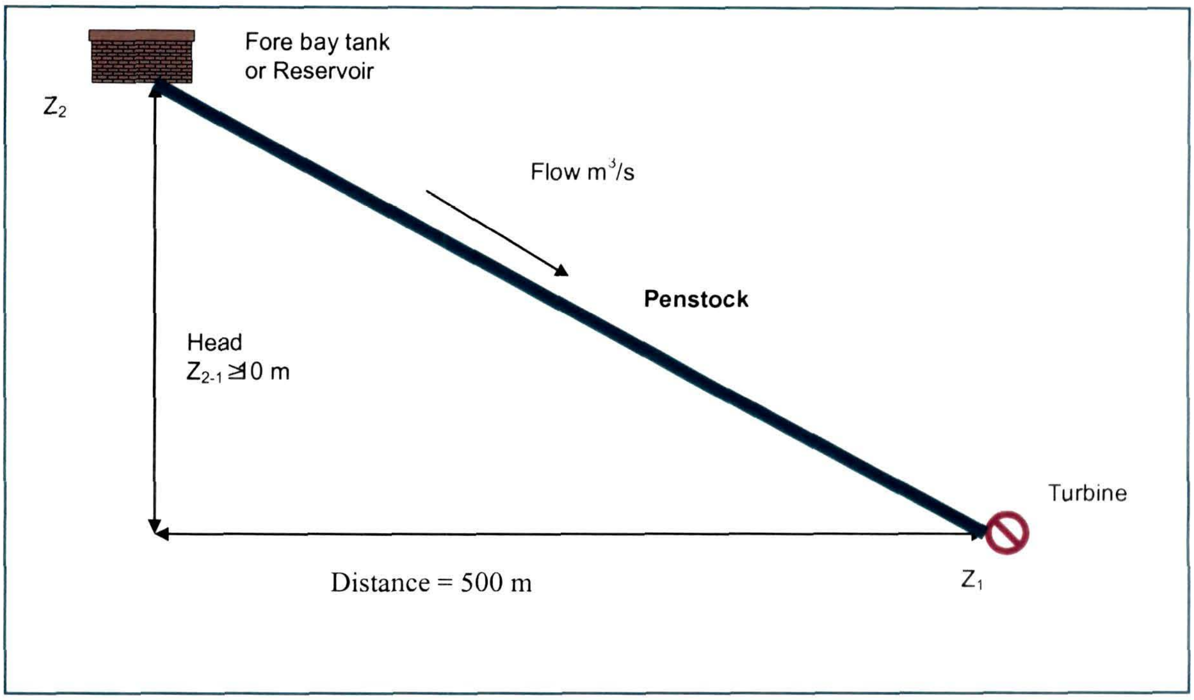


Fig 4.11: Conceptual layout of hydro-power generating unit

The confluence point of two streams was translated as outlet points to be used in the hydrological model (SWAT) for assessment of flow availability. The watersheds were delineated considering the identified outlets. The SWAT model was run to obtain the discharge at those selected outlets. An assumption was made that change in discharge between two outlet was negligible. Hence if more than two locations were available between two outlets, the discharge was assumed to be the same.

4.7.2 Flow Duration Curve (FDC)

A flow-duration curve (FDC) provides the percentage of time (duration) a daily or monthly (or some other time interval) stream flow is exceeded over a historical period for a particular river basin (Vogel *et al.*, 1994). In the present study a flow duration curve was constructed for all the selected outlets for Myntriang and Umkhen watershed.

The SWAT model was run for the period 1984-1993 for which rainfall and temperature data was available. The simulated discharge was obtained at all selected outlets for all the years. The daily discharges were converted into 10 daily average discharges for all the outlets.

The construction of a FDC using the simulated stream flow was performed through non-parametric procedures consisting of two main steps:

(i) the simulated stream flows q_i, i = 1,2 ,. . . ,N, are ranked to produce a set of ordered stream flows q(i), i = 1,2 ,. . . ,N, where N is the sample length, and q(1) and q(N) are the largest and the smallest discharges, respectively;

(ii) Each ordered observation q(i) is then plotted against its corresponding duration D_i, which is generally dimensionless and coincides with an estimate, *pi*, of the exceedence probability of q(i). The exceedence of probability pi was obtained using Weibull plotting position (WPP)

$$p_i = P(Q > q_{(i)}) = \frac{i}{N+1} \tag{4.7}$$

For obtaining the power potential discharges at 50%, 75% and 90% dependability flow was considered. The dependability flow was considered so that planning can be taken up based on other factors related to concerned area.

4.8 Summary

In this chapter the study area in terms of Kopili river basin in general and Umkhen and Myntriang watershed in particular was described in terms of location, geography, geomorphology, physiographic and climate. The SWAT modeling techniques, the input data requirements, collection and sources, data processing, generation of outputs, database files, model calibration, validation, evaluation criteria was discussed. Based on the model outputs hydrological behavior of the watersheds was also discussed. The principle of hydro power assessment, methodology and flow duration curve was also discussed.

CHAPTER- 5

RESULTS AND DISCUSSION

Chapter 5
RESULTS AND DISCUSSION

With an aim to predict water yield, sediment yield and the hydro power potential of the Myntriang and Umkhen watershed, hydrological model was developed using SWAT2000. The results of the study are presented and discussed in this chapter. The results are presented and discussed in the following sequences:

(i) Characterization of Myntriang and Umkhen watershed by digitization of:

- Terrain map *i.e.*, Digital Elevation Model,
- Delineated watershed map,
- Drainage network map,
- Soil map, and
- Land use map

(ii) Calibration of SWAT model for Myntriang and Umkhen

(iii) Validation of water yield for Myntriang watershed and Umkhen

(iv) Comparison of Hydrological behaviour with respect to rainfall-runoff conversion characteristics

(v) Comparison of hydrological behaviour of sub-watersheds in terms of

- Average annual water yield
- Water yield of sub watersheds during lean and peak seasons
- Average annual sediment yield

(vi) Characterization of stream network of Myntriang and Umkhen for:

- Assessment of drop availability along the streams
- Generation of flow duration curve
- Estimation of potential power

5.1 Characterization of Myntriang and Umkhen watershed by Digitization

In earlier discussion (Section 4.3.2), the methodology for creation of various input maps required for simulation of hydrological processes in SWAT 2000 was described. Five different maps *viz.*, DEM, stream network, watershed delineation, soil map and land use for Myntriang and Umkhen watershed have been generated. Basically these maps are required inputs of the SWAT2000 model. In addition to the primary use, these maps have other uses from hydrology and resource management point of view. As discussed in Materials and Methods, these maps were generated independently for the two watershed following standard procedures. The AVSWAT2000 model operates taking these maps as inputs. Considering the scope and possibility uses of the maps for Myntriang and Umkhen watershed these maps are presented and discussed below

5.1.1. Digital Elevation Model (DEM) *i.e.,* terrain map

As discussed earlier the contours for this study were obtained from toposheets of Survey of India at 20 m contour interval. The DEM's for Myntriang and Umkhen watersheds were obtained from the interpolation of the digitized contour and are shown in Figs 5.1 and 5.2 respectively.

The areas under 100 m elevation class were determined and presented in Table 5.1. The Hypsometric (area-elevation) representation of elevation range and respective percentage areas are also derived from DEM is presented in Fig 5.3.

Umkhen watershed is at higher elevation with a maximum altitude of 1860 m whereas highest elevation of Myntriang watershed has been found to be 1095 m. In case of Myntriang watershed substantial portion of area was found within an elevation range of 400 to 700 m comprising 77.66% of the total area of the watershed. The percentage of area below 400 m elevation range was only 7.41%.

In case of Umkhen watershed substantial area was within the elevation range of 600 m to 1100 m (75.18%). Below 400 m elevation, Umkhen provides only 41.10 sq km area having 3.41% share.

Further investigations of the area distribution within elevation range of 500-600 m for Myntriang and 800 to 1000 m for Umkhen watershed at 10 m elevation range were made. It was observed that for Myntriang watershed the elevations with more than 10% of the area share were 500 m to 510 m, 530 m to 540 m, 550 m to 560m, 570 m to 580 m and 590 to 600 m. Each of the remaining five elevation ranges shared less than 10% of total area falling with 500 m to 600 m range.

Table 5.1 Area under each elevation class

Elevation Range (m)	Myntriang Watershed			Umkhen watershed		
	Area (sq km)	Cumulative area	Fraction of area in each elevation range	Area (sq km)	Cumulative area	Fraction of area in each elevation range
80-100	1.96	1.96	0.73	0.55	0.55	0.05
100-200	3.30	5.26	1.23	2.06	2.61	0.17
200-300	4.75	10.01	1.78	3.12	5.72	0.26
300-400	9.82	19.82	3.67	10.98	16.70	0.91
400-500	39.29	59.11	14.69	24.40	41.10	2.03
500-600	113.41	172.52	42.41	74.00	115.09	6.15
600-700	54.94	227.47	20.55	109.39	224.48	9.09
700-800	23.06	250.52	8.62	149.60	374.08	12.43
800-900	10.13	260.66	3.79	270.81	644.89	22.50
900-1000	5.23	265.89	1.96	243.67	888.56	20.24
1000-1100	1.49	267.38	0.56	131.50	1020.06	10.92
1100-1200				62.79	1082.84	5.22
1200-1300				45.47	1128.31	3.78
1300-1400				31.31	1159.62	2.60
1400-1500				15.11	1174.73	1.26
1500-1600				14.66	1189.39	1.22
1600-1700				7.19	1196.58	0.60
1700-1800				4.61	1201.19	0.38
1800-1900				2.48	1203.67	0.21

In Umkhen watershed it was found that the elevation difference in the range of 800 m to 1000m interval could not show substantial variation of area share. The maximum area comprising only 8.16% falls in the range of 870 to 880 m followed by 7.07% in the range of 890 m to 900 m. The remaining areas were almost equally shared by each elevation range.

The presence of substantial area at higher elevation range of 500-600 m elevation for Myntriang and 800 to 1000 m elevation for Myntriang watershed may be attributed to the presence of Shillong plateau. The information on the elevation ranges and their area sharing would be useful in planning and management of the watershed.

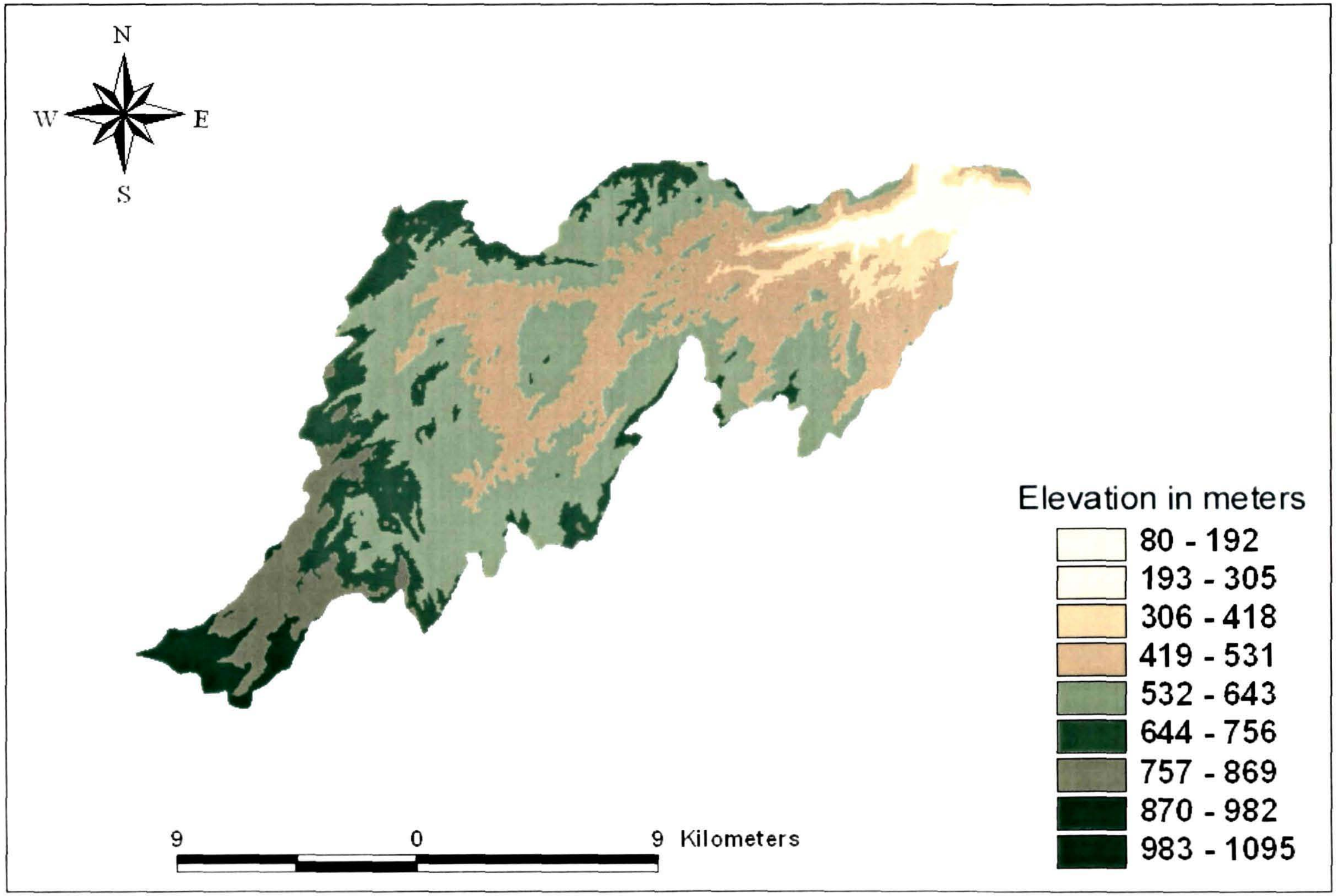


Fig 5.1: DEM of Myntriang watershed

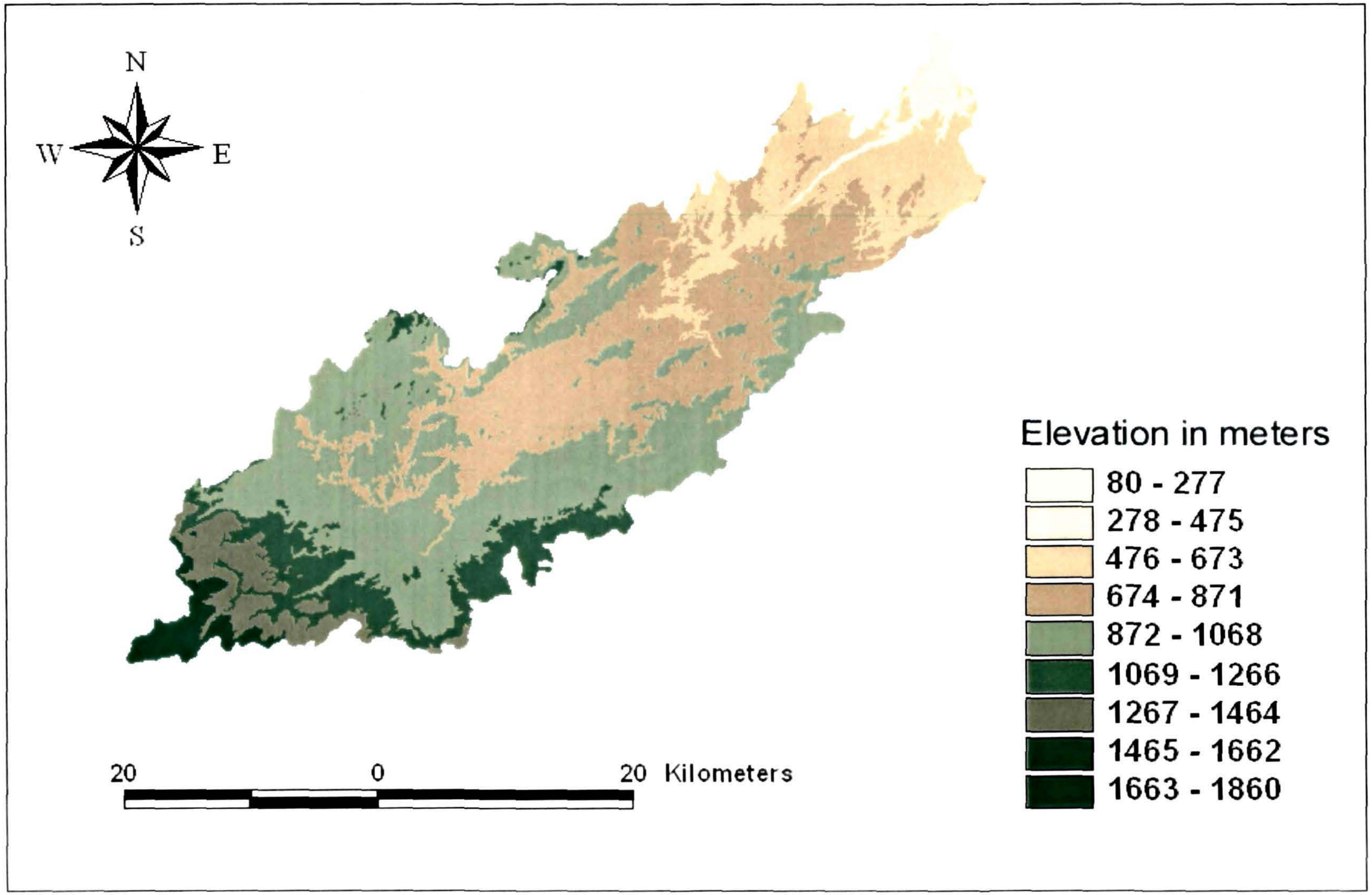


Fig 5.2: DEM of Umkhen watershed

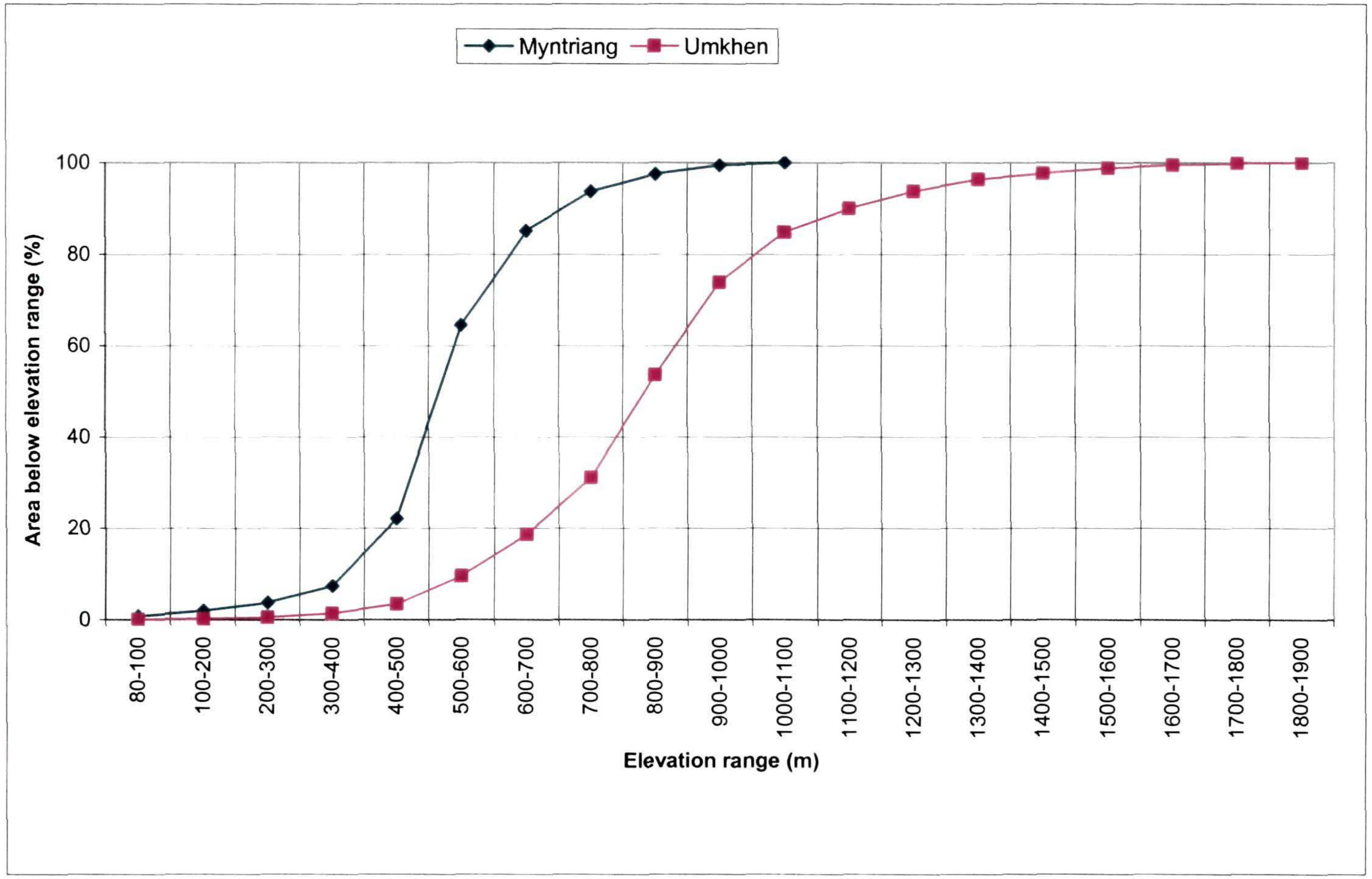


Fig 5.3: Hypsometric curve for Myntriang and Umkhen watershed

5.1.2 Delineated watershed map

Myntriang and Umkhen watersheds were delineated from the respective toposheets. The model computes area under each watershed. Areas under these watersheds were also computed using an independent technique and compared with the area computed by model. In this technique digitized map of the watersheds were used to estimate the area on the basis of ridge lines on the digitized maps through manual intervention.

The area delineated by the model was found to be 260.76 sq km for Myntriang watershed as against manually judged area of 267.39 sq km and for Umkhen watershed the model computed 1183 sq km as against 1203 sq km obtained from manual intervention. The differences in area calculated by manual procedure and area calculated by the model were found to be 2.47% for Myntriang watershed and 1.67% for Umkhen watershed. The difference might be due to error in manual methods and model estimated areas were considered for further analysis.

The watersheds were further delineated into sub watersheds. The threshold area adopted for delineation of sub watersheds was taken as 50 sq km (5000 ha). The reason of taking 50 sq km as the threshold was that the policies of Government of India for implementation of watershed programs consider this amount of area as the planning unit (MoA, 2000). The process resulted in three sub watershed for Myntriang and thirteen sub watersheds for Umkhen (Fig 5.4 and 5.5). The area of each sub watershed of Myntriang and Umkhen are shown in Table 5.2 and 5.3.

Table 5.2 : Area under each sub watershed in Myntriang watershed

Sub Watershed	Area of Sub watershed (sq km)	% of total area
MSW1	135.13	51.82
MSW2	61.49	23.58
MSW3	64.13	24.60
Total	260.75	100.00

Table 5.3: Area under each sub watershed in Umkhen watershed

Sub Watershed	Area of Sub watershed (sq km)	% of total area
USW1	15.53	1.31
USW 2	125.39	10.60
USW 3	80.88	6.84
USW 4	87.22	7.37
USW 5	17.50	1.48
USW 6	117.52	9.93
USW 7	136.81	11.56
USW 8	67.36	5.69
USW 9	69.61	5.88
USW 10	185.42	15.67
USW 11	74.06	6.26
USW 12	155.45	13.14
USW 13	50.01	4.27
Total	1182.76	100.00

From the Table 5.2 it can be observed that with about 52% area share of the Myntriang, MSW1 was the major one. Whereas remaining two watersheds are almost of equal sizes. In Umkhen, four watersheds *viz.,* USW2, USW7, USW10 and USW12 occupied more than 10% area each whereas sub watershed USW1 and USW5 occupied less than 2% of total area of Umkhen.

The information of the delineated sub watersheds is useful for identification of problems as compared to identification of problems in larger size watersheds and also for prioritization. Watersheds of smaller size have a distinct advantage of having homogenous climate, geography and land use which are not attainable in large watersheds. Moreover smaller watersheds having smaller group of population are anticipated to bear identical characteristics and therefore easier to plan and manage. The importance of delineation of main watershed into smaller sub watershed were emphasized by many research workers including Mishra *et al.* (1984), Biswas *et al.* (1999), Satapathy (2001), Pandey *et al.* (2002) and Suresh et al. (2004).

Mishra *et al.* (1984) studied the effect of topoelemensts with sediment production rate of sub watersheds in Damodar valley. Sujata *et al.* (1999) prioritized sub watersheds in Nayagram Block in Midnapore District of West Bengal (India) based on morphometric parameters. Satapathy (2001) stated that planning process of larger watershed with heterogeneity in watershed

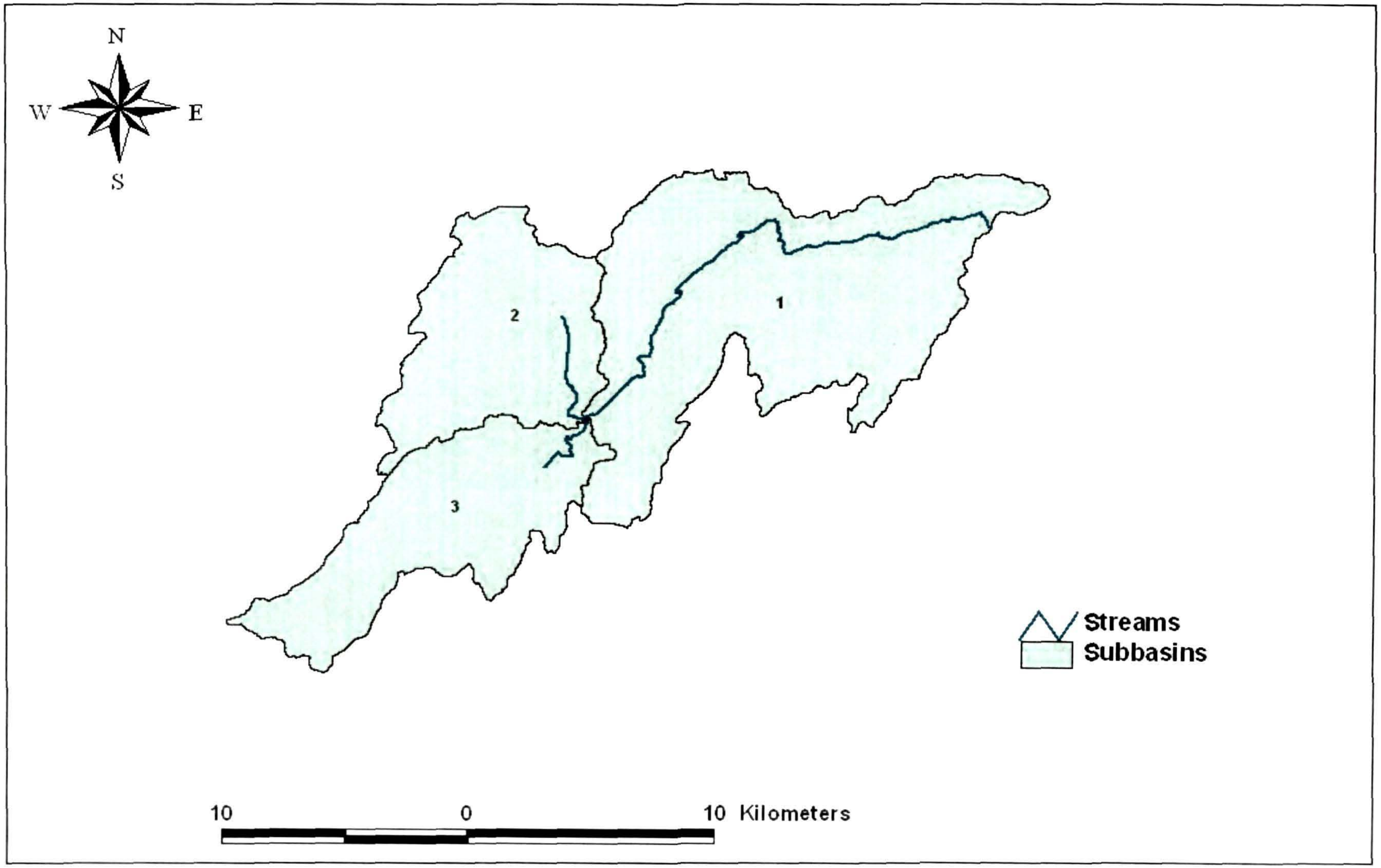


Fig 5.4: Delineated watershed and sub watershed map of Myntriang watershed

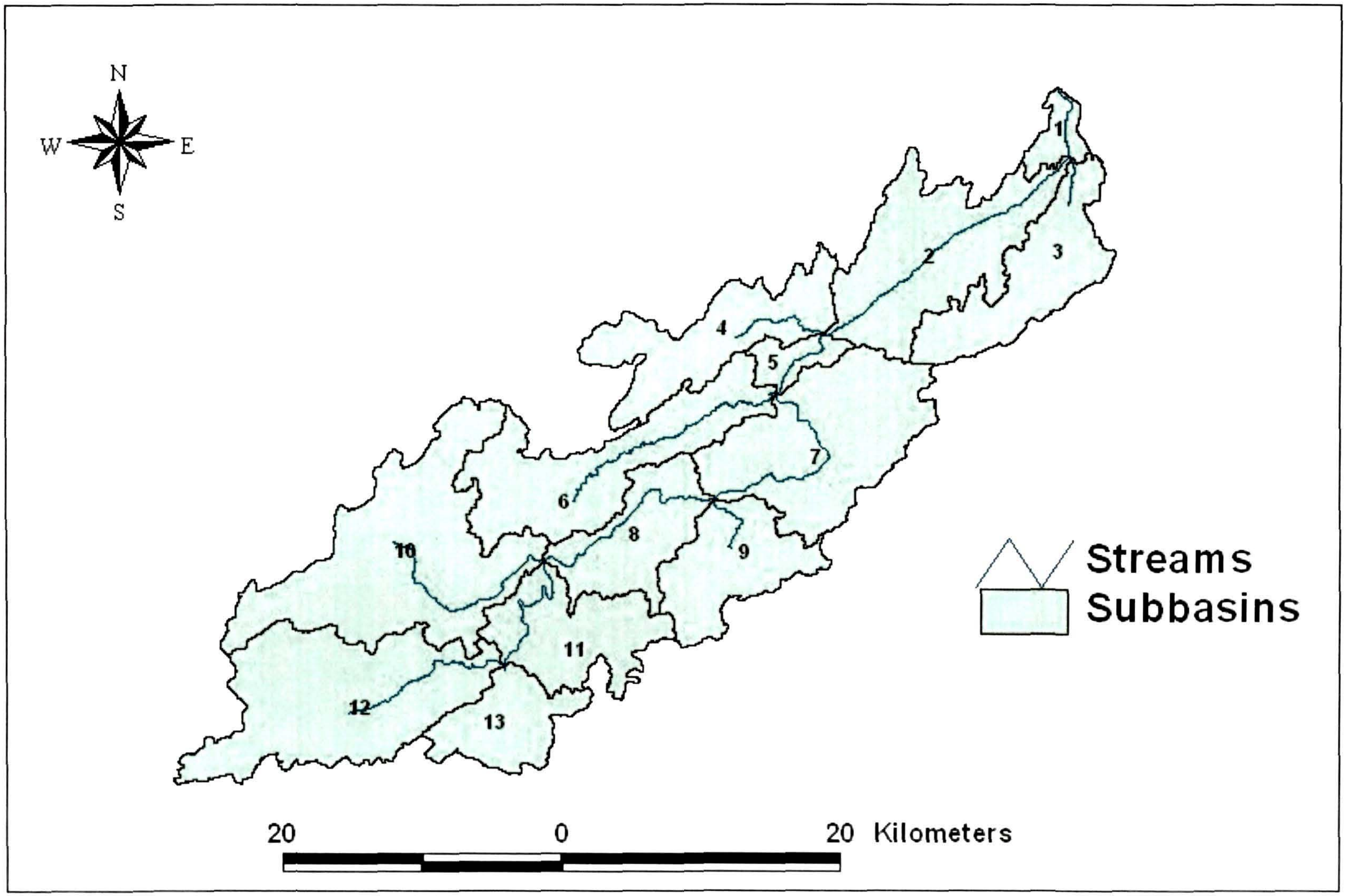


Fig 5.5: Delineated watershed and sub watershed map of Umkhen watershed

characteristics and socio-economic condition is complex and necessitates large financial outlay. In the similar lines, Suresh *et al.* (2004) stated that attempt to assess the erosion hazard and prioritize sub-watersheds for treatment would aid for better planning in combating this menace. The sub-watersheds needing immediate attention can be prioritized for treatment based on the water yield and sediment yield characteristics of the sub- watersheds that are easier to estimate in smaller watershed. Pandey *et.al,* (2002) prioritized the sub-watershed using SWAT model based on sediment production characteristics.

Prior to the present study, delineated sub watersheds for Myntriang and Umkhen were not available. Thus, it is expected that such information on hydrologically delineated watershed would assist to plan and implement natural resources based program for upliftment of the region. Specifically it would be useful for planning and implementation of need based programmes such as water harvesting structures, soil conservation programmes, plantation programmes, crop planning.

5.1.3 Drainage network map

The drainage map as extracted from toposheet at 1: 50000 scales are shown in Fig 5.6 and 5.7. The stream ordering was done as per Strahler method (Strahler, 1957).

The result of stream ordering showed that Myntriang is 6^{th} (sixth) order and the Umkhen is of 7^{th} (seventh) order stream.

The automatic delineation also showed that the main channel of the digitized drainage and the generated of the stream network closely matched with the main stream as given in the topographic map, thereby indicating the correctness of the digitization process and the DEM generated in this study. The automatically delineated watershed along with sub watershed map is shown in Figs 5.4 and 5.5.

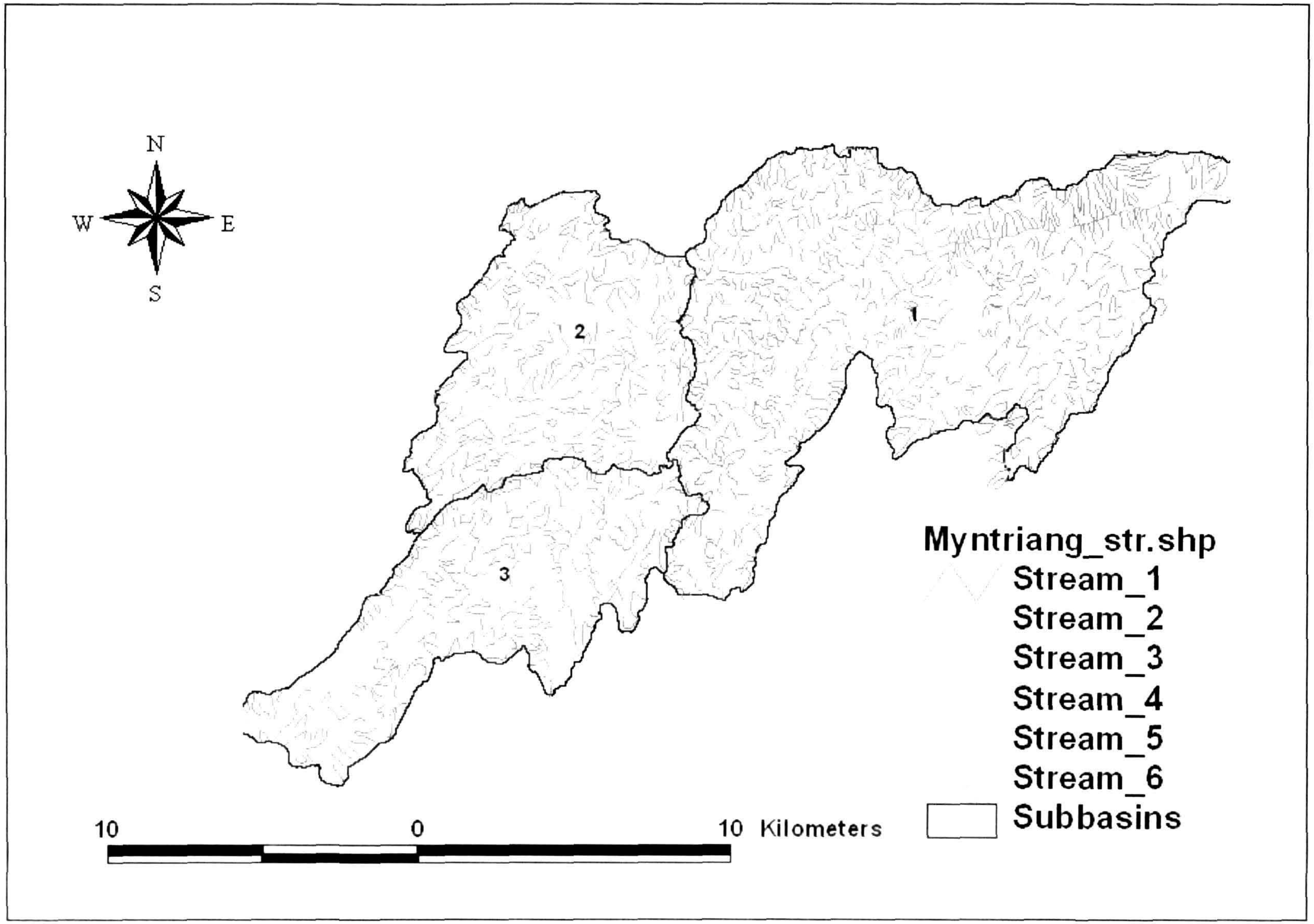


Fig 5.6: Drainage network of Myntriang watershed

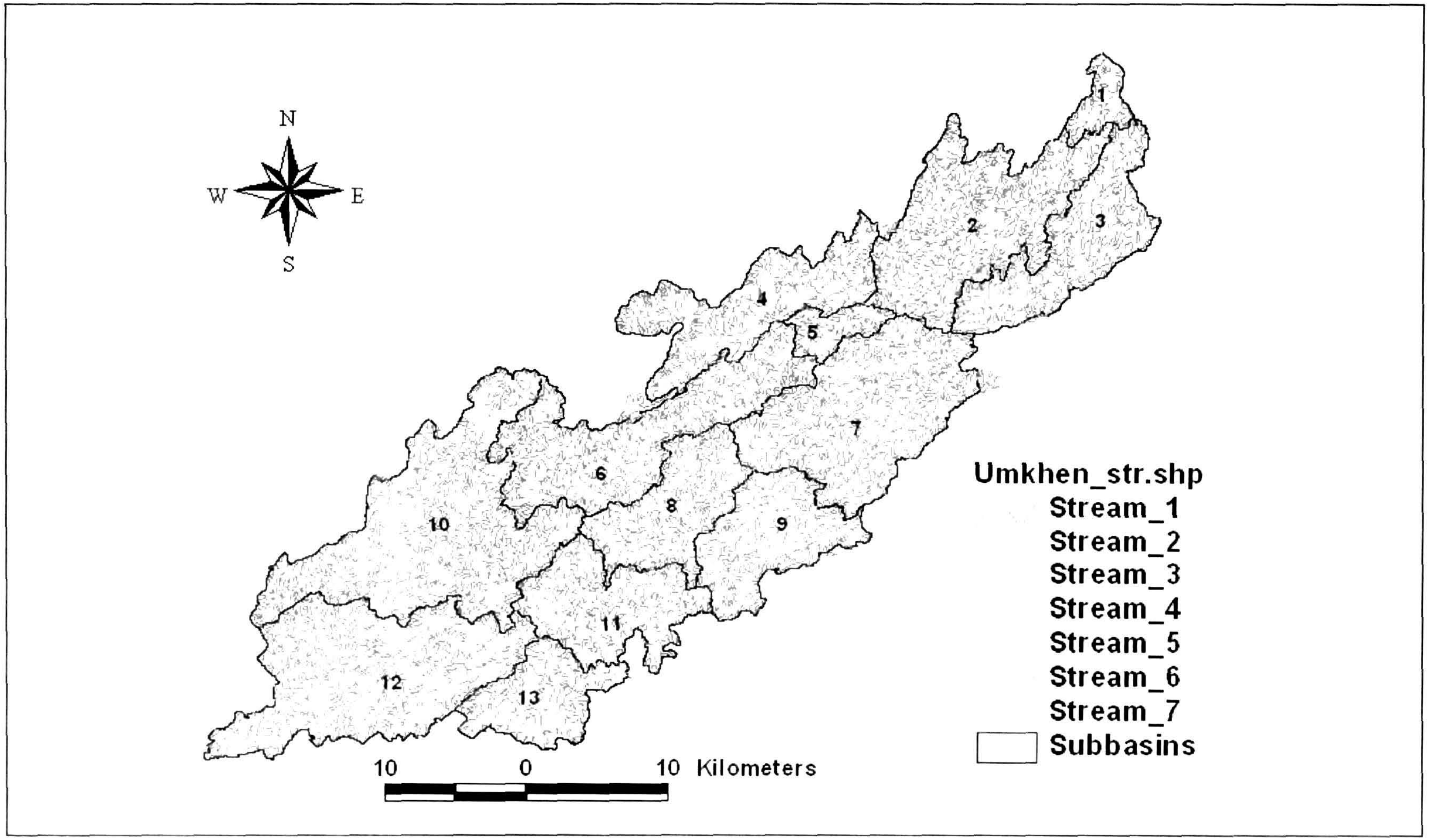


Fig 5.7: Drainage network of Umkhen watershed

Drainage network provides various information of the watershed *viz.*, age, erosion characteristics and hydrology, thereby provides criteria for prioritizing the watershed requiring immediate treatment measures. Drainage networks exhibits four basic qualities *viz.*, topology (linkage properties), scale (drainage density, length and area relationship), orientation (direction and shape properties of streams, slopes and divides) and relief (gradient and hypsometric relationship). The method of quantitative analysis of channel network was introduced by Horton (1932 and 1945). Most quantitative studies of drainage networks have considered only one or two of these qualities, although strong interrelationship occurs between all aspects of drainage organization (Howard, 1971).

Drainage characteristics of a watershed had been used by many researchers to identify various properties of a watershed such as hydrological, geological, climatological, history of drainage formation, erosion hazards etc which provides vital inputs for planning watershed treatment measures (Kumari *et al.* 2001; Kumar et al. 2001; Biswas *et al.* 1999; Suresh *et al.* 2004).

Kumari *et al.* (2001) stated that the drainage pattern reflects a wide range of influences, including morphology, geological structure, climate and history of drainage development. On the similar lines Kumar *et al.*, (2001) also said that the information of drainage can help in providing solution to several hydrological problems in ungauged watersheds with limited data situations. Biswas *et al.*, (1999) prioritized sub-watersheds in Nayagram Block in Midanapore district of West Bengal (India) using drainage characteristics. Suresh et al., (2004) also prioritized 10 sub-watersheds in Tarai development project based on morphometric parameters. Singh (2006) used the drainage characteristics for water resources development plan in Sur catchments in Maharastra (India).

Before the present study the drainage network with stream ordering was not available for Myntriang and Umkhen. Thus, the map generated in this study could provide vital information drainage density, stream frequency, bifurcation ratio, shape index, circulatory ratio, tortuosity index and infiltration number. The drainage density for Myntriang and Umkhen watershed were found to be 3.98 and 3.55. Drainage density gives an idea about the underlying rocks. Low drainage density indicates highly resistant and permeable sub soil material whwereas high drainage density indicates region of weak, impermeable sub surface materials and show high relief (Strahler, 1964). The stream frequencies for both the watershed were 9.4 and 8.25. The stream frequency is the ratio of number of streams of all orders divided by the area of the watershed. The higher the stream frequency it means that new channels have grown or lengthening of the existing stream. These morphological information could be used to select suitable treatments such as the places where scope for (i) water harvesting exists, (ii) bunding and terracing is required based on the watershed characteristics and also to (iii) explain the behaviour of watershed.

5.1.4 Soil map

The soil map of the study area i.e. Myntriang and Umkhen watersheds are shown in Fig 5.8 and 5.9. The soil thematic maps of these study watersheds were specifically prepared based on the information available with National Bureau of Soil Survey and Land Use Planning (NBSSLUP) under Indian Council of Agricultural Research (ICAR) which is a Government of India recognized soil survey and land use planning organization. The effort in this study was to prepare detail soil map of the watersheds. The result indicated that Myntriang watershed consists of five different classes of soil where as Umkhen watershed consists of eleven soil classes. The details of the soil and the area covered under each soil class are given in Appendix 14 (a) and (b).

Apart from the use of these maps in the present model, it would also be useful for planners and scientists particularly working for these two watersheds. A single type of soil dominates in Myntriang watershed with AS03 (*Coarse-loamy, Typic Dystrochrepts; Clayey, Typic Hapludalfs)* mapping unit whereas there are several major soil types under Umkhen watershed. They are in the decreasing order of area coverage are AS 67 (*Fine-loamy, Typic Hapludalfs; Coarse-loamy, Typic Hapludalfs)*; ME 01 (*Typic Kandiudults, Typic Dystrochrepts)* AS03 (*Coarse-loamy, Typic Dystrochrepts; Clayey, Typic Hapludalfs*); ME 05 (*Typic Kandihumults Typic Dystrochrepts*); ME 10 (*Typic Kandihumults Typic Haplumbrepts*) and AS09(*Fine Aquic Dystric Eutrochrepts Fine silty, Dystric Eutrochrepts*).

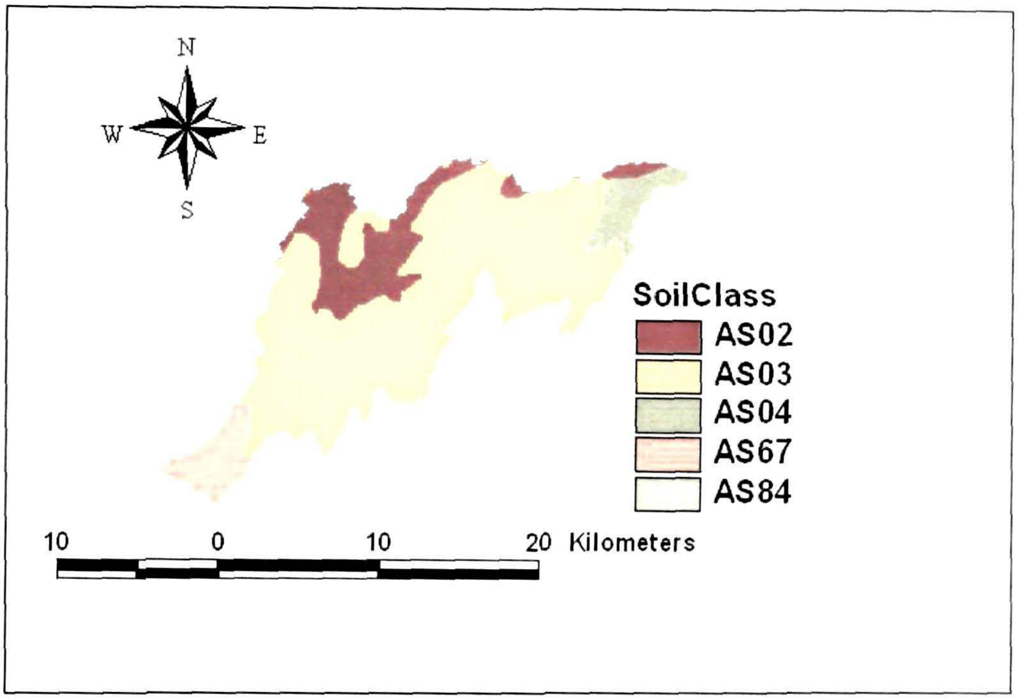


Fig 5.8: Soil Map of Myntriang watershed

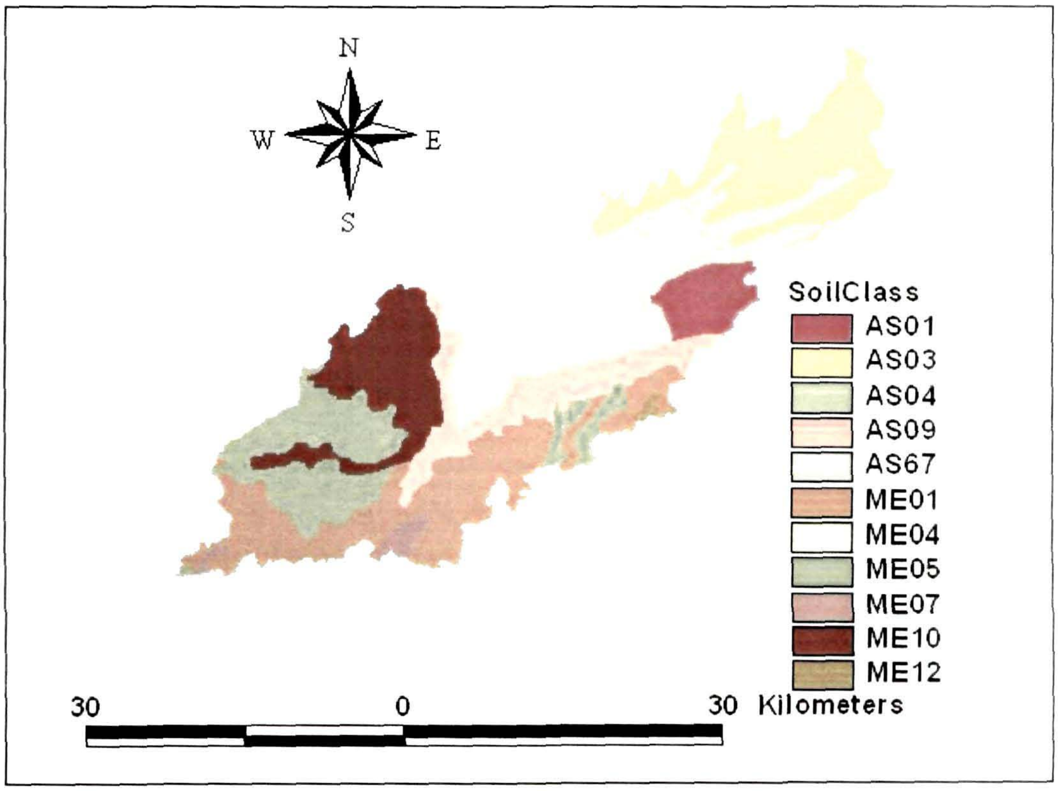


Fig 5.9 Soil Map of Umkhen watershed

Variation of soil characteristics such as depth, drainability, texture is reflected by each soil mapping unit. Distribution of mapping unit thus would affect the hydrology differently resulting in spatial variation in hydrological behavior.

5.1.5. Land use theme

The model requires land use maps of the watersheds. The specific land use maps of the study watersheds were prepared based on the land use maps of relevant sites covering those watersheds. The land use map of both the watershed (Umkhen and Myntriang) are shown in Fig 5.10 and 5.11. The details of the land use are given in Appendix 15 (a) and (b).

The land use map indicated a forest dominant land use pattern in both the watersheds. Different types of forest covers were noticed. A typical farming practice "shifting cultivation" followed in the hilly region of North-eastern India was also prominent here. In Myntriang watershed the area under shifting cultivation was found about 63% of the total area of the watershed, whereas in Umkhen the shifting cultivation was practiced in about 33% of the total area. ARSAC (1990) classified shifting cultivation into two categories *viz.*, current and abandoned. The areas where shifting cultivation was practiced when the mapping was done was termed as current and other areas where the shifting cultivation had been practiced in earlier years were termed as abandoned shifting cultivation areas. It has been reported that shifting cultivation causes accelerated erosion and quicker runoff due to denuding of the vegetation (Prasad *et al.,* 1990; Narayana, 1990).

No previous work referring to effect of shifting cultivation of Myntriang and Umkhen could be consulted. However, numbers of studies describing the ills of shifting cultivation are available in some specific regions. Das (1990) quoted that in Machkund reservoir that is dominated by tribal population practicing shifting cultivation, the sediment production rate was 3.80 Ha-m per 100 sq km against the safe limit of 3.57 Ha-m per 100 sq km. Prasad *et al.* (1990) compiled research findings of various research workers related to quantitative facts on soil erosion hazards associated with various systems

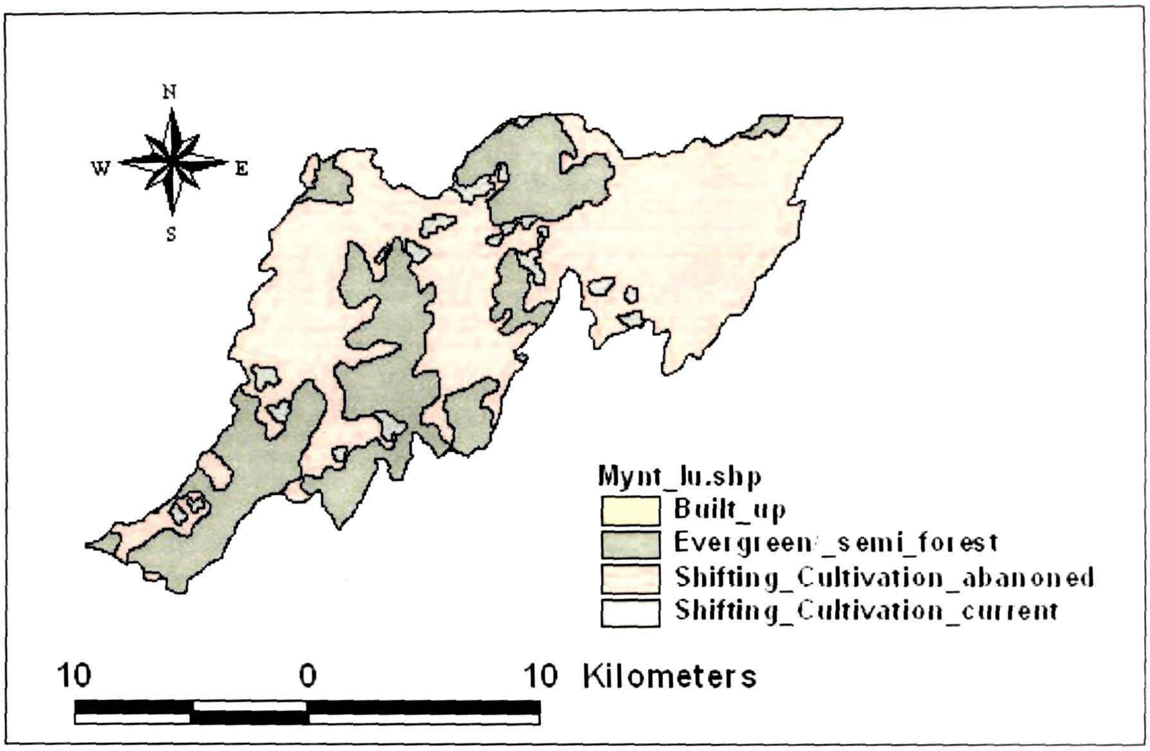


Fig 10: Land Use map of Myntriang watershed

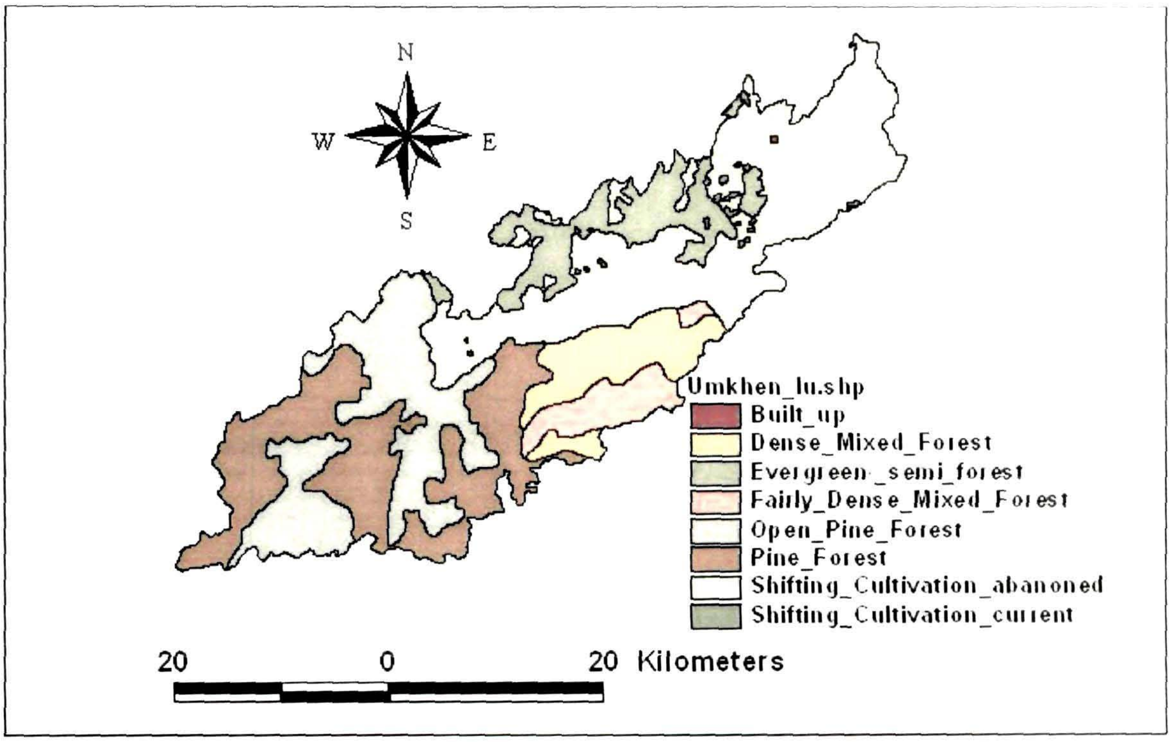


Fig 5.11: Land use map of Umkhen watershed

practiced on hill slopes. From the compilation it can be inferred that soil erosion under shifting cultivation practice resulted in higher sediment yield of 30.2 to 170.2 t/ha on small experimental plot and 5.1 to 83.2 t/ha/year of field level plot. Narayana (1990) from his study concluded that soil loss was highest in North Eastern states of India and attributed the reason to shifting cultivation.

The lack of developmental activities coupled with low level of infrastructures available (including power) in Myntriang and Umkhen might be major reason of extensive area under hazardous practice of shifting cultivation.

Apart from shifting cultivation, evergreen forest, pine forest, dense mixed forest were some of the major land covers of the watershed. The lack of major habitat area was the characteristic feature of both the watersheds.

5.2 Calibration of Model for Myntriang and Umkhen

The details of the model calibration and its requirements have already been discussed in section 4.5. The daily values of surface runoff recorded at the outlet of the study watershed during January 1988 to December 1990 were used for calibration of the model. Adjustments of the model parameters were continued until the modeled water yields showed good agreement with the observed values.

The values of calibrated parameters of Myntriang and Umkhen watersheds are presented in Table 5.4. All the values were chosen within their prescribed range as suggested in SWAT2000 users manual (Neitsch *et al.*, 2002). Daily observed rainfall and temperature data of the corresponding years (1988-1990) were used for calibration of the model. Hargreaves method was selected for computation of ET since it gave better results as per the availability of the data.

Table 5.4 : Parameters used for calibration of watershed

Sl No	Parameters	Calibrated values for Myntriang	Calibrated values for Umkhen	Recommended range
1	Surface runoff curve number (CN_2) for land use			
	(a) Forest Evergreen	56	52	35-98
	(b) Shifting cultivation	61	50	35-98
	(c) Pine	-	62	35-98
2	Base flow recession alpha factor (days)	0.48	0.48	0-1
3	Threshold depth of water in the shallow aquifer	1	1	0-500
4	Soil evaporation compensation factor	0.1	0.1	0-1
5	Available water capacity of the soil layer (mm /mm soil)	0.14	0.2	0-1
6	Threshold water depth in the shallow aquifer for flow (mm)	0	20	0-5000
7	Manning 'n' overland flow	0.1	0.1	0.01- 0.12

The increase in curve number (CN2) values indicates increase in surface runoff and vice versa. In Myntriang, CN2 for the two major land covers were calibrated as 56 for forest evergreen and 61 for abandoned shifting cultivation. In Umkhen the CN_2 for pine forest was calibrated at higher value (62) than other two dominant land uses *viz.,* mixed forest (50) and evergreen forest (52). In all the cases, the calibrated curve number values were found to lie within the recommended ranges. The variations of the calibrated values might be due to variations of the land use pattern, characteristics of soils and moisture conditions.

The baseflow recession factor is a direct index of groundwater flow response to changes in recharge (Smedema and Rycroft, 1983). The previous studies reported that values of baseflow recession factor vary from 0.1 to 0.3 for land with slow response. However, a rapid response caused the value to change up to 0.9 -1.0. In the present study the calibrated value of both the watershed was found uniform as 0.48 which indicates moderate response to recharge.

SWAT models the movement of water into overlying unsaturated layers as a function of water demand for evapotranspiration. The process has been termed '*REVAPMN*'. This process is significant in watersheds where the saturated zone is nearer to the surface or where deep-rooted plants are growing. The SWAT recommends a range of threshold values within 0 to 500. The calibration value was found as 1 for both the watersheds, indicating higher water transfer from shallow aquifer to the root zone.

The soil evaporation compensation factor (*esco*) was included in the model to allow to modify the depth distribution to meet the soil evaporative demand. As the value for *esco* is reduced, the model is able to extract more of the evaporative demand from lower levels. The calibrated value of *esco* is 0.1 (recommended range is 0 to 1) which indicates increased evaporation in the both the watersheds.

The amount of water held in the soil between field capacity and permanent wilting point is considered to be the water available for plant extraction. The range of available water capacity of a soil layer is 0 to 1. In Myntriang watershed the calibrated value for this parameter is 0.14 where as in Umkhen the value is 0.2. It indicates the available water capacity in Umkhen watershed is higher than Myntriang watershed. However, the values in both the watershed is at the lower side of the range thereby indicating lower water retention.

The shallow aquifer contributes base flow to the main channel or reaches within the sub basin. Base flow is allowed to enter the reach only if the amount of water stored in the shallow aquifer exceeds a threshold value (*GWQMN)*. The model gave a wider range of *GWQMN* (0 to 5000). In the present study, the value of *GWQMN* for Myntriang was calibrated at 0 whereas for Umkhen it was 20 thereby indicating quicker shallow aquifer flows in Myntriang as compared to Umkhen.

The Manning's roughness coefficient (*n*) indicates the resistance to flow of water over surface. The value of '*n*' in both the watershed was calibrated at 0.1 whereas the range is 0.01 to 0.12. It may be attributed to the land use as most of the area in both the watershed falls under forested category.

The calibrated values discussed above were obtained after a series of model run following standard procedures (Chen and Mackay, 2004; Ba¨rlund et al., 2007; Kannan et al., 2007; Tolson and Shoemaker, 2007). The values calibrated at best agreement of "observed" and "model prediction" were considered for further simulation. Thus, the set of calibrated values considered for the present study are assumed to provide accurate model prediction.

5.3 Validation of model using observed data

The water yields of the two watersheds (Myntriang and Umkhen) were obtained from the simulation run of SWAT 2000. The water yield was converted into 10 daily averages and compared with the observed values of water yields for model validation. As discussed in the chapter 4, the rainfall pattern in the study area starts during April and continues up to September. Therefore, the validation results of the simulation run were also presented as rainy (April to September) and non rainy (October to March) periods.

The model outputs of both the watersheds were separately validated first by comparing the observed data with simulated results and then by set of validation criteria. The validated results are presented and discussed below.

5.3.1 Comparison of observed water yield with simulated output of model

Simulated and observed values of water yield (10 daily average values) for the period of January 1991 to June 1993 are plotted against the respective time scale as shown in Fig. 5.12 for Myntriang and Fig. 5.13 for Umkhen watershed.

From the comparison it is observed that the model predicts the trend of water yields in accordance with the observed values almost over the entire period of observation. However, as far as prediction of water yields for a particular instance was concerned, the model either overestimated or

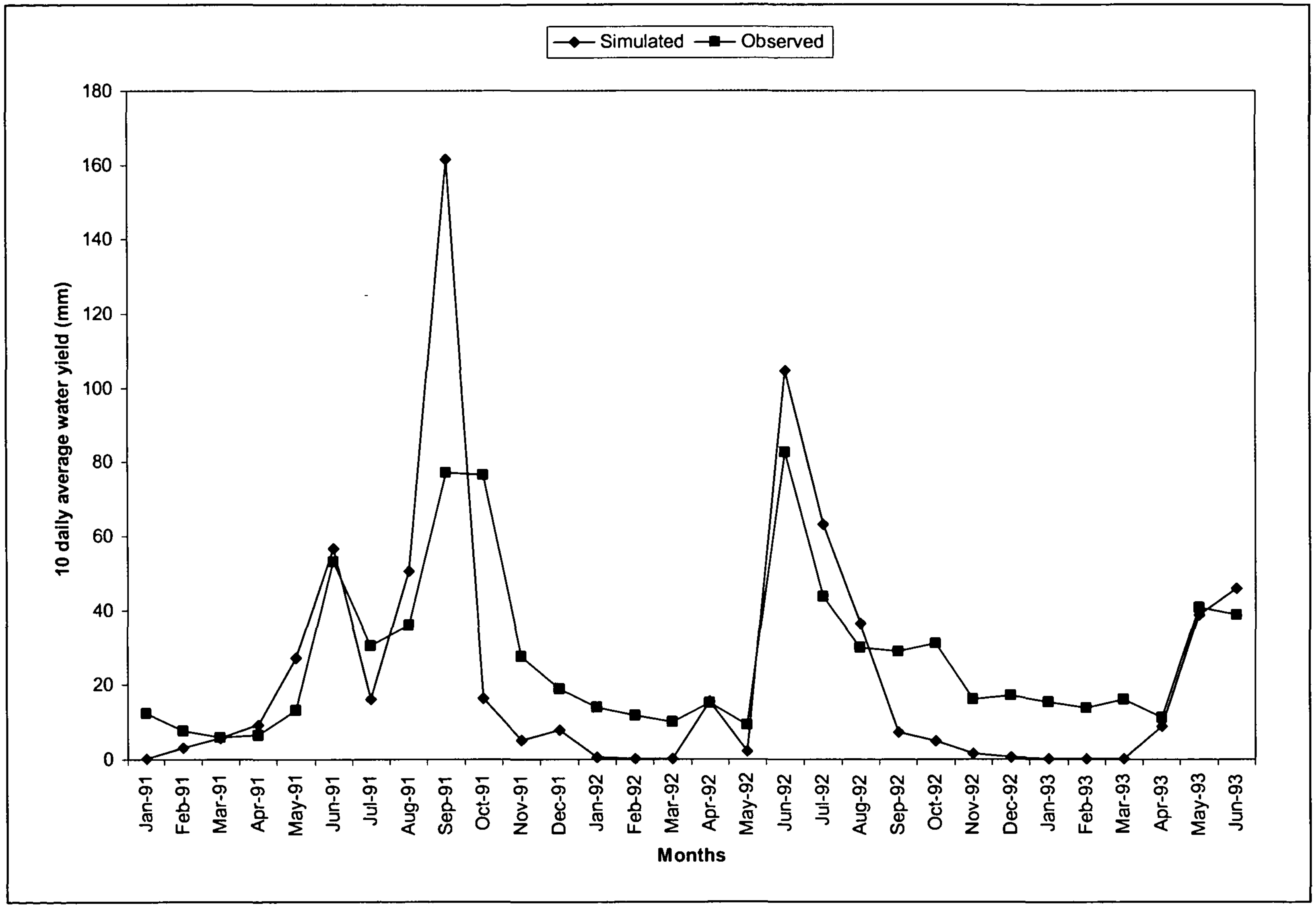


Fig 5.12: Comparison of simulated and observed values of water yield for Myntriang watershed

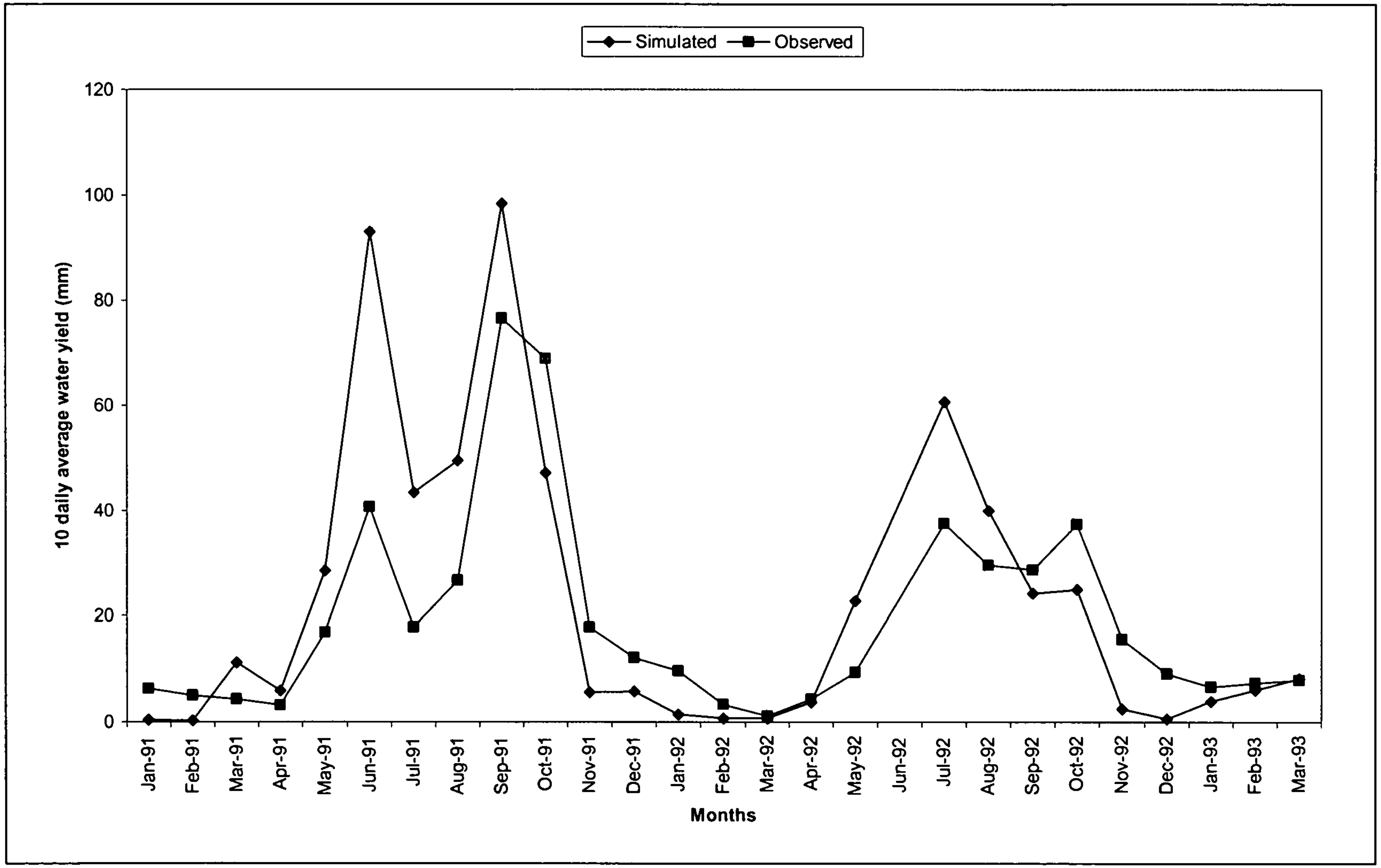


Fig 5.13: Comparison of simulated and observed values of water yield for Umkhen watershed

underestimated the water yields. In general overestimation of the rising (including peaks) sides and underestimation of the recession sides had been common features for both the watersheds. Specifically, simulated water yields were less as compared to observed water yields during the non rainy period (October to March) for both Myntriang and Umkhen. During the rainy period starting from April to September the simulated value of water yield were higher as compared to the observed values of water yields. The models were calibrated uniformly considering the annual sets of data without treating rainy or non-rainy period separately. The season dependency behaviour of models might be attributed to the error of calibration. The seasonal variations of water yield were also investigated by some researchers. Abbaspore *et al.*, (2007) attempted to explain the variation of discharges in dry and wet periods while modeling hydrology in Thur watershed of Switzerland. According to them surface runoff in wet period and lateral flow in dry period were dominating contributors of water yield. In the present investigation, though such flow partitioning was not done, dominance of such dissimilar flow pattern with varying precipitation levels might be the reason of seasonal flow variation.

It is also been reported that calibration of models at a watershed scale is a challenging task because of the possible uncertainties that may exist in the form of process simplification, processes not accounted for by the model, and processes in the watershed that are unknown to the modeler (Abbaspour *et al.*, 2007). The pattern and reason of disagreements were also described by some earlier research workers (Chen and Mackay, 2004; Tolson and Shoemaker, 2007; Kannan *et al.*, 2007). The reasons of such inaccuracies were also explained by Gupta *et al.*, (2005) as uncertainties in inputs, model uncertainty and parameter uncertainty. It was also reported that partitioning of errors into its specific components was difficult, particularly in cases common to hydrology where model is non linear and different sources of error may interact to produce the measured deviation. Romanowicz *et al.*, (2005) stated that in most of the cases simulation model underestimates the observed values. They further concluded that SWAT was very sensitive to internal and external pre-processing of soil and land use data. Van Liew and Garbrecht,

(2003) and Kannan *et al.,* (2007) attributed to the limitation of curve number updating processes of the model. It was further, explained that the disagreement in SWAT prediction was due to the use of curve number method which updated the curve number values based on overall water content of the entire soil profile. Another reason might be the rain gauge data availability. Though for the hilly watershed, recommended rain gauge density should be about one gauge per 130 square km (Raghunath, 1986), for the present study the gauge density was less and the value was about one gauge per 400 square km. The inaccuracies of the Myntriang and Umkhen watershed modeling might also be attributed to such uncertainties and requires further investigation.

Considering the objectives of the present investigation and consulting the earlier research findings on the prediction characteristics of hydrological modeling, the inaccuracy of prediction obtained in the present study seems to be justified and therefore ignored.

5.3.2 Model validation

Apart from investigating the prediction accuracy as discussed above the model was also assessed through some "efficiency criteria". Efficiency criteria are defined as mathematical measures of how well model simulation fits the available observations (Beven, 2001).

To study the efficacy of the model to predict water yields of Myntriang and Umkhen watershed, three different efficiency criteria *viz.,* (i) Coefficient of determination (R^2), (ii) Nash-Sutcliffe simulation efficiency (E) and (iii) Index of agreement (d) were applied. The validation criteria were also separately applied for rainy and non rainy period to assess their prediction capability in these seasons. The results of the validation are presented in Tables 5.5 for Myntriang and Umkhen watersheds.

Coefficient of determination (R^2)

The different values of R^2 were obtained in the three cases *viz.,* entire period, rainy and non-rainy reason. Moreover, the R^2 values also reflected the spatial dependency in addition to season dependency values for both the watersheds are different. A constant value (R^2 = 0.70) was obtained for both the watershed while considering the entire period. But the determination of R^2 after segregation of data into rainy and non-rainy periods resulted different values. It seems the model prediction is better in Myntriang during rainy season (with R^2 = 0.80) while for Umkhen non-rainy prediction is better (R^2 = 0.93).

Table 5.5 Values of validation parameters

Sl No	Validation parameters	Entire period		Rainy period		Non rainy period	
		Myntriang	Umkhen	Myntriang	Umkhen	Myntriang	Umkhen
1	Coefficient of determination (R^2)	0.70	0.70	0.80	0.68	0.70	0.93
2	Nash-Sutcliffe Efficiency (E)	0.35	0.64	0.23	0.0	0.64	0.86
3	Index of Agreement (d)	0.87	0.91	0.82	0.83	0.91	0.96

Coefficient of determination R^2 can also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values. Therefore it estimates the combined dispersion against the single dispersion of the observed and predicted series. The range of R^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all whereas a value of 1 means that the dispersion of the prediction is equal to that of the observation.

The observed and simulated values of water yield for both the watershed were plotted on scatter diagram for each of the three cases (Figs. 14 to 19) and the resulted linear regression equations were shown on the plots.

The R^2 criteria used for model validation were also analysed through additional information. The values of the gradient "*b*" and the intercept "*a*" of

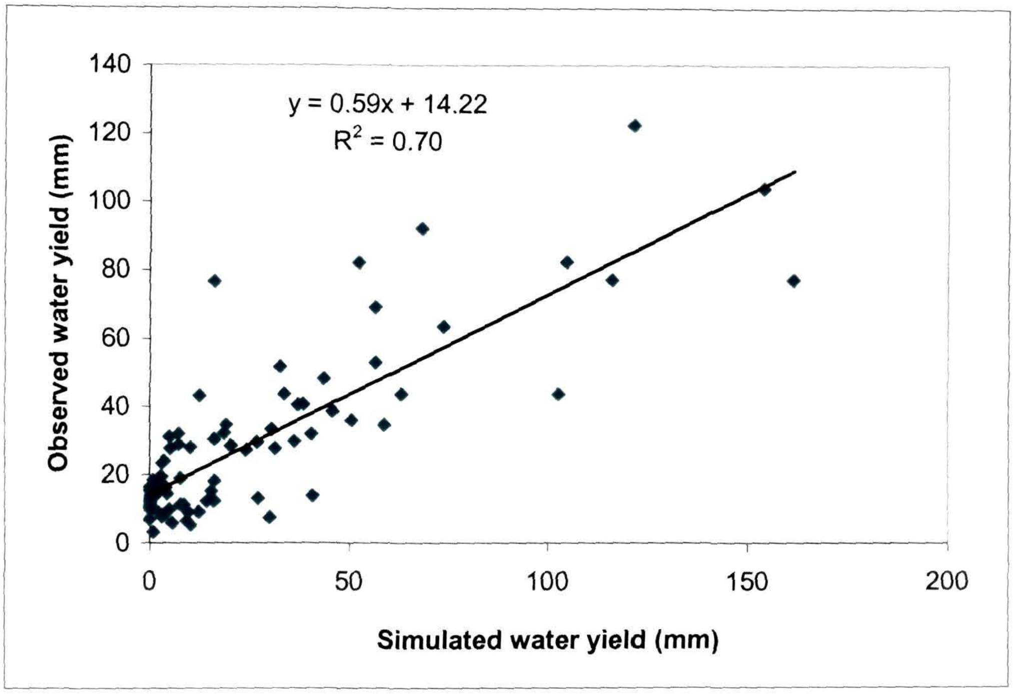


Fig 5.14: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Myntriang watershed

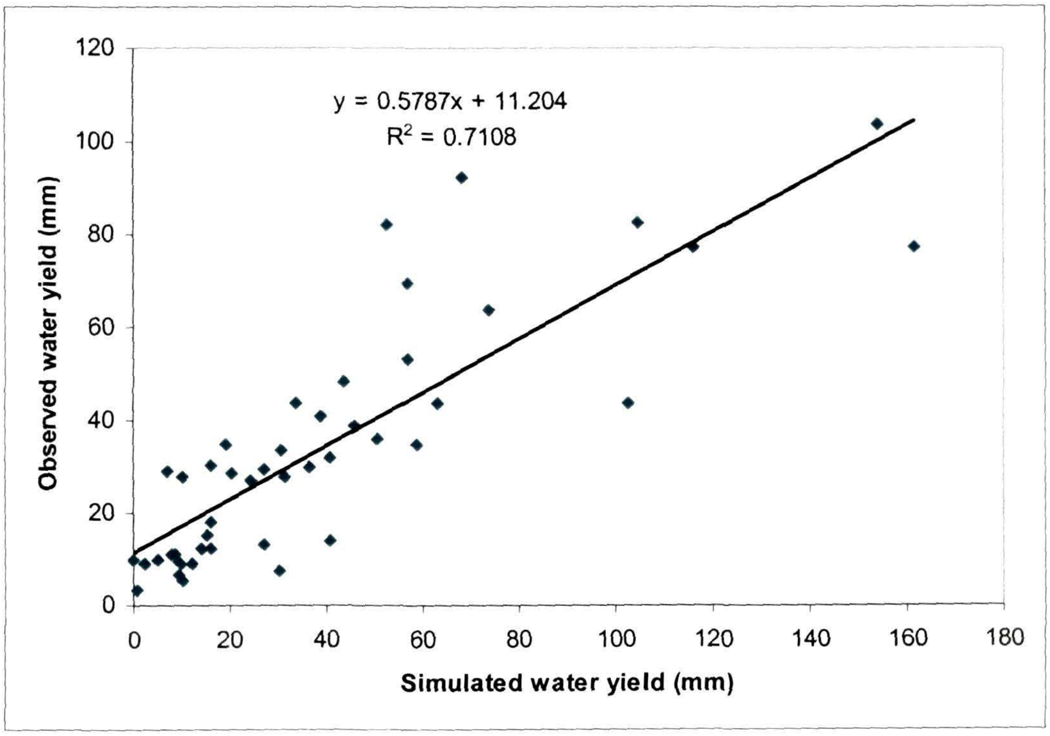


Fig 5.15: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Myntriang watershed for rainy period

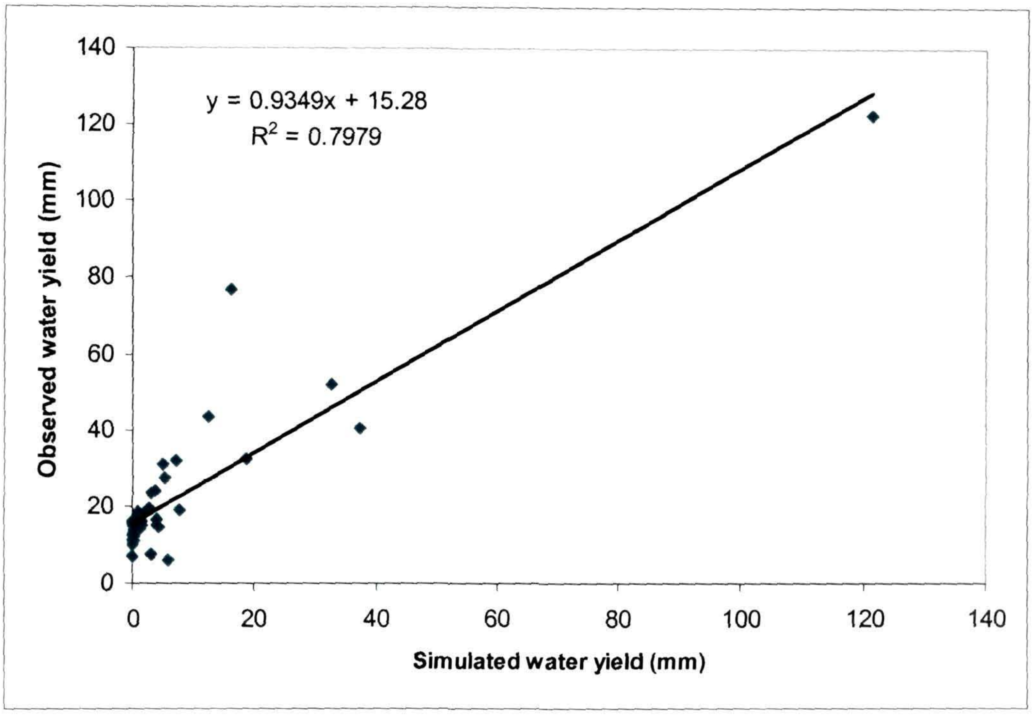


Fig 5.16: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Myntriang watershed in non rainy period

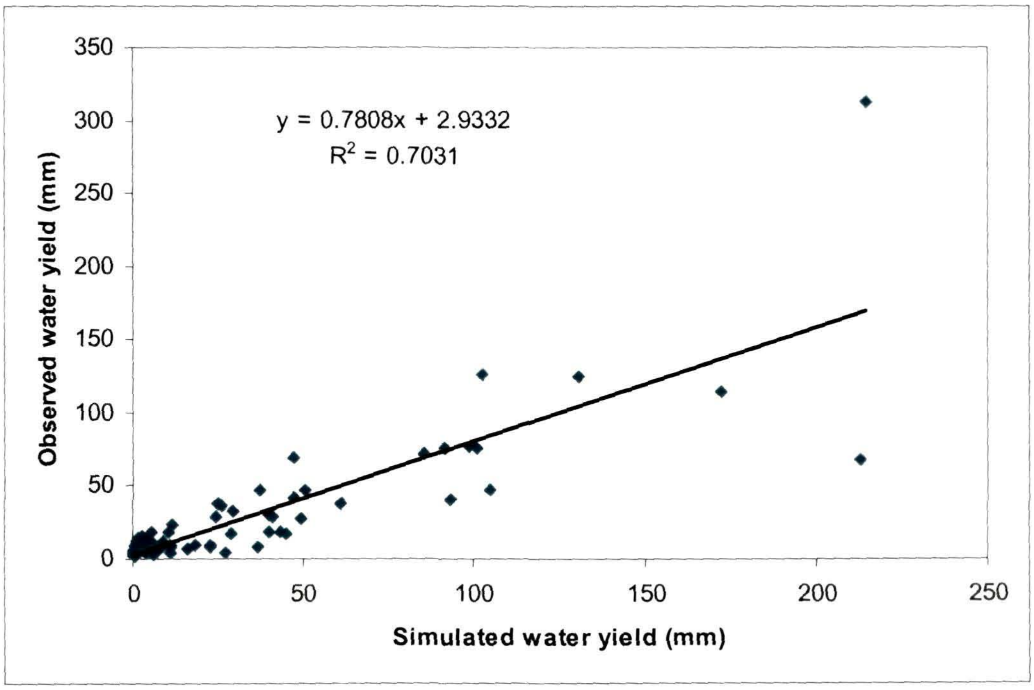


Fig 5.17: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Umkhen watershed

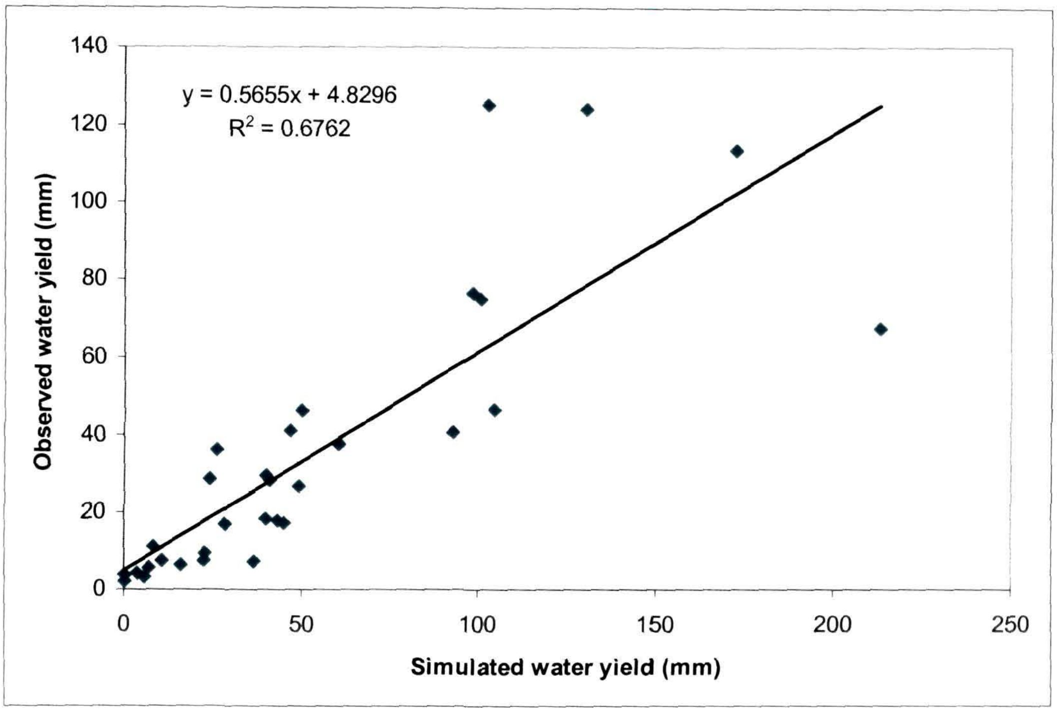


Fig 5.18: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Umkhen watershed in rainy period

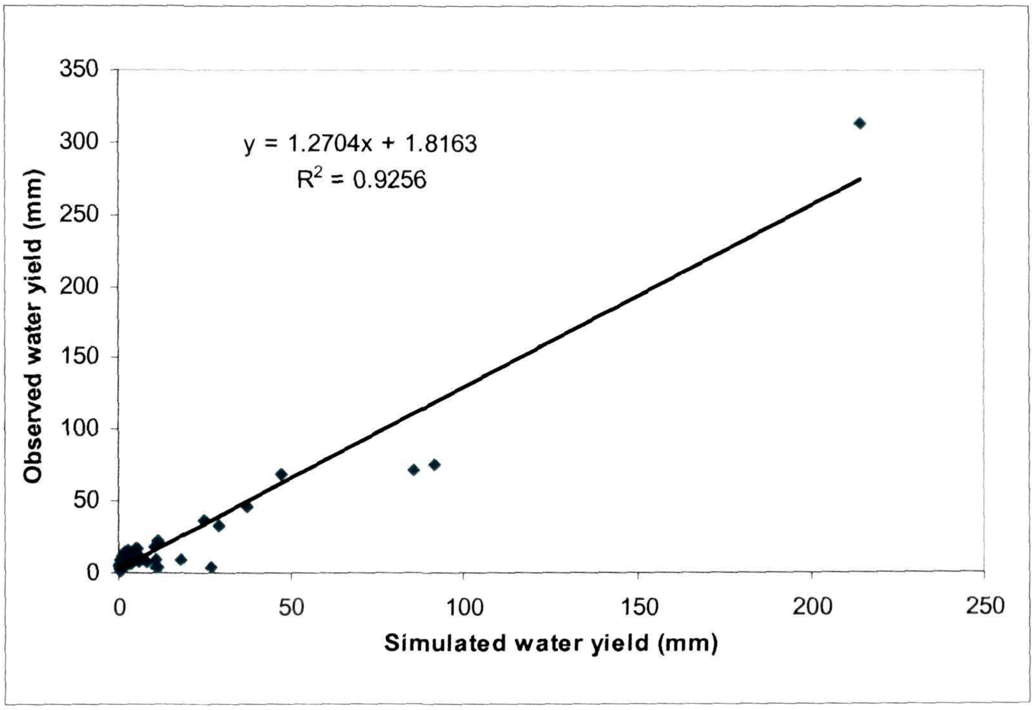


Fig 5.19: Scatter diagram of 10 daily average observed and simulated water yield (mm) in Umkhen watershed in non rainy period

the regression equations provides the additional information of fitness. For a good agreement the intercept '*a*' should be close to zero whereas *b* should approach unity.

In Myntriang the values of intercept during entire validation period was 14.22 where as for rainy and non-rainy periods the intercepts were 11.20 and 15.28, respectively. However, for Umkhen the intercepts were 2.93, 1.82 and 4.83 for entire period, non rainy and rainy period respectively.

Sintondji (2005) while validating the SWAT model output for weekly water flows in Terou-Igomakaro watershed of 2336 sq km area in West Africa found that about 73% of the variability was explained (R^2 = 0.73). In similar studies by Tolson and Shoemaker (2007) in Cannonsville watershed of 1178 sq km in USA resulted in R^2 values of 0.64 to 0.80 for daily flow in 6 different gauge stations. For all these works the models results were considered validated. In the similar way, the simulated results of Myntriang and Umkhen were also considerd validated based on R^2 criteria.

Nash and Sutcliffe efficiency (E)

The Nash and Sutcliffe efficiency (*E*) was applied as another criteria for evaluating the efficiency of the model.

The estimated values of Nash and Sutcliffe efficiency (*E*) for (i) the entire period, (ii) rainy period and (iii) non-rainy period were 0.35, 0.23 and 0.64 for Myntriang whereas for Umkhen the values were 0.64, 0 and 0.86 respectively.

Earlier user of this criteria stated that normalization of the variance of the observation series resulted in relatively higher values of *E* in watershed with higher dynamics and lower values of *E* in watershed with lower dynamics. If this is true, then Umkhen during non-rainy period happened to be most dynamics with highest value of *E*. The fact is also supported by the comparative *E* values of Myntriang and Umkhen while considering the entire data.

It has been reported that the range of *E* lies between 1 (perfect fit) and -∞. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause *et al.*, 2005). In the present study the estimated values of *E* were positive in all the cases. However, in both the watersheds, non-rainy predictions were better than rainy period prediction. The reasons of such variability of predictions with reference to season could not be ascertained and needs further investigation. However, Kannan *et al.*, (2007) observed similar variability of *E* values while estimating wet and dry conditions separately in Colworth watershed in UK. They obtained *E* as 0.57 in wet condition (October 1999 to December 2000) and 0.61 for dry condition (January, 2001 to May 2002) while modeling for runoff.

The Nash and Sutcliffe efficiency (*E*) has been used by many other researchers world wide for assessing performance of SWAT models and estimated *E* were found to vary between 0.41 to 0.80 (Sintondji, 2005; Bärlund *et al.*,2007; Tolson and Shoemaker,2007).

Index of Agreement (d)

Similar to R^2 and *E*, the index of agreement (*d*) were also estimated to assess model efficacy for the three cases in both the watersheds. The estimated values of *d* for (i) entire period, (ii) rainy and (iii) non-rainy period were 0.87, 0.82 and 0.91 for Myntriang watershed and 0.91, 0.83 and 0.96 for Umkhen watershed respectively. The index of agreement *d* was proposed by Willmot (1981) to overcome the insensitivity of *E* and R^2 to differences in the observed and predicted means and variances. The range of d is similar to that of R^2 and lies between 0 and 1 (Legates and McCabe, 1999). The prediction efficacy in Umkhen seems to be better than the Myntriang as indicated by the values of *d*. The size of watershed might be the reason of such prediction variability. The value of *d* as obtained by Sintondji (2005) for weekly water flows in Terou-Igomakaro watershed of 2336 sq km area in West Africa was 0.91 which was similar to the present results.

From all the results of the three validation criteria discussed above it could be concluded that depending upon the season and watersheds the level of predictability varies. If R^2 criteria are considered the model predictions were better in Umkhen during non-rainy period than Myntriang. However, if predictions during rainy period were to be considered model bettered in Myntriang. Similar pattern of prediction variability were also noticed with remaining two validation criteria. However, the estimated values of the validation parameters as well as their trends were supported by earlier model prediction results. Keeping in view of this it can be considered that the model is validated and acceptable for use.

5.4 Rainfall to runoff conversion capability of Myntriang and Umkhen watersheds

Once the model was validated, attempts were made to demonstrate its uses. Initially, the SWAT model was used to assess the hydrological behavior of the watersheds under study. Comparison of the two neighboring watersheds *viz.*, Myntriang and Umkhen was made for evaluating the hydrologic response to rainfall.

The percentage of rainfall that leaves the watershed was estimated for Myntriang and Umkhen on annual basis. The results indicated that in response to an average annual rainfall of 1830.8 mm (recorded during January 1991 to June 1993) the Myntriang watershed yielded 1126.23 mm of water per annum. Thus about 61.5% of precipitation was converted into discharge from Myntriang. On the other hand, it was observed that Umkhen watershed could convert only 51.90% of the precipitation falling on it (1388.35 mm average annual water yield against 2674.60 mm of annual precipitation).

The reported study on hydrologic response of watershed under semi-arid region of Zimbabwe could be consulted (Mugabe *et al.,* 2007). It was reported that, the large difference in rainfall conversion efficiency between a wet year (36%) and a dry year (12%) was an indication of changes in the runoff generation mechanisms, which depend on the rainfall amount and its distribution, which controls soil moisture and the groundwater levels The high conversion rate of precipitation into runoff in the present case might be attributed to the characteristics features of soil, morphology and climate.

The present study did not investigate the quickness of the response of rainfall to runoff conversion. However, Myntriang convert more amounts into discharge than Umkhen. The reason for such behaviour would need further investigation.

Further, the monthly average rainfall data during the recorded period was used to simulate the corresponding water yield for both the watersheds. The simulated water yields were plotted against the recorded rainfall (Figs 5.20 and 5.21). Considering the gradients of such plots as "rainfall to runoff conversion" factor, it can be commented that Myntriang had higher conversion than Umkhen even though later received more rainfall compared to Myntriang. This result is in line with the annual average estimation for these watersheds discussed above. While investigating such behaviour in terms of soil characteristics, presence of "imperfectly drained" soil (AS09) was noticed in Umkhen. Presence of such soil coupled with other flow retarding characteristics and larger size of the watershed might be the reasons of low conversion of rainfall into runoff.

The R^2 values for Myntraing and Umkhen watersheds were also estimated and observed that more than 96% of variability could be explained by the independent variable.

5.5 Comparison of hydrological behavior of sub watersheds

The SWAT model was also used to delineate the study watersheds. The descriptions of the 16 such delineated sub-watersheds (MSW-1 to MSW-3 in Myntriang and USW-1 to USW-13 in Umkhen) were presented in section 5.1.3. For management of the water resources and its beneficial utilization, the knowledge of hydrological processes on spatial and temporal scale is useful. The SWAT2000 model outputs were used for comparison of hydrological behavior of these sub-watersheds. It is anticipated that the information available from the model for sixteen sub-watersheds under Myntriang and Umkhen would be useful for planning developmental activities and also taking

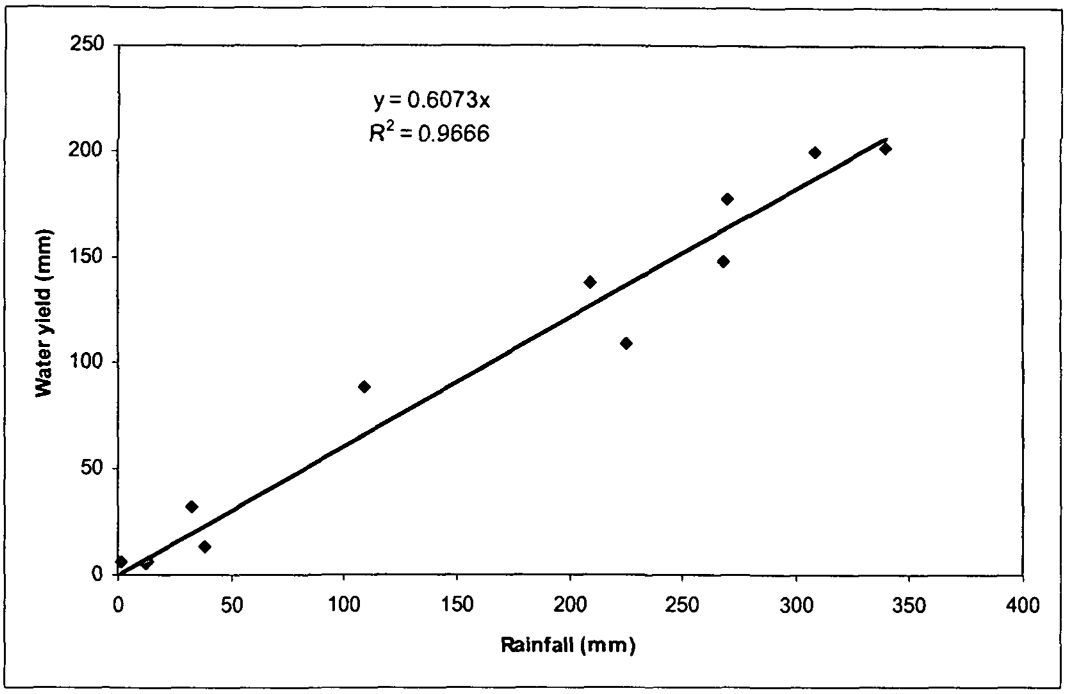


Fig 5.20: Relationship between monthly rainfall and water yield in Myntriang watershed

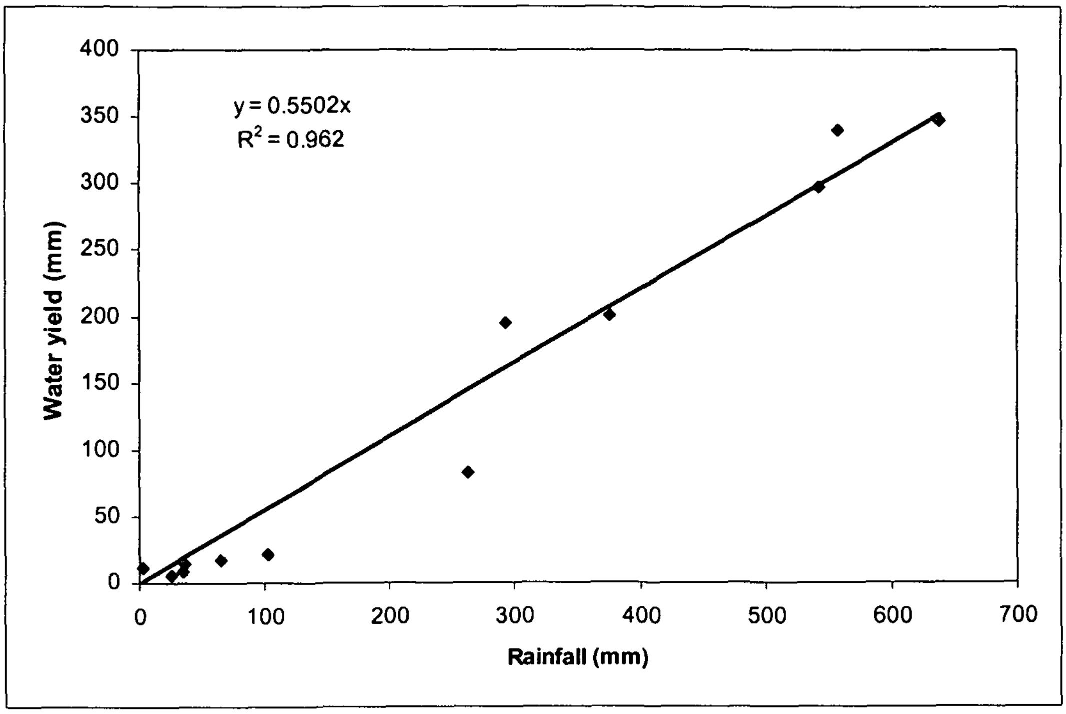


Fig 5.21: Relationship between monthly rainfall and water yield in Umkhen watershed

up conservation measures to protect the down stream areas. In this study the comparison of hydrological behavior in the sub watersheds of Myntriang and Umkhen watersheds were made in terms of:

- Average annual water yield
- Water yield in lean and peak season
- Average annual sediment yield

5.5.1. Average annual water yield

The average annual water yields from each of the sub-watersheds were modeled for the period of 1991 to 1993 and presented in Figs. 5.21 and 5.22.

From the Figs 5.22 and 5.23 it was observed that spatial variation of water yield was prominent in both the watersheds. Amongst the three sub-watersheds in Myntriang, MSW-3 yielded the highest water yield followed by MSW-1 and MSW-2. Depending on the average annual water yields the sub-watersheds in Umkhen were categorized into five groups. In descending order of water yields the sub-watersheds groups in Umkhen were (i) USW-6 and USW-9, (ii) USW-8, USW-11, (iii) USW-1, USW-2, USW-4, USW-5, USW-12, (iv) USW-10 and USW-13 (v) USW-3 and USW-7. From the spatial distribution it is also observed that variations of water yields of the sub-watersheds did not depend only on the geographic proximity. Even the sub-watersheds located far apart (USW-12 and remaining sub-watersheds of that groups) yielded same amount of water.

The information on the variation of water yielding characteristic will help in identifying the watersheds with their level of water yields. The Kopili River causes heavy flood damage in the plain district of Nagaon and Maorigaon in Assam (India). The information is expected to help in planning conservation measures such as water retention structure and flood control structures for moderating flood by prioritizing treatment in high water yielding watersheds.

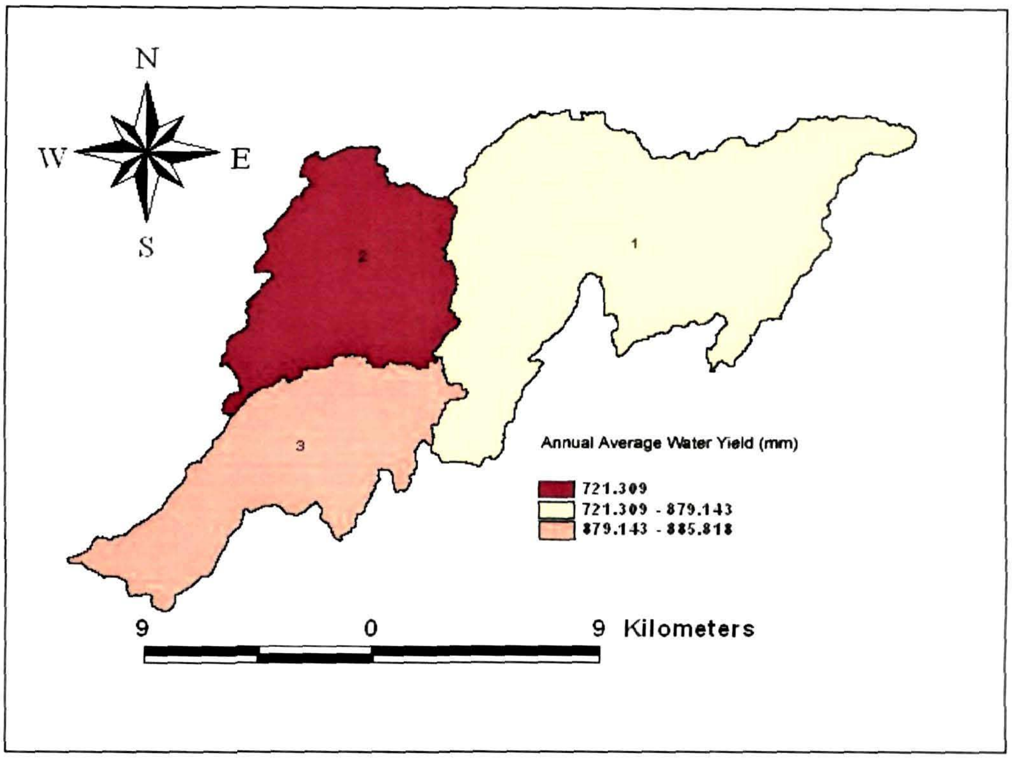


Fig 5.22: Average Annual Water yield (mm) in Myntriang Watershed

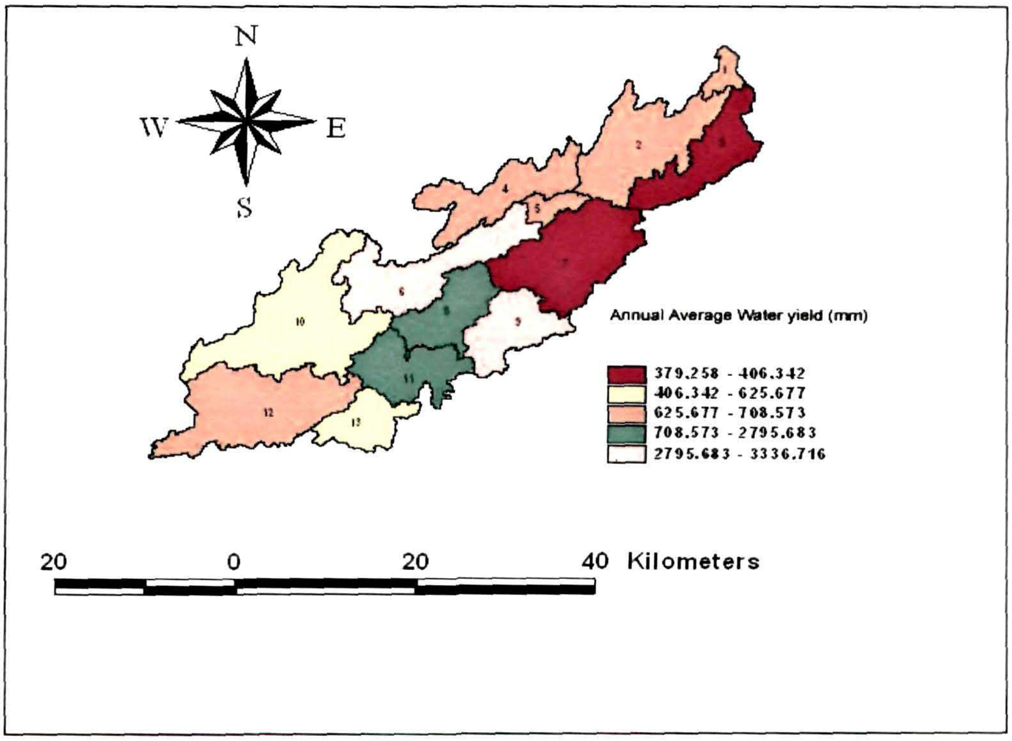


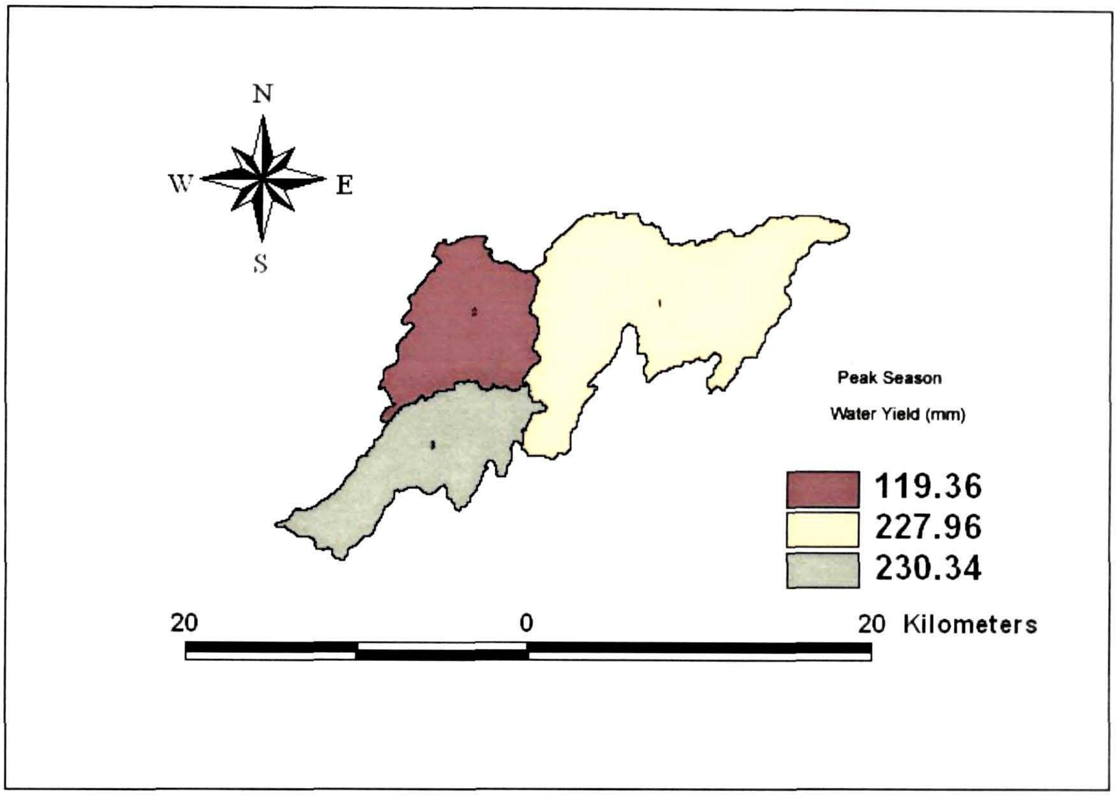
Fig 5.23: Average Annual Water yield (mm) in Umkhen Watershed

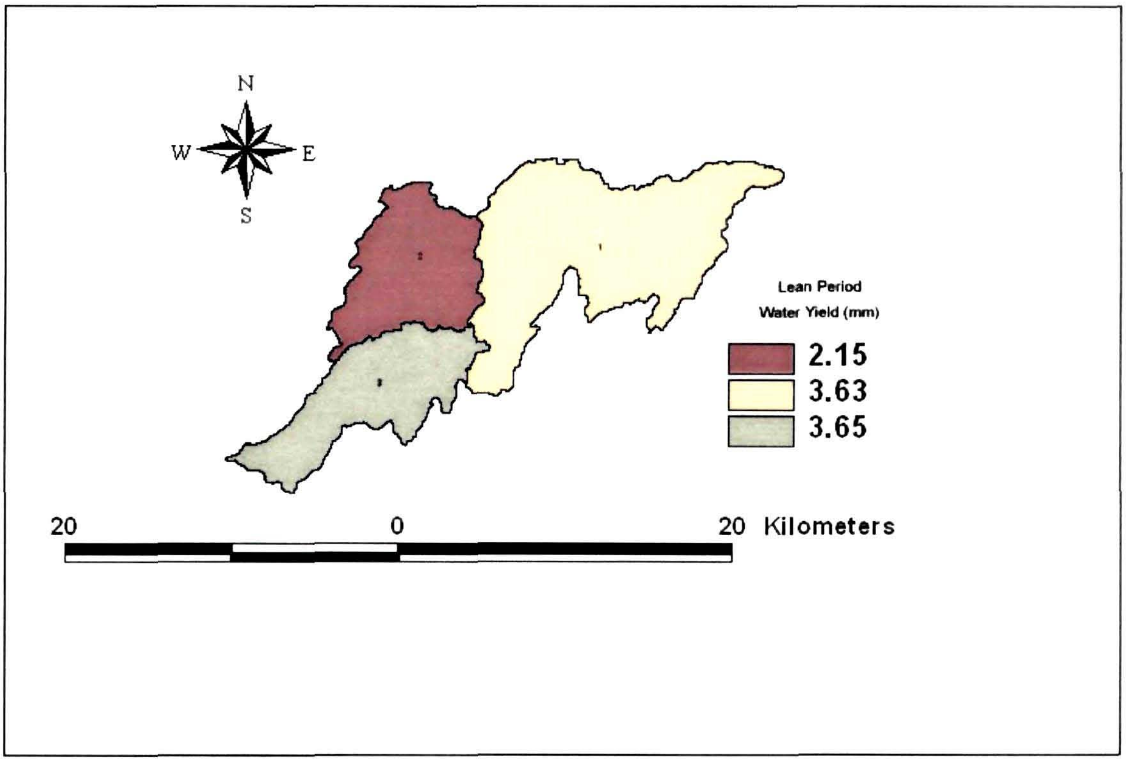
5.5.2 Water yield of sub watersheds in lean and peak season

The output of the model was used to compare the behaviour of sub watershed during lean and peak flow seasons. The rainfall pattern of the selected sites indicates that the month of February had recorded minimum rainfall and June recorded the highest rainfall in all rainfall gauging stations. Thus February was considered lean season and June was considered as peak seasons. The average water yields during lean and peak seasons were studied for the period of 1991-1993 for both Myntriang and Umkhen watershed. The water yield outputs for each sub watersheds are shown in Figs 5.24 and 5.25.

From the Figs 5.24 and 5.25 it was found that the water yields in the peak and lean season had spatial variation. In Myntriang MSW 3 yielded maximum water in both peak and lean seasons (230.34 mm and 3.65 mm). The trend is similar to the average annual water yield for the watershed. The water yields from Umkhen watershed were categorized into five groups. The water yields in the lean season in descending order were (i) 11.57 mm - 14 38 mm (USW-6, USW-13) (ii) 8.76 mm to 11.57 (USW-8, USW-9); (iii) 5.95 mm to 8.76 mm (USW-11); (iv) 3.14 mm- 5.995 mm mm (USW-12, USW-10, USW-5, USW-4, USW-2, USW-1); and (v) < 3.14 mm (USW-3 and USW-7). The same steps were followed to obtain water yield for the peak season in descending order of water yield were found to be (i) 514.60 mm – 803.65 mm (USW-13, USW-6); (ii) 222.83 mm – 514.60 mm (USW-8, USW 11) (iii) 170.13 mm – 222.83 mm (USW-9); (iv) 81.96 mm – 170.13 mm (USW-5, USW-4, USW-2, USW-1) and (v) < 81.96 mm (USW-12, USW-10, USW-3 and USW-7). The variations of water yields in both the watersheds were not similar to the pattern of annual average water yield discussed in the previous section.

The information on spatial and temporal pattern of water availability would provide a basis for the planner for taking necessary steps to conserve water during lean season (USW-3 and USW-7) and to moderate the floods during peak season (USW-13 and USW-6). Further, if the water resource development projects are taken up in these watersheds for generation of energy, alternate steps should be taken in watershed producing low water yield in the lean season.





5.24: Peak and lean season behaviour of sub watersheds of Myntriang

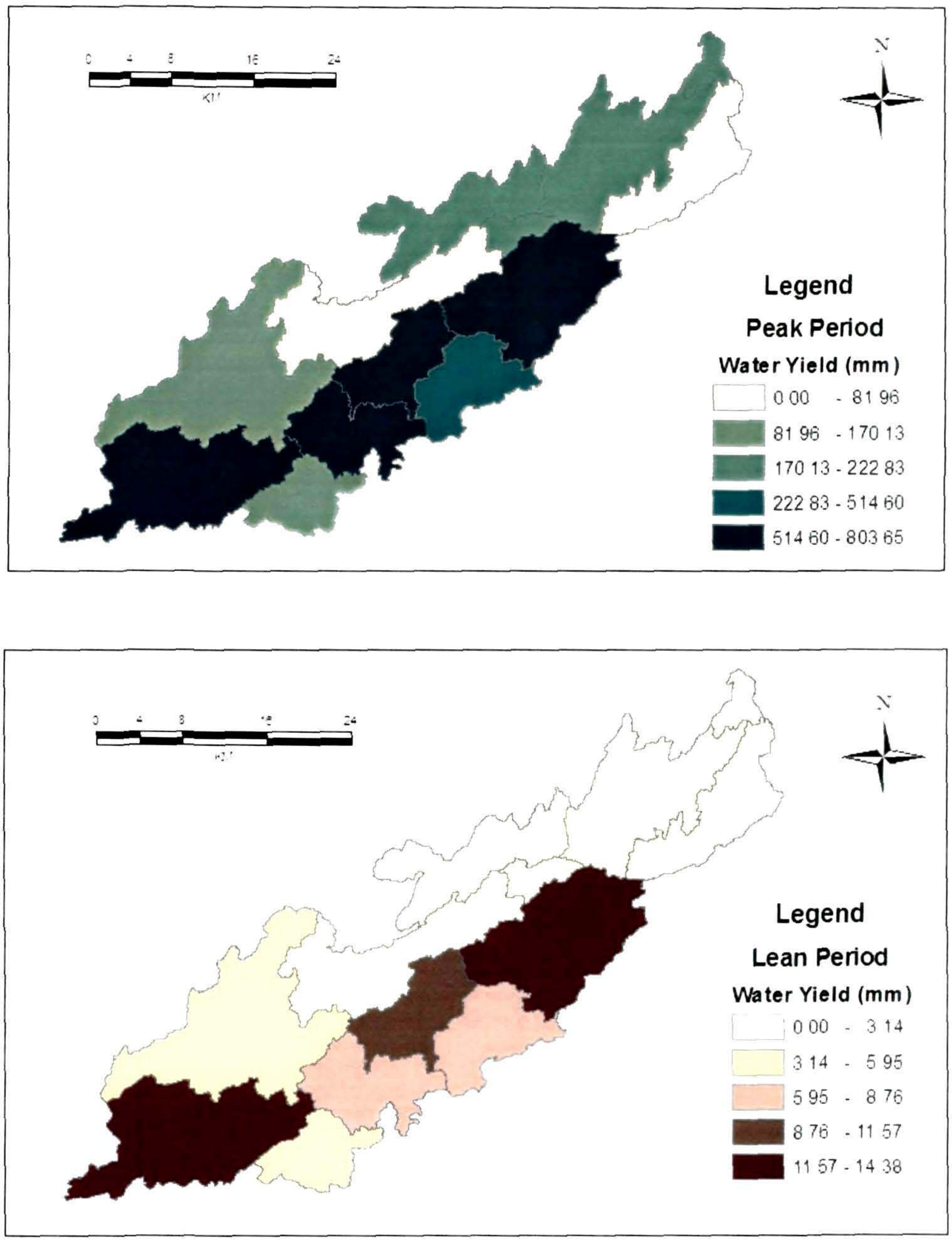


Fig 5.25: Lean and peak season behaviour of sub watersheds of Umkhen

5.5.3 Average annual sediment yield

The average annual sediment yield from each of the watershed was modeled using SWAT2000 during the period of 1991 to 1993. As discussed earlier, the available module of SWAT model was used to estimate annual sediment yield. However, due to non availability of observed data, the simulated results of sediment yield neither could be calibrated nor could be validated. Considering the importance of conservation of natural resources, the simulated results of sediment yield are presented and discussed assuming minimum prediction error.

Spatial variations of sediment yield in Myntriang and Umkhen are shown in Fig. 5.26 and Fig 5.27. The spatial maps indicate that for Myntriang watershed, MSW1 and MSW3 showed lower level sediment yield than MSW2. About 15 kg/ha annual sediment yield was found to produce in MSW2. Simulated values of sediment yield was higher in Umkhen than Myntriang. Moreover, extent of spatial variations was also higher in Umkhen than Myntriang. The sub-watershed USW 13 yielded about 1559 kg/ha/annum sediment yield which was the highest in the watershed. Similarly four sub-watersheds namely USW6, USW8, USW9 and USW11 also produced substantial amount annual sediment and needed attention. The levels of sediment yields of the remaining eight sub-watersheds were lower.

Reviews indicated that watersheds with different types of human interventions produced different quantities of sediment yield. Lal (1987) stated that in tropics the different land clearance treatments yielded different quantities of sediment ranging from 10 kg/ha/year for traditional farming to 17500 kg/ha for clearance treatment involving excessive human intervention. The clearance treatment in the study watershed involves complete clearing of the top vegetation through shifting cultivation practices that is prevalent in both the watersheds. From the land use pattern of the study area it was observed that in most of the areas the practice of shifting cultivation was "abandoned type of shifting cultivation" where human intervention reduces. The spatial variation of sedimentation yield in the watersheds might be due to spatial variations of levels of human intervention.

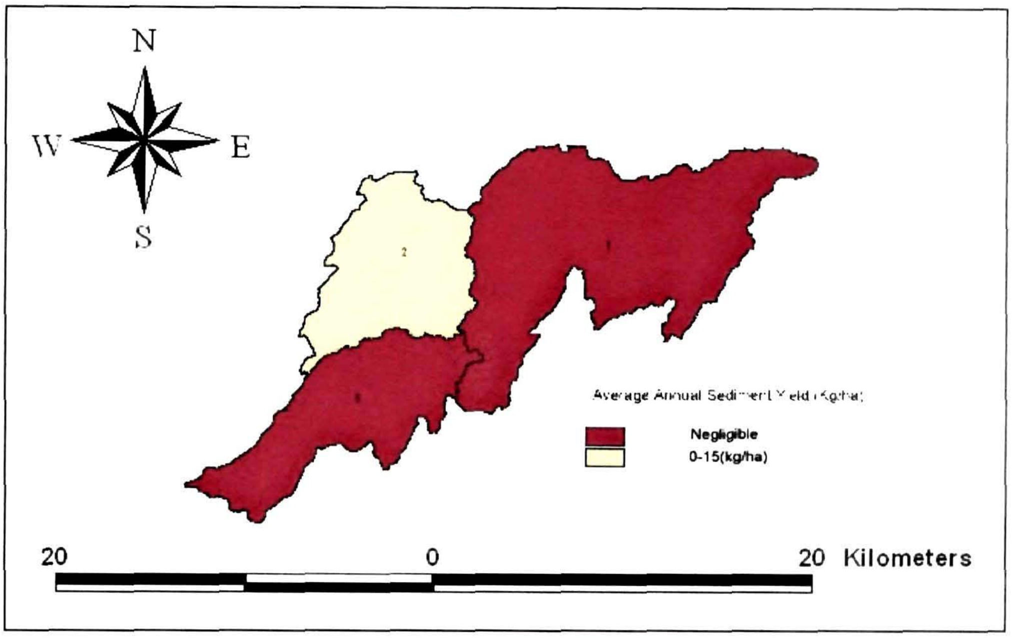
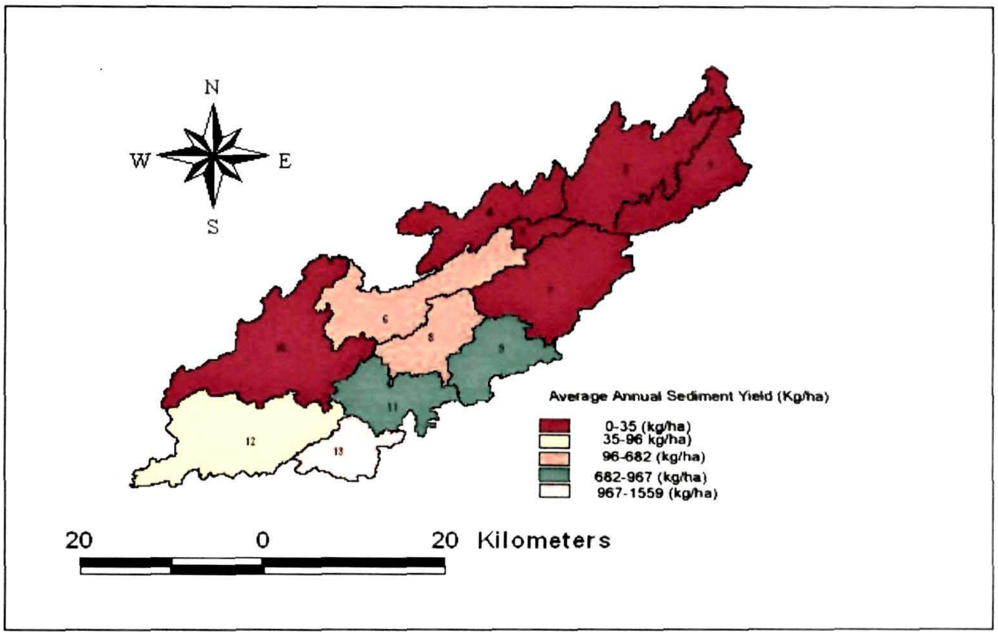


Fig 5.26: Average Annual Sediment yield in Myntriang Watershed



5.27: Average Annual Sediment yield in Umkhen Watershed

The above simulated results indicated that the model could become a tool for identifying the sub-watershed requiring prioritization for soil erosion control measures. There are number of engineering soil conservation measures such as check dams, terraces, drainage line treatments suitable for hilly areas. The information of simulated results would assist selection of appropriate type of soil conservation measures. Moreover, the knowledge of sedimentation would also be useful for planning of hydro-power facility.

5.6 Assessment of hydro power potential

The strength of SWAT2000 was utilized to estimate rate of water discharge at spatial and temporal scale in Myntriang and Umkhen. The information of spatial variation of discharge coupled with spatial maps of the watersheds was used to characterize the streams and hence to estimate hydro-power potential of Myntriang and Umkhen. For estimation of potential hydro power, the available head and flow rate were investigated. The methodologies of head and flow assessment were discussed in section 4.7. The results of stream characterization in terms of (i) drop (*i.e.* available head along the identified stream), (ii) flow and (iii) hydro-power potential are discussed below.

5.6.1 Stream characterization and estimation of available Head

As described in the Methods and Materials, available head to generate hydro-power along the selected streams were estimated for Myntriang and Umkhen by overlaying DEM and stream network. Only 5^{th} and higher order streams were considered and marked these streams such as MA, MB, MC, MD for Myntriang and UA, UB UC for Umkhen. The network of such streams with corresponding naming are presented in Fig 5.28 and 5.29. Six streams in Myntriang and nine streams in Umkhen were found for estimation of natural hydropower potentialities. Each of these fifteen streams was divided into equal segment at a distance of 500 m apart and the consecutive elevations of the selected points were used for estimation of available head. The profile characteristics of these 15 selected streams were also recorded. The detail features of these streams are presented in Tables 5.6 and 5.7. The stream profiles are shown in the Figs. 5.30. and 5.31 for Myntriang and Umkhen respectively.

Table 5.6: Profile characteristics of the stream in Myntriang watershed

Sl No	Stream	Stream length (m)	Maximum elevation (m)	Minimum elevation (m)	Number of locations with head of 10 m and above	Overall slope (%)
1	MA	44000	763	80	23	1.55
2	MB	12000	539	498	1	0.34
3	MC	6000	557	481	4	1.26
4	MD	8000	499	179	7	4.00
5	ME	3500	426	168	5	7.37
6	MF	3000	400	95	5	10.17
	Total number of potential sites				45	

In Myntriang, the longest stream A (44 km length) provided only 23 potential sites with more than 10 m drop out of total 89 selected sites at 500 m apart. The drops available in the remaining sites were less than 10 m and therefore, were not considered for assessment of natural sites for hydro power (Table 5.6). The stream A flows from an elevation of 763 m to an elevation of 80 m resulting 1.55% average slope. In this watershed, stream D proved to be second most potential stream having seven potential sites within its 8 km length if sufficient discharge were available. The stream had 4% overall slope. Stream B, though second longest amongst the six streams, due to flatness (overall slope 0.34%), resulted only lone potential site. The shortest stream F, with 10% of slope would produce five numbers of potential sites within 3 km. Altogether, in Myntriang there were 44 numbers of potential sites along the six identified streams for natural hydropower generation.

In Umkhen a total of 107 potential sites were found for locating natural hydro power stations stretching in the nine selected streams. Of the nine identified streams, stream A was the longest (102 km length) that had 49 potential sites with more than 10 m drop out of 205 sites in that stream. The stream flows from the highest elevation of 1202 m at the upstream to an elevation of 80 m at the outlet of the watershed resulting in an overall slope of

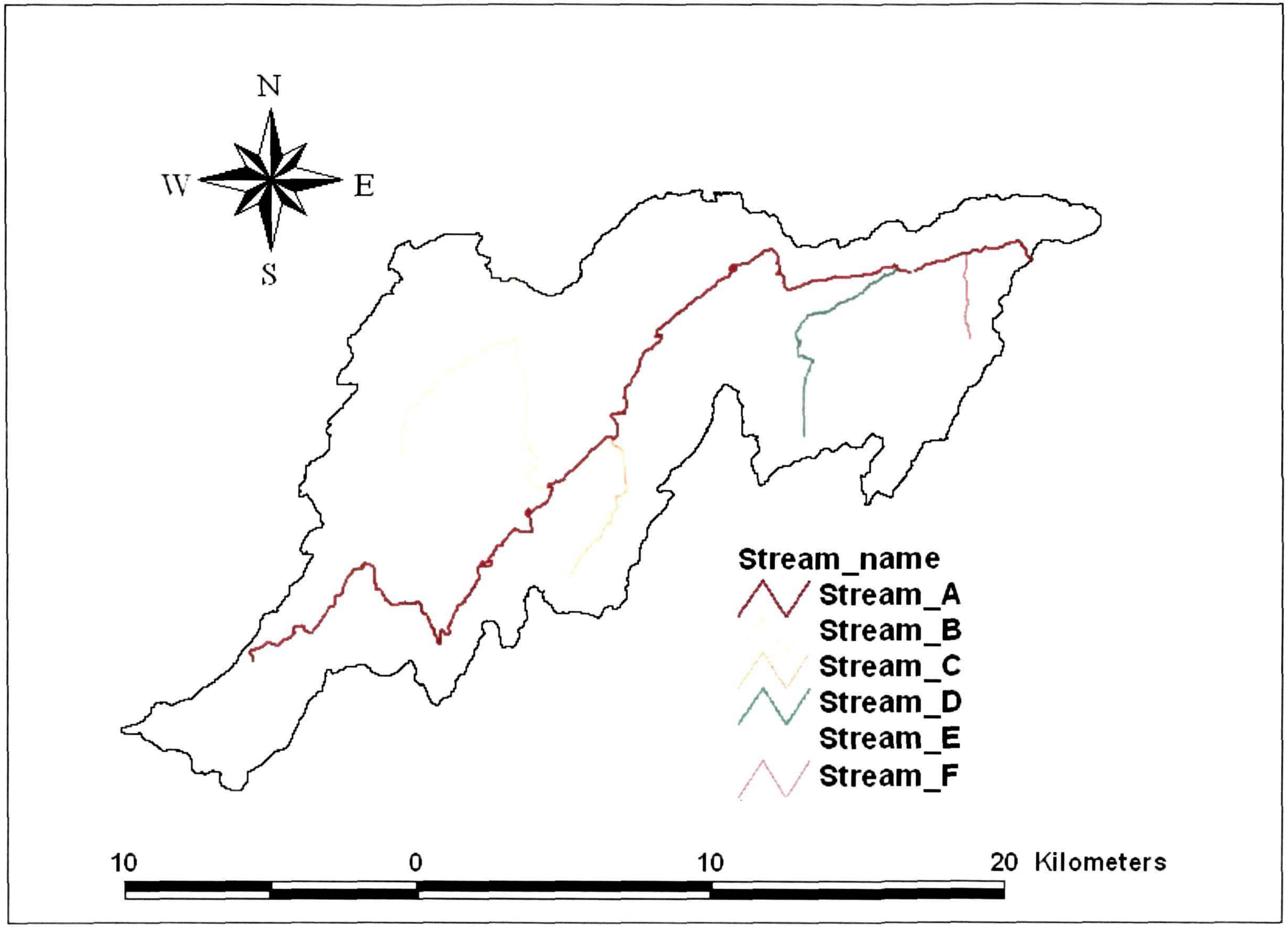


Fig 5.28: Marking of stream in Myntriang watershed

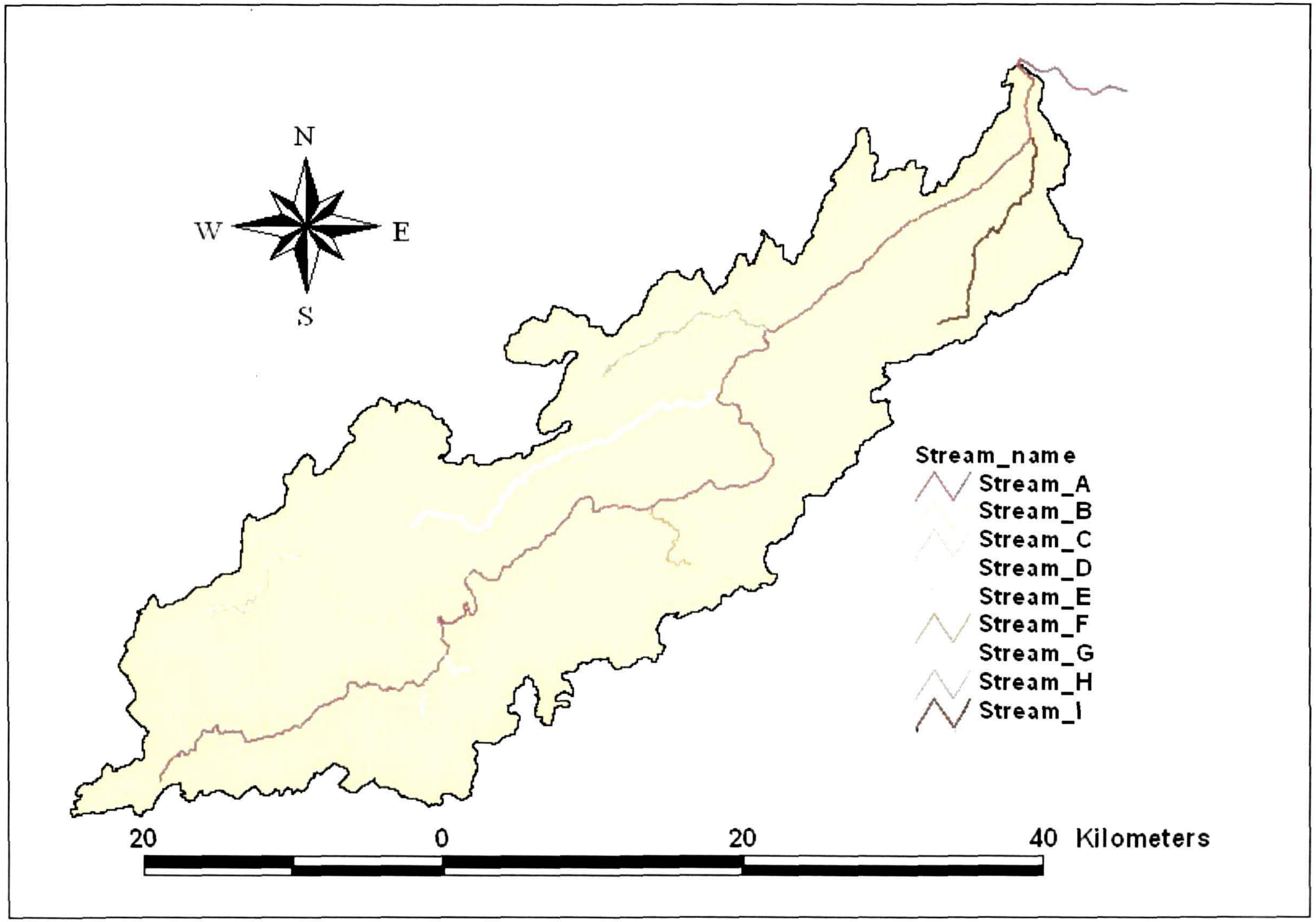


Fig 5.29: Marking of stream in Umkhen watershed

1.10% (Table 5.8). Other potential streams included stream H and stream I with identical overall slope of 1.93% each. The maximum and minimum elevation in stream H and I varied from 819 m to 616 m and 820 m to 291 m, respectively.

In stream H there were 13 potential sites within a length of 16.5 km where as in stream I, 12 sites were identified within 17.5 km. Stream E although was the shortest of all the identified streams, the slope was highest (4.76%) and would provide 4 potential sites.

Table 5.7: Profile characteristics of the stream in Umkhen watershed

Sl No	Stream	Stream length (m)	Maximum elevation (m)	Minimum elevation (m)	Number of locations with head of 10 m and above	Overall slope (%)
1	UA	102000	1202	80	49	1.10
2	UB	30000	819	617	8	0.67
3	UC	12000	955	859	5	0.80
4	UD	2500	898	859	2	1.56
5	UE	2500	976	857	4	4.76
6	UF	7500	858	739	6	1.59
7	UG	31000	819	616	8	0.65
8	UH	16500	820	501	13	1.93
9	UI	17500	629	291	12	1.93
	Total number of potential sites				107	

The stream profiles demonstrated the variation of gradients in Myntriang and Umkhen watersheds (Figs. 5.30 and 5.31) along with their length. Knowledge of such variations coupled with the information of corresponding discharge rate would assist selection of potential sites for hydro-power generation. Such information on stream characterization in digitized form would also be useful for planner engaged for the development of this remote and inaccessible region.

5.6.2 Construction of Flow Duration Curve (FDC)

Flow duration curves were constructed for all the identified sites in Myntriang and Umkhen using simulated results of SWAT2000. The physically

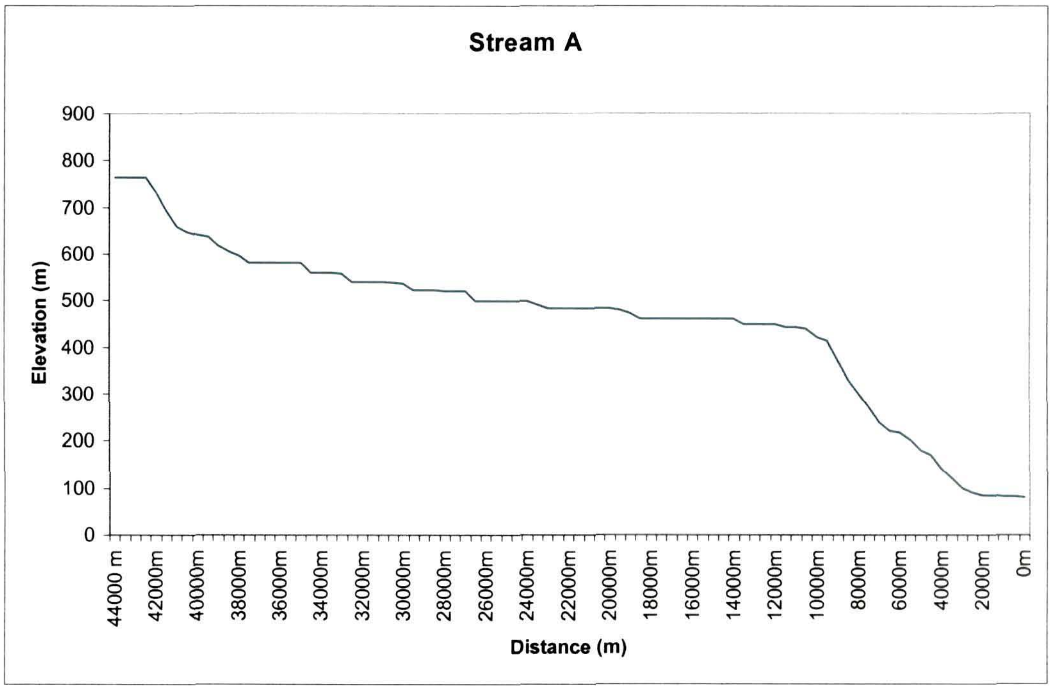


Fig 5.30 (a): Profile of some selected streams of Myntriang watershed

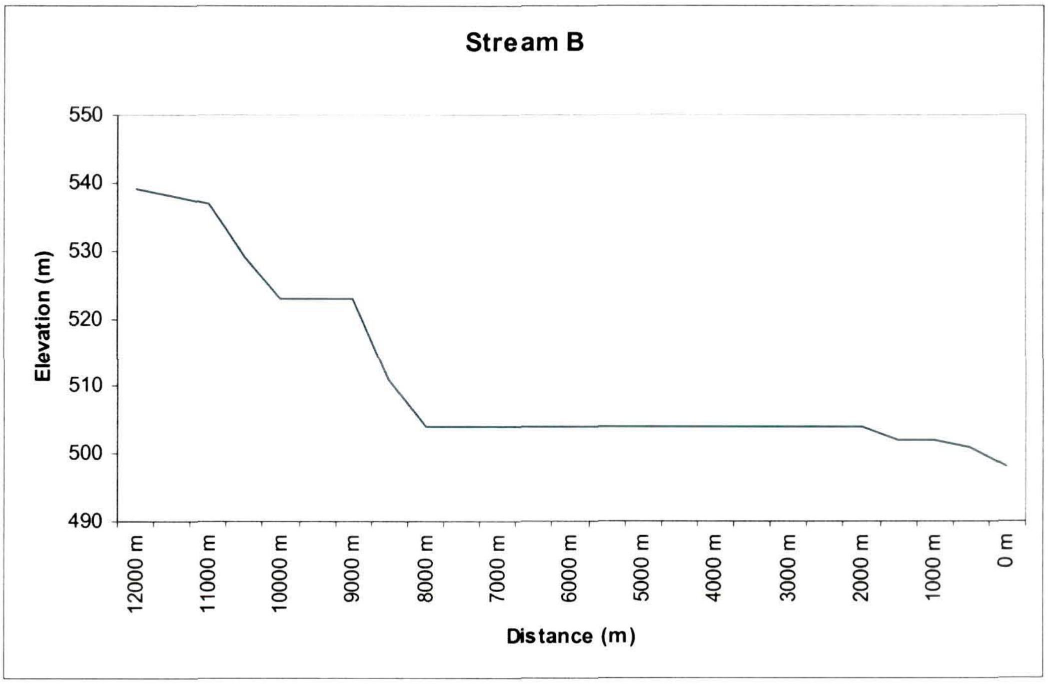


Fig 5.30 (b): Profile of some selected streams of Myntriang watershed

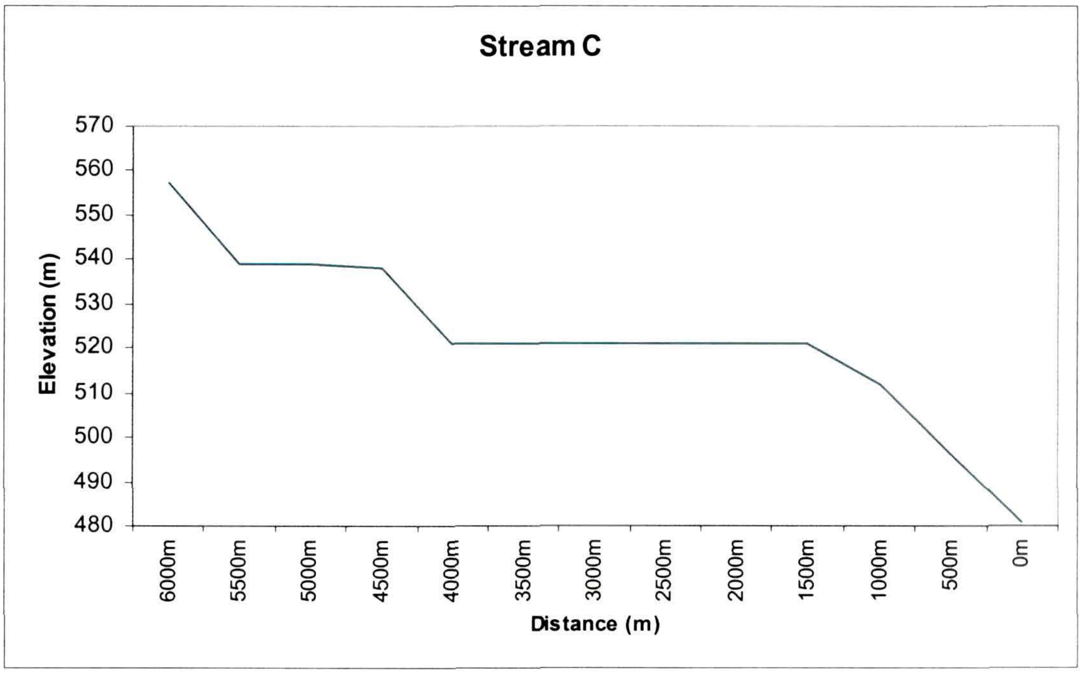


Fig 5.30 (c): Profile of some selected streams of Myntriang watershed

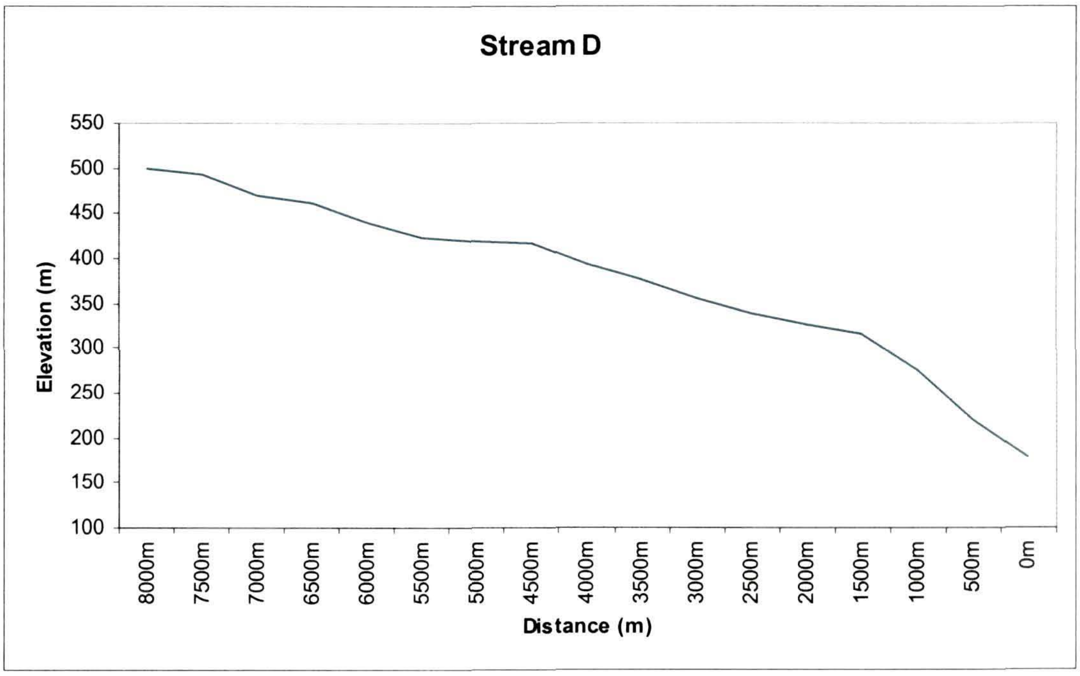


Fig 5.30 (d): Profile of some selected streams of Myntriang watershed

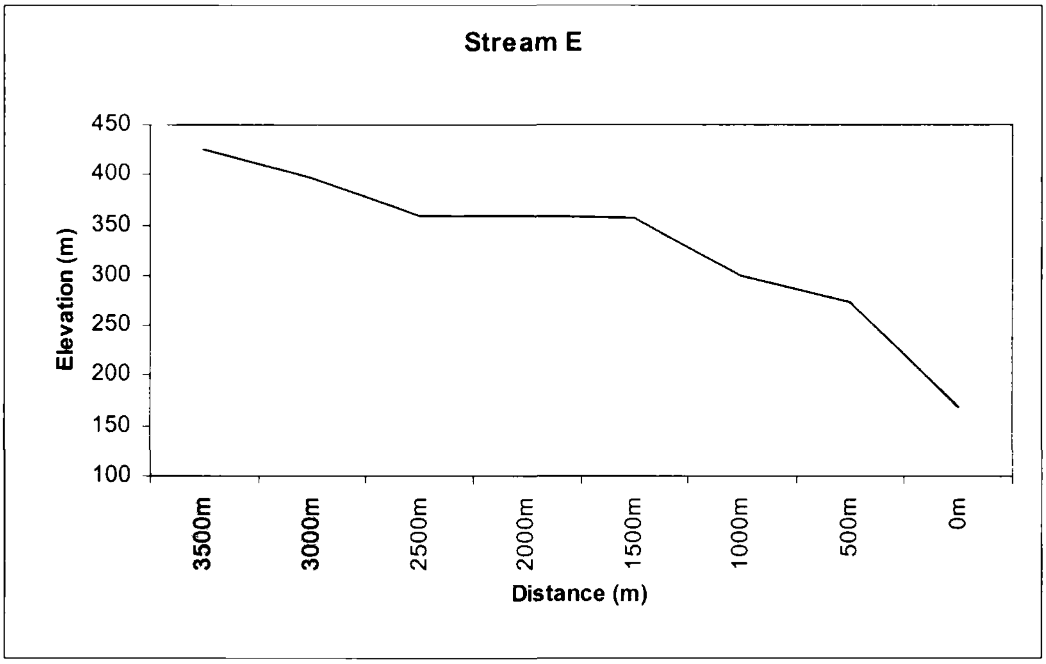


Fig 5.30 (e): Profile of some selected streams of Myntriang watershed

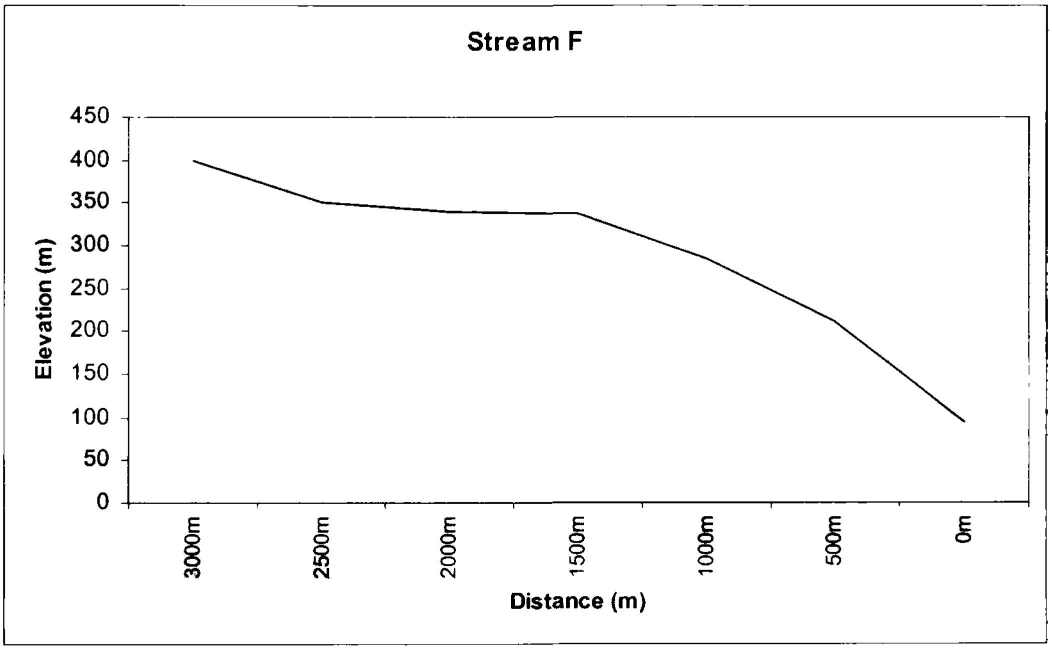


Fig 5.30 (f): Profile of some selected streams of Myntriang watershed

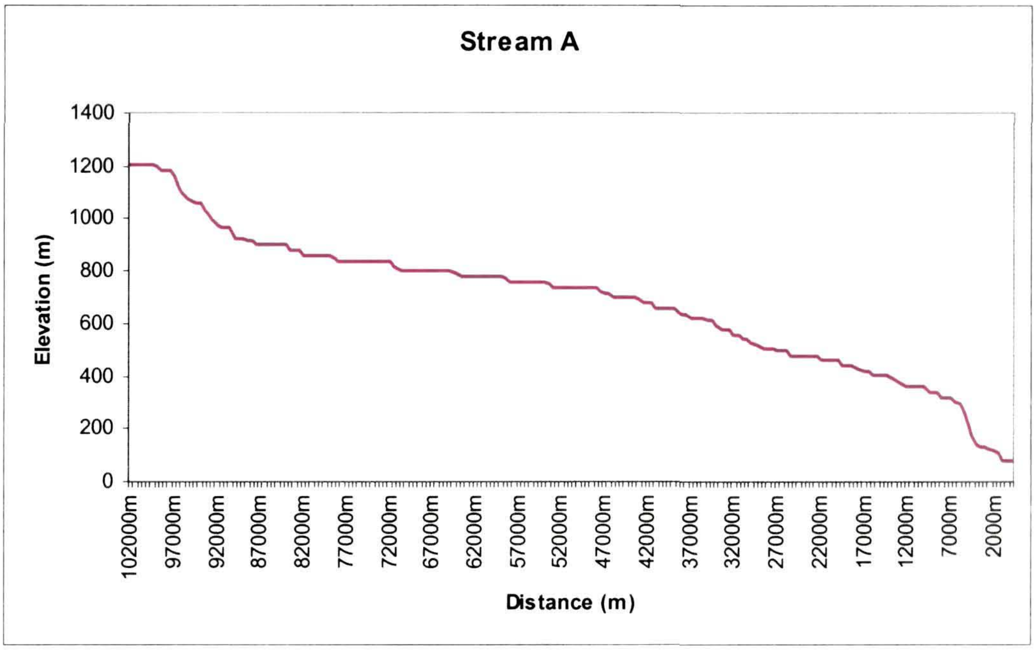


Fig 5.31(a): Profile of some selected streams of Umkhen watershed

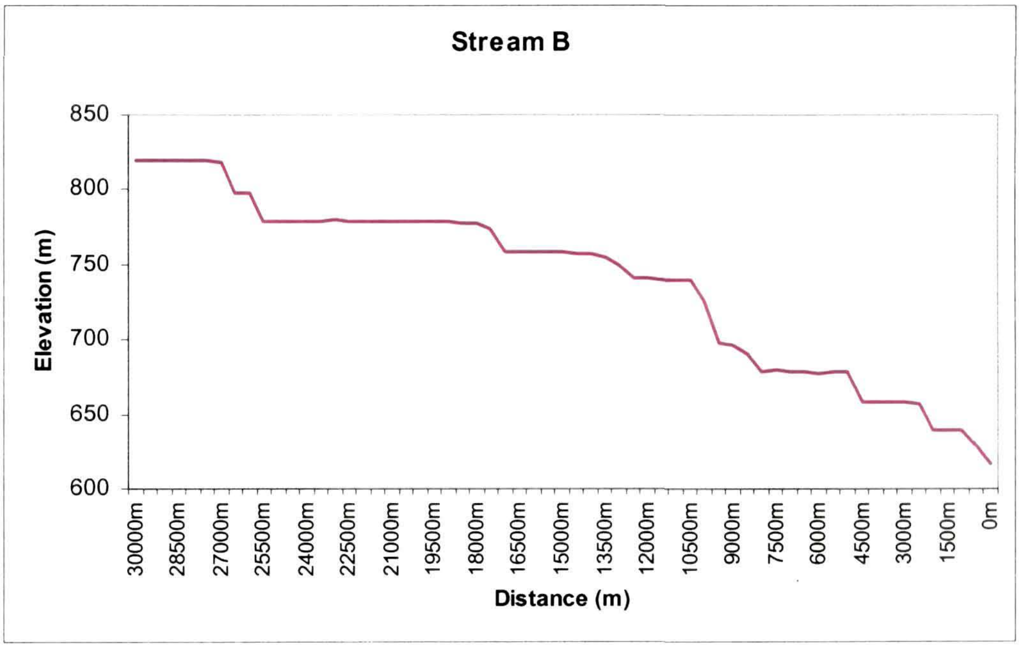


Fig 5.31(b): Profile of some selected streams of Umkhen watershed

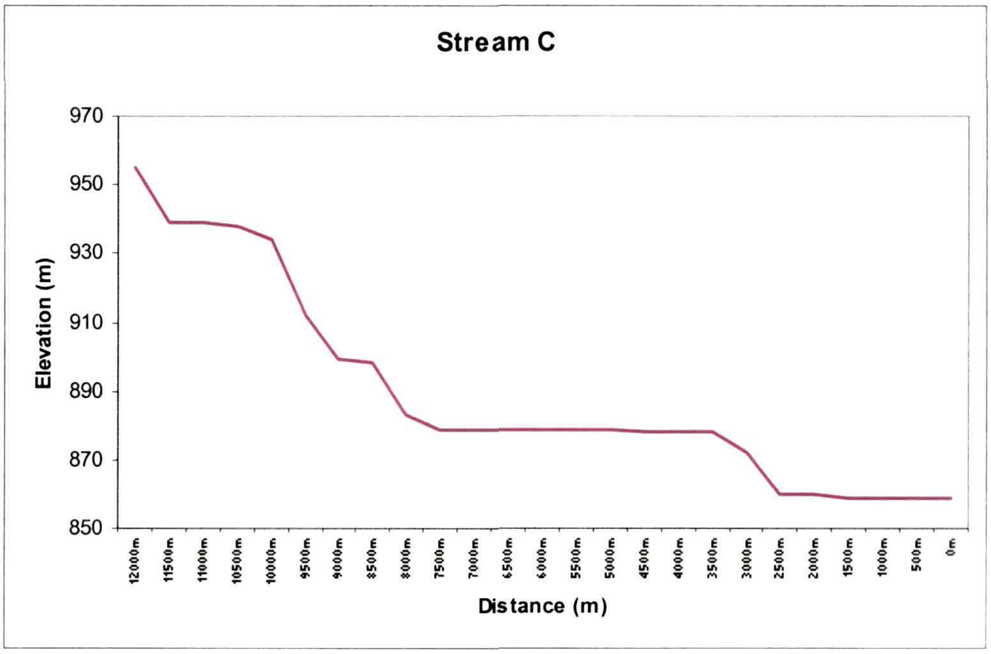


Fig 5.31(c): Profile of some selected streams of Umkhen watershed

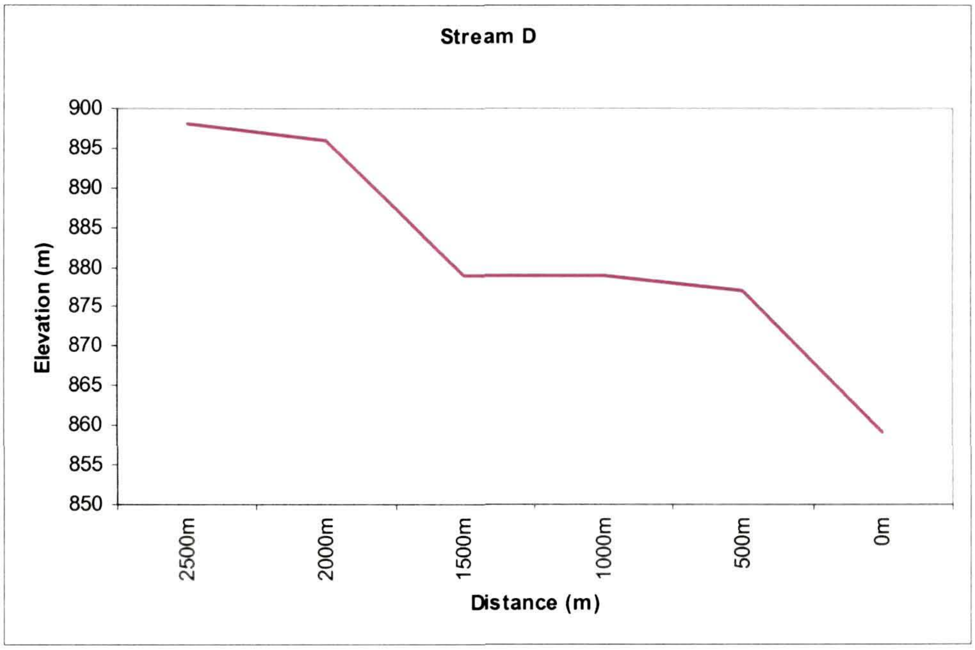


Fig 5.31(d): Profile of some selected streams of Umkhen watershed

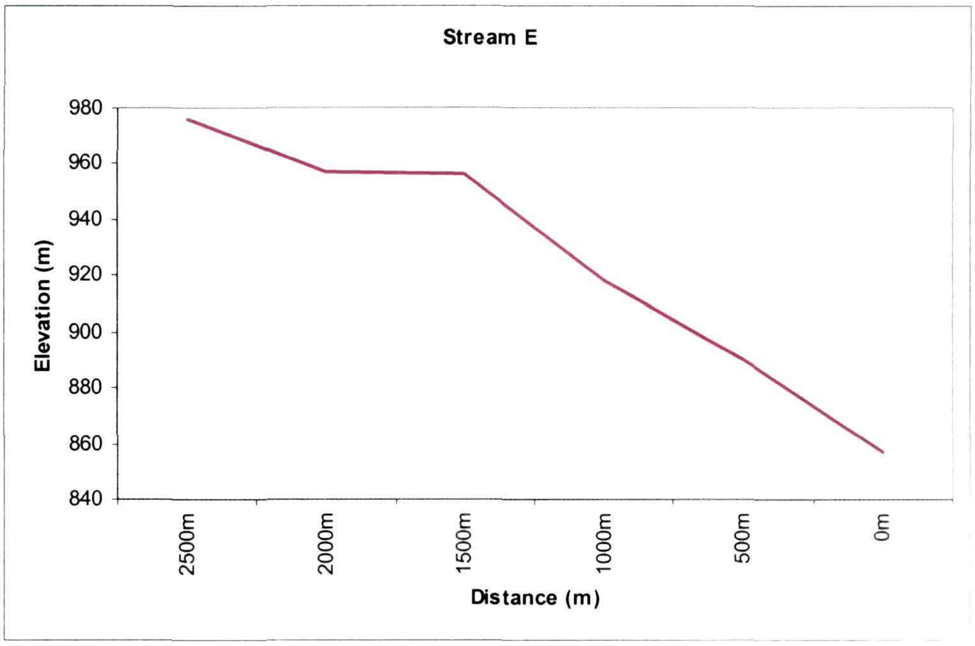


Fig 5.31(e): Profile of some selected streams of Umkhen watershed

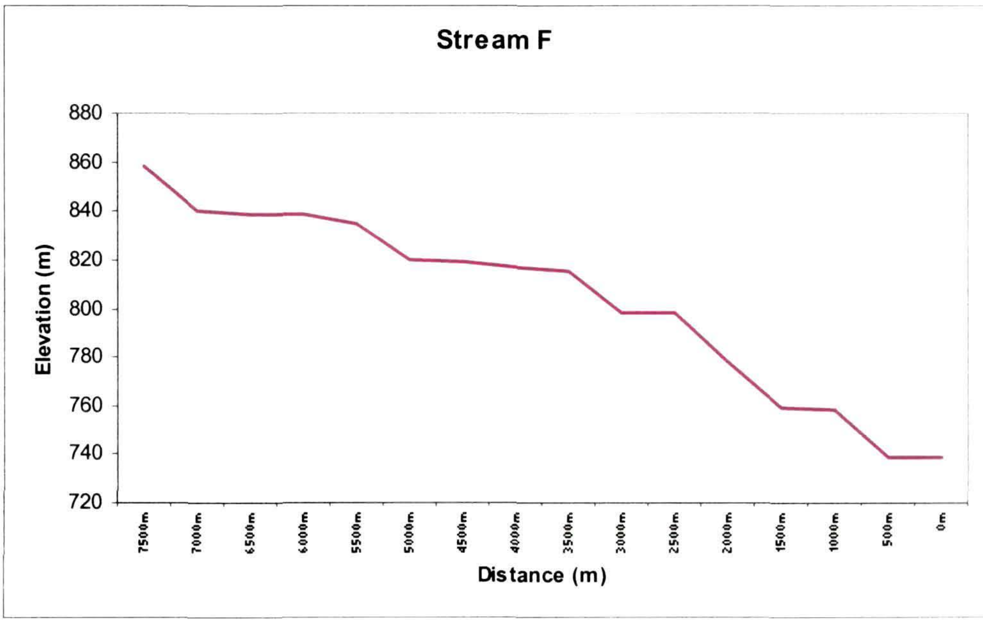


Fig 5.31(f): Profile of some selected streams of Umkhen watershed

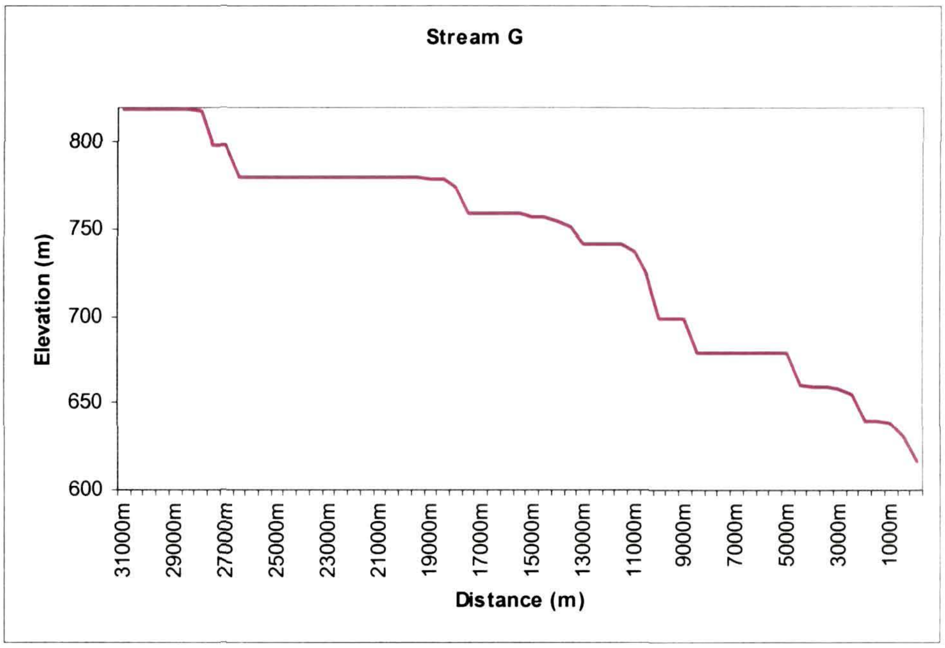


Fig 5.31(g): Profile of some selected streams of Umkhen watershed

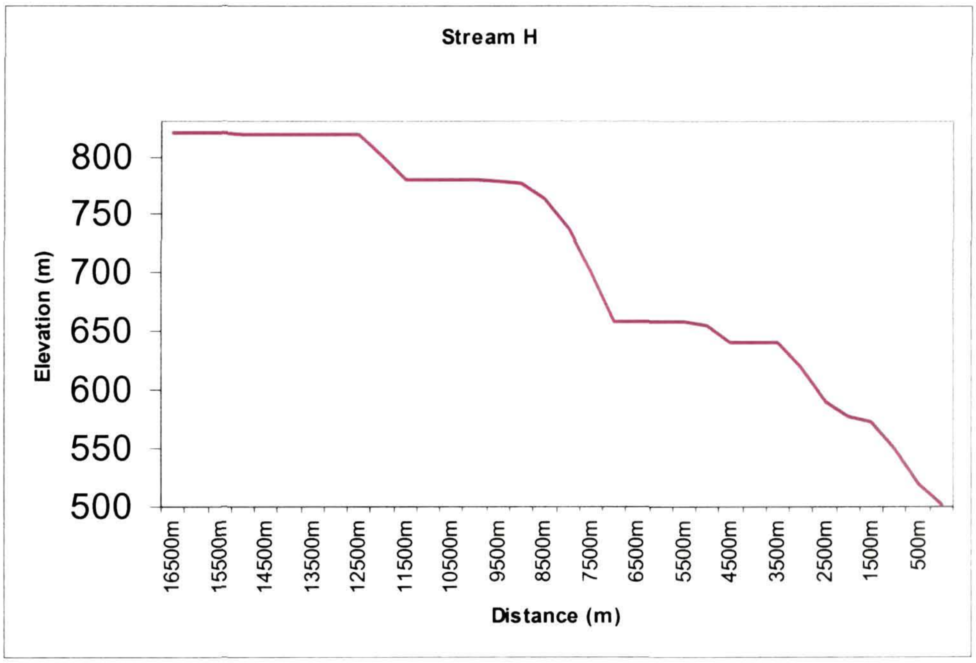


Fig 5.31(h): Profile of some selected streams of Umkhen watershed

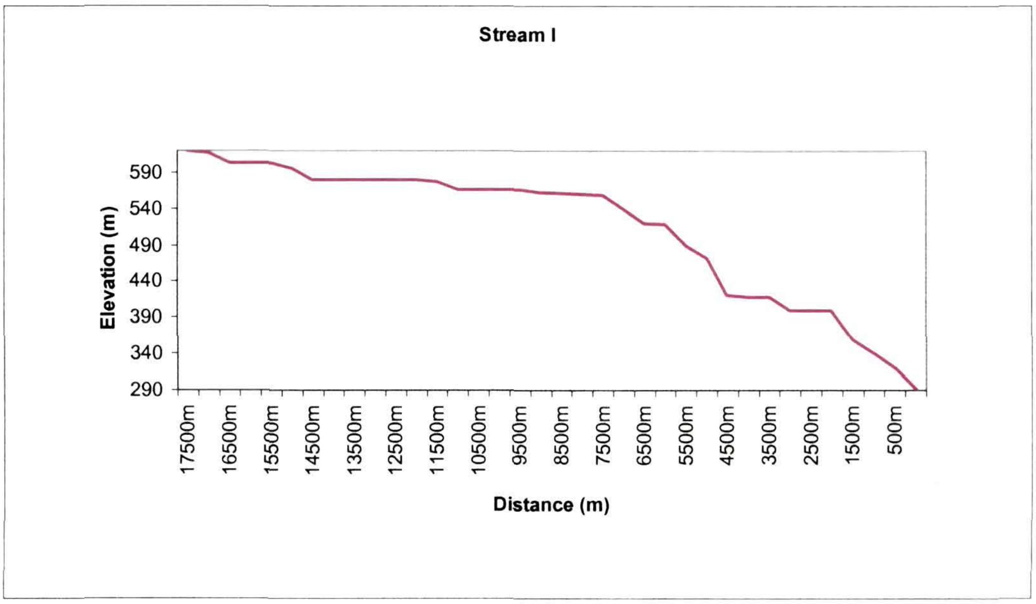


Fig 5.31(i): Profile of some selected streams of Umkhen watershed

based model SWAT2000 have the capability to explicitly simulate various processes within the watershed which may vary in space and time in any study watershed (Tolson and Shoemaker, 2007). The "ten daily discharges" were obtained for the entire period of 1984-1993 for which data was available for rainfall and temperature. Modeled water yields are assumed to predict future scenario without considerable changes. For generating the flow series, the watersheds were divided into sub-watersheds with the criteria that the points where two streams of 4^{th} order and above confluence were converted into outlets points. In this way, the pre-process operation of SWAT2000 divided Myntriang watershed into 12 sub-watersheds and Umkhen watershed into 60 sub-watersheds. An assumption was made that the discharge variation between two outlets were negligible which meant that if there were more than one location between two outlet points identical discharge was considered. The 72 numbers of delineated sub-watersheds of Myntriang and Umkhen are shown in Figs 5.32 and 5.33.

The flow duration curve (FDC) was constructed using *Weibull Plotting Position* method (discussed in section 4.7.2). As the Myntriang watershed was divided into 12 sub-watersheds and Umkhen into 60 sub-watersheds, an equal

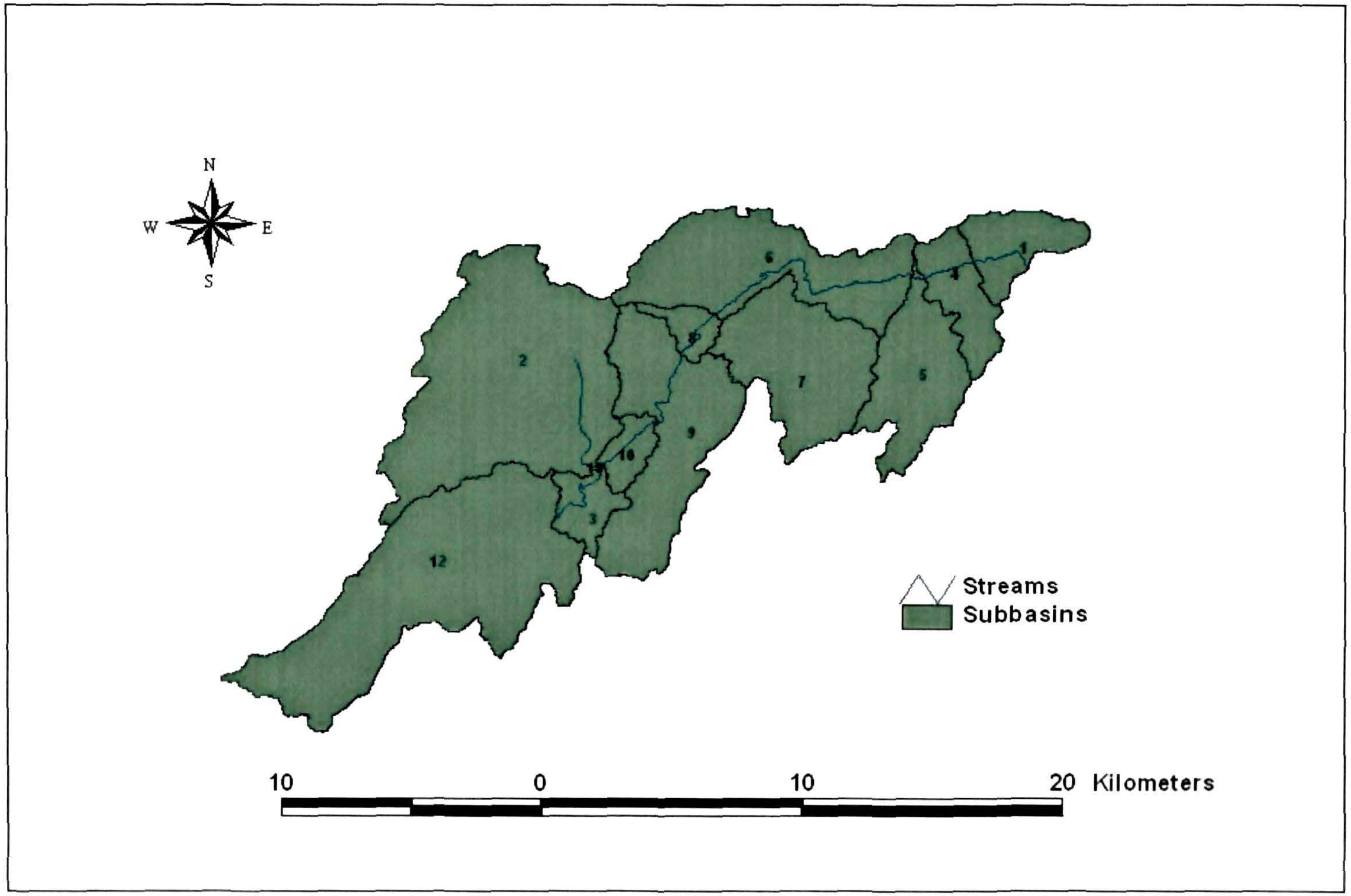


Fig 5.32: Sub basins and Outlets for hydro power in Myntriang Watershed

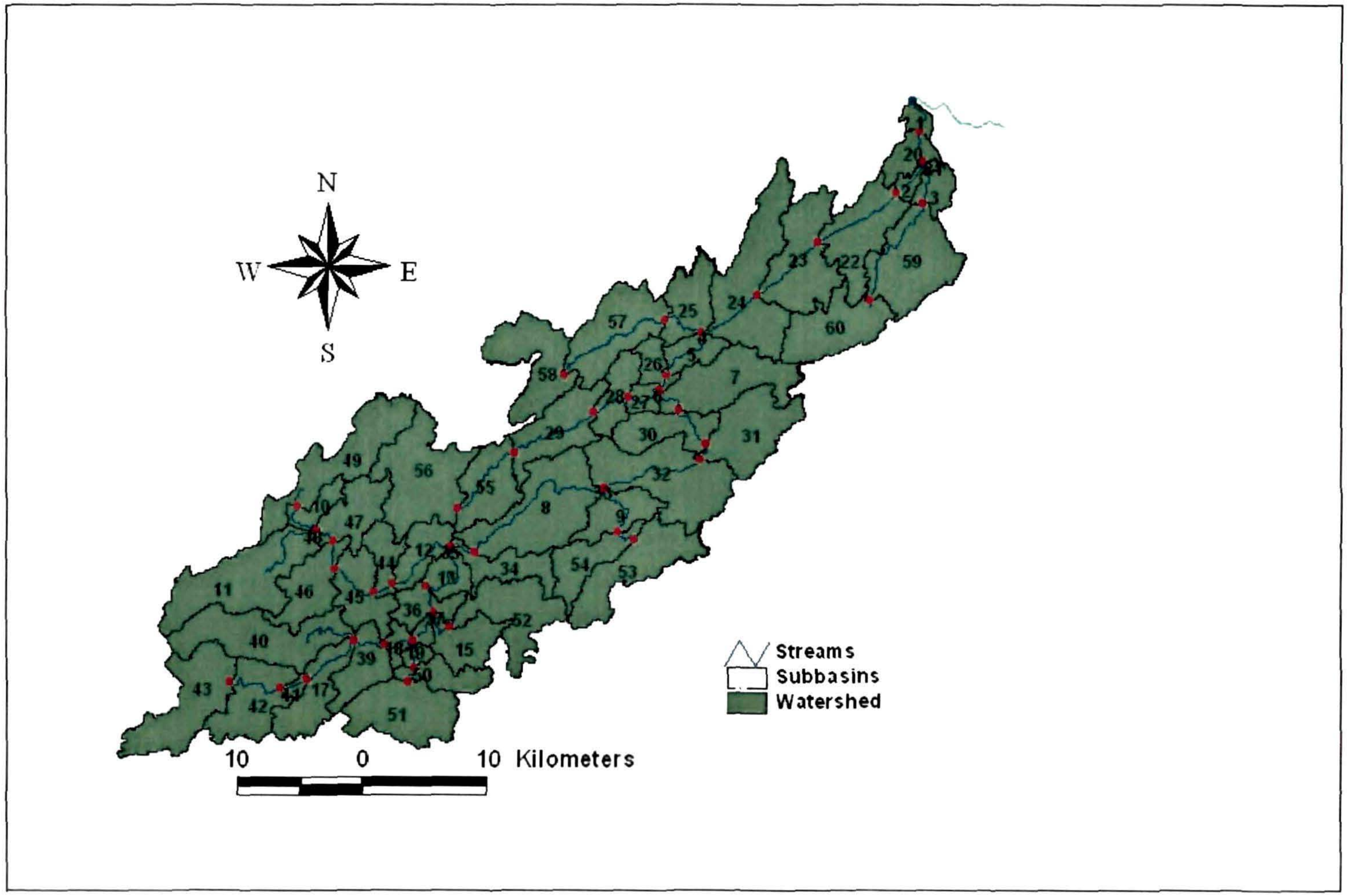


Fig 5.33: Sub watersheds and outlets for hydro power in Umkhen watersheds

number of FDC's were available. As a representative sample, only two FDC's each for Myntriang (sub-watershed 1 and sub-watershed 12) and Umkhen (sub-watershed 1 and sub-watershed 50) are presented in Figs 5.34 and 5.35 and discussed below.

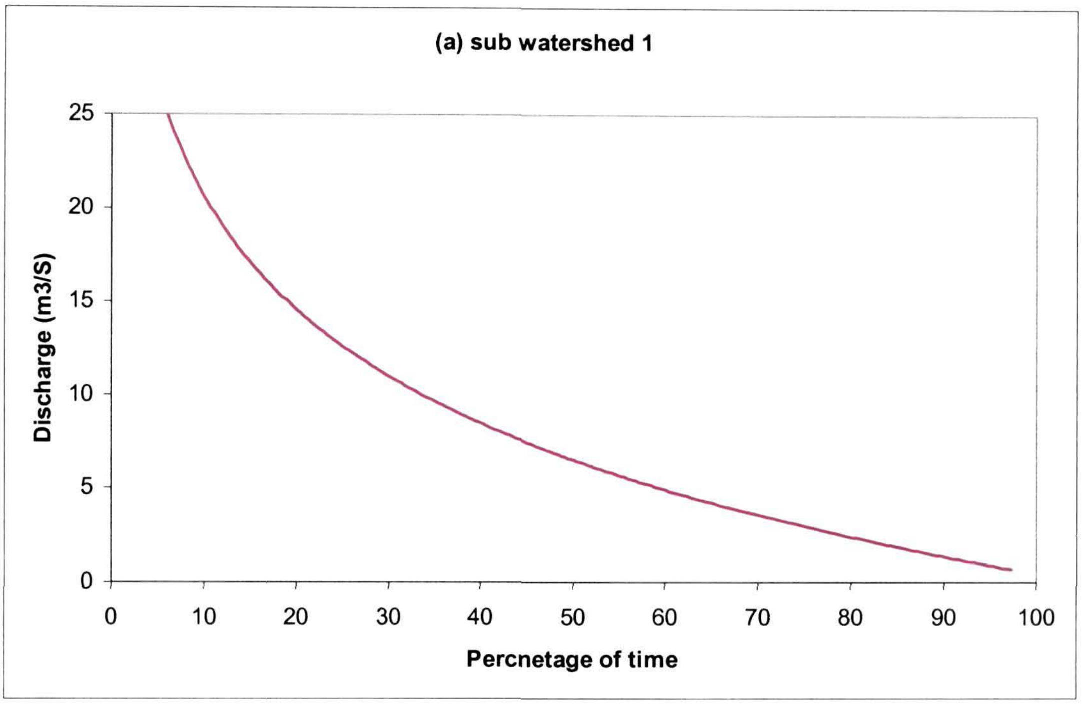
From the FDC of sub-watershed 1 it was found that maximum flow of 22.73 cumecs was available only for 3% of the time whereas 50% dependability flow was 4.46 cumecs. The flow at 75% and 90% dependability were 1.19 and 0.59 cumecs. On the other hand, the maximum flow obtained in sub-watershed 12 was 5.92 cumecs. The dependability flow at 50%, 75% and 90% were 1.61, 0.16 and 0.067 cumecs, respectively.

While analyzing the FDCs of Umkhen watershed, it was found that maximum discharge of 268.78 cumecs was obtained for 2.7% of time in sub watershed 1. The discharges at 50%, 75% and 90% dependability of the sub-watershed were 40.01, 7.07 and 3.44 cumecs. Whereas for sub watershed 50, the maximum flow was 23.42 cumecs with 50%, 75% and 90% dependability flow values of 4.12, 0.71 and 0.29 cumecs.

The importance stream characterization through FDC has been almost universally realized. It is a pre-requisite of hydro-power planning besides other uses (Castellarin *et al.*, 2004). Now the attempt of the present investigation to construct FDCs based on simulated model outputs expected to fulfill such needs for Myntriang and Umkhen. From the comparative assessment of the representative sub-watersheds, it was observed that, strength of sub-watershed could be evaluated on the basis of respective FDCs.

5.6.3 Power potentiality

After characterizing the streams in terms of (i) head and (ii) FDCs corresponding to 72 numbers of simulated sub-watersheds, finally the available hydro powers at the identified sites were estimated. As mentioned earlier, only naturally available sites, where power could be generated without constructing reservoir, were identified. The power potentiality was obtained at



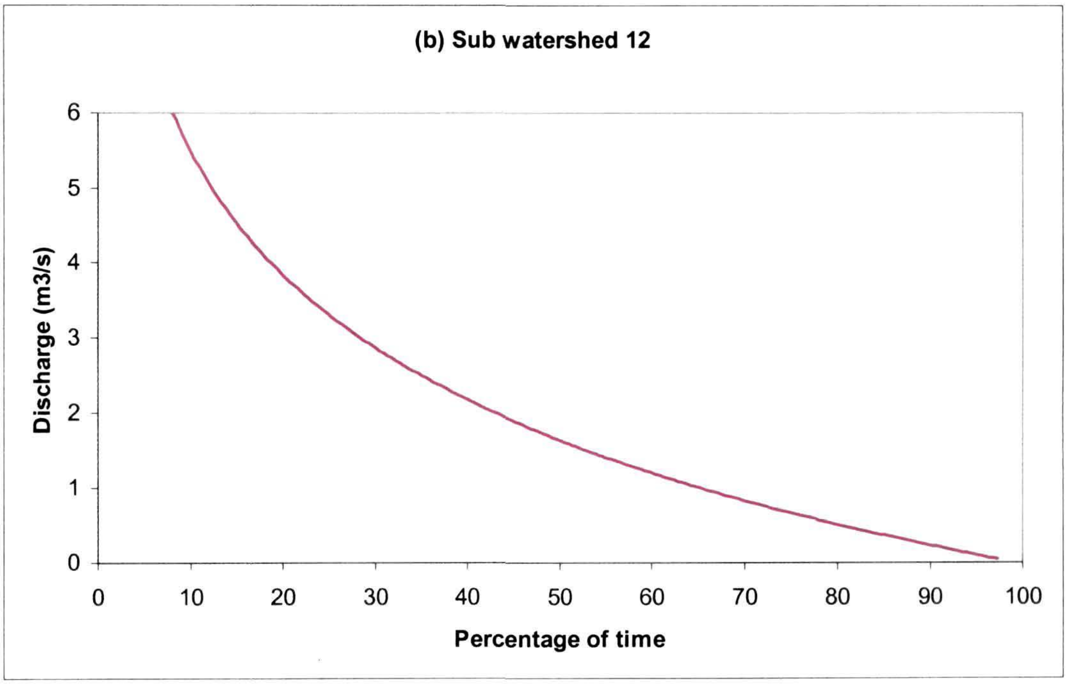
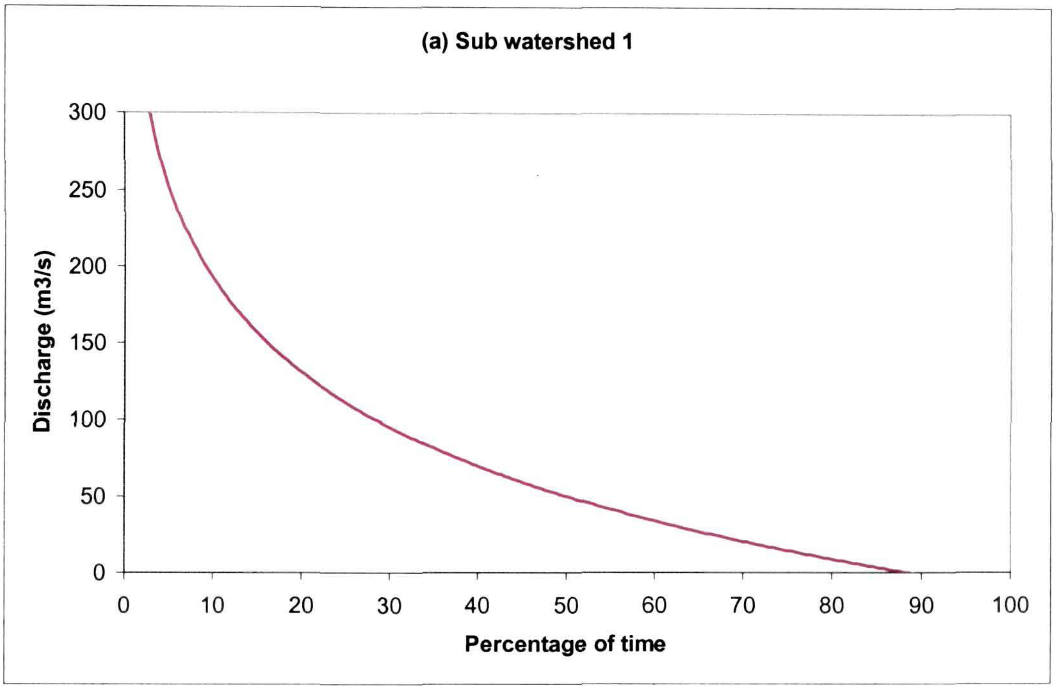


Fig 5.34: Two typical Flow Duration Curve for (a) Sub watershed 1 and (b) Sub watershed -12 of Myntriang watershed



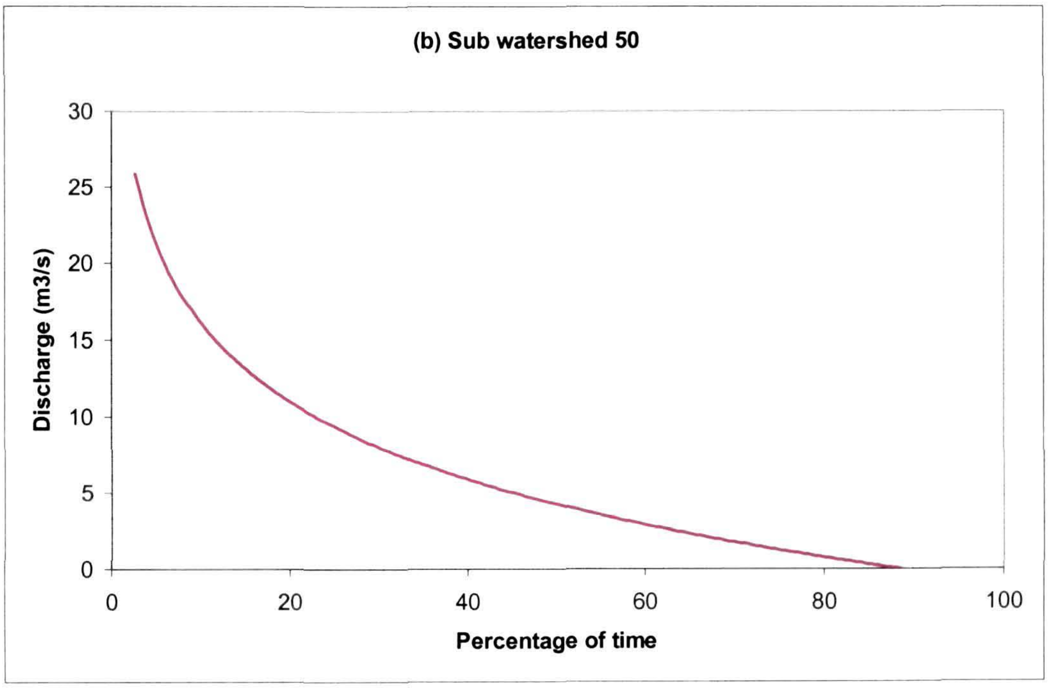


Fig 5.35: Two typical Flow Duration Curve for (a) Sub watershed 1 and (b) Sub watershed -12 of Umkhen watershed

50%, 75% and 90% dependability flow. The details methodologies of the power estimation were discussed in section 4.7.

Though the SWAT based model analysis could be extended for assessing the sites for larger projects also, the present investigation was limited to natural sites in Myntriang and Umkhen watersheds only. No such study was reported covering any parts of the states of Assam and Meghalya (India). However, various studies have been conducted to estimate hydro power potential through hydrological analysis in other regions (Das and Paul 2006, Dudhani *et al.*, 2006).

The details of the theoretical hydro-power estimation indicating (i) available head, (ii) power in kW corresponding to three predefined levels of dependability and (iii) locations of each of the 72 identified sites in Umkhen and Myntriang watersheds were obtained and presented in Appendices 16.

Estimated aggregate power potential of each of the 15 streams in Myntriang (MA, MB, MC, MD, ME and MF) and Umkhen (UA, UB, UC, UD, UE) at three level of dependability along with percentage of power share by each are presented in Table 5.8

The combined power potentiality of Myntriang and Umkhen was estimated as 144.85 MW with 50% dependability. However, with increasing dependability the expected power potentiality reduced to 21.51 MW and 11.40 MW at 75% and 90% dependability respectively. Umkhen being the larger watershed would produce substantiality larger amount of power compared to Myntriang. This was true at all the three levels of dependability. The estimated share of power by Umkhen was 91%, 84% and 87% of the combined power corresponding to 50%, 75% and 90% dependability respectively.

When power density of both the watersheds were determined, considering the total expected power per unit of land area of the watershed, it was found that smaller watershed (Myntriang) would produce lesser power density (49 kW/sq km) compared to the bigger one (Umkhen) with about 112 kW/sq km (at 50% dependability). The actual population count of the watersheds was not known. Therefore per capita availability of expected hydro power could not be determined. Assuming uniform population density, power density may be considered as an indirect index of evaluation of per capita hydro power availability. Further, investigation of such indices at sub-watershed level was not performed in the present investigation.

Table 5.8: Stream wise estimated aggregate hydro power in Myntriang and Umkhen

Streams	**Power Potential in MW**					
	Dependability 0.50		**Dependability 0.75**		**Dependability 0.90**	
	MW	**% share**	**MW**	**% share**	**MW**	**% share**
MA	6.38	50.31	1.75	51.59	0.78	51.30
MB	0.07	0.58	0.02	0.48	0.01	0.63
MC	0.40	3.17	0.09	2.68	0.05	3.41
MD	0.50	3.91	0.11	3.15	0.06	3.83
ME	0.64	5.03	0.14	4.06	0.01	0.49
MF	4.69	37.01	1.29	38.04	0.61	40.33
Total power in Myntriang	***12.67***	100.00	***3.39***	100.00	***1.52***	100.00
UA	117.40	88.82	15.65	86.37	8.81	89.17
UB	1.53	1.16	0.20	1.10	0.15	1.52
UC	0.49	0.37	0.06	0.33	0.03	0.30
UD	0.71	0.54	0.12	0.66	0.05	0.51
UE	1.07	0.81	0.19	1.05	0.09	0.91
UF	2.03	1.54	0.33	1.82	0.12	1.21
UG	1.81	1.37	0.24	1.32	0.18	1.82
UH	6.24	4.72	1.31	7.23	0.45	4.55
UI	0.90	0.68	0.08	0.44	0.03	0.30
Total power in Umkhen	**132.18**	100.00	**18.12**	100.00	**9.88**	100.00
Grand total	**144.85**		**21.51**		**11.40**	

It is also observed that only few streams of both the watersheds dominated power production. In Myntriang, the stream MA proved to be the major one with more than 50% share of the total power potentiality of that watershed at all levels of dependability flows, followed by MF with more than 37% power share. Remaining streams *viz.*, ME, MD, MC and MB were the minor producers with about 5%, 4% 3% and 1% of share corresponding to 50% dependability. With increased level of dependability, there had been some alteration of the share of hydro power by the streams.

In case of Umkhen watershed, UA would produce the maximum power (more than 86% of the total power potential of that watershed) at all levels of dependability flows. Other streams in the watershed were minor producers. These streams on the basis of power potential in descending order are UH (5%), UF (1.5%), UG (1.4%), UB (1.2%), UE (0.8%), UI (0.7%), UD (0.5%) and UC (0.4%) corresponding to 50% dependability flows. Similar to Myntriang, the alteration in power potential was observed at increased level of dependency in Umkhen watershed also.

Referring specific region of India, Ramchandran *et al.,* (2004) reported about the Government's policy to promote small hydro in Karnataka (India). It is further reported that state Government had already given permission for 79 projects amounting to 465 MW out of which 8 projects amounting to 49 MW has been installed in the existing irrigation canal. In case of mini micro level hydro electric projects, 30 locations with a potential of 40.37 MW have been identified and 12 projects with a potential of 17.20 MW have been installed in Karnataka. There are however, many other instances where Governments are taking steps to promote growth of small hydro in developing countries.

India in general and north-eastern parts including Assam in particular has been worst sufferer of power shortage. With the current level of power production, the remote and inaccessible localities, like the Myntriang and Umkhen cannot expect to get power supply from conventional sources. Therefore, effort to harness potential hydro-power of such localities could lead to much needed development and also help to solve the chronic power shortage problem of this region. The results of the present study are expected to assist the planning of such a hydro-power production programme. The spatial distribution of power potential (Appendix 16) would be valuable information for selection of specific technology and also for prioritization. The knowledge of dependability level power production would also assist to investigate the several options including hybrid power production.

Size of hydro power generation is one of the criteria for both technology and policy matters. There is wide variation in size classes throughout the world. Jiandong *et al.*, (1997) classified the small hydro project into three categories *viz.*, micro (less than 100 kW); mini (101 kW to 2000 kW) and small hydro power (2001 kW to 10000 kW) based on the resolution taken in Kathmandu SHP conference and Hangzhou SHP conference. They further mentioned that no strict definition have been followed internationally with different countries adopting different ranges. However, no countries have crossed beyond 25,000 kW to define small hydro power (SHP). Maher and Smith (2001) have defined another category as pico hydro with maximum electrical output of 5 kW. The categorization of hydro power stations based on Govt. of India specification was used in the present study.

The potential hydropower production in Myntriang and Umkhen are presented in Table 5.9.

The results of the present investigation indicated that 21.34 MW of hydro power could be generated through 106 distributed power stations in Myntriang and Umkhen watersheds. These were less than 500 kW power stations and expected to get attention. The decentralized power production based on hydro resources has been one of the priority areas of the Governments of this region. Some success story of using and managing such micro-mini hydro power stations by rural groups have been reported recently in Arunachal Pradesh (India). The APEDA the nodal agency in Arunachal Pradesh for promoting small hydro projects is also planning to set up Village Energy Management Committee (VEMC) for operation and maintenance of the projects and also will be responsible for collection of energy tariffs. (MNRE, 2007).

The range have been obtained and presented at 50% dependability flow only keeping in mind the installation of hybrid system with other sources of energy such as biomass, solar or even fossil fuel depending on the location specific suitability. Even the power generated at six location in stream UA (46.21 MW) can also be connected to grid and revenue can be generated. For higher dependability flow the theoretical potential was substantially low.

Table 5.9: Number of potential hydro power stations in Myntriang and Umkhen watershed at 50% dependability flow

Sl No	Stream	Power Potential Ranges				
		below 0.5 MW	above 0.5 and up to 1 MW	above 1 MW and up to 5MW	above 5 MW and up to 15 MW	above 15 MW and up to 25 MW
1	MA	20	3	-	-	-
2	MB	1	-	-	-	-
3	MC	4	-	-	-	-
4	MD	7	-	-	-	-
5	ME	5	-	-	-	-
6	MF	1	2	2	-	-
7	UA	15	1	27	6	-
8	UB	8	-	-	-	-
9	UC	5	-	-	-	-
10	UD	2	-	-	-	-
11	UE	4	-	-	-	-
12	UF	6	-	-	-	-
13	UG	8	-	-	-	-
14	UH	8	5	-	-	-
15	UI	12	-	-	-	-
Total		106 (21.34 MW)	11 (7.08 MW)	29 (70.23 MW)	6 (46.21 MW)	-

5.7 Summary

In this chapter the resultant terrain map of the study watershed Myntriang and Umkhen was generated. The terrain was then divided into various elevation ranges and area under each elevation range was also calculated. Such information provides the information for prospective areas for development. The pre processing of the terrain map by SWAT generated sub watershed maps of the study watershed. For creation of sub watershed map a threshold value of 50 sq km was considered in confirmation of Government of India policies for watershed management. Such information is useful for prioritizing watershed requiring attention.

The drainage map of the study watershed was also created and ordering was done as per Strahler method. The information related to drainage network provides vital information regarding the watershed such as age, erosion characteristics and hydrology.

Other input maps for SWAT2000 viz. soil map and land use maps were also created from standard sources.

The maps created as mentioned earlier were used a input map to SWAT model and model run was performed using rainfall, temperature data for the period of 1988 to 1990. The model was then calibrated by adjusting model parameters within the prescribed range as given in the model calibration tool to obtain best results. Altogether 6 parameters were adjusted in Myntriang watershed and 7 parameters were adjusted for Umkhen watershed. The calibrated model was then tested using different set of rainfall and temperature values (1991-93). The validation was performed by using set criteria viz., coefficient of determination (R^2), model efficiency (E) and Index of agreement (d). The values of the validation criteria was compared with the values obtained by other researchers and thus was considered acceptable for use.

The hydrologic behavior of the watershed were studied for rainfall to runoff conversion capability, average annual water yield, water yield for peak and lean season and average annual sediment yield.

The strength of the SWAT2000 developed for the study watershed was used to assess hydro power potential. For estimating the theoretical hydro power potential the location of sites with available head more than or equal to 10 m were identified. Total of 45 sites were available for Myntriang and 107 potential sites were obtained for Umkhen.

The discharge values were obtained at the identified sites by running the model for the period of 1984 to 1993. The simulated values were used to construct the flow duration curve. The discharge and the elevation drops were used to estimate the hydro power potential. The potential was estimated at three dependibities viz., 50%, 75% and 90%.

CHAPTER- 6

SUMMARY AND CONCLUSION

Chapter 6
SUMMARY AND CONCLUSION

Land and water are the two vital natural resources contributing towards the sustenance of the living world. The growing pressure of population and rapid industrialization has led to exploitation of these natural resources. However, there are instances when these resources particularly water resources remain under utilized due to the paucity of information regarding its availability. The assessment of water resources on spatial and temporal scale is the prime concern for planning and management.

The North eastern region of India occupies 8.11% of the country and posses vast water resources. However, development of water resources in this region is in nascent stage as compared to other regions of the country. The hydro power is one of the sectors that could be developed if the water resources are accurately assessed and efficiently utilized. As per various studies the total hydro power potential of North eastern region of India is assessed as 33094 MW, out of which only 2% has been realized.

The Kopili River which is a major tributary of the River Brahmaputra (India) is a fitting example where its water resources remain un-assessed. The present study considers watersheds in Kopili river basin for assessment of water resource and hydro power.

Reliable assessments of water resources over space and time have been a challenging job due to several reasons. With the advent of modern computational facility coupled with development of hydrological model to mimic real world, the assessment of water resources is becoming easier. With the availability of GIS (Geographical Information System) and remote sensing technologies these models are becoming more physically based. Thus better simulation of physical world is possible.

In the present study attempt was made to assess the water resources of Myntriang and Umkhen sub watersheds of Kopili river basin. The objectives of the study were to identify a suitable hydrological model, calibrate the selected model for study watershed, and make spatial and temporal assessment of water and sediment yield after validation. The model was also used for assessment of hydropower potentiality in the study area.

Out of the available spatial hydrological models SWAT was selected due to its compatible features for the present study. Hydrological investigation for Myntriang and Umkhen watershed was done based on the principles as encompassed in SWAT model.

The methodology for using SWAT model included (i) collection of meteorological data (rainfall, temperature and stream discharge data) pertaining to study watershed and (ii) processing of thematic maps (contour map for generation of digital elevation model, stream network, soil and land use for physically representing the study watersheds). Further, generated Digital Elevation Model (DEM) was processed to delineate sub watersheds at pre defined threshold value of 50 sq km. Automatic stream delineation was also performed and compared with digitized streams to test the accuracy of the delineated sub watersheds. Manual calibration of the model was performed to fit the model parameters for simulation of hydrological processes of Myntriang and Umkhen at close agreement. Observed data of the study watershed was used for calibration. The fitted model was tested for validation using another set of observed discharge data. Coefficient of determination (R^2), model efficiency (E) and index of agreement (d) were determined for testing prediction performance comparing simulated results with observed results. Finally, based on the model outputs on spatial and temporal scale for study watersheds, hydro power was assessed. For assessing hydro power potential, the longitudinal profiles of the streams were extracted using DEM and stream network. The locations having drops equal to or more than 10 m and at 500 m interval were considered for hydro power assessment. The confluence of streams of 4th order and above was considered as outlets for modeling discharge. From the discharge obtained for each outlet, the flow duration curve was constructed to obtain dependability flow at 50%, 75% and 90% availability. Based on the dependability flow and the longitudinal profile, the hydro power was estimated on the selected sites.

The findings of the study are summarized below:

(i) The DEM of the study watershed indicated that there exists substantial area at raised elevation where undulation is moderate. The DEM indicated that 77% of the area available at an elevation of 400 to 700 m above msl for Myntriang watershed whereas in Umkhen watershed 75% of the area falls in the elevation range of 600 to 1100 m above msl.

These areas can be developed for agricultural, industrial or other useful purposes. The present result of hydrological model coupled with above findings would help planner and decision maker to plan suitable cropping pattern based on the variation of availability of the water resources on temporal scale. The knowledge of hydropower potentiality along with the DEM would also assist micro level planning for development.

(ii) The management of natural resources on watershed basis is a universally accepted fact. However, accurate delineation of sub watershed at desired threshold size has been the major concern for implementation of watershed management program. The present study has produced hydrologically delineated sub watershed of Myntriang and Umkhen. The automatic delineation of sub watersheds resulted in three sub watershed in Myntriang and 13 sub watersheds in Umkhen. The result seems to be useful for management of the natural resources for developmental purposes.

(iii) The study have resulted stream network map with stream ordering, soil map and land use map of the study watershed. These maps would be useful for interpreting watershed behavior and also to analyze the hydrological response to rainfall events. The stream ordering and stream network map provide watershed characteristics such as its age, erosion and runoff producing capabilities and also assist to prioritize sub watershed based on the hydrological responses. The soil and the land use are responsible for hydrological response in terms of interception losses, infiltration and deep percolation and sub surface flow.

The Myntriang watershed was 6^{th} order watershed and Umkhen was 7^{th} order watershed. There were five soil classes in Myntriang and 11 soil classes in Umkhen watershed. Four land use categories were available in Myntriang and eight land use categories in Umkhen.

(iv) Model was calibrated to simulate the water and sediment yield of Myntriang and Umkhen watersheds and also validated based on selected criteria. The demonstration of the use of a hydrological model SWAT for Myntriang and Umkhen watershed for simulation of water and sediment yield has opened scope for varied applications such as planning water harvesting structure, erosion control structure, planning flood moderation in the plain areas downstream, creation of irrigation structure and planning irrigation scheduling, estimate hydropower on temporal basis.

(v) Rainfall to runoff conversion capability was assessed using model outputs. Myntriang watershed yielded higher conversion efficiency (61.5%) compared to Umkhen watershed (51.9%). This information helps to predict amount of water that will be available at the outlet under different rainfall event. The necessary protection against floods can be planned in the downstream and also to harvest in the upper watershed.

(vi) Spatial variation in water yield was observed in both the Myntriang and Umkhen watersheds. The variation of water yield amongst its sub watershed was more in Umkhen than in Myntriang. The maximum simulated water yield in Umkhen was 3336.72 mm which was substantially higher than the lowest value of water yield (379.26 mm) in another sub-watershed. In Myntriang water yield varied from a maximum of 885.82 mm to a minimum of 721.31mm.

The information on water yield is useful for prioritizing the watershed for treatment. Treatment of entire watershed at a time may not economically feasible. The sub watershed generating higher average annual water yield can help in planning and managing in terms of flood control and erosion whereas watershed generating low water yield can be treated for water harvesting.

(vii) Spatial variation in sediment yield was also observed in both the watersheds. The maximum simulated sediment yields were 15 kg/ha and 1559 kg/ha in Myntriang and Umkhen respectively. The sub-watershed resulting higher level of sediment yields needs appropriate management programme, particularly in Umkhen watershed.

(viii) Water yield during peak (rainy) and lean (non rainy) period were also obtained through model simulation. The rainfall pattern indicated that average rainfall during June was the highest and February was the lowest. The model output showed temporal variation of water yield in the sub watersheds ranged from 230 .34 mm to 3.65 mm during peak and lean period respectively in Myntriang watershed. Similarly in Umkhen watershed water yield ranged from 803.65 mm in peak season to 11.57 mm during lean season.

The results on the temporal variation provides important information for planning hydraulic structures in a watershed. Most of the hydraulic structures are planned to handle the extreme rainfall events whereas structures planned for hydro power generation are concerned to lean flow to assess the availability of minimum energy. The information that has been derived in the present study can help the professionals working for the development of the region depending on the temporal variation of the water resources. Further such information can provide valuable input for designing suitable cropping pattern in the study watershed.

(ix) The DEM and the stream network maps Myntriang and Umkhen watersheds were used to obtain the longitudinal profile of the major streams in the watershed (5^{th} order and above). The information on the longitudinal profile helps in identifying the energy associated with the flow in the stream. In Myntriang 45 potential sites were available whereas 107 potential sites were available in Umkhen.

(x) Construction of Flow duration curves (FDC) by traditional processes requires collecting long term discharge data at all selected sites. Avoiding such a long process, the hydrological model of the present study was also used to construct the FDC for the potential hydro-power sites at 50%, 75% and 90% dependability flow for assessment of hydro power in both the watersheds. The FDCs would also be useful for designing hydraulic structures.

(xi) The estimated hydro power potential at 50%, 75% and 90% dependability for Myntriang watershed were 12.67 MW, 3.39 MW and 1.52 MW respectively. In Umkhen the power potentiality at the above three dependability flows were 144.85 MW, 21.51 MW and 11.40 MW, respectively.

(xii) The potential power obtained at each sites were arranged into five categories *viz.*, (a) below 0.5 MW, (b) 0.5 to 1 MW, (c) 1 to 5 MW, (d) 5 to 15 MW and (e) 15 to 25 MW. At 50% dependability flow total of 106 (21.34 MW) sites were obtained for the category below 0.5 MW. In the second category total of 11 sites (7.08 MW) were available. In the third category total of 29 sites with potential ranging from 1 to 5 MW were obtained. Further 6 sites with power potential range of and 5 to 15 MW were obtained in the fourth category. No sites were available with power potential between 15 to 25 MW at 50% dependability flow.

The growth of hydro power development in North eastern region is very slow probably due to non availability of detailed information about the potentialities. The decision for decentralized power generation would be easier based on these results.

The specific conclusions of the present study are:

(i) The applicability of a physically based spatial hydrological model (SWAT2000) was successfully demonstrated in two specific watersheds in North Eastern region of India.

(ii) The simulation run of SWAT2000 resulted in information of delineated sub watersheds. Further elevation wise distributions of each sub watersheds were also obtained.

(iii) The model output could provide information on the spatial and temporal variation of water and sediment yield on sub watershed basis.

(iv) The capability of the SWAT2000 model was demonstrated to assess hydropower potential on spatial and temporal basis. For the power deficient North eastern region of India, precise assessment of Hydropower would assist effective planning, design and implementation.

Specific contribution of the study

(i) A methodology for assessing water resource and hydropower potential in the watersheds lacking sufficient hydrological data is developed

(ii) Application of physically based hydrological model using advance GIS tools to simulate hydrological processes was demonstrated in hilly watershed in NE region of India.

(iii) The study resulted in generation of spatial and temporal maps of water yield for Myntriang and Umkhen watershed in Kopili river basin.

(iv) Generation of maps showing the spatial variability of sediment yield of Myntriang and Umkhen watershed in Kopili river basin.

(v) Flow duration curve (FDC's) of 12 outlets in Myntriang and 60 outlets of Umkhen watersheds were generated.

(vi) Theoretical hydro power potential in the study watershed was assessed at 50%, 75% and 90% dependability flow. The study also identified probable location and corresponding potential for hydro power generation at different dependability flow.

Limitation of the present study

(i) The present study considers values for soil texture, bulk density, porosity, available water capacity of soil layer, saturated hydraulic conductivity and soil albedo obtained from standard sources. The non availability of the insitu values of the study watershed has been one of the limitations.

(ii) Land use map considered for the present study has been taken from two different sources viz., Assam Remote Sensing Application Center

(ARSAC) for the portion falling in the state of Assam and from Cotton College for the portion falling in Meghalaya. These maps were prepared during different time period. The land use pattern was not classified as per the model requirement. Non availability of detailed land use map corresponding to the study period (1988 to 1993) can be considered to be a limitation.

(iii) Present study assessed the sediment yield without validation of simulated sediment yield this is due to non availability of sediment yield data.

(iv) Technically achievable hydro power could not be assessed due to non availability of information concerning to competing demand of the available water resources.

Suggestions for the future work

(i) Identification of parameters critical to watershed behavior. This can be obtained by performing sensitivity analysis and the uncertainty analysis of the adjusted parameters of the study watershed.

(ii) Assessment of competing demand of the available water resources to assess the achievable hydropower potential. The competing demands can be irrigation, domestic use and development of industries

(iii) The seasonal variability of simulated discharge.

(iv) The water density at the tip of each watershed.

(v) The design aspects of the water resources structures for water resources planning, management and development.

BIBLIOGRAPHY

1. Abbaspour, K.C.; Yang, J A. ; Maximov, I. ; Siber, R. ; Bogner, K. ; Mieleitner, J. ; Zobrist, J.; Srinivasan, R.(2007). Modeling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of Hydrology, 333, 413- 430.*
2. Abbot, M.B. ; and Refsgaard, J.C. (1996): Distributed Hydrological Modeling. *Kluwer Academic Publishers Dordrecht, Netherlands. 321 p.*
3. Abbot, M.B. ; Bathurst, J.C.; Cunge, J.A.; O'Conell P.E. ; Ramussen, J. ; (1986a). An introduction to the European Hydrological System- System Hydrologique European, SHE', 1: History and Philosophy of a physically-based distributed modeling system. *Journal of Hydrology, 87, 45-49.*
4. Abbot, M.B. ; Bathurst, J.C.; Cunge, J.A.; O'Conell P.E. ; Ramussen, J. (1986b). An introduction to the European Hydrological System- System Hydrologique European, SHE', 2: Structure of a physically based distributed modeling system. *Journal of Hydrology, 87, 61-77.*
5. Adinarayana, J.; Krishna, N. (1996). Integration of multi-seasonal remotely sensed images for improved land use classification of a hilly watershed using geographical information systems. *International Journal of Remote Sensing 17 (9), 1679–1688.*
6. Aggarwal, S.K. (1996). Hydropower development in India at crossroads. *India Power, April–June, pp. 37–44.*
7. Al Khudhairy, D.H.A. (2002). Monitoring wetland ditch water levels using Landsat TM and ground- based measurements. International *Journal of Photogrammetric Engineering and Remote Sensing 68 (8), 809–818.*
8. Allen, R.G. (1986) A Penman for all seasons. *J. of Irrigation and Drainage Engineering., ASCE,* 112(4): 348-368.
9. Allen, R.G. ; Jensen, M.E. ; Wright,, J.L. ; Burman, R.D. (1989) Operational estimates of evapotranspiration. *Agron. J.* 81: 650-662.
10. Arnold, J.G., Allen, P.M., Berharrdt, G. (1993). A comprehensive surface ground water flow model. *Journal of Hydrology, 142, 47-69.*

11. Arnold, J.G., Srinivasan, R,; Muttiha, R.S.; Williams, J.R. (1998). Large area hydrologic modeling and assessment Part-I: Model Development., *J. AWRA., 34 (1), 73-89.*

12. Arnold, J.G.; Srinivasan, R.; Ramanarayanan, T.S.; DiLuzio M. (1999). Water resources of a Texas gulf basin. *Water Science Technology. 39 (3), 121-133.*

13. Arnold, J.G.; Williams J.R.(1995) SWRRB-A watershed scale model for soil and water resources management. P 847-908.*In V.P.Singh (ed) Computer Models of watershed hydrology. Water Resources Publication.*

14. ARSAC (1990). District Report on land use and land cover, Karbi Anglong District, Assam. *Assam Remote Sensing Application Center, Guwahati (Assam) India.12pp.*

15. Arwa D. O. (2001). GIS Based Rainfall Runoff Model for the Turasha Sub Catchment Kenya, *MSc. thesis. International institute for aero space survey and earth sciences, Enschede, the Netherlands.*

16. Ba¨rlund, I; Kirkkala, T; Malve, O.; Ka¨ma¨ri, J. (2007). Assessing SWAT model performance in the evaluation of management actions for the implementation of the Water Framework Directive in a Finnish catchment; *Environmental Modeling & Software 22 (2007) 719-724.*

17. Balsar, D.A. (2002). Sustainable generation portfolio. IEEE Power Engineering Review.

18. Beasley, D.B.; Huggins, L.F.; Monke, E.J. (1980). ANSWERS: a model for watershed planning. *Trans. of ASAE. 23(4)*:938-944.

19. Behra, S.; Panda, R.K. (2006). Evaluation of management alternatives for an agricultural watershed in a sub-humid subtropical region using a physical process base model. *Journal of Agriculture, Ecosystems and Environment, 113, 62-72.*

20. Beven, J.Keith. (2000). Rainfall-Runoff Modeling The Primer, *John Willey & Sons Ltd, New York. P.360.*

21. Beven,K.J.; Kirkby,M.J. (1979). A physically based model variable contributing area model of basin hydrology. *Hydrological Science Bulletin. 24: 43-69 .*

22. Bhuyan, S.J.; Koelliker, J.K. ; Marzen, L.J. ; Harrington,Jr, J.A. (2003). An integrated approach for water quality assessment of a Kansas watershed.. *Journal of Environmental Modeling and Software. Vol. 18 (5), 473-484p.*

23. Bingner, R.L. (1996). Runoff simulated from Goodwin creek watershed using SWAT. *Trans ASAE, 39(1), 85-90.*

24. Biswas, S. ; Sudhakar. S.; Desai, V.R. (1999). Prioritization of Sub watersheds based on Morphometric Analysis of Drainage Basin: A Remote Sensing and GIS Approach. *Journal of Indian Society of Remote Sensing. Vol. 27 No 3, 155-166.*

25. Bloom, A.L. (1992). Geomorphology: A systematic analysis of late Cenozoic land forms. *Prentice hall of India Pvt. Limited, New Delhi, 532p.*

26. Bruggeman, A; Meijden, G. (2003). Assessment of water use in a small watershed in Northern Syria, using SWAT. *In Proceedings of 3rd International SWAT conference organized by Swiss Federal Institute for Environmental and Science and Technology, Switzerland and SWAT team at Zurich, Switzerland during11-15th July, 2003. 50-60p.*

27. Castellarin, A.; Galeati, G.; Brandimarte, L.; Montanari, A.; Brath, A. (2004). Regional flow-duration curves: reliability for ungauged basins. *Advances in Water Resources (27)953-965.*

28. Chakrabarti, D.K.; Verma, R.P.; Gautam, A.M.; Narasimha, S. (1987). Geomorphological Map of North-Eastern Part of India- A Landsat Overview. *A collection of Scientific Papers, Geological Survey of India, Records Volume 115 Parts III & IV. Published by order of the Government of India 65-73.*

29. Chen, D.M.; Stow, D. (2003). Strategies for integrating information from multiple spatial resolutions into land-use/land-cover classification routines. *Photogrammetic Engineering and Remote Sensing 69 (11), 1279–1287.*

30. Chen, E.; Mackay, D. S. (2004). Effects of distribution-based parameter aggregation on a spatially distributed agricultural nonpoint source pollution model. *J. Hydrology, 294, 211-224p.*

31. Chetry, N.; Saikia, R. (2002). Atlas of resources, Infrastructure and development. *An publication of tne output of the Department of Science and Technology Sponsored Project on Integration and Management of Multi-Source Data Using GIS for Development Plan/ Strategy for Kathiatoli Development Block within Kopili Basin in North East India. ; Department of Geography, Cotton College Guwahati. 52p.*
32. Chow, V.T. (1959). Open channel hydraulics, *Mc Graw-Hill, New York.*
33. CI (2001). Version 1. *Issued by the Registrar General of India, (*Census Info. India) *New Delhi.*
34. Das, S. ; Paul, P.K. (2006). Selection of Site for Small Hydel Using GIS in the Himalayan Region of India. Journal of Spatial Hydrology, *Vol.6, No.1 Spring 2006, 18-28.*
35. DE (1987). Department of Environment, Handling Geographical Information. *Report of the Committee of Enquiry chaired by Lord Chorley. HMSO, London.*
36. Dudhani, S.; Sinha, A.K.; Inamdar, S.S. (2006). Assessment of small hydropower potential using remote sensing data for sustainable development in India. *Energy Policy, 34, 3195-3205.*
37. Dutta, S, ; Mishra, A.; Kar, S.; Panigrahy, S. (2006). Estimating Spatial Curve Number for Hydrologic Response analysis of a small Watershed. *Journal of Spatial Hydrology, Vol. 6 (2) 57-67.*
38. Engman, E.T. (1983). Roughness coefficient for routing surface runoff. *Proc. Spec. Conf. Frontiers of Hydraulic Engineering.*
39. ESHA, SERO, IEFE. Blue energy for a green Europe (BlueAGE). Strategic study for the development of small hydropower in the European Union. Report of Altener Programme. Brussels: ESHA; 2001 (Available from http://www.esha.be/).
40. Fontaine, T.A.; Cruickshank, T.S.; Arnold, J.G.; Hotchkiss, R.H. (2002). Development of snowfall snow melt routine for mountaneous terrain for the soil and water assessment tool (SWAT), *Journal of Hydrology, 262, 209-223.*
41. Frey, G.W.; Linke, D.M.; (2002). Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy 30, 1261–1265.*

42. Gallart, F.; Latron, J.; Llorens, P.; Beven, K. (2007). Using internal catchment information to reduce the uncertainty of discharge and baseflow predictions. *Journal of Advances in Water Resources. Vol. 30 (4), 808-823p.*

43. Gassman, P.W.; Reyes, M.R.; Green, C.H.; Arnold, J.G. (2007). The Soil and Water Assessment Tool: Historical development, applications and future research direction. www.brc.tamus.edu/swat.

44. Gossain, A.K.; Rao, S. (2005). Small hydropower assessment using GIS and hydrological modeling- Nagaland case study. *In proceedings of the National seminar on Renewable energy and energy management organized by North Eastern Regional Institute of Water and Land Management, Tezpur (India) during 23-24th August, 2005. 33-46p.*

45. Gossain, A.K.; Rao, S.; Ray, D.B. (2003). Vulnerability assessment of climate change impact on Indian water resources using the SWAT model. *In Proceedings of 3rd International SWAT conference organized by Swiss Federal Institute for Environmental and Science and Technology, Switzerland and SWAT team at Zurich, Switzerland during11-15th July, 2003. 231-240 p.*

46. Goudie, A.; Lewin, J.; Richards, K.; Anderson, M.; Brut, T.; Whalley,B.; Warsley, P. (1990). Geomorphological Techniques. *Edited for British Geomorphological Research Group. University of Oxford. 570p.*

47. Green, W.H.; Ampt, G.A. (1911). Studies on Soil Physics, Part I, The flow of air and water through Soils. *Journal of Agricultural Sciences, Vol. 4, No 1.*

48. Gupta, H.V.; Beven, K.J.; Wagener, T. (2005). Model calibration and uncertainty estimation. *In: Anderson, M.G. (Ed), Encyclopedia of Hydrological Sciences. Wiley, New York, pp. 2015-2031.*

49. Hargreaves, G.H. (1975). Moisture availability and crop production. *Tran. ASAE, 18. 980-984.*

50. Hargreaves, G.H.; Samani, Z.A. (1982). Estimating potential evapotranspiration. Tech note, *J. Irrigation and Drainage Engineering. 108 (3), 225-230.*

51. Hargreaves, G.H.; Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture, 1, 96-99.*

52. Hargreaves, G.L.; Hargreaves G.H.; Riley, J.P. (1985). Agricultural benefits for Senegal River Basin., *J. of Irrig and Drain Engg.* 111(2): 113-124.

53. Hayhoe, H.N.; Stewart,D.W. (1996).Evaluation of CLIGEN and WXGWN weather data generator under Canadian conditions. *Canadian Water Resources Journal*, 21(1): 53- 67.

54. Hershfield, D.M. (1961). Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. *US Department of Commerce Tech Paper No 40.*

55. Horton, R.E. (1932). Drainage basin characteristics. *Transactions of American Geophysics Union, Vol., 13 pp. 350-361.*

56. Horton, R.E. (1945). Erosional development of streams and their drainage basin: hydro physical approach to quantitative morphology. *Bull: Geological Society of America. Vol. 56, pp 275-370.*

57. Howard, A.D. (1971). Optimal angles of stream junction: Geometric stability to capture and minimum power criteria. *Water Resources Research, 7(4): 863-873.*

58. Huber, W.C.; Dickinson, R.E. (1988). Storm Water Management Model Users Manual Ver 5, EPA/600/3-88/001. *Environmental Protection Agency, Athens, GA.*

59. IMD (1999). Climatological Tables of Observatories of India 1951-1980., Controller of Publications, Government of India, New Delhi., 782pp.

60. IT (2005). The best states to live in. India Today. *August 15, 2005, 30-49p.*

61. Jain, M.K.; Soni, B. (1998). GIS based Rainfall-Runoff Modeling of a catchment. *J of Hydraulic Engineering Vol XXI No 1-4., 53-65.*

62. Jang, S.; Cho, M.; Yoon, J.; Yoon, Y.; Kim, S.; Kim, L.; Aksoy, H. (2007). Using SWMM as a tool for hydrological impact assessment. *J. Desalination, Vol. 212, issue 1-3, 344-356.*

63. Jenson, S.; Domingue, J. (1988). Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing, 54: 1593-1600.*

64. Jiandong, T.; Naibo, Z.; Xianhuan, W.; Jing, H.; Huishen, D. (1997). Mini Hydro power. *Published by John Wiley & Sons, West Sussex, England. 312p.*

65. Kaijuka, E. (2007). GIS and Rural Electricity Planning in Uganda. *Journal of Cleaner Production, 15, 203-217.*

66. Kannan, N.; White, S.M.; Worrall, F.; Whelan, M.J. (2007). Hydrological modeling of a small catchment using SWAT-2000 – Ensuring correct flow partitioning for contaminant modeling. *Journal of Hydrology (2007) 334, 64– 72.*

67. Karanth, K.R. (1989). Hydrogeology. *Published by Tata McGraw Hill Publishing Company Limited, Delhi. 458p.*

68. Knebl,M.R.; Yang, Z.L.; Hutchison, K.; Maidment, D.R. (2005). Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMSRAS: a case study for the San Antonio River Basin Summer 2002 storm event. *Journal of Environmental Management, Volume 75 (4), 325-336p.*

69. Konecny, G (2003). Geoinformation Remote Sensing, Photogrammetry and GIS. *Taylor & Francis, London and New York.* 248p.

70. Krause, P.; Boyle, D.P.; B¨ase, F. (2005). Comparison of different efficiency criteria for hydrological model assessment, *Advances in Geoscience (5), 89-97p.*

71. Krishnan, M.S. (1968) Geology of India and Burma, *Higginbothams Madras, 536p.*

72. Kumar, R.; Lohani, A.K.; Kumar, S.; Chatarjee, C.; Nema, R.K. (2001). GIS based Morphometric analysis of Ajay River basin up to Sarath gauging site of South Bihar. *Journal of Applied Hydrology. Vol XIV, No 4., pp 45-54.*

73. Kumar, R.; Singh, R.D.; Sharma, K.D. (2005). Water Resources of India. *Current Science Volume 89, No 5. 794-811.*

74. Kumari, S.; Nair, R.; James, E.J. (2001). Geomorphic Developments of Micro-watershed of Chittar basin with respect to sinuosity index. *Joumal of Applied Hydrology, Vol XIV, No 1, 13-17.*

75. Lal, R. (1987). Need for approaches to, and consequences of the land clearing and developments in the tropics. *In: Tropical Land Clearing for Sustainable Agriculture: Proc. Of an IBSRAM Inaugural Workshop. 15-27. IBSRAM Proc. No. 3, Bangkok, Thailand.*

76. Legates, D. R.; McCabe Jr., G. J. (1999). Evaluating the use of "goodness-of-fit" measures in hydrologic and hydro climatic model validation, *Water Resour. Res., 35, 1, 233–241, 1999.*

77. Leyland, B. (1995). Designing Hydro schemes for remote areas. *India Power, October–December, pp. 3–10.*

78. Lukman, A.P. (2003). Regional impact of climate change and variability of water resources (Case study, lake Naivasha basin, Kenya). *MSc Thesis, Intemational Institute for Aerospcae Survey and Earth Sciences, Enschede, The Netherlands.*

79. Maher, P.; Smith, N. (2001). Pico hydro for village power. *Published under funding of UK Department for Intemational Development.*

80. Meinzer, O.E. (1923). The occurrence of Ground Water in the United States with a Discussion of Principles. *US Geological Survey Water Supply Paper, 489, 321p.*

81. Metacalf and Eddy. (1971). Storm Water Management Model *Vol 1. Water Resources Engineers, University of Florida.*

82. Mishra, A. (2004). Modeling hydrologic processes and non point source of pollution of water in small multivegetated watershed. *Unpublished Ph.D thesis, AgFE, Department, IIT, Kharagpur (India), 223pp.*

83. Mishra, N.; Satyanarayana, T.; Mukherjee, R.K. (1984). Effect of Topo Element on the sediment production rate from the sub watersheds in upper Damodar Valley. *Joumal of Agric. Engg., ISAE: 21 (3). 65-79.*

84. Mishra, S.K.; Singh, V. P. (2002). SCS-CN-based hydrologic simulation package, *Chapter–13 in Mathematical Models in Small Watershed Hydrology, Edited by V. P. Singh and D. K. Frevert, Water Resources Publications, Colorado, 391-464.*

85. Mishra, S.K.; Singh, V.P. (1999). Another look at the SCS-CN method, *Journal of Hydrologic Engineering, ASCE, 4, 257-264.*

86. Mishra, S.K.; Singh, V.P.; Sansalone, J.J.; Aravamuthan.V. (2003). A modified SCS-CN Method: Characterization and Testing, *J. Water Resources Management, Kluwer Academic Publisher (17) 37-68.*

87. Mizukoshi, H.; Aniya, M. (2002). Use of countour-based DEMs for deriving and mapping topographic attributes. *Photogrammetic Engineering and Remote Sensing 68 (1), 83–93.*

88. MNRE (2007). Arunachal Pradesh shows the way for electrification of remote villages through small hydro power. *Akshay Urja, Publication of Ministry of New and Renewable Energy, Government of India. Vol (3) Issue 2,27p.*

89. MoA (2000). WARASA-JAN SAHBHAGITA. Guidelines for National Watershed Development Project for Rainfed Area (NWDPRA). *Ministry of Agriculture, Government of India.*

90. Mohammed, H.; Yohannes, F.; Zeleke, G. (2004). Validation of agricultural non-point source (AGNPS) pollution model in Kori watershed, South Wollo, Ethiopia. *International Journal of Applied Earth Observation and Geoinformation, Vol. 6 (2), 97-109p.*

91. Monteith, J.L. (1965). Evaporation and the environment.. *In The state and movement of water in living organism, XIXth Symposium. Soc. for Exp.Biol., Swansea, Cambridge University Press.* P.205-234

92. MoWR (1998). Water Resources Development in India (1947-1997)" *Ministry of Water Resources, Government of India.*

93. Moxon, S. (1999). Making big business of small hydro. *International Water & Dam Construction, November, pp. 16–20.*

94. Mugabe, F.T.; Hodnett, M.; Senzanje, A. (2007). Comparative hydrological behaviour of two small catchments in semi-arid Zimbabwe. *Journal of Arid Environments, 69, 599-616.*

95. Mulvany, I.J. (1850). On the use of self registering rain nd flood gauges. *Proc. Of Institution of Civil engineers of Ireland, 4,2, 1-8.*

96. Mustafa, Y.M.; Amin, M.S.M.; Lee, T.S.; Shariff, A.R.M. (2005). Evaluation of Land Development Impact on a tropical Watershed

Hydrology Using Remote Sensing and GIS. *Journal of Spatial Hydrology, Vol 5,No 2, 16-30.*

97. Mutreja, K.M. (1990). Applied Hydrology,. *Published by Tata McGraw-Hill Publishing Company Limited, New Delhi.959pp.*

98. Naidu, B.S.K. (1998). Strategy for small hydro development in India. *In: Proceedings of the Financing and Commercialization of Hydel Power in India, CBIP, India, pp. 1–17.*

99. Narayan, D. (1990). Soil Conservation : estimated soil loss in different region. (*cross reference from Shifting cultivation, authored by Jha, L.K., 1997, APH Publishing Corporation).*

100. Nash, J.E.; Sutcliffe, J.V. (1970). River flow forecasting through conceptual model Part-I- a discussion of principles. *Journal of Hydrology 10, 282-290.*

101. National Resource Conservation Service, National Engineering Handbook, (1985). Section 4: Hydrology, Soil conservation Service, US Department of Agriculture, Washington, D.C.

102. Natural Resources Conservation Service Soil Survey Staff, (1996). National soil survey handbook, title 430-VI, US Government Printing Office, Washington, D.C.

103. NBSS&LUP (1999a). Soils of Assam for Optimizing land use, *National Bureau of Soil Survey and Land Use Planning Pub 66. Soils of India Series, 43p.*

104. NBSS&LUP (1999b). Soils of Meghalaya for Optimizing land use, *National Bureau of Soil Survey and Land Use Planning Pub 52. Soils of India Series, 44p.*

105. NEC (1993). Morphological Studies of River Brahmaputra, *North Eastern Council, Government of India.*

106. NEC (2002). Basic statistics of North Eastern Region. *North Eastern Council, Shillong, Government of India, 406pp*

107. Neitsch, S.L.; Arnold, J.G.; Kiniry, J.R.; Williams, J.R. (2002). Soil and Water Assessment Tool theoretical documentation, *Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Grassland, 808 East Blackland Road, Temple, Texas, 458p.*

108. Nicks, A.D. (1974). Stochastic generation of the occurrence, pattern and location of maximum amount of daily rainfall. *In Proc. Symp. Statistical Hydrology, Tucson, AZ. Aug-Sept. 1971. USDA Misc. Publ. 1275. US Gov. Print. Office, Washington D.C. 154-171p.*

109. Nunes,V.; Josh, L.; Genta, J.L. (1996). Micro and Mini Hydroelectric Power Assessment In Uruguay, *WRES, 1235-1238.*

110. Pandey, V.K. (2002). Modeling of an agricultural watershed using remote sensing and GIS linked hydrological model. *Unpublished Ph.D. thesis, AgFE, Department, IIT, Kharagpur (India).*

111. Pandey, V.K.; Panda, S.N.; Sudhakar, S.; Raghuwanshhi, N.S. (2002). Prioritization of Sub watersheds using Remote Sensing and Physically Based Hydrological Model. *In International Conference on Hydrology and Watershed Management,Vol-II; 18-20 December, 2002. 536-546.*

112. Prasad, R.N.; Singh, A.; Verma, A. (1990). Shifting cultivation and land degradation. In: Shifting cultivation. *in North East India, Muzumdar, D.N. ed., Omsons Publications, Allahabad, 143-148p.*

113. Priestley, C.H.B.; Taylor, R.J. (1972). On the assessment of surface heat flux and evaporation using large scale parameters. *Mon. Weather Rev.* 100: 81-92.

114. Punys, P.; Pelikan, B. (2007). Review of small hydropower in the new Member States and Candidate Countries in the context of the enlarged European Union. *Renewable and Sustainable Energy Reviews11 (2007) 1321–1360.*

115. Raghunath, H.M. (1986). Hydrology, Principles, Analysis and Design. *Published by Wiley Eastern Limited, New Delhi. 482pp.*

116. Rallison, R.E.; Miller, N. (1981). Past, present and future SCS runoff procedure. *In V.P. Singh (ed.). Rainfall runoff relationship. Water resources Publication, Littleton, CO, 353-364 p.*

117. Ramachandra, T.V.; Jha, R.K.; Vamsee Krishna, S.; Shruthi, B.V., (2004). Spatial Decision Support System for Assessing Micro, Mini and Small Hydel Potential. *Journal of Applied Science 4(4), 596-604.*

118. Ramakrishnan, P.S. (1992). Shifting Agriculture and Sustainable Development: A interdisciplinary Study from North Eastern India. *In: Man and Biosphere Book Series 10, UNESCO, Paris and Parthenon*

Publishing, Camforth, Lancs, U.K.424 pp. (Re published by Oxford Univ. Press, New Delhi, 424 pp., 1993).

119. Rao, M.; Fan, G.; Thomas, J.; Cherian, G.; Chudiwale, V.; Awawdeh, M. (2006). A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP). *Environmental Modeling & Software xx , 1-11.*
120. Rao, Mohan, R. (1988). Application of remote sensing for development of groundwater resources in parts of Lalit Pur district of Uttar Pradesh. *In: Proceedings of the All India Seminar on Groundwater Development, Lakhnow, India, April 7–8.*
121. Rao, Y.Babu.; Vishwanatahm, R.; Chandraiah, C. (2003). Critical Study of Reservoir Capacity and rate of Sedimentation of Srisailam reservoir by using Remote sensing method and hydrographic surveys. *In Proc of 4th International R&D conference on Water and Energy for 21st Century, 28-31 January, 2003, Aurangabad, Maharashtra, India. Vol. I- 162-173.*
122. Richardson, C.W.; D.A. Wright. (1984). WGEN: a model for generating daily weather variables. *U.S. Department of Agriculture, Agricultural Research Service, ARS-8.*
123. Ritchie, J.T. (1972). Model for predicting evaporation from a row crop with incomplete cover. *Water Resources Research. (8): 1204-1213.*
124. Romanowicz, A.A.; Vanclooster, M.; Rounsevell, M.; Junesse, I. La. (2005). Sensitivity of the SWAT model to the soil and land use data parametrisation: a case study in the Thyle catchment, Belgium. *Ecological Modeling 187 (2005) 27–39.*
125. Rosegrant, M.W.; Cai, X.; Cline, S.A. (2002). Global Water Outlook to 2025 Averting an impending crisis. *Food policy Report published by International Food Policy Research Institute, Washington D.C., USA and International Water Management Institute, Colombo, Sri Lanka. 25pp.*
126. Saikia, R. (1990). Geomorphology of the Kopili Basin, North East India. *Unpublished Ph.D. thesis, Department of Geography, Gauhati University.*
127. Sarma, V.A.K.; Krishnan, P.; Budhilal, S.L. (1987). Laboratory methods-Soil resources mapping of different states of India. *Tech Bull, NBSS Pub 14, NBSS&LUP (ICAR), Nagpur (India), 49p.*

128. SAST .(1992). Research and Technological Development for the supply and use of freshwater resources. Report on the monitoring and modeling. Expert report prepared by I Kruger Consult AS and Danish Hydraulic Institute for the Monitor- SAST Project No 6. Commission of the European Communities. *Satnbury, J (Ed) (1986) Proceedings of the international conference on water quality of the inland natural environment. Bournemouth, England, June 10-13. BHRA.*

129. Satapathy, K.K. (2001). Watershed Management: Concept and Approach., *In Proceedings of the Workshop on Watershed Management in North Eastern Region., Organized by Brahmaputra Board, Ministry of Water Resources, Government of India, Guwahati and Ministry of Agriculture, Government of India, New Delhi.81-90.*

130. Sehgal, J.L.; Saxena, R.K.; Vadivelu, S. (1987). Field Manual-Soil resources mapping of different states of India. *Tech Bull, NBSS Publ. 13, NBSSLUP, Nagpur (India), 73p.*

131. Semenov, M.; Brooks, R.; Barrow, E.; Richardson C. (1998). Comparison of the WGEN and LARS-WG stochastic weather generators for diverse climates. *Climate Research 10, p. 95-107.*

132. Sharpley, A.N.; J.R. Williams, eds. (1990). EPIC-Erosion Productivity Impact Calculator, 1. *Model documentation. U.S. Department of Agriculture, Agricultural Research Service, Tech. Bull. 1768.*

133. Sherman, L.K.; (1932). The relation of runoff to size and character of drainage basin. *Trans. Amer. Geophys. Union 13, 322-339.*

134. Singh, G.; Venkatramanan, C.; Sastry, G.; Joshi, B.P. (1990). Manual of Soil and Water Conservation Practices, *Oxford and IBH Publishing Co Pvt Limited, New Delhi, 385pp.*

135. Singh, S.R. (2006). A drainage morphological approach for water resources development of the Sur catchment, Vidharbha region. *Journal of Indian Society of Remote Sensing, Vol 34(1), 79-88.*

136. Sintondji, Luc Oliver C. (2005). Modeling the Rainfall-runoff process in the upper Ouĕmĕ catchment (Terou in Bĕnin Republic) in a context of global change: extrapolation from local to the regional scale. *Unpublished Ph.D. thesis, Mathematics and Natural Resources Department, University of Bonn, 205pp.*

137. Sloan, P.G.; Moore, I.D. (1984). Modeling subsurface stormflow on steeply sloping forested watersheds. *Water Resources Research. 20 (12), 1815-1822 p.*

138. Smedema, L.K.; D.W. Rycroft. (1983). Land drainage—planning and design of agricultural drainage systems, *Comell University Press, Ithica, N.Y.*

139. Soil Conservation Service. (1972). Section 4: Hydrology, *In National Engineering Handbook, SCS.*

140. Soltani, A. (2000). Evaluation of WEGEN for generating long term weather data for crop simulation. *Agriculture and Forest Meteorology* 102, p. 1-12.

141. Strahler, A.N. (1958). Dimensionless analysis applied to fluvially eroded landforms. *Bull. Geological Soc. Of America, 69, 279-300.*

142. Suresh, M.; Sudhakar, S.; Tiwari K.N.; Chowdary, V.M. (2004). Prioritization of Watersheds Using Morphometric Parameters and Assessment of Surface Water Potential Using Remote Sensing. *Joumal of Indian Society of Remote Sensing. Vol. 32 No 3, 249-259.*

143. Svoboda, A. (1991). Changes in flood regime by use of the modified Curve Number Method, *Hydrological Science Joumal*, Vol.35, No 5/10, pp.461-470.

144. Tolson, B.A.; Shoemaker, C.A. (2007). Cannonsville Reservoir Watershed SWAT2000 model development, calibration and validation; *Joumal of Hydrology (2007) 337, 68– 86.*

145. Tondi, G.; Chiaramonti, D.(1999). Small hydro in Europe helps meet CO2 target. *Intemational Water & Dam Construction, July, pp. 36–40.*

146. Tripathi, M. P. (2003). Hydrological modeling using SWAT for effective management *In Proceedings of 3rd Intemational SWAT conference organized by Swiss Federal Institute for Environmental and Science and Technology, Switzerland and SWAT team at Zurich, Switzerland during11-15th July, 2003. 279-290p.*

147. USDA Soil Conservation Service (1972). Section 4: *National Engineering Handbook, Washington DC.*

148. Van Liew, M.W.; Garbrecht, J. (2003). Hydrologic simulation of the little Wichita river experimental watershed using SWAT. *Journal of American Water Resources Association, 39 (2), 413-426.*

149. Vogel, R.M.; Fennessey, N.M.(1994). Flow-duration curves. I: New interpretation and confidence intervals. *J Water Resour Plann Manage ASCE 1994;120(4):485–504.*

150. Wallis, T.W.R.; Griffiths J.F. (1995). An assessment of the weather generator (WXGEN) used in the erosion/productivity impact calculator. *Agriculture and Forest Meteorology,* 73, p. 15-133.

151. Williams, J.R. (1975). Sediment-yield prediction with universal equation using runoff energy factor. p. 244-252. *In Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment-yield workshop, USDA Sedimentation Lab., Oxford, MS, November 28-30, 1972. ARS-S-40.*

152. Williams, J.R. (1995). Chapter 25: The EPIC model p.909-1000 *In V.P.Singh (ed.) Computer Models of watershed hydrology. Water Resources Publications*

153. Willmot, C. J. (1981). On the validation of models, *Physical Geography, 2, 184–194.*

154. Willmot, C.J. (1984). On the evaluation of model performance in physical geography, *In Spatial Statistics and Models, edited by: Gaile, G. L and Willmot, C.J., D. Reidel, Dordrecht, 443-460.*

155. Wischmeir, W.H.; Johnson, C.B.; Cross, B.V. (1971). A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation 26:189-193.*

156. Wischmeir, W.H.; Smith D.D. (1965). Predicting rainfall erosion losses from crop land east of rocky mountains. *U.S. Department of Agriculture, Agricultural handbook No 282. 48p.*

157. Wischmeir, W.H.; Smith D.D. (1978). Predicting rainfall erosion losses: a guide to conservation planning. *Agricultural handbook 282. USDA.ARS.*

158. World Water Council. (2000). www.watercouncil.org

159. Wurbs, R. A.; James, P.W. (2002). Water Resources Engineering, *Prentice Hall, Upper Saddle River, NJ 07458.*

160. Yogendra Prasad, (2000). Conventional Sources of Energy-need for Sustained Emphasis on Hydro Electricity Development, India Power Vol. VIII(2), April–June,.

161. Young, R.A.; Onstad, C.A.; Bosch, D.B.; Anderson, W.P. (1994). Agricultural Non-Point Source Pollution Model, Version 4.03 AGNPS USER'S GUIDE. *USDA, Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS) National Sedimentation Laboratory.*

162. Yu, B.; Rose, K. J.;Coughhlan; Fentie, B. (1997). Plot-scale rainfall runoff characteristics and modeling at six sites in Australia and South-East Asia, *Hydrological Science Journal, Vol.35, No 5/10, pp.461-470.*

APPENDIX

Appendix- 1

Geological time scale (figures in bracket show the total duration of Groups or System in Million of Years) *(Krishnan, 1968)*

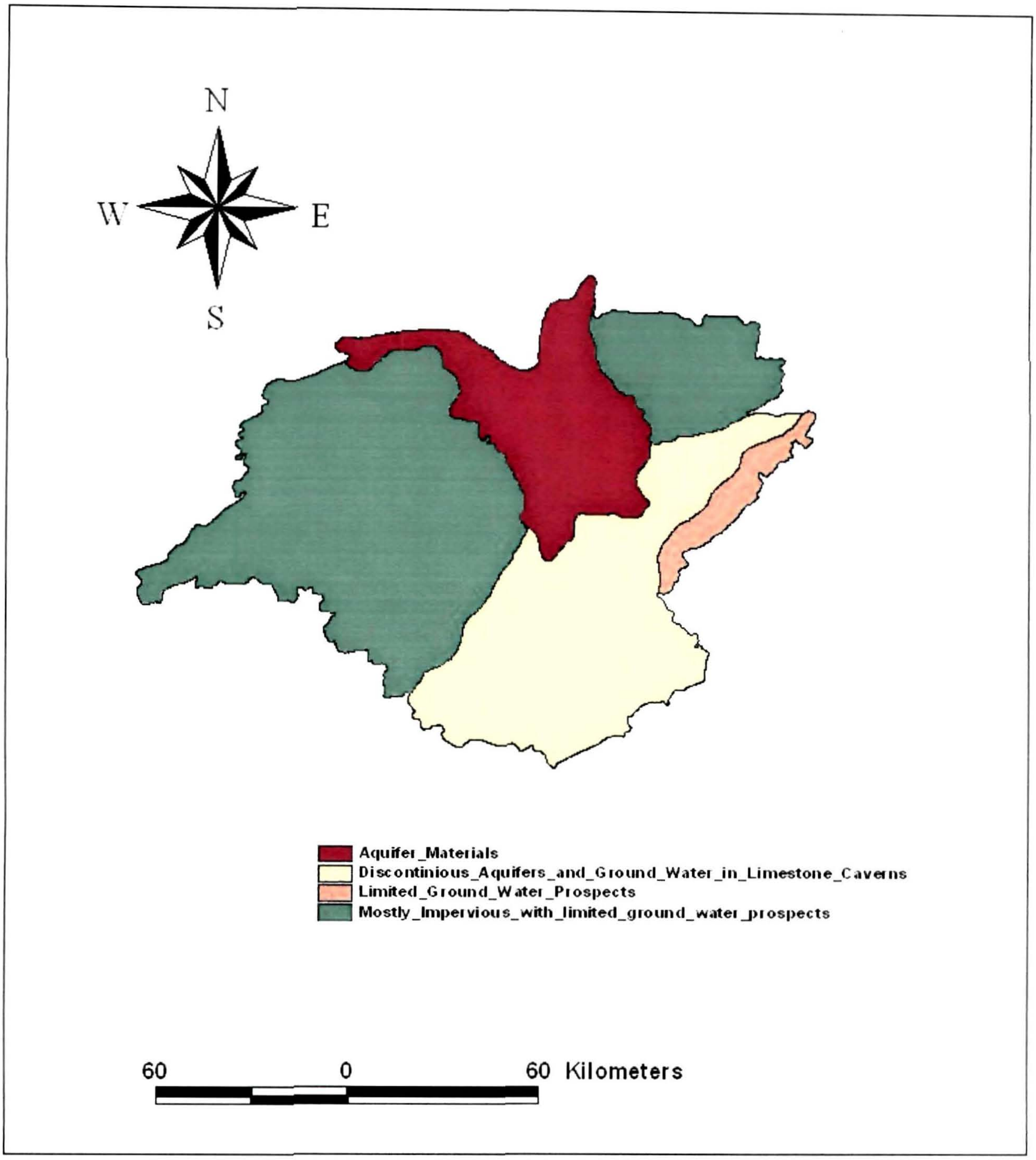
Group	System
Quaternary (1)	Recent (0.01)
	Pleistocene (1)
Tertiary	Piliocene (7)
or	Miocene (17)
Cenezoic (65)	Oligocene (13)
	Ecocene (27)
Mesozoic (180)	Cretaceous (75)
	Jurassic (60)
	Triassic (40)
Palaeozoic (370)	Permian (50)
	Carboniferous (60)
	Devonian (60)
	Silurian (35)
	Ordovician (60)
	Cambrian (100)
Proterozoic	Precambrian (2500)
or Precambrian	
Archean	Archaean (3600)
or	
Azoic	

Appendix- 2 (a)

The geological formations of the Kopili basin are classified into the following order of sequence (Saikia, 1990)

Geological age	Group formation		Rock Type
Recent	Newer alluvium		Clay, sand, silt and shingle
Pleistocene	Older alluvium		Clay, coarse sand and shingle, gravel etc
Pliocene	Dihing group	Dihing formation	Pebble, sandy clay, conglomerate, grit and sand stone
Miocene	Tipam groups	Tipam formation	Greay to grayish conglomerate to gritly ferugenous sandstone, clay shae and conglomerate.
	Surma group		Shale, sandy shale, mudstone, ferugenous, sandstone, conglomerate
Oligocene	Barail Group	-	Shale, sandy, shale, cargonecous shale, interbeded with hard sand stone
Eocene	Disang group	-	Splintary dark greay shale, with thin sand stone beds
	Jaintia Group	Kopili	Shalle, sand stone, and marl
		Shella	Sylhet, sandstone, clay Sylhet limestone, fossiliferous limestones
Jurrassic		Sylhet trap	Traces of trap rocks
Pre-Cambrian	Shillong group		Quartzite, Phyllite and schist
Archean	Gneissic complex		Complex metamorphic rocks composed of Gneiss, mica schist, quartz-schist, granite and diorite intrussives

Appendix- 2 (b)



Hydrogeology Map of Kopili River Basin

Appendix- 3

System Requirements for AVSWAT

The SWAT2000/Arcview Interface requires:

- ✓ Personal computer using a Pentium I processor or higher, which runs at 166 megahertz or faster,
- ✓ 64 megabytes RAM minimum
- ✓ Microsoft Windows 95, 9, NT 4.0 or Win2000 operating system with most recent kernel patch
- ✓ VGA graphics adapter and monitor. *The interface works best when the resolution is set to 800 x 600 or 1024 x 768 pixels, the color palette is set to 8-bit (256 colors) or 16-bit (32768 colors) and the display font size is set to **small fonts**.*
- ✓ 50 megabytes free memory on the hard drive for minimal installation and up to 300 megabytes for a full installation
- ✓ ArcView 3.1 or 3.2 (software)
- ✓ Spatial Analyst 1.1 or later (software)
- ✓ Dialog Developer 3.1 or later (software)

Appendix- 4 (a)

The input Arc View Map themes for SWAT

Sl No	Theme	Purpose
1	ArcView GRID- Digital Elevation Model (DEM)	The interface allows the DEM to use integer or real numbers for elevation values. The units used to define the map resolution and the elevation are not required to be identical. The map resolution must be defined in one of the following units: meters, kilometers, feet, yards, miles, decimal degrees. The elevation must be defined in one of the following units: meters, centimeters, yards, feet, inches
2	Arc View GRID or Shape- Land Cover/ Land use	The categories specified in the land cover/ land use map will need to be reclassified into SWAT land cover/ plants types. The user has three options for reclassifying the categories. The first option is to use USGS category codes when creating the map (or use a USGS land use/ land cover map). The interface contains an ArcView table that identifies the different SWAT land cover/ plants types used to model the various USGS land uses. The second option is to select the SWAT land cover/ plant type or urban code for each category when the land cover/ land use map theme is loaded in the interface. The third option is to create a look up

		table that identifies the 4-letter SWAT code for different categories of land cover/ land use on the map.
3	Arc View GRID or Shape- Soil	The categories specified in the soil map will need to be linked to the soil databse (US soils data only) included with the interface or to the User Soil database, a custom database designed to hold data for soils for soils not included in the US Soil database.
4	ArcView GRID or Shape or Draw manually- DEM Mask (optional)	The interface allows a mask to be superimposed on the DEM. The interface differentiates the mask grid into areas classified as category 0 (no data) and areas classified as any category > 0. Areas of the DEM grid for which mask grid has value of 0 will not be processed for stream delineation.
5	Arc View Shape- Stream delineation (Optional)	The interface allows a ployline shape file with the stream delineation to be superimposed on the DEM. The stream delineation shape file is needed for areas where the relief is so low the DEM map grid is unable to accurately predict the location of the streams.

Appendix- 4 (b)

The input Arc View Tables and text files for SWAT

Sl No	Table or text files	Purpose
1	Subbasin Outlet location Table (dBase table)	To specify the additional subbasin outlet locations. The use of a location table to import locations for subbasin outlets is recommended when the user plans to compare observed or measured data with SWAT results
2	Watershed inlet location table (dBase table)	The watershed inlet location table is used to specify the location of : point sources and drainage watershed inlets.
3	Land use Look up table (dBase or ASCII)	The land use look up table is used to specify the SWAT land cover/plant code or SWAT urban land type code to be modlled for each categry in the land use map grid.. Because the information can be entered manually this table is not required to run the interface. The table may be formatted as dBase table of as a comma delimited text table.
4	Soil Look up Table (dBase or ASCII)	The soil look up table is used to specify the type of soil to be modeled for each categry in the soil map grid. The format of the table will vary depending on the option chosen to link the soil data to the soil map. Because the information can be entered manually this table is not required to run the interface.
5	Weather generator gage location table (dBase)	It contains information regarding custom weather generator stations.

6	Gage location Table (dBase) for precipitation, temperature, solar radiation, wind speed or relative humidity)	When measured data are used, a table is required to provide the location. The gage location table is used to provide the location.
7	Data table (dBase or ASCII) for precipitation, temperature, solar radiation, wind speed or relative humidity)	The table stores daily data of the weather parameters. There will be one data table for every location. The table may be formatted as a dBase table or comma delimited text table.

Appendix- 5(a)

Weather data for Shillong Station

	PCPMM	PCPSTD	PCPSKW	PR_W(1, mon)	PR_W(2, mon)	PCPD
January	13.10	1.92	7.18	0.09	0.31	3.54
February	19.88	3.10	8.38	0.12	0.34	4.45
March	45.47	4.71	4.84	0.16	0.46	7.26
April	118.94	8.01	2.86	0.29	0.65	14.52
May	260.45	16.40	4.03	0.55	0.76	22.38
June	439.50	25.28	3.77	0.63	0.85	25.29
July	455.83	26.86	3.21	0.69	0.86	26.03
August	288.48	16.67	3.71	0.65	0.84	25.00
Septemeber	275.60	15.82	3.48	0.51	0.83	22.91
October	197.77	20.55	6.19	0.26	0.65	14.00
November	35.97	6.66	11.53	0.10	0.49	5.17
December	15.17	3.47	12.67	0.05	0.42	2.69

	TMPX	TMPSTDMX	TMPMN	TMPSTDMN	SolarAV	Dewpt	WNDAV(m/s)
January	14.57	1.91	5.70	1.72	15.04	4.80	1.14
February	16.90	2.52	7.22	2.30	19.22	4.15	1.58
March	21.04	2.64	11.00	2.45	21.78	6.05	2.03
April	23.26	2.50	13.81	2.25	21.06	11.50	2.42
May	23.33	2.02	15.46	1.69	18.22	15.15	2.00
June	23.72	1.80	17.35	1.09	14.47	17.60	1.42
July	23.66	1.74	17.79	0.78	14.94	18.20	1.22
August	23.97	1.60	17.64	1.06	14.69	18.00	1.11
Septemeber	23.15	1.68	16.60	1.14	13.39	17.20	0.92
October	21.67	1.70	14.20	1.82	14.58	14.10	0.81
November	18.99	2.04	10.50	2.26	14.72	9.80	0.83
December	15.93	1.96	6.94	2.09	15.48	5.85	0.78

Appendix- 5 (b)

Weather data for Haflong Station

	PCPMM	PCPSTD	PCPSKW	PR_W(1, mon)	PR_W(2, mon)	PCPD
January	13.00	2.54	8.24	0.04	0.33	1.67
February	26.63	4.16	7.61	0.06	0.37	3.33
March	122.94	13.24	5.11	0.12	0.53	6.56
April	237.46	16.95	3.16	0.26	0.59	12.67
May	287.43	21.88	4.28	0.31	0.57	13.00
June	436.29	27.81	3.12	0.41	0.72	17.66
July	302.97	19.26	3.93	0.43	0.69	18.33
August	256.71	15.16	2.76	0.45	0.58	16.55
Septemeber	131.52	10.60	3.75	0.29	0.42	10.22
October	141.07	14.49	5.36	0.14	0.50	6.89
November	62.96	11.32	8.03	0.07	0.40	3.33
December	2.74	1.18	15.83	0.00	0.67	0.33

	TMPX	TMPSTDMX	TMPMN	TMPSTDMN	SolarAV	Dewpt	WNDAV
January	18.69	1.93	10.29	1.95	15.04	10.25	1.14
February	20.96	2.34	12.55	2.85	19.22	9.85	1.58
March	24.88	2.59	16.28	2.82	21.78	12.50	2.03
April	25.18	2.80	18.02	2.66	21.06	16.83	2.42
May	25.58	2.57	19.23	2.16	18.22	19.40	2.00
June	26.07	2.59	20.51	1.95	14.47	21.35	1.42
July	26.79	2.43	21.03	1.55	14.94	21.75	1.22
August	27.06	2.60	20.93	1.67	14.69	21.90	1.11
Septemeber	27.10	2.14	20.46	1.29	13.39	21.65	0.92
October	25.69	2.18	18.91	2.27	14.58	19.80	0.81
November	22.77	1.98	15.44	2.00	14.72	15.95	0.83
December	20.09	1.99	11.45	2.16	15.48	12.40	0.78

Appendix- 5 (c)

Weather data for Chaparmukh Station

	PCPMM	PCPSTD	PCPSKW	PR_W(1, mon)	PR_W(2, mon)	PCPD
January	17.40	5.08	14.39	0.03	0.17	1.20
February	26.34	4.85	8.37	0.09	0.27	2.47
March	85.27	15.07	12.95	0.09	0.41	4.20
April	227.36	18.85	4.40	0.21	0.51	9.47
May	241.52	16.48	2.81	0.24	0.50	10.08
June	516.57	33.43	3.23	0.32	0.58	12.92
July	591.84	33.73	2.96	0.36	0.58	14.71
August	449.64	26.85	2.45	0.36	0.45	12.07
September	359.55	26.99	4.19	0.21	0.51	9.46
October	140.65	18.21	6.37	0.09	0.47	4.46
November	26.84	7.16	10.90	0.03	0.31	1.07
December	15.53	3.78	8.74	0.02	0.18	0.73

	TMPX	**TMPSTDMX**	**TMPMN**	**TMPSTDMN**	**SolarAV**	**Dewpt**	**WNDAV**
January	21.52	3.00	10.15	1.38	15.04	13.53	0.89
February	24.51	2.41	12.11	1.52	19.22	14.35	1.03
March	28.13	2.56	15.99	3.32	21.78	16.70	1.22
April	30.49	2.67	20.28	3.30	21.06	20.65	1.28
May	31.74	2.44	22.97	2.65	18.22	23.60	1.19
June	32.91	2.19	25.15	1.60	14.47	25.20	1.31
July	32.94	1.87	25.50	1.09	14.94	26.00	1.22
August	33.55	1.53	25.41	1.33	14.69	26.00	1.06
September	32.60	1.69	24.46	1.60	13.39	25.50	1.08
October	30.57	1.69	22.36	2.08	14.58	23.50	0.89
November	27.69	1.61	17.12	3.13	14.72	19.70	0.81
December	23.63	2.37	11.72	2.42	15.48	15.60	0.78

Appendix- 6

Hydrologic soil group classification

Group code	Soil Characteristics (USDA soil texture)	Infiltration rate (mm/hr)	Runoff potential
A	Deep well to excessive drained sand or gravel (sand, loamy sand and sandy loam)	High (>7.6)	Very low
B	Moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. (Silt loam and loam)	Moderate (3.8-7.6)	Low
C	Soils having low hydraulic conductivity, poorly drained and moderately fine to fine textures. (Sandy clay loam)	Low (1.3-3.8)	Moderate
D	Clay soils with a high swelling potential, soils with permanent high water table, soils with clay layer at or near surface and shallow soils over a nearly impervious materials. (Clay loam, silty clay loam, sandy clay, silty clay and clay)	Very low (0.0-1.3)	High

Appendix- 7

General relationship among texture, bulk density and porosity of soils

Textural class	Bulk Density (Mg/m^3)	Porosity (%)
Sand	1.55	42
Sandy loam	1.40	48
Fine sandy loam	1.30	51
Loam	1.20	55
Silt loam	1.15	56
Clay loam	1.10	59
Clay	1.05	60
Aggregated clay	1.00	62

Source:http://www.soils.rr.ualberta.ca/Pedosphere/content/section03/page03_03.cfm

Appendix - 8

Available Water Capacity of Soil Layer (mm/ m soil)

Sl No	Textural Class	Available Water Capacity of Soil Layer (mm/ m soil)
1	Clay	200
2	Clay loam	200
3	Silt loam	208
4	Loam	175
5	Fine sandy loam	142
6	Sandy loam	125
7	Loamy sand	100
8	Sand	83

(Source: British Columbia, Ministry of Agriculture, Food and Fisheries, 2002)

Appendix- 9

Soil Textural classes and related saturated hydraulic conductivity classes

Texture	Textural Class	General	Ksat Class	Ksat Rate (mm/day)
Coarse sand	Coarse	Sandy	V. rapid	> 1219.45
Sands			Rapid	364.95-1219.45
Loamy sands				
Sandy loam	Moderately coarse	Loamy	Moderately rapid	121.91-364.95
Fine sandy loam				
Very fine sandy loam	Medium		Moderate	36.55-121.91
Loam				
Silt loam				
Silt				
clay loam	Mod. fine		Mod. slow	12.18-36.55
Sandy clay loam				
Silt clay loam				
Sandy clay	Fine and very fine	Clayey	Slow	3.63-12.18
Silty clay				
Clay				
Cd horizon Natric horizon, fragipan, ortstein			V. slow or impermeable	0.00-3.63

(Source: http://instaar.colorado.edu/deltaforce)

Appendix -10

Table: Color modifiers for soil albedo

Sl No	Color	Albedo[1]
1	Brown	0.13
2	Red	0.14
3	Black	0.09
4	Gray	0.13
5	Yellow	0.17

1 Add 0.01 for lighter modifiers and subtract 0.01 for dark modifiers. If the additional modifier "very" is present, add or subtract 0.02.

(Source: ICRSAT literature.htm)

Appendix- 11(a)

Soil database for Myntriang and Umkhen watershed

Soil Mapping unit Number	Soil Hydrologic Group	Depth (mm)	Colour	% Sand	% Silt	% Clay	Very fine Sand	Others	Coarse fragments	Fraction of porosity
1	2	3	4	5	6	7	8	9	10	11
MEGHALAYA										
ME07	A	110	10YR3/3M	83.5	7.4	9.1	4.77	78.73	30	0.4
	A	170	10YR4/4 M	79.9	10.4	9.7	3.29	76.61	10	0.4
	A	390	10YR5/6 M	79.4	12.1	8.5	3.74	75.66	10	0.4
	A	200	10YR 6/6 M	89.6	2.1	8.3	2.48	87.12	70	0.46
		870								
ME01	C	150	10YR 4/3 M	43.3	17.6	39.1	10.9	32.4	5	0.54
	C	140	10YR 4/4 M	21	39.9	39.1	3.1	17.9	5	0.54
	B	230	5YR 4/6 M	15.4	35.3	49.3	2.1	13.3		0.51
	C	480	5YR 4/6 M	19.3	25.8	54.9	6.7	12.6		0.58
	C	350	2.5YR 4/6 M	23	21.4	55.6	2.4	20.6	15	0.58
	C	400	2.5YR 4/6 M	21.5	28	50.5	5.3	16.2	30	0.58
		1750								
ME10	B	120	7.5 YR 4/4 m	31.5	40	28.5	5.4	26.1	-	0.54
	B	150	5YR 3/4 M	28.4	44.1	27.5	1	27.4	-	0.54
	B	170	5YR 4/6 M	22.3	42.3	35.4	3.9	18.4	-	0.54

	C	810	2.5YR 4/6 M	29.5	23	47.5	4.1	25.4	-		0.58
		1250									
ME12	C	200	5YR 3/2 M	24.6	31.7	43.7	2.6	22	-		0.58
	C	200	5YR 3/3 M	21.3	26.7	52	2.4	18.9	-		0.58
	C	200	5YR 4/6 M	19.2	24.7	56.1	1.4	17.8	-		0.58
	C	300	2.5 YR 4/6 M	22.4	25.8	51.8	2.2	20.2	-		0.58
	C	400	2.5 YR 5/8	23.3	26.6	50.1	3.3	20	-		0.58
		1300									
ME05	B	130	10 YR 5/6 M	62.3	21.2	16.5	13.3	49		10	0.6
	B	350	7.5 YR 5/6 M	60.8	22.2	17	9.8	51.1		15	0.6
	B	370	7.5 YR 4/6 M	60	17.5	22.5	4.5	5.5		25	0.5
		850									
ME04	C	100	7.5 YR 4/4 M	26	45.8	28.2	3.4	22.6			0.54
	C	200	5YR 4/6 M	14.6	40.9	44.5	1.7	12.9			0.5
	C	420	2.5 YR 4/6 M	9.9	42	48.1	1.5	8.4			0.5
	C	580	2.5 YR 3/6 M	11.3	32.1	56.6	1.4	9.9			0.58
	C	470	2.5 YR 4/6 M	12.4	32.7	54.9	2.2	10.2			0.58
	C	230	2.5 YR 4/6 M	16	29.1	54.9	2.1	13.9			0.58
		2000									
ASSAM											
AS02	B	210	10YR 4/4	50.5	20.5	29				2.7	0.5
	B	270	7.5YR 5/6	40	20.5	39.5				3.5	0.5

	C	300	7.5 Yr 5/6	34	22.5	43.5		2	0.58
	C	470	7.5 Yr 5/6	34.5	22	43.5		1.3	0.58
	C	630	7.5 Yr 5/7	28.1	30.1	41.8		1	0.58
		1880							
AS03	B	140	2.5 Y 4/2	38.5	54.5	7	-		0.5
	B	370	10 YR 5/4	31.4	51.6	17	-		0.5
	C	280	10 YR 5/6	27.5	43	29.5	-		0.5
	C	320	10 YR 5/8	21	36	43	-		0.58
	C	690	75 YR 5/8	23.1	40.4	36.5	-		0.5
		1800							
AS04	B	160	2.5 Y 3/2 M	6.4	49.6	44			0.48
	C	300	10 YR 4/3 M	10.5	37.5	52			0.58
	C	430	10 YR 4/3 M	10.9	32.9	56.2			0.58
	B	360	11 YR 4/3 M	12.6	48.9	38.5			0.48
		1250							
AS09	A	220	10YR 3/3	51	47	2			0.36
	B	380	10 YR 5/6	42.3	48.7	9			0.47
	B	250	10 YR 6/8	28.1	48.4	23.5			0.47
	B	550	7.5 YR 5/8	25.6	49.4	25			0.47
		1400							
AS64	B	220	10 YR 3/3	51	47	2			0.58
	B	380	10 YR 5/6	42.3	48.7	9			0.47
	B	250	10 YR 6/8	28.1	48.4	23.5			0.47
	B	550	7.5 YR 5/8	25.6	49.4	25			0.47
		1400							
AS67	B	150	7.5 YR 5/4	69.8	8.7	21.5			0.5

B	350	6 YR 4/6	56.5	12	31.5	0.5
C	190	2.5 YR 4/8	43.7	19.3	37	0.5
C	460	2.5 YR 4/6	44.7	25.8	29.5	0.5
C	950	2.5 YR 5/6	44.7	22.8	32.5	0.5

Appendix 11 (b)

Soil Mapping unit Number	Soil Hydologic Group	Depth (mm)	Colour	Moist bulk density	Available water capacity of the soil (mm/mm)	Saturated hydraulic conductivity (mm/hr)	Organic carbon	Moist soil albedo	USLE K	Texture
1	2	3	4	5	6	7	8	9	10	11
	MEGHALAYA									
ME07	A	110	10YR3/3M	1.6	0.1	562.513	3.12	0.15	0.0468	loamy sand
	A	170	10YR4/4 M	1.6	0.1	562.513	1.8	0.15	0.0622	loamy sand
	A	390	10YR5/6 M	1.6	0.1	562.513	1.32	0.15	0.0721	loamy sand
	A	200	10YR 6/6 M	1.7	0.083	633.255	0.9	0.15	0.0307	sand
		870								
ME01	C	150	10YR 4/3 M	1.2	0.2	8.81993	2.46	0.15	0.1038	clay loam
	C	140	10YR 4/4 M	1.2	0.2	8.81993	1.36	0.15	0.1565	clay loam
	B	230	5YR 4/6 M	1.3	0.208	6.11576	0.56	0.15	0.1971	silty clay loam
	C	480	5YR 4/6 M	1.1	0.2	4.62105	0.3	0.15	0.1749	clay
	C	350	2.5YR 4/6 M	1.1	0.2	4.62105	0.18	0.15	0.1627	clay
	C	400	2.5YR 4/6 M	1.1	0.2	4.62105	0.12	0.15	0.1732	clay
		1750								
ME10	B	120	7.5 YR 4/4 m	1.2	0.2	8.81993	2.9	0.15	0.1276	clay loam
	B	150	5YR 3/4 M	1.2	0.2	8.81993	2.15	0.15	0.1340	clay loam
	B	170	5YR 4/6 M	1.2	0.2	8.81993	1.64	0.15	0.1472	clay loam
	C	810	2.5YR 4/6 M	1.1	0.2	4.62105	0.59	0.15	0.1539	clay
		1250								
ME12	C	200	5YR 3/2 M	1.1	0.2	4.62105	1.7	0.15	0.1348	Clay
	C	200	5YR 3/3 M	1.1	0.2	4.62105	1.3	0.15	0.1468	Clay
	C	200	5YR 4/6 M	1.1	0.2	4.62105	1	0.15	0.1607	Clay

	C	300	2.5 YR 4/6 M	1.1	0.2	4.62105	0.8	0.15	0.1621	Clay
	C	400	2.5 YR 5/8	1.1	0.2	4.62105	0.7	0.15	0.1637	Clay
		1300								
ME05	B	130	10 YR 5/6 M	1.7	0.125	124.369	0.78	0.15	0.1258	sandy loam
	B	350	7.5 YR 5/6 M	1.7	0.125	124.369	0.38	0.15	0.1326	sandy loam
	B	370	7.5 YR 4/6 M	1.4	0.142	22.7059	0.28	0.15	0.1266	sandy clay loam
		850								
ME04	C	100	7.5 YR 4/4 M	1.2	0.2	8.81993	2.53	0.15	0.1368	clay loam
	C	200	5YR 4/6 M	1.4	0.175	3.66261	0.95	0.15	0.1979	silty clay
	C	420	2.5 YR 4/6 M	1.4	0.175	3.66261	0.57	0.15	0.2481	silty clay
	C	580	2.5 YR 3/6 M	1.1	0.2	4.62105	0.4	0.15	0.2194	clay
	C	470	2.5 YR 4/6 M	1.1	0.2	4.62105	0.21	0.15	0.2133	clay
	C	230	2.5 YR 4/6 M	1.1	0.2	4.62105	0.17	0.15	0.1895	clay
		2000								
ASSAM										
AS02	B	210	10YR 4/4	1.4	0.142	22.7059	0.77	0.15	0.1324	sandy clay loam
	B	270	7.5YR 5/6	1.4	0.2	8.81993	0.62	0.15	0.1415	clay loam
	C	300	7.5 Yr 5/6	1.1	0.2	4.62105	0.59	0.15	0.1491	Clay
	C	470	7.5 Yr 5/6	1.1	0.2	4.62105	0.56	0.15	0.1484	Clay
	C	630	7.5 Yr 5/7	1.1	0.2	4.62105	0.21	0.15	0.1653	Clay
		1880								
AS03	B	140	2.5 Y 4/2	1.4	0.208	25.9007	0.79	0.15	0.1661	silty loam
	B	370	10 YR 5/4	1.4	0.208	25.9007	0.5	0.15	0.1765	silty loam
	C	280	10 YR 5/6	1.4	0.2	8.81993	0.4	0.15	0.1758	clay loam
	C	320	10 YR 5/8	1.1	0.2	4.62105	0.4	0.15	0.1812	Clay
	C	690	75 YR 5/8	1.4	0.2	8.81993	0.25	0.15	0.1818	clay loam
		1800								
AS04	B	160	2.5 Y 3/2	1.4	0.2	3.66261	1.75	0.15	0.2491	silty clay

			M							
	C	300	10 YR 4/3 M	1.1	0.2	4.62105	0.6	0.15	0.2330	Clay
	C	430	10 YR 4/3 M	1.1	0.2	4.62105	0.48	0.15	0.2233	Clay
	B	360	11 YR 4/3 M	1.4	0.204	6.11576	0.42	0.15	0.2385	silty clay loam
		1250								
AS09	A	220	10YR 3/3	1.7	0.125	25.9007	0.69	0.15	0.1559	sandy loam
	B	380	10 YR 5/6	1.4	0.175	24.9879	0.44	0.15	0.1652	Loam
	B	250	10 YR 6/8	1.4	0.175	24.9879	0.39	0.15	0.1794	Loam
	B	550	7.5 YR 5/8	1.4	0.175	24.9879	0.36	0.15	0.1849	Loam
		1400								
AS64	B	220	10 YR 3/3	1.5	0.125	25.9007	69	0.15	0.1204	sandy loam
	B	380	10 YR 5/6	1.4	0.175	24.9879	0.44	0.15	0.1652	Loam
	B	250	10 YR 6/8	1.4	0.175	24.9879	0.39	0.15	0.1794	Loam
	B	550	7.5 YR 5/8	1.4	0.175	24.9879	0.36	0.15	0.1849	Loam
		1400								
AS67	B	150	7.5 YR 5/4	1.4	0.185	22.7059	0.72	0.15	0.0953	sandy clay loam
	B	350	6 YR 4/6	1.4	0.185	22.7059	0.39	0.15	0.1173	sandy clay loam
	C	190	2.5 YR 4/8	1.4	0.2	8.81993	0.45	0.15	0.1389	clay loam
	C	460	2.5 YR 4/6	1.4	0.2	8.81993	0.33	0.15	0.1472	clay loam
	C	950	2.5 YR 5/6	1.4	0.2	8.81993	0.33	0.15	0.1437	clay loam

Appendix 12

Types of Input and Output files created by SWAT 2000 during simulation process

File Type	File content
Watershed Configuration File	The watershed configuration file contains information used by the model to simulate processes occurring within the sub basin and to route the stream loadings through the channel network of the watershed.
Control Input/ output file	The control input/ output file contains the names of the files associated with the sub basins, database files, climate files, watershed-level input and output accessed by the model during a simulation.
Input Control Code File	This required file specifies the duration of the simulation, the printing frequency, and selected options for various processes.
Basin input file	General watershed attributes are defined in the basin input file. These attributes (drainage area, base flow factor and initial soil water content) control a diversity of physical processes at the watershed level. This file contains the input for the entire basin.
Precipitation, Temperature,	The model requires daily precipitation,

Solar radiation and Humidity input files	maximum and minimum air temperature, solar radiation and relative humidity values. These values may be read from records of observed data or may be generated. The files are able to hold records for more than one gauge.
Evapotranspiration file	The model requires daily potential evapotranspiration values. In the present study Hargreaves temperature method has been used.
Sub basin general input file	The sub basin general input file contains information related to a diversity of features within the sub basin. The file contains properties of tributary channels within the subbasin, the amount of topographic relief within the sub basin and its impact on the climate, variables related to climate change, the number of HRUs in the subbasin and the names of HRU input files.
Weather generator input file	The weather generator input file contains the statistical weather parameters needed to generate representative daily climatic data for the sub basins. (Appendix 5 (a), (b) and (c)) provide the data bases of the .weather generator file.
Hydrologic response unit file	The HRU input file contains information related to a diversity of features. Data contained in this file can be grouped into the various categories i.e. area, parameters affecting surface and subsurface water flow, erosion, irrigation applied and management.

Soil File	It contains the soil physical properties of the study watershed as represented in Appendix 6.
Ground water file	This required file contains information about the shallow and deep aquifer in the subbasin. Because land covers differ in their interaction with the shallow aquifer, information in this input file is allowed to be varied at the HRU level.
Main channel input file	This required file contains parameters governing water and sediment movement in the main channel of the subbasin.
Output files	These files are the summary output files. The main model output files are the summary file, .sub basin files and reach. The sub basin output file reports output for over 50 variables related to water, sediment, nutrients, and crops. The channel reach output file includes water, sediment, and entering and leaving the reach. The output variables that were used to evaluate the model performance and to develop management scenarios for the study watershed include surface runoff and sediment yield.

Appendix- 13

Calibration Parameter

Sl No	Parameters	Range
	Crop.dat	
1	Minimum value of USLE C factor for water erosion applicable to the land cover/ plant.(USLE_C)	0.001 to 0.05
	Basin input (.bsn)	
2	Maximum melt rate for snow during (mm/C/day) where °C pertains to air temperature.(SMFMX)	0 to 10
3	Minimum melt rate for snow during the year (occurs on winter solstice) (mm/C/day) (ref the air temperature).(SMFMN)	0 to 10
4	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing.(SPCON)	0 to 0.01
5	Exponent parameter for calculating sediment reentrained in channel sediment routing.(SPEXP).	1 to 1.5
6	Nitrogen percolation coefficient (NPERCO)	0 to 1
7	Phosphorus percolation coefficient (PPERCO)	10 to 17.5
8	Phosphorus soil partitioning coefficient (PHOSKD)	100 to 200
	Chemical (.chm)	
9	Initial labile (soluble) P concentration in surface soil layer (Kg/ha).(SOL_LABP)	0 to 100
10	Initial organic N concentration in surface soil layer (kg/ha) (SOL_ORGN)	0 to 10000
11	Initial organic P concentration in surface soil layer (Kg/ha) (SOL_ORGP)	0 to 4000
12	Initial NO3 concentration (mg/kg) in the soil layer (SOL_NO3)	0 to 5

	Ground Water (.gw)	
13	Base flow alpha factor (days) ALPHA_BF)	0 to 1
14	Threshold depth of water in the shallow aquifer required for return flow to occur (mm) (GWQMN)	0 to 5000
15	Ground water "revap" coefficient (GW_REVAP)	0.02 to 0.2
16	Threshold depth of water in the shallow aquifer for "revap" to occur.(REVAPMN)	0 to 500
	HRU General (.hru)	
17	Soil evaporation compensation factor (ESCO)	0 to 1
18	Average slope steepness (m/m) SLOPE	0 to 0.06
19	Average slope length (m) SLSUBBSN	10 to 150
	Sub basin general (.sub)	
20	Temperature laps rate (C/km) (TLAPS)	0 to 50
	Main channel (.rte)	
21	Channel cover factor (CH_COV)	-0.001 to 1
22	Channel erodibility factor (CH_EROD)	-0.05 to 0.6
23	Effective hydraulic conductivity in main channel alluvium (mm/hr) (CH_K2)	-0.01 to 150
	Management (.mgt)	
24	Biological mixing efficiency (BIOMIX)	0 to 1
25	USLE equation support practice (P) factor (USLE_P)	0.1 to 1
26	SCS Runoff curve number for moisture condition II (CN2)	35 to 90
	Soil (.sol)	
27	Available water capacity of the soil layer (mm/mm soil)	0 to 1

Appendix- 14 (a)

Soil Distribution in Myntriang watershed

Sl No	Mapping Unit	Area (sq km)	Characteristics	Soil Taxonomy
1	AS02	44.3696	Very deep, well drained, clayey soils occurring on moderately sloping side slopes of hills having loamy surface with moderate erosion; *associated with*: Very deep, well drained, loamy skeletal soils occurring on moderately sloping side slopes of hills with moderate erosion hazard and slight stoniness.	Clayey, Typic Hapludults; Loamy- Skeletal, Typic Dystrochrepts
2	AS03	189.2068	Very deep, well drained, coarse loamy soils occurring on moderately steep sloping side slopes of hills having loamy *surface and moderate erosion*; *associated with*: Moderately deep, well drained clayey soils occurring on moderately sloping side slopes of hills with moderate erosion hazard and slight stoniness.	Coarse-loamy, Typic Dystrochrepts; Clayey, Typic Hapludalfs
3	AS04	15.8932	Very deep, well drained, fine soils occurring on gently sloping to undulating upland having loamy surface with moderate erosion; associated with: Very deep, well drained, fine soils occurring on gently sloping plain with slight stoniness and moderate erosion hazard.	Fine, Typic Hapludalfs; Fine Dystric Eutrochrepts
4	AS67	17.8612	Very deep, excessively drained, fine loamy soils occuring on gently to moderatly sloping side slopes of hills having loamy surface with moderate erosion; *associated with*: Very deep, well drained, coarse loamy soils occuring on gently sloping side slopes of hills with moderate erosion	Fine-loamy, Typic Hapludalfs; Coarse-loamy, Typic Hapludalfs
5	AS84	0.0544	Marshy land	
		267.3852		

Appendix 14 (b)

Soil Distribution in Umkhen watershed

Sl No	Mapping Unit	Area (sq km)	Characteristics	Soil Taxonomy
1	AS01	54.741	Very deep, well drained, fine soils occurring on gently to moderately sloping side slopes of hills having loamy surface with moderate erosion; *associated with*: Deep somewhat excessively drained, loamy-skeletal soils occurring on moderately sloping side slopes of hills with severe erosion hazard and slight stoniness	*Fine, Typic Hapludalfs* *Loamy-skeletal, Umbric Dystrochrepts*
2	AS03	195.218	Very deep, well drained, coarse loamy soils occurring on moderately steep sloping side slopes of hills having loamy surface and moderate erosion; *associated with*: Moderately deep, well drained clayey soils occurring on moderately sloping side slopes of hills with moderate erosion hazard and slight stoniness.	*Coarse-loamy, Typic Dystrochrepts; Clayey, Typic Hapludalfs*
3	AS04	0.824	Very deep, well drained, fine soils occurring on gently sloping to undulating upland having loamy surface with moderate erosion; associated with: Very deep, well drained, fine soils occurring on gently sloping plain with slight stoniness and moderate erosion hazard.	*Fine, Typic Hapludalfs; Fine Dystric Eutrochrepts*
4	AS09	107.475	Very deep, imperfectly drained, fine soils occurring on level to nearly level plain having clayey surface with slight erosion; associated with: Deep, imperfectly drained fine silty soils occurring on very gently sloping flood plain with slight erosion and slight flooding.	*Fine Aquic Dystric Eutrochrepts* *Fine silty, Dystric Eutrochrepts*
5	AS67	312.600	Very deep, excessively drained,	*Fine-loamy, Typic*

			fine loamy soils occuring on gently to moderatly sloping side slopes of hills having loamy surface with moderate erosion; *associated with*: Very deep, well drained, coarse loamy soils occuring on gently sloping side slopes of hills with moderate erosion	*Hapludalfs; Coarse-loamy, Typic Hapludalfs*
6	ME01	219.374	Deep, excessively drained, fine soils on moderately sloping side slopes of hills having loamy surface with moderate erosion hazard; *associated with*: Moderately deep, excessively drained, coarse loamy soils on gently sloping hill tops with very severe erosion hazard and strong stoniness	*Typic Kandiudults* *Typic Dystrochrepts*
7	ME04	2.175	Deep, excessively drained fine soils on moderately steep side-slopes of hills having loamy surface with moderate erosion hazard and strong stoniness; *associated with*: Moderately deep, excessively drained, loamy- skeletal soils on very gently sloping hill ops with severe erosion hazard and strong stoniness	*Typic Kandihumults* *Typic Dystrochrepts*
8	ME05	160.771	Deep excessively drained fine soils on moderately sloping side slopes of hills having loamy surface with moderate erosion hazard; *associated with* : Moderately deep, excessively drained, fine loamy soils on gently sloping hill tops with severe erosion hazards and strong stoniness	*Typic Kandihumults* *Typic Dystrochrepts*
9	ME07	14.293	Moderately deep, excessively drained, coarse loamy soils on very steeply sloping hill escarpment having sandy surface with severe erosion hazard and strong stoniness;	*Umbric Dystrochrepts* *Typic Udorthents*

			associated with: Deep excessively drained, coarse-loamy soils on steeply sloping hill tops with severe erosion hazard and strong stoniness	
10	ME10	131.226	Deep excessively drained, fine soils on moderately steep side slopes of hills having loamy surface with moderate erosion hazard; associated with: Deep, somewhat excessively drained, fine loamy soils on moderately steep side slopes of hills with slight erosion hazards	*Typic Kandihumults* *Typic Haplumbrepts*
11	ME12	4.967	Deep excessively drained , fine soils on moderately steep side slopes of hills having loamy surface with moderate erosion hazard; *associated with*: Moderately deep, excessively drained fine-loamy soils on gently sloping hill tops with very severe erosion hazard and strong stoniness	*Typic Kandihumults* *Typic Dystrochrepts*
	Total	**1203.664**		

Appendix 15(a)

Details of the land use in Myntriang watershed

Sl No	Type of land use	Area (sq km)	Percentage area
1	Built up area (Residential low density)	0.03	0.01
2	Evergreen / semi forest (Forest evergreen)	87.19	33.44
3	Shifting cultivation abandoned (Forest mixed)	163.44	62.68
4	Shifting cultivation current (Agricultural land close grown)	10.10	3.88
	Total	260.75	100

** The names inside the parenthesis are as per the designation of SWAT 2000*

Appendix 15(b)

Details of the land use in Umkhen watershed

Sl No	Type of land use	Area (sq km)	Percentage area
1	Built up area (Residential low density)	0.38	0.03
2	Evergreen / semi forest (Forest evergreen)	115.27	9.74
3	Fairly dense mixed forest (Forest evergreen)	54.473	4.60
4	Open pine forest (Pine)	232.81	19.67
5	Pine forest (Pine)	280.96	23.74
6	Dense mixed forest (Forest mixed)	97.27	8.22
7	Shifting cultivation abandoned (Forest mixed)	394.99	33.38
8	Shifting cultivation current (Agricultural land close grown)	7.14	0.6
	Total	1183.30	100

** The names inside the parenthesis are as per the designation of SWAT 2000*

Appendix- 16 (a)

Stream wise power potential (kW) in Myntriang watershed

Stream A

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	7	3000	21	431.59	119.49	56.65
2	8	3500	20	411.04	113.80	53.96
3	9	4000	30	616.56	170.69	80.93
4	10	4500	10	183.94	50.52	24.03
5	11	5000	20	270.76	88.29	38.26
6	12	5500	17	230.14	75.05	32.52
7	14	6500	18	243.68	79.46	34.43
8	15	7000	32	433.21	141.26	61.21
9	16	7500	30	406.13	132.44	57.39
10	17	8000	30	406.13	132.44	57.39
11	18	8500	43	582.13	189.82	82.26
12	19	9000	40	541.51	176.58	76.52
13	21	10000	18	243.68	79.46	34.43
14	28	13500	12	162.45	52.97	22.96
15	38	18500	11	132.80	36.72	17.48
16	54	26500	21	176.05	21.11	11.17
17	60	29500	13	105.85	10.20	4.46
18	66	32500	18	146.56	14.13	6.18
19	70	34500	21	170.99	16.48	7.21
20	76	37500	16	130.28	12.56	5.49
21	78	38500	13	105.85	10.20	4.46
22	79	39000	19	154.70	14.91	6.52
23	82	40500	11	89.57	8.63	3.78
		Total		**6380**	**1750**	**780**

Stream B

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	19	9000	12	72.95	16.24	9.62

Stream C

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	2	0	15	91.23	20.60	11.77
2	3	500	16	97.32	21.97	12.56
3	10	4000	17	103.39	23.35	13.34
4	13	5500	18	109.48	24.72	14.13
		Total				

Stream D

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	2	0	42	105.07	22.66	12.36
2	3	500	55	137.59	29.68	16.19
3	4	1000	40	100.06	21.58	11.77
4	5	1500	10	25.02	5.40	2.94
5	6	2000	12	30.02	6.47	3.53
6	7	2500	18	45.03	9.71	5.30
7	8	3000	21	52.53	11.33	6.18
		Total				

Stream E

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (KW) 50%	75%	90%
1	2	0	105	262.66	56.65	3.09
2	3	500	27	67.54	14.57	0.79
3	4	1000	56	140.09	30.21	1.65
4	7	2500	38	95.06	20.50	1.12
5	8	3000	29	72.54	15.65	0.85
		Total				

Stream F

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	2	0	116	1931.34	530.48	252.36
2	3	500	74	496.63	136.41	64.89
3	4	1000	53	1030.05	282.92	134.59
4	6	2000	12	698.96	191.98	91.33
5	7	2500	49	533.42	146.51	69.70
		Total				

Appendix- 16 (b)

Stream wise power potential (kW) in Umkhen watershed

Stream A

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	4	1500	24	5540.16	727.88	392.37
2	5	2000	13	3000.92	394.27	212.54
3	9	4000	12	2715.80	361.40	214.25
4	10	4500	33	7468.45	993.85	589.19
5	11	5000	52	11768.47	1566.07	928.42
6	12	5500	43	9727.40	1295.02	696.02
7	13	6000	29	6560.34	873.38	469.41
8	15	7000	12	2714.62	361.40	194.24
9	18	8500	17	3845.72	511.98	275.17
10	21	10000	19	4279.51	572.22	306.61
11	27	13000	10	2252.38	301.17	161.37
12	28	13500	12	2702.85	361.40	193.65
13	34	16500	10	2235.70	300.68	160.88
14	37	18000	13	2906.41	390.88	209.15
15	41	20000	23	5142.11	691.56	370.03
16	46	22500	12	2682.84	360.81	193.06
17	53	26000	18	3418.59	452.20	286.94
18	62	30500	13	2453.04	325.84	206.60
19	64	31500	14	2641.73	350.90	222.49
20	66	32500	18	2986.44	399.13	233.97
21	69	34000	15	2472.12	331.82	193.50
22	70	34500	19	3131.35	420.31	245.10
23	76	37500	16	2596.12	350.02	206.40
24	79	39000	16	2596.12	350.02	206.40
25	84	41500	17	2744.20	371.90	218.47
26	87	43000	11	1551.75	206.11	119.24
27	88	43500	11	1551.75	206.11	119.24
28	94	46500	16	2257.08	299.79	173.44
29	97	48000	19	2680.29	356.00	205.96
30	108	53500	11	1038.09	134.89	83.09
31	118	58500	14	1321.21	171.68	105.75
32	130	64500	14	1321.21	171.68	105.75
33	144	71500	11	755.37	103.59	55.57
34	145	72000	17	1167.39	160.10	85.89
35	158	78500	10	225.63	39.24	15.70
36	166	82500	18	369.52	46.10	25.29
37	169	84000	22	304.31	40.04	15.63

38	177	88000	16	166.38	21.97	8.63
39	182	90500	46	478.34	63.18	24.82
40	186	92500	19	191.05	25.16	9.32
41	187	93000	19	191.05	25.16	9.32
42	188	93500	20	201.11	26.49	9.81
43	189	94000	25	251.38	33.11	12.26
44	192	95500	10	58.37	7.36	2.94
45	193	96000	22	128.41	16.19	6.47
46	194	96500	31	180.95	22.81	9.12
47	195	97000	32	186.78	23.54	9.42
48	196	97500	20	116.74	14.72	5.89
49	199	99000	21	122.58	15.45	6.18
		Total		**117400.11**	**15646.56**	**8810.99**

Stream B

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW)		
				50%	**75%**	**90%**
1	2	500	11	162.94	20.50	15.65
2	3	1000	11	162.94	20.50	15.65
3	6	2500	18	266.64	33.55	25.60
4	11	5000	20	296.26	37.28	28.45
5	18	8500	10	118.70	15.21	11.28
6	21	10000	28	332.36	42.58	31.59
7	22	10500	14	166.18	21.29	15.79
8	36	17500	15	26.49	4.42	2.06
		Total		**1532.52**	**195.32**	**146.07**

Stream C

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW)		
				50%	**75%**	**90%**
1	6	2500	12	75.93	9.42	5.30
2	17	8000	15	94.91	11.77	6.62
3	19	9000	13	82.26	10.20	5.74
4	20	9500	22	139.20	17.27	9.71
5	24	11500	16	101.24	12.56	7.06
		Total		**493.54**	**61.21**	**34.43**

Stream D

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW)		
				50%	75%	90%
1	2	500	18	363.75	62.69	25.60
2	5	2000	17	343.55	59.20	24.18
		Total		**707.30**	**121.89**	**49.79**

Stream E

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW)		
				50%	75%	90%
1	2	500	33	299.45	51.80	24.28
2	3	1000	28	254.08	43.95	20.60
3	4	1500	38	344.82	59.64	27.96
4	6	2500	19	172.41	29.82	13.98
		Total		**1070.76**	**185.21**	**86.82**

Stream F

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW)		
				50%	75%	90%
1	3	1000	19	410.06	66.17	24.23
2	5	2000	19	410.06	66.17	24.23
3	6	2500	20	431.64	69.65	25.51
4	8	3500	17	366.89	59.20	21.68
5	12	5500	15	188.35	31.64	11.77
6	16	7500	18	226.02	37.96	14.13
		Total		**2033.02**	**330.79**	**121.55**

Stream G

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (KW)		
				50%	75%	90%
1	2	500	15	339.92	45.62	34.58
2	6	2500	16	362.58	48.66	36.89
3	11	5000	19	410.87	55.85	42.32
4	19	9000	19	189.19	25.16	17.71
5	22	10500	26	258.89	34.43	24.23
6	23	11000	12	119.49	15.89	11.18
7	28	13500	10	99.57	13.24	9.32
8	37	18000	15	34.26	5.42	2.21
		Total		**1814.76**	**244.27**	**178.44**

Stream H

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (kW) 50%	75%	90%
1	2	500	18	396.42	82.11	28.25
2	3	1000	31	682.73	141.41	48.66
3	4	1500	22	484.52	100.36	34.53
4	6	2500	13	286.30	59.30	20.40
5	7	3000	29	638.68	132.29	45.52
6	8	3500	20	440.47	91.23	31.39
7	11	5000	15	290.62	61.80	21.34
8	16	7500	41	794.36	168.93	58.32
9	17	8000	37	716.87	152.45	52.63
10	18	8500	27	523.12	111.25	38.41
11	19	9000	13	251.87	53.56	18.49
12	25	12000	20	387.50	82.40	28.45
13	26	12500	18	348.75	74.16	25.60
		Total		**6242.20**	**1311.25**	**452.00**

Stream I

Sl No	Location	Chainage (m)	Drop	Power Potentiality at Dependability Flow (KW) 50%	75%	90%
1	2	500	29	112.37	9.96	4.27
2	3	1000	20	77.50	6.87	2.94
3	4	1500	19	73.62	6.52	2.80
4	5	2000	40	155.00	13.73	5.89
5	8	3500	19	73.62	6.52	2.80
6	11	5000	52	130.08	10.20	5.10
		Total		**622.19**	**53.80**	**23.80**