ABSTRACT

INTEGRATED MICRO-WATERSHED MANAGEMENT IN MEGHALAYA PLATEAU - A GEOGRAPHICAL ANALYSIS

By

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A THESIS

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Thesis

ABSTRACT

Land and water are the most vital natural resources and these are under tremendous stress due to ever increasing biotic pressure. The optimal management of these resources with minimal adverse environmental impact is essential not only for sustainable development, but also for the human survival. Watershed management implies the rational utilization of land and water resources for optimum agricultural production with minimum hazard to natural resources. The concept of watershed management is the essential adoption of soil and water conservation practices in the watershed.

The natural landscape of Meghalya Plateau, especially its southern slopes, have been subjected to intensive acceleration of hydrological processes The areal variation of the average annual rainfall of the state with respect to its southern plateau has been found to vary from 1,200 mm to 12,000 mm. The occurrence of 90 % of the annual precipitation over the shallow soils and poor vegetal cover of the southern slopes creates seasonal floods during monsoon and, at the same time, this area reels under acute shortage of drinking water during the lean season. In addition, the increased human interference in terms of land mining and quarrying and faulty agricultural practices being resorted to along the hilly slopes, has degraded the land resources through heavy soil loss. In fact, against 55.83 % of the geographical area of Meghalya being affected by different types of land degradation, 52 % land of the total geographical area of the state, is affected by soil erosion.

In order to understand the natural intricacies of Meghalya Plateau, the watershed area of river Umiew, located on the southern slopes of Meghalya Plateau, has been selected for detail study. The watershed of Umiew river is located in the East-Khasi Hills District of Meghalaya between the average altitude of 1,650 m to 2,000 m with the average annual rainfall of 2,000.54 mm as recorded at IMD, Shillong.. The area of the watershed extends from 25^0-25' to 25^0-31' N latitudes and 91^0-45' to 91^0-52.7'E longitudes.

While dealing with the integrated management of micro-watersheds, the anthropogenic influence, though it directly concerns the management issues of

the watersheds, has not been dealt here. Therefore, this study is mainly concentrating on the analysis of geo-hydrological characteristics of Umiew watershed located in the East Khasi Hills District of Meghalya and its influence on soil erosion and water conservation. The hydrological studies include:

(i) The Rainfall Frequency Analysis,

(ii) The Derivation of synthetic Unit Hydrograph,

(iii) The Effect of Erosivity Index on Sediment Loss,

(iv) The Probability Analysis of occurrence of rainfall, and

(v) The Rainfall -Intencity-Duration Frequency Analysis.

Influence of geo-hydrological characteristics on the soil erosion and water conservation has been analyzed by delineating this watershed area into nine micro-watersheds namely, Mawphlang (Um1), Umgot (Um2), Mawreng (Um3), Nongkrem (Um4), Nongkynrih (Um5), Basio (Um6), Laitkroh (Um7), Laitkynsew (Um8) and Dympep (Um9) with the sizes varying from 5.59 Km^2 to 44.04 km^2. The soil erosion sensitiveness of the micro-watersheds have been done through their prioritization. These micro watersheds have been subjected to morphometric analysis for detecting soil erosion risk proneness and their prioritization as per erosion risk assessment. The analysis has generated data on morphometric parameters (physical characteristics) which could be used to relate quantitatively the process of sediment yield taking place from these micro-watersheds. The Integrated Land and Water Information System (ILWIS)-3.1 version and a Geographical Information System (GIS) software, have been used for the generation and analysis of morphometric parameters, relief features, slope and the land use pattern. The land use pattern of the delineated micro-watersheds existing on 2nd November, 2000 has been interpreted with the help of satellite imagery acquired by IRS-1D from LISS-III Sensor. The rainfall characteristics to the adjoining areas of this Umiew watershed have also been analyzed for predicting the availability of weekly rainfall at different probability levels. An attempt has been made to analyse the weekly rainfall data pertaining to Shillong IMD station for the monsoon period from 1996-2002 for predicting the availability of weekly rainfall at the probability levels of 10%, 20%, 50% and 80%. The rainfall erosivity index has been computed by analyzing the daily rainfall data of IMD, Shillong for the monsoon period from 1996-2002. The selected watershed is very close to IMD observatory located in upper Shillong. The influence of erosivity index on the sediment yield rate has been studied. The relationship between the monthly flow of river Umiew and its sediment yield, and also between the monthly erosivity index and sediment yield during monsoon months, have been established by carrying out logarithmic regression analysis. In the absence of long term rainfall and observed discharge of river Umiew, the applicability of Synthetic Unit Hydrograph for the estimation of peak discharge of river for the specific return period, has also been checked up.

The findings, which have emerged after the detail study, are indicated below:

(1) Prioritization of the micro-watershed which is done by considering geo-morphic and land use characteristics of the study area, clearly reveals that the micro-watersheds, irrespective of their various stages of landscape evaluation has become soil erosion sensitive. The soil erosion interventions may be applied to the micro-watersheds depending upon the degree of sensitivity with which the micro-watersheds are affected to.

(2) The IDF chart prepared by applying log-Pearson Type-III distribution function is applicable to find out the theoretical values of rainfall intensity for any duration from 15 minutes to 120 minutes and for the return periods of 5 years to 50 years.

(3) The rainfall intensity for the desired frequency has been can be computed from this chart for the duration equal to the time of concentration of the watersheds and the same has been may be used in the rational method for estimating peak runoff from small watersheds. Thus, log-Pearson Type-III is the ideal distribution for showing the rainfall pattern of the southern slopes of Meghalaya.

(4) While comparing the Intensity-Duration-Frequency (IDF) chart, prepared by applying log-Pearson Type-III distribution function with IDF relationship developed by ICAR, Barapani, Shillong, it is obvious from analysis that the

variation in the distribution of rainfall intensity of lower duration storms are recorded higher and vice-versa. It shows that the lower duration rainstroms are more fluctuating with frequent occurrences in the area.

(5) The log-Pearson Type-III distribution function is also found best fitted function as compared with others for the prediction of soil loss through the Universal Soil Loss Equation.

(6) Since the monthly rainfall computed from the observed rainfall values at 80 % probability level has been fairly higher to the tune of 105.25 mm and 106.42 mm respectively. The month of May itself can be utilized for the seedling and transplantation of kharif paddy. The rainfall during the months of July to September may be utilized for meeting the requirement of the paddy by making a provision of supplemental irrigation during this period.

The variations in the size and frequency of occurrences of rainfall in the micro-watershed areas have caused high variability in the monsoon discharge of the river Umiew. The range of variation between the observed minimum and maximum discharge during the monsoon months in 1996 has been found to be in the ratio of 1:227.5 to 1:3.29. For providing the supplemental irrigation under the scenario of high seasonal variability in the monsoon discharge of Umiew river, a three tier system for the conservation and utilization of rain water in the micro-watersheds of river Umiew could be introduced with certain modifications over the system of conservation suggested by Gupta and Narayan (1974) and Narayan and Pandey (1976). The modified features of suggested design are as:

A series of dugout storage ponds with adequate capacity, estimated on the basis of water availability study, may be panned at different elevation of the lands under all the nine micro-watersheds of river Umiew. These dugout storage ponds may be connected suitably by the drainage channels. The impounded water from the dugout ponds located at higher elevation, after getting utilised by the crop, the excess drainage water may be collected by the dugout ponds located at next lower elevation. This way the rain water tapped at higher altitude of the micro-watershed area may be utilized optimally by the lands located at different elevations. The remaining excess water may then be discharged into the regional drainage system.

(7) It has been found from the average values of the monthly erosion index that the month of June, July, August and October have considerable erosion potential (Table-6.2). The agricultural field used to have crop canopy during October and remains almost barren. In order to safe guard the agricultural field from soil erosion adoption of proper crop management and soil conservation measures are essential to minimize the effects of rain storm. Similar suggestions have also been offered by the Indian Council of Agricultural Research (ICAR) for its model micro-watersheds developed at Barapani (Satapathy, 1996).

(8) The analysis of rainfall and erosion index has indicated that erosion index is influenced more by the higher intensity of rainfall than its overall magnitude. The single storm erosion index and sediment yield rate data of river Umiew for the period 1996-98 reveal that erosion index contributes significantly in enhancing the sediment yield rate. Wischmeier (1957) has also substantiated this finding that, if all factors other than rainfall are held constant, the annual erosion losses from cultivated areas are directly proportional to the yearly values of the erosion index.

(9) The analysis of discharge and sediment-erosivity index has revealed that there is a noticeable time lag between the rain drop striking the soil surface and its effect in the form of sediment yield. The reason for this time lag could be attributed to the time consumed right from the soil particles getting detached by the impact of rain drop upto getting these particles transported by overland flow through the connecting streams of different orders and finally coming into the main stem of river Umiew.

(10) In the absence of long-term rainfall and observed flow data, no empirical model can be developed or extended. However, the Regional Unit Hydrograph (RUH) relationship developed by CWC is the suitable may be used with a fair degree of accuracy in computing the Peak-discharge of river Umiew.

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I, Dilip Kumar Singh, hereby declare that the subject matter of the thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to any body else, and that the thesis has not been submitted by me for any research degree in any other University/Institution.

This is being submitted to the **NORTH EASTERN HILL UNIVERSITY** for the degree of Doctor of Philosophy in Geography.

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Dilip Kumar Singh 25/09/03
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Place – Patna

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Chapter-1

Introduction

1.0 Introduction

Land and water are the most vital natural resources and these are under tremendous stress due to ever increasing biotic pressure. The optimal management of these resources with minimal adverse environmental impact is essential not only for sustainable development, but also for human survival. Watershed is an ideal unit calling for multidisciplinary approach to the resources management for ensuring continuous benefit on sustainable basis. Integrated watershed management is a prerequisite not only for land, water and bio-mass management of degraded areas but also for conservation of protected areas, so that, bio-diversity and genetic riches are protected for future generations.

Watershed management implies the rational utilization of land and water resources for optimum agricultural production with minimum hazard to natural resources. The concept of watershed management is the essential adoption of soil and water conservation practices in the watershed. The aims of these conservation practices are proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction, and increasing productivity from all land uses.

With increasing awareness about the problems related to environment, the use of watershed terminology is becoming popular. Development programs envisaged under watershed purview include almost every activity, which concerns land, water and biomass production. Though the watershed development approach was adopted as early as 1949, status wise as of today, it yet stands fragmented in terms of activities, programs and fundings (Vaidyanathan, 1991).

1.0.1 Conceptual Premises : Originating from the science of hydrology, the term watershed management has over the years acquired much wider implications. This term is now used for a variety of development projects involving natural resource management. The implications, quite often, are understood differently by different persons, including those engaged in planning and implementing watershed management projects. The conceptual differences on the implications of such development arise primarily due to the adoption of differing thrust areas. In this context, mainly three approaches have been conceptualised. These approaches are: Technical, Empowerment and Conservation. The *technical* approach includes the application of large scale soil and water conservation measures including afforestation within the natural boundary of a watershed. The development philosophy of the watershed under *empowerment* approach is issued as one of the instruments for bringing about various social, cultural, political and economic changes in favour of the disadvantaged groups and taking up useful activity for capacity building and empowerment of such groups. Lastly, the *conservation* approach which refers to the integrated development of the natural resource base through intensive community participation for the creation of community assets. Any part of natural environment such as, land, water, air, forest, plant, wildlife, fish and even human population which are being utilized to promote human welfare is regarded as natural resource. These three approaches are shown through flow diagram in Fig.- 1.1.

Bali (1998) has suggested that Watershed management is the harmonious development and management of land and water resources within the natural boundaries of a watershed, so as to promote or produce on a sustainable basis, abundance of plants and animals and their products and still deliver clean and controlled flow of water to the downstream. Gregersen *et al.* (1987), based on these conceptual premises, have indicated that Watershed management is the process of formulating and carrying out a course of action involving the manipulation of natural, agricultural and human

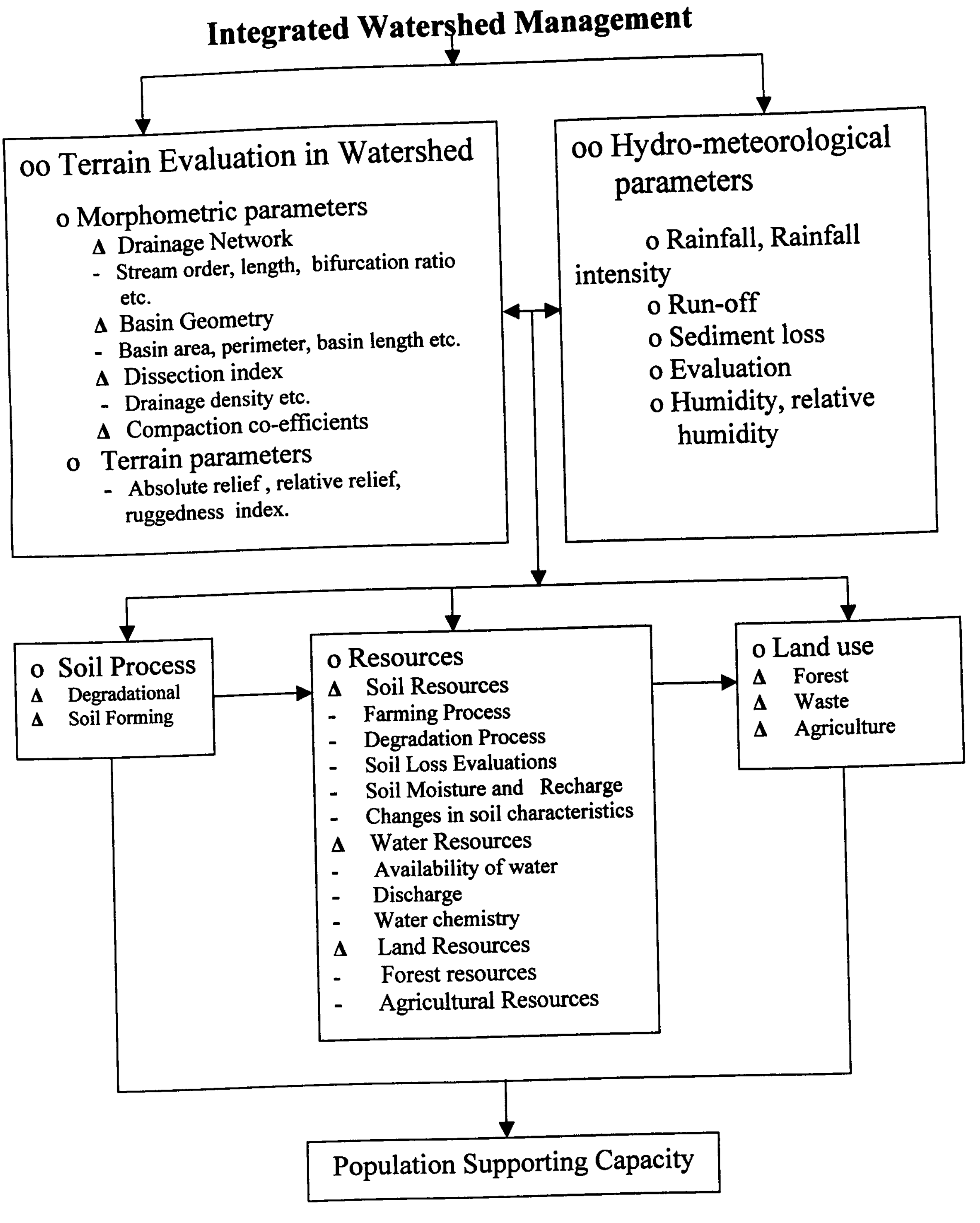
Integrated Watershed Management
oo Terrain Evaluation in Watershed
o Morphometric parameters
Δ Drainage Network
- Stream order, length, bifurcation ratio etc.
Δ Basin Geometry
- Basin area, perimeter, basin length etc.
Δ Dissection index
- Drainage density etc.
Δ Compaction co-efficients
o Terrain parameters
- Absolute relief, relative relief, ruggedness index.
oo Hydro-meteorological parameters
o Rainfall, Rainfall intensity
o Run-off
o Sediment loss
o Evaluation
o Humidity, relative humidity
o Soil Process
Δ Degradational
Δ Soil Forming
o Resources
Δ Soil Resources
- Farming Process
- Degradation Process
- Soil Loss Evaluations
- Soil Moisture and Recharge
- Changes in soil characteristics
Δ Water Resources
- Availability of water
- Discharge
- Water chemistry
Δ Land Resources
- Forest resources
- Agricultural Resources
o Land use
Δ Forest
Δ Waste
Δ Agriculture
Population Supporting Capacity

Fig. –1.1

resources in a watershed to provide goods and services that are desired by and suitable to the society, but under the condition that soil and water resources are not adversely affected. This must consider the social, economic and institutional factors operating within and outside the watershed.

As a rule, conservation requirements should be evaluated and incorporated in agricultural development plans for the opening up of new lands and for changes in land use aimed at increased production (Dhruva Narayana *et al.* 1983). A course of action to halt degradation must be consciously followed to ensure that the land will be used effectively for the present and future generations.

Watershed development approach is an intensive one and may sometimes appear to the traditionalists to be initially expensive (in a relative sense) over the "seed and fertilizer approach" (Dhruva Narayana *et al.* 1983). The Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun had undertaken the economic evaluation of the watershed approach in some of the operational Research Watershed Projects. These watershed projects are located at Fakot in Tehri-Garhwal District, Uttar Pradesh (Anonymous 1978) , Sukhomajri in Chandigarh (Mishra *et al.* 1981) and G. R. Halli in Chitradurga District, Karnataka (Anonymous 1981). In each case, complete watershed of 300-400 ha have been covered for development. The works involved under this development were fuel-fodder plantations in the denuded catchments, construction of erosion control structures like check dams, graded bunds, construction of small water storage reservoirs, adoption of appropriate cropping systems, cultural methods and water management practices. These economic evaluations have shown that the integrated watershed development approach is economically beneficial. The overall benefit cost ratios have been found greater than 1.8:1, specially in places where dependable water resource is developed in such a programme.

1.0.2 Statement of the Problem: Prevalence of the intensive acceleration of hydrological processes and the increased conflicting human interactions with natural resources in terms of land, water and vegetative cover, leads the natural landscape to a severe problem of degradation in Meghalya Plateau.

Some areas of this plateau, especially the areas of southern slopes, namely, Cherrapunjee, Sela and Baghmara areas, are under the conditions of severe soil erosion risk. As a result of high rate of soil loss, these areas contain a thin layer and poor vegetal cover and have been declared as "Wet Desert Areas". On the other hand, there is a dearth of data on land uses and land degradation at micro level, which is one of the main constraints in rationalizing the problem.

Therefore, to understand the intricacies of the multi faceted problems of Meghalya plateau, the watershed of river Umiew which is located between 91°- 46′ to 91°- 56′ E longitudes to 25°- 26.5′ to 25°- 32′ N latitudes on the Southern slopes of East Khasi Hills, has been identified to study the influence of such extreme geo-hydrological condition on soil erosion and water conservation.

The slope of drainage pattern of the upper most reaches of the watershed moves towards Southern slope of the Shillong Peak. This is the highest peak in the East Khasi Hills having an altitude of 1964 m. The Umiew River initially flows towards Eastern Side for about 10 km and then to the West upto the confluence with its major tributaries, namely Umtyngar and Umjyllieng. The river then flows towards the South below the confluence along the Southern slope of Khasi Hills and enters into Bangladesh beyond shella at Indo-Bangladesh Border. It joins there with the river Surma. The area of Umiew watershed upto the proposed dam site at Mawphlang is 136.45 km^2.

1.0.3 Objectives of the Study: The catchment or watershed is a natural integrator of all the hydrologic phenomena pertaining to its boundaries and ,as such, it is a logical unit for planning optimum developments of soils and water resources (Holtan 1969). While dealing with the integrated management of micro-watersheds, the anthropogenic influence, though it directly concerns the management issues of the watersheds, has not been dealt here. Therefore, this study is mainly concentrating on the analysis of geo-hydrological characteristics of Umiew watershed located in the East Khasi Hills District of Meghalya and its influence on soil erosion and water conservation. The hydrological studies include:

(i) The Rainfall Frequency Analysis,

(ii) The Derivation of Synthetic Unit Hydrograph,

(iii) The Effect of Erosivity Index on Sediment Loss,

(iv) The Probability Analysis of occurrence of rainfall, and

(v) The Rainfall -Intencity-Duration Frequency Analysis

1.0.4 Materials and Methods: The geo-ecological zonation of Meghalaya plateau has been done into four parts. The zonations include the Central part, Western, North – Eastern part and Southern slopes of the Khasi hills between the flat lands of Shillong Massif and Dawki fault.These zonations are based on the basis of inter relationships and interactions of geomorphological, hydrological and land use characteristics of the area. The geo-ecological characteristics of these zones have been dealt in details under Chapter-3. by covering the physiography, Geology - structure and tectonics, land systems and hydrological characteristics. The relief features and the slopes of Meghalaya plateau, which have the direct bearing on hydrological attributes, micro-climatic conditions and land use and land cover patterns, have been dealt under Chapter-3. The thematic maps related to soils of Meghalaya generated by National Bureau of Soil Survey and Land use Planning (NBSS & LUP) and dealing with soil drainage, water holding capacity of the soils, soil reaction, soil depth, organic carbon, surface texture and erosion potential, have also been discussed in this chapter in general and with reference to the analysis of soil samples collected from different places of Umiew watershed area. The analysis of these soil samples has been done for organic carbon, soil texture and water quality.

The areas of drainage basins situated in the central parts of Meghalaya, have moderate to poor drainage density (below 4.5 km per sq km.). Most of the parts of Garo hills and the tributaries of Kopili river of the North-Eastern parts of the plateau have excellent and extremely excellent drainage density of more than 4.5 km per sq km, though the precipitation is very less in these areas. The drainage basins situated on the Southern slopes of the Khasi hills between the flat lands of Shillong massif and Dawki fault, have excellent drainage density (more than 4.5 km per sq km) with fast flowing water in the gorges and river valleys. The distribution patterns of drainage density in Meghalya are shown in Fig. 3.3 under Chapter-3.

The analysis of geo-hydrological characteristics of Umiew watershed has been done by delineating it into nine micro-watersheds. Subsequently, these micro watersheds have been subjected to morphometric analysis for detecting soil erosion risk proneness and their prioritization as per erosion risk assessment. The details of this analysis has been covered under chapter-4. The analysis has generated data on morphometric parameters (physical characteristics) which could be used to relate quantitatively the process of sediment yield taking place from these micro-watersheds. The Integrated Land and Water Information System (ILWIS)-3.1 version and a Geographical Information System (GIS) software, have been used for the generation and analysis of morphometric parameters, relief features, slope and the land use pattern. The land use pattern of the delineated micro-watersheds has been interpreted with the help of satellite imagery acquired by IRS-1D from LISS-III Sensor on 2nd November, 2000.

The rainfall characteristics to the adjoining areas of this Umiew watershed have also been analyzed for predicting the availability of weekly rainfall at different probability levels. However, the higher probability levels have been suggested for planning the agricultural activities.

The review of literature covered under para-Hydrometerology in chapter-2 has revealed that the scientific explanation of hydro-meterological phenomena prevailing in Meghalaya Plateau has not been made through detail investigation. In this direction, an attempt has been made to analyse the weekly rainfall data pertaining to Shillong IMD station for the monsoon period from 1996-2002 for predicting the availability of weekly rainfall at the probability levels of 10%, 20%, 50% and 80%. The planning of agricultural activities in Umiew watershed has been suggested on the basis of availability of monthly rainfall at 80% probability during monsoon months.

An attempt has been made to compute the rainfall erosivity index by analyzing the daily rainfall data of IMD, Shillong for the monsoon period from 1996-2002 and to study its influence on the sediment yield rate. The relationship between the monthly flow of river Umiew and its sediment yield, and also between the monthly erosivity index and sediment yield during monsoon months, have been established by carrying out logarithmic regression analysis. The discharge and erosivity index have been taken as independent variables and that of sediment yield being the dependent variable. The correlation test is used to find out the best possible relationship between them. The analysis of the observed discharge and sediment yield rate data of river Umiew and the computed maximum single storm erosion index has been forwarded to assess the impact of erosion index on the sediment yield rate.

In the absence of long term rainfall and observed discharge of river Umiew, the applicability of Synthetic Unit Hydrograph for the estimation of peak discharge of river for the specific return period, is checked up.

The assessment for the degradation of the natural resources, particularly the soil loss, is done. The strategies required for effective and efficient utilization of rainfall during dry spell of monsoon, lean period and during abrupt withdrawals of monsoon have also been chalked out. In view of prevalence of high variations between the observed maximum and minimum monsoon discharge, the modified system of water conservations in the form of laying down a series of well connected dug out wells at different altitudes of watershed areas, is suggested.

The entire material of the processed tables and explanations are arranged into seven chapters. The tabulated large calculations have also been appended with the text for the support of study material.

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Chapter-2

Chapter-2

Review of Literature

2.0 Introduction

Out of four indispensable natural resources that sustain life – air, sunshine, soil and water- the first two are substantially beyond human influence and control. The remaining two that are soil and water, may be amended by management to provide a better environment for human beings. As such, watershed, which is a natural integrator of all the hydrologic phenomena pertaining to its boundaries, is to be a logical unit for planning optimum development of soil and water resources specially in hill and mountain areas.

The literature review presented here mainly refers to works which are directly or indirectly useful for and related to the background of the present study, The literature on watershed studies has been classified under four major aspects of available literature, namely, (i) the Watershed Studies in India, (ii) the Watershed Development and Management with special reference to Development of Soil and Water Resources, (iii) the Hydrological Studies related to Watershed Management, and (iv) the Consequences of Hydrological Events like Soil Erosion and Land Degradation.

2.1 The Watershed Studies in India

Considerable studies have been reported on large watersheds and river catchments in India but, a few studies are important to refer here with regard to micro wartersheds of the country. Conceptually, micro watershed is a small "cosmos" in which the study of micro biotic and abiotic factors of nature may be visualised. The detailed watershed studies may reveal the type of conservation measures suitable for the efficient management of the resources available in these watersheds.

A variety of relationships among the resources and environmental parameters are established through watershed studies. Raghunath, *et al.* (1967) reported that by adopting contour farming, cultivated on 25 % slope, the runoff was reduced from 52 to 29 mm and soil loss from 39.0 to 14.9 t/ha for a specific environment of Ooty. The experiments of Tejwani *et al.* (1975) in Doon foot hills of Western Himalyas have shown that contour cultivation reduces runoff and prevents soil erosion. Bhatia and Chaudhary (1978) have done similar studies for the middle Ganga plains considering Kanpur plains. Rambabu, *et al.* (1974) have observed for Dehra Dun that, as a result of field bunding of agricultural watershed, there has been a 62% reduction in runoff and 40% reduction in the peak runoff rate through field bunding in the foot hill areas of Doon Valleys. Bansal and Husenappa (1977) in their studies done at Dehra Dun have reported that a bunded agricultural watershed of 12 ha had less runoff and peak discharge than another unbunded watershed of 294 ha. Similar results have been reported from Chandigarh by Sudh, *et al.* (1977), where bunding of agricultural land reduced runoff, peak, discharge and soil loss. Bunded area also gave 10 % more crop yield than unbunded area. At Agra, it has been observed that field bunding of an agricultural watershed (22.3 ha) reduced the runoff by 45 % (Bhatia *et al.* 1978).

There are a few studies on methodological aspects specially on the assessment of run off and discharge from the watershed. Gupta, *et al.* (1970) have concluded that peak runoff rates can be estimated by the nomographs prepared on the basis of (i) rational formula, (ii) Cook's method, and (iii) hydrologic soil cover complex method for small watersheds upto its areal extent of 300 ha. The studies conducted by Nema and Kamanwar (1976) on the soil and water conservation in watershed at Vasad area have shown that, when 1422 tons of sediment from an untreated catchment of 67 ha is delivered to a treated catchment of 72 ha, the most of shares of these sediments are either contained or retained in the latter catchment. Such studies provide a proper way to the assessment of natural resources and changes there in over time.

2.2 Watershed Development and Management with special reference to Development of Soil and Water Resources

Catchment management implies rational utilization of land and water resources for optimum and sustained production with the minimum hazard to natural resources. It essentially relates to soil and watar conservation in the watershed which means proper land use and the protection of land against all forms of deterioration and also implies maintaining soil fertility, conserving water for farm use, proper management of local water for drainage, flood protection and the increase of productivity in different land uses (Tejwani 1979).

The International Institute of Tropical Agriculture and other International Centres are now turning to the broader issues of watershed management. Watershed management is concerned with control of water, particularly control of water which is tranferred from the upper to the lower parts of catchment areas. The amount of water moving out from the upper parts of watershed depends on the difference between rainfall and evapotranspiration. The evapotranspiration itself depends on the vegetation, the depth, and the water holding capacity of the soil and the surface runoff. Thus, the amount of water running off and leaving the upper catchment and the seasonal flow of the stream are primarily dependent on the land use management (Russel, 1979). According to Dixon (c.f. Chow, 1964), watershed management is conservation and improvement of the soils, sediment abatement, runoff retardation, forests and grass land improvement, and protection of water supply. Keeping these aspects of watershed, the following measures of land improvement are adopted as:

(i) the Soil Conservation Practices,

(ii) the Forest and Range Management Practices,

(iii) the Head-water Control Structures,

(iv) the Debris Detention Dams, and

(v) the Small Reservoirs and Farm Ponds.

Presently, the scattered programmes of soil conservation, afforestation, minor irrigation, animal husbandary, sheep development activities, which are undertaken on an ad-hoc basis should be well-knit into the watershed projects following a study of climate, land, water and plant resources on one hand and man and animal resources on the other so as to bring about sustained natural resources development based on the principles of integration of resources and ecology, economics, employment generation and energy conservation in the watershed.

The conservation measures for land and water are contour bunds, check dams, terraces, gully plugging, vegetable cover (strip cropping), afforestation, land management, stream bank protection etc. (Raghunath, 1985). These measures are necessary to retard the velocity of runoff to control soil erosion and to absrob more water in the soil.

The choice of the management practices should be based on information of hydrologic cycle of the watershed. A coordinated effort of engineers, agronomists, culturists, farmers, geologists, hydrologists and economists would be very much desirable in an integrated management venture of small catchment (Pereira, 1979).

2.3 the Hydrological Studies related to Watershed Management

The entire area of a river basin whose surface runoff due to storm rains flows into the river in the basin, is considered as a hydrologic unit and is called a drainage basin, watershed or catchment area of the river (Morisawa 1968).

The small watershed and its characteristics have been described by the Committee on Runoff of the American Geophysical Union (Chow 1964) as follows:

"From the hydrologic point of view, a distinct characteristic of the small watershed is that on which the effect of overland flow rather than the effect of channel flow is a dominating factor affecting the peak runoff. Consequently, a small watershed is very sensitive to high intensity rainfall of short duration and to land use. On larger watersheds, the effect of channel flow or the basin storage effect becomes very pronounced so that such sensitivities are greatly suppressed. Therefore, a small watershed may be defined as one that is so small that its sensitivities to high intensity rainfall of short duration and to land use are not suppressed by the storage characteristics. By this definition, the size of a small watershed may be found from a few ha to 1000 ha. The upper limit of the area depends on the conditions at which the above mentioned sensitivities become practically lost due to channel storage".

In light of the above statement, drainage basins or watersheds may be classified as large and small, not on the basis of their sizes, but on the effects of certain dominating factors as explained by the Committee on Runoff of American Geophysical Union.

The types of hydrologic analyses made on a small catchment are largely depend on the availability of hydrologic data as suggested by Ogorosky and Mockus (c.f. Chow 1964):

Type 1: Determination of 'hydrologic elements is made for a rainfall or runoff events of a specific date or time, such as the determination of the hydrograph for a catchment for a given storm or the determination of the total water yield for a given calender year. Determination of this type requires local hydrologic data of relatively high accuracy.

Type 2: Determination of hydrologic elements is made on the basis of probability such as the determination of (a) the peak flow of a certain frequency or (b) the annual water yield of a certain frequency or (c) the annual water yield of a certain percent chance from a given catchment. Such types of determinations of hydrologic elements are based on frequency studies available in the specific reports or may be drawn by the use of a long record of a hydrologic station . According to Ogorosky and Mockus, the major factors to be considered in a hydrologic study on small watersheds are:

(i) Precipitation (rainfall),

(ii) Evapotranspiration,

(iii) Catchment characteristics such as size, shape, slope, soil type, soil erosion, and

(iv) Runoff characteristics with respect to lag-time, quantity of flow, and its spatio-temporal distribution.

The watershed characteristics pertaining to morphometry can be ascertained from soil maps, areal photographs and topographic maps. The law of drainage basin development and shape factor can be arrived at using conventional methods (Schumm 1956, Miller 1953, Taylor and Scwartz 1952, Strahler 1957, Melton 1958, Morisawa 1959, Hack 1957). Peak runoff decreases as the catchment area increases due to higher time of concentration. A fan shaped catchment produces greater flood intensity than a fern shaped catchment (Knapp 1979). According to Viessman, et al. (1977), *the catchment characteristics affecting runoff are:* geologic factor, morphometric parameters, and physiographic characteristics of watershed.

If streamflow data are neither available at all nor available for sufficiently long time for the purpose of detail analysis, runoff can be estimated by mathematical modelling (Zoch 1934, Dooge 1959, and Diskin 1964). Information on runoff volume is necessary for estimation of storage capacity and for designing structure for disposal of surplus water (Wasiullah and Rambabu 1970). It may be estimated by parametric methods. Contour cultivation, contour bunding, and bench terraces reduce runoff, peak discharge and soil loss (Tejwani *et al.* 1975, Raghunath *et al.* 1967, Bhatia and Chaudhary 1978, Rambabu *et al.* 1974, Bansal and Husenappa 1977, Sud *et al.* 1977).

2.4 The Consequences of Hydrological Events like Soil Erosion and Land Degradation

Soil erosion is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and siltation in natural streams elsewhere. Excessive erosion from the area may lead to severe loss of valuable fertile surface soils which affect the agricultural productivity. It also reduces the water retention capacity of the land and, hence, may result in increased runoff. The eroded surface soils from the basins are deposited in the downstream region. This could effect the natural balance in the flood plains and also the resevoirs etc.

2.4.1 Classification of Erosion: Soil erosion has been classified by erosive agents causing the occurrences and affecting the course of erosional processes. The erosive agents are water, glacier, snow, wind, man, animals, etc. Here the review of Soil Erosion would be confined to water erosion due to rainfall erosivity.

There is a direct relationship between total run off and soil loss from agriculture areas. The factors influencing soil erosion are climate, soil, vegetation and topography. Of these, the vegetation and to some extent the soils are controlled. The climatic factors and topographic factors are beyond the power of man to control.

Soil erosion is divided into two major types – geologic erosion and accelerated erosion. Geologic erosion occurs when the soil is in its natural environment under the protective cover of native vegetation and hence, sometimes referred to as natural erosion. It includes soil forming as well as soil eroding processes which maintain the soil in a favourable balance, suitable for the growth of most plants. Soil loss in excess of geologic erosion is called accelerated erosion.

Water erosion is subdivided into raindrop's, sheet, rill, gully and stream channel erosion. Raindrop's is soil splash resulting from the impact of water drops directly on soil particles or on thin water surfaces. Rain water, which cannot absorb into the soil and ,therefore, flows over the land, carries with it fertilizer ingredients in solution and particles of soil and manure in suspension. Sheet erosion is the uniform removal of soil in thin layers from sloping land through overland flow. This starts in an insidious way skimming the surface uniformly. If the slope of the land is more, the moving water instead of flowing evenly tends to concentrate in depressions and develops erosive power and thereby cutting the field into small incision called rills. When this rill erosion is neglected, the flowing water increases sufficiently in volume as well as in velocity and makes deep cuts in the land which are called gullies. Ultimately the field is badly cut up resulting in such a form that it results in decreasing agricultural productivity, increasing the stream pollution and reduced capacities and lives of water reservoirs.

The erosional processes that result from mechanical forces such as rainfall impact, splash, and water film transport and that occur in the region between two rills can be defined as Interill soil erosion (Meyer 1981).

The rate of interrill soil erosion relates to factors such as slope steepness, rainfall, and soil properties. The overall erosional processes have been recently separated into interrill and rill sub-processes.

The mechanism of rainfall impact can be considered as transfer and redistribution of dynamic energy from raindrops to surface soil particles in contact with the raindrops, thereby inducing separation of soil particles and their transport by surface runoff. (Liebenow *et al.* 1990).

In many studies, such as those by Neal (1938), Foster et al. (1977), Foster (1982) and Watson and Laflen (1986), equations similar to equation (1) were used to indicate interrill soil erosion rate (D_i) as :

$$D_i = K_i \, S_f \, I^p \quad \ldots \quad \ldots \quad \ldots \qquad (1)$$

where, K_i is the interrill soil erodibility factor, I is rainfall intensity, S_f is an interrill slope steepness factor, and p is an exponent.

2.4.2 The Rainfall Intensity: A more general statistical equation was developed by Meyer (1981) wherein the relationships between interrill soil erosion rate (D_i) in g $m^2 \, s^{-1}$ and rainfall intensity in mm hr^{-1} could be expressed exponentially as :

$$D_i = a \, I^p, \quad \ldots \quad \ldots \quad \ldots \qquad (2)$$

where a and p are the coefficient and exponent of best fit respectively. It was also found that p is equal to 2 for soils with <20% clay content and decreases with an increase of clay content up to 20%.

2.4.3 The Slope Steepness: In general, the interrill slope steepness factor (S_f), expressed in sine function of the surface slope (θ degree), is used to describe the relationship between soil erosion and slope steepness.

Watson and Laflen (1986) studied three different soil samples with slopes of 10-50% and found that the relationship between slope and steepness factor can be described as :

$$S_f = a \sin^b \theta + c, \quad \ldots \quad \ldots \quad \ldots \qquad (3)$$

Liebenow *et al.* (1990) developed a new equation with the analysis of experimental data with slopes of 52% which can be expressed as :

$$S_f = 1.05 - 0.85 \exp(-4 \sin \theta), \quad \ldots \quad \ldots \quad \ldots \qquad (4)$$

From equations (3) and (4), it can be visualised that there is a reduced effect of slope steepness on interrill erosion as the slope increases. It has been reported that runoff increases with the increase in slope steepness upto 45% and thereafter it decreases with further increase in slope (Singh 1985). It is due to the fact that the amount of rainwater falling per unit area of land surface decreases with the increase of slope. The topographical effect on the variation of rainfall was studied in hilly micro watershed area at Barapani in Meghalaya by means of a network of seven rain gauges spread over the area during 1987 and 1988. It was observed that the annual rainfall decreases with the increase of elevation due to the combined effect of wind and topography (Satapathy 1996).

2.4.4 The Soil Properties: The resistance of soil to erosion is strongly related to soil properties, including soil texture, cohesion strength and aggregate state. The sediment transport capacity of interrill uniform flow is significantly related to the median particle diameter (d 50). The inetrrill soil erosion has been found to be related to shear strength (Watson and Laflen 1986, Bradford *et al.* 1987) and clay content (Meyer 1981, Al-Durrah and Bradford 1981, Elliot *et al.* 1989). In addition, the splash erosion from one single rain drop is also related to soil shear strength (Cruse and Larson 1977, Al-Durrah and Bradford 1981).

The continuing depletion of soil resources and non-point source pollution problems stimulate the need to estimate soil conservation goals and standards. In order to create a soil erosion control planning process, the maximum acceptable rate of soil erosion and sediment yield must be specified. At the sites where soil erosion standards are not being met, land use changes or management practices working against the adopted standards have to be identified and corrected (Ventura *et al.* 1988). Soil erosion control planning needs information on the best possible locations for several different kinds of erosion control measures.

2.4.5 Universal Soil Loss Equation: The Universal Soil Loss Equation (USLE) is an erosion model designed to predict the long term average soil loss from a specified land in a specified cropping and management system. The equation predicts only the losses from sheet and rill erosion under specified conditions (Wischmeier and Smith 1978). It enables to determine the land management erosion rate relationships for a wide range of rainfall, soil slope, crop and management conditions and to select alternative cropping and management combinations that limit erosion rates to acceptable levels. The Universal Soil Loss Equation (USLE) is notated as :

$$A = RK\,\underline{LS}\,CP, \quad \ldots. \quad \ldots \quad \ldots. \qquad (5)$$

where, A = the soil loss in tonnes per hectare per year, R = the rainfall erosivity factor which is the number of rainfall erosion index units on annual basis for a particular location, K = the soil erodibility factor which compares the actual erosion to that erosion from a clean, tilled, followed, uniform slope of 9% and length of 22.13 m, L = the slope length factor is the ratio of soil loss from the field slope length to that from a 22.13 m length under identical conditions, S = the slope steepness factor is the ratio of soil loss from the field slope gradient to that from 9% slope under otherwise identical conditions, C = the cover and management factor is the ratio of soil loss from an area with specified cover and management to that from and identical area in tilled continuous fallow, and P = the support practice factor which is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight row farming up and down the slope.

Knowing the values of rainfall erosivity, soil erodibility and slope, one can calculate the effectiveness of various erosion control measures to use, if one decides to introduce a cultivation system into and area with soil loss not exceeding an acceptable erosion rate. The literature available on these soil loss factors may be referred to here.

(a) The Rainfall Erosivity Factor (R): The soil erosivity factor is quantified by the R term in the equation (5). Both rainfall determines the R factor and the energy imparted to the land surface by the rain-drop impact. Wischmeier (1959) found that one hundredth of the product of the kinetic energy of the storm (KE) and the 30 min. intensity (I_{30}) is the most reliable single estimate of rainfall erosion potential and termed it as EI_{30}. Annual total of storm value is referred to as the rainfall erosion index. The location value of this index is R in the USLE.

Soil loss measurement made in 23 states of the United States showed that when factors other than rainfall were held constant, storm soil losses from cultivated fields were directly proportional to the product value of total kinetic energy of the storm and its maximum 30 min intensity (EI_{30}). However, there have been few exceptions in tropical countries in Africa and Asia.

Experiments conducted in Western Nigeria indicated a Lesser correlation between EI_{30} and soil loss (Lal 1976). In India (specially for the areas of Dehradun, Coimbatore and Ootacamund), attempts were made to find out correlations between EI_{30} values and soil loss from bare plots. The results indicated that EI_{30} values gave a better correlation ($r = 0.74$) with soil loss at Dehradun (Ram Babu *et al.* 1970). Till sufficient soil loss data from field plots for large number of storms from various locations become available to disprove the reliability of EI_{30} value in estimating soil loss, EI_{30} can continue to be the most reliable estimate of rainfall erosion potential in our country.

The monthly seasonal and annual EI_{30} values for 45 stations situated in Northern, Central, Western, Eastern and Southern Zone of India have been computed and reported elsewhere (Ram Babu *et al.* 1978). Except southern zone, nearly 75-98% of the total EI_{30} values are concentrated during June-September (rainy months).

Based on average annual EI_{30} data for 45 stations and computed values of 180 stations, an iso-erodent map of India was prepared (Ram Babu *et al.* 1978). The map can be improved upon further when data from larger number of recording rain gauge stations become available.

The values of erosion index which are expected to exceed, on the 1 in 2 years, 1 in 5 years and 1 in 10 years return periods were also reported by Ram Babu *et al.* (1978). This would help in estimating soil loss that will be exceeded 1 in 2, 5 and 10 years return periods by assigning 2, 5 and 10 years return period values of erosion index for R factor in USLE.

(b) The Soil Erodibility Factor (K): The soil erodibility factor (K) in the USLE relates to the rate at which different soils erode. Under the conditions of equal slope, rainfall, vegetative cover and soil management practices, some soils will erode more easily than others due to inherent soil characteristics.

The soil erodibility factor in USLE was originally determined quantitatively from the run-off plots. The direct measurement of K on unit run-off plots reflect the combined effects of all variables that significantly influence the ease with which a soil is eroded or the particular slope other than 9% slope. The soil loss is adjusted through slope factor S.

The adjusted soil loss, $A = Ao / S$, ... (6)

where A = soil loss expected from 9% continuous fallow plot having been tilled up and down the slope and length of 22.13m, Ao = observed soil loss in S% slope fallow plot of 22.13 m length, S = slope gradient factor for S% slope.

In the unit plot each of the parameters L,S,C and P has a value of 1.0. The estimated K is then computed by various workers :

K = Total adjusted soil loss (A)/(R), ... (7)

In India, there is a wide variation in the soils of different agro-climatic regions and it would not be possible to evaluate the soil erodibility factor (K) of these soils from run-off plot studies. It is, therefore, suggested that the future studies should be undertaken to determine the value of K based on the monograph suggested by Wischmeier *et al.* (1978). The studies have shown that erodibility factor determined by runoff plots and monograph compare quite well (Wischemeier *et al.* 1978).

(C) The Slope Length Factor (L): The slope length factor is the ratio of soil loss from the field slope length to that from the 22.13m length plots under identical conditions.

Data from slope length experiments have indicated that soil loss is a function of $(Lp)^m$, where Lp represents plot length in metres (or in other units) and m is constant. Zingg (1940) proposed a value of m = 0.6. This was changed to 0.5 + 0.1 (Smith and Wischmeier 1962). Taking an average value of m = 0.5, the slope length chart has been developed by Wischmeier and Smith (1965).

In India, the results of the studies related to the effect of length of slope on soil loss in not very conclusive. At Rehmankhera site of the central ganga plains (near Lucknow), studies were conducted on plots of 18, 37, 57 m lengths on 0.5% slope. Fifteen years data showed that soil loss decreased with increasing slope length. At Chandigarh in the foothills of Western Himalyas, the soil loss decreased consistently with the increase in slope length (90-120 m and 150 m) in all years of study (Gurmel Singh *et al.* 1981). These are quite contrary to the relationship suggested by Wischmeier and Smith (1978). Rao (1981) conducted study on the plots of 25, 37.5, 50 and 60 m length considering 2% slope in the lower Ganga plains in Bengal at Kharagpur. The study showed that the soil loss had increased with the increase in slope length up to 50m. At 60m length, the soil loss did not exactly follow the same pattern.

It is found that the magnitude of soil erosion does not seem to increase appreciably with increasing the slope length (Table.2.1). The results showed that the soil loss has increased with the increase in slope length up to 44m. At 66m length, the soil loss did not follow the same pattern, which seems similar to the equation suggested by Wischmeier and Smith (1978).

Table-2.1: Soil Loss (t/ha) from Land Slopes of Varying Lengths (Vasad).

Length of slope (m)	1982	1983	Average
11	19.3	63.0	41.2
22	24.0	67.4	45.7
44	23.2	71.5	47.4
66	15.2	59.1	37.2

Source: Dhruvanarayana (1993).

(d) The Slope Gradient Factor (S) : The slope gradient factor (S) is the ratio of soil loss from the field slope gradient to that from the 9% slope under other wise identical conditions. Zingg (1940) was the first worker to give the comprehensive review of the work on slope factor and concluded that soil loss varies as the 1.49 power of % slope. In 1947, Musgrave recommended the use of 1.35 power of % slope. Smith and Wischmeier (1962) combined the data of several workers and formed a very good least squares fit to the equation.

$$A = 0.43 + 0.30\,s + 0.043\,s^2, \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

where, A is the soil loss and s is % slope.

This equation was further modified for determination of the S factor of the USLE as given below :

$$S = 0.43 + 0.30s + 0.043s^2 / 6.613, \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

The slope gradient equation has been recently modified by Wischmeier and Smith (1978) as follows :

$$S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065, \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

where, S is slope gradient factor and θ is angle of the slope.

In black soils of Bellary (Karnataka), the soil loss data were collected from run-off plots on 1 and 2% slopes. It was observed that the soil loss followed the pattern suggested by Zingg (1940) and the value of exponent "m" was found to be 1.39 with standard error of 0.127 (Tejwani *et al.* 1975).

At Rehmankera (Lucknow) and Kharagpur, the studies were conducted on different slopes of 0.5, 1.5 and 3.0% and 2.0, 3.5 and 5.0% respectively. At both the places, the soil loss increased with increase in the degree of slope for all the years of study (Gurmel Singh *et al.*, 1981).

Wischmeier *et al.* (1958) also obtained a non-linear form of relationship between soil loss and slope.

(e) The Topographic Factor (LS): The LS is a expected ratio of soil loss per cent area from field slope to that from 22.13 m length of 9% slope. Although L and S factors can be determined separately by the method described earlier, the procedure has been further simplified by combining the L and S factors together. Based on observations from crop land on slopes ranging from 3 to 18% and on length from 10 to 100m, Wischmeier and Smith (1978) derived this equation for the topographic parameters as:

$$LS = \left(\frac{X}{22.13}\right)^m (65.41 Sin^2\theta + 4.58 Sin\theta + 0.065), \quad \ldots \quad \ldots \quad \ldots \qquad (11)$$

where, X is the slope length in meters, θ is the angle of slope and m is a variable depending upon the steepness of slope. Based on the above equation, a nomograph for determining LS factor was developed for convenience (Wischmeier and Smith, 1978).

(f) The Cropping Management Factor (C): The cropping management factor is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean, tilled fallow on identical soil and slope and under the same rainfall conditions.

Erosion from a field is greatly influenced by density, kind of crop cover and root growth, water-use by the growing plants and amount of prior crop residues in the plough layer. These conditions differ significantly within the period from planting to harvest of the corp. It is also affected by the distribution of the erosive rains within the year. Considering these factors, Wischmeier and Smith (1978) sub-divided the crop season into 6 growth periods. The cover factor for various types of crops and the 6 cultivation stages have been given in a series of tables in Wischmeier and Smith (1978). These 6 crop growth stages generally do not fit well in the Indian conditions where the crop growing season is much shorter than the crop season on which the original crop stages have been defined. In India, it may be quite sufficient to divide the 100-120 days crop-growth period of *Kharif* season into

3 or 4 uniform crop-growth stage periods. Some of the Indian researches (Rao 1981) have divided the growth period up to 3 stages as given below:

Stage 1 - Germination and Seedling (Establishment stage): Seedling to 1-month Stage of crop growth,

Stage 2 - Active vegetative Stage (Maturity stage): From 1 to 2 months crop Growth, and

Stage 3 - Final growth and maturity: End of Stage 2 to crop harvest Stage.

The ratio of soil loss under a given crop stage period (derived from run-off plot data) is given a weightage in accordance with the percentage rainfall factor (R) of that particular period to obtain the C values. Percentages of monthly R factor which can be used for various crop-stage periods have been determined for 45 stations in India (Gurmel Singh *et al.* 1981). Based on the detailed data of soil loss from run-off plots for various crop stages, the values of C for common crops of Kharagpur, Kota and Vasad (Baroda) regions have been worked out by Rao (1981) and Nema *et al.* (1978) respectively.

(g) The Supporting Conservation Practice Factor (P): In general, whenever slopping land is to be cultivated and exposed to erosive rain, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the run-off and ,thus, reduce the amount of soil it carries. Most important of the supporting practices are contour cultivation, strip cropping, terrace system and waterways for the disposal of excess rainfall.

Factor P in the USLE is the ratio of soil loss with a specific supporting practice to the corresponding loss with up-and down cultivation. The work related to supporting practice factor (P) for Indian condition has been reviewed.

(i) Contour Cultivation : The studies conducted on large field plots of 91.5 x 15.2 m size at Dehradun and at Ootacamund, 25 m x 4.65 m at Kanpur and at Hazaribagh, the P factor for contour cultivation was determined and its values are presented in Table-2.3 (Tejwani *et al.* 1975, Bhatia *et al.* 1977, Gurmel Singh *et al.* 1981).

(ii) Bunding and Terracing (Contour Bunding) : Chandigarh Research Centre has worked out the average value of P as 0.28 for bunded plots for the alluvial soils having 1.5% slope (Agnihotri *et al.* 1997). Maize crop was grown in the plots having 150 m length.

(iii) Graded Bunding , Channel Terrace and Strip Cropping : Based on the data collected at Dehradun in large field size plots (100m x 20m and 100m x 15m) on 4% slope, the values for the erosion control practice factor P have been worked out (Table-2.2) (Singh *et al.* 1981).

Table-2.2: Supporting Conservation Practice Factor (P) at Dehradun, Ootacamund, Kanpur and Hazaribagh.

Treatment	Dehradun 4% slope (Maize)	Ootacamund 25% slope (Potato)	Kanpur 2.2% slope (Jowar)	Hazaribagh 5% slope (Maize)
(a) Up-and-down slope cultivation	1.00	1.00	1.00	1.00
(b) Contour cultivation	0.74	0.51	0.39	0.31
(c) Bare cultivated fallow treated with shallow furrows	-	0.59	-	-

Source: Singh, *et al.* (1981) .

(iv) Bench terracing : The value of P for bench terracing (0.5% longitudinal gradient, 2.5% inward gradient) has been worked out to be 0.027 for Ootacamund having 25% slope (Tejwani *et al.* 1975).

Table -2.3 : P factor under Different Conservation Practices (Dehradun)

Treatment	P Factor
(a) Up-and-down cultivation	1.00
(b) Contour farming	0.68
(c) Channel terraces with contour farming	0.38
(d) Channel terraces (at 1.5 times usual spacing) with graded furrows	0.36
(e) Strip cropping 3:1 (Maize : cowpea)	0.51
(f) Strip cropping 4:1 (maize : Cowpea)	0.62

Source: Dhruvanarayana (1993).

There is not much information available for P factor for other India. In the absence of such data, it is suggested that the values proposed by Wischmeier and Smith (1978) given in Table-2.4 may be used till the values are determined for various locations in India.

Table-2.4 : P values for Contour-Farmed-Terraced Fields.

Land slope (in %)	Farm planning	
	Contour factor	Strip crop factor
1 to 2	0.60	0.30
3 to 8	0.50	0.25
9 to 12	0.60	0.30
13 to 16	0.70	0.35
17 to 20	0.80	0.40
21 to 25	0.90	0.45

Source: Dhruvanarayana (1993)

(v) Erosion Measurement on Watershed Basis : These runoff plots and the USLE give estimates of total soil detached and displaced over short distances, but do not indicate the sediment delivered to the reservoir. Much of the deposition and reduction in sediment yield occurs between the sediment sources and reservoirs. This reduction is estimated with a sediment delivery ratio. Sedimentation in a reservoir, defined by trap efficiency depends on factors such as the ratio of run-off inflow to reservoir capacity, sediment size, shape and stage of the reservoir, outlet works and methods of reservoir operation. In India, reservoir sedimentation is estimated from the suspended load of the stream feeding the reservoir and by periodic direct measurement of sediment deposition in reservoirs.

The USLE is most comprehensive and includes six variables as defined earlier. The average annual soil loss (in t/ha) is the product of these factors (Tripathi and Singh 1993, Singh 1999). In fact, this is a parametric method of soil loss estimation rather than the experimental one. However, through experimental plots, the constant values of concerned parameters may be changed in accordance with the environmental conditions of hydrotope and ecotopes of the landscape.

In Indian conditions, USLE has been used for different environmental conditions giving emphasis on the specific parameters of the river catchment. Khosla (1953) used size of catchment as only the parameter to evaluate annual volume of sediment yield to establish linear relationship between them. Dhuvnarayana and Rambabu (1983) state that the sediment yield is the function of rainfall, runoff and erosion index as hydrological parameters. Therefore, the estimation of run-off is an indirect method of assessing soil loss. The suspended and dissolved material in the runoff water may be determined by multiplying the amount of runoff with concentration of components/sediment particle expressed by Tripathi and Singh (1993) as: Xa (soil loss kg/ha) = (kg of soil material/ha-cm of run-off). The arid and semi-arid climatic conditions have lesser effect of rainfall intensity in the estimation of sediment yield than the humid conditions of river catchment. In the arid zone of the country, the sediment yield is predicted only 1 to 14 t/ha/year in the eastern most parts of Rajasthan (Dutta, *et al.,* 1995). The morphological characteristics of the drainage basin are the major factors of sediment yield in such arid conditions which are estimated through the use of the Remote Sensing Data and GIS technique (Singh 1994, Singh and Sharma 1994, Seth *et al.* 1995-96). Contrary to it, in the extreme rain conditions, landcover and landuse parameters are the determining factors of sediment yield in humid zone of the country as Indian Council of Agricultural Research (ICAR) for North Eastern Region, Barapani has estimated the soil loss at the rate between 3.3 and 147 t/ha/yr in these areas (Singh and Singh 1980, Sathapathy 1996). Another study of soil loss in the humid conditions of North-Eastern part of the country, the Arunachal Himalayas of the young tertiary mountains, was conducted by applying USLE parameters and found that in such conditions of high rainfall, the average annual rate of soil loss is estimated from 50 to 150 t/ha/yr with its areal variations from 18.3 t/ha/yr in Bichon river basin of the west to 285.6 t/ha/yr in Sisri river basin of the folded loop topography of the Eastern Himalayas (Singh 1999). However, a study conducted on geomorphology and land use under rainshadow conditions prevailing on the northern slopes of Meghalaya plateau, shows that soil erosion rates vary from 7.7 to 20.2 t/ha/yr (Syiemlieh 1997).

2.4.6 Sediment Yield : The soil erosion from the drainage basin is a result of complex process which is controlled by the various climatic, topographic, geologic, geomorphic and land use characteristics. A number of studies have been carried out to investigate the erosion rate and the governing physical factors. Several models have been proposed based on these studies.

Using data from some river catchments and some reservoirs in India, Dhruva Narayana *et al.* (1983) had given separate relationships for sediment yield in terms of annual runoff, annual rainfall, catchment area and erosion index as:

$$T_1 = 5.5 + 11.1\,Q, \quad \ldots \quad \ldots \quad \ldots \qquad (12)$$

$$T_1 = 5.3 + 12.7\ Q * W, \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

where, T_1 = annual sedimentation rate in mt./year, Q = annual runoff in M.ha.m., $W = T_1/A$, and A = catchment area.

Garde *et al.* (1983) analysed data from 31 large and small reservoirs in India. The absolute volume of eroded material was expressed in terms of hydrometerologic landuse and catchment variables in the following form:

$$Vs = 1.182 * 10^{-6} * P^{1.29} * A^{1.03} * D_d^{0.40} * S^{0.08} * F_c * 2.42, \quad \ldots \quad (14)$$

where A = catchment area in km ^{2,} L= stream length in km, S = catchment slope, D_d = drainage density, F_c= vegetation cover factor, P = annual mean precipitation in mm, and V = sediment yield rate in $Mm^3/100$ km/year.

Garde and Kothyari (1987) analysed erosion data along with other data characterising 50 Indian catchments to obtain a relationship for annual sediment yield. The data from 104 other catchments spread evenly over India has been made for the estimation of erosion rates from the catchments. An iso-erosion map of India has been prepared on the basis of this study. They concluded that the landuse variable has been found to be the most influential factor affecting the sediment yield followed by catchment slope, rainfall and drainage density.

$$Vs = 1.067 * 10^{-6} * P^{1.38} * A^{1.29} * D_d^{0.40} * S^{0.13} * F_c * 2.51, \quad \ldots \quad (15)$$

(for abbreviations, see above equation 14)

Morgan *et al.* (1990) developed a process based soil erosion prediction model. In this model, attention is focused towards the dynamic nature of soil erodibility, tillage and crop cover. The model estimates the volume of rainfall reaching the ground surface as direct through fall, leaf drainage and stream flow, the volume surface depression storage in relation to micro-topographic roughness, the rate of detachment of soil particles by rain drop impact as a function of the energy of the direct material that is splashed into the flow and thereby made available for transport, and the rate of detachment of soil particles by surface flow and the transport capacity of the runoff.

Mc Cool *et al.* (1990) revised USLE to estimate the soil loss more accurately from both crop and rangeland areas. All factors R,K,LS,C and P have received attention. R values for the western United States were developed from hourly precipitation data. A time variant K factor was included. New length and steepness (LS) factor relationships were developed. C factors were computed by a sub-surface approach and P factors were developed using CREAMS model.

Subramaniayan *et al.* (1990) have assessed soil loss for the catchments of river valley Projects of India. In this study, soil loss of 27 catchments have been given with the geographic setting of each catchment. These 27 catchments have varying size, physiographic characteristics and socio-economic conditions and spread over different river systems of India such as Ganga, Yamuna, Brahmaputra, Indus, Krishna, Cauvery, Godavari and other small rivers of the country. Further, it has been suggested that for selecting excessisively eroding catchments and for locating the highly degraded watersheds within these catchments, appropriate information on rate of erosion of Sediment Production Rate (SPR) is essential.

Dutta *et al.* (1995) carried out soil erosion study in the eastern most part of Rajasthan using USLE. The different parameters required such as soil, land use/land cover and geomorphic characteristics etc. were derived using Remote Sensing and GIS. Soil loss predicted using above equation was less and ranging between 1 to 14 t/ha/year.

2.4.7 Relation between EI_{30} and Soil Loss : The degree of steepness of the slope and the rainfall erosivity are important factors among others affecting soil erosion. Erosivity, which is the property of rainfall, can be evaluated quantitatively as the potential capacity of the rain. Though erosion is known to be related to the degree of slope and the potential capacity of the rain, there are several factors such as soil and rainfall characteristics which are specific for the location and not necessary the same under all conditions. It thus becomes necessary to quantify the relationships under a set of given conditions. It also indicates the need for carrying out studies which may be location specific.

In order to determine the effect of EI_{30} on the extent of soil loss (E_S) at different degree of slopes, prediction equations were computed along with the correlation coefficients. The results obtained are as follows:

$$n = 14$$

$$E_S = 10.60 + 0.0013^{**}EI_{30}, \quad \dots \quad \dots \qquad (17)$$

$$(0.00047)$$

$$r = 0.96^{**}$$

$$E_S = 56.39 + 0.032^{**}EI_{30}, \quad \ldots \quad \ldots \quad (18)$$
$$(0.00022)$$
$$r = 0.94^{**}$$

$$E_S = 106.90 + 0.055^{**}EI_{30}, \quad \ldots \quad \ldots \quad (19)$$
$$(0.00049)$$
$$r = 0.91^{**}$$

$$E_S = 225.06 + 0.079^{**}EI_{30}, \quad \ldots \quad \ldots \quad (20)$$
$$(0.00089)$$
$$r = 0.89^{**}$$

The above prediction equations (17), (18), (19) and (20) were computed from the data on soil loss obtained from the bare runoff plots with 0,2,3 and 4 percent slopes, respectively. EI_{30} was significantly correlated with soil loss, as obtained by Wischmeier *et al.* (1958) and Ram Babu *et al.* (1970). However, experiments conducted in the tropics indicated a lower correlation coefficient between EI_{30} and soil loss (Ahmad and Breckner 1974, Lal 1974).

2.5 Concluding Remarks

The climate of Meghalya is humid tropical with an average annual monsoon rainfall of around 3000 mm but, in south-central slopes of Meghalya plateau, the occurrences of rainfall have been experienced in the range of 11,000 mm – 12,000 mm. As a result of this sharp spatial variation of rainfall, around 90 % of the total annual precipitation takes place on the southern slopes of the plateau which contains shallow depth of soil and poor vegetal cover. This creates the condition of floods during monsoon and acute shortage of water even for drinking during the lean season. The water erosion has been identified as a major problem for the degradation of natural resources which is covering around 52 % of the geographical area of Meghalya.

Reviewing the concerned literature on the watershed studies, specially on the hydrological processes operating in it, the USLE which has five important factors of geo-hydrological conditions of landscape, are useful to estimate runoff and soil loss in the watershed area.

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Chapter-3

Chapter-3

Geo-hydrological Condition

3.0 Introduction

Management of natural as well as human resources for their proper utilization and suitable development of a particular state or region needs their detail inventories. A resource matrix of multi dimensions, with the environmental parameters to understand the interacting patterns and interrelated features of resources phenomena, is also required. It plays a significant role in interaction between man and environment which forms a part of ecosystem. Such interacting phenomenal features adopt two different ideologies. These ideologies follow different principles and approaches but, are interrelated to each other on some broad principles.

The first ideology is based on the models of 'elemental interactions' and 'areal differentiations' for interpretation of phenomenal complexities. The generalizations of interacting complexities can be visualised in shaping the regions of different levels (Hartshorne 1957). This ideology is based on the 'principle of togetherness' which is useful for delineating the boundaries of phenomenal features on the basis of their homogeneous characteristics (Hagerstrand 1976).

In fact, this frame of ideology provides us a sound base to proceed towards boundary delineation of homogeneous geo-ecological characteristics of a systematic whole. A diverse nature of these characteristics can be studied in assembling them under one umbrella. The ideological aspect lead us towards the geographical concept of 'process-from reasoning' and 'coordination' of the interacting geo-ecological phenomena, which is relevant in the present context in forming the geo-ecological zones (Singh, 1996).

The geo-ecological zonation refers here to delineate the zones on the basis of interrelationships and interactions of geomorphological, hydrological and landuse characteristics of the area. For this, watershed-wise data set of the attributes of these characteristics are required.

3.1 Geo-ecological Characteristics

The state of Meghalaya is located in the North-Eastern part of the country. It lies between 25^0- 00' to 26^0-10'N latitudes and 89^0- 45' to 92^0 -47' E longitudes. The geographical area of Meghalaya is 22,430 sq.km which is 8.79 % area of the North Eastern Region and 0.68 % area of the country. It is bordered to its North-West, North, East and South-east by the state of Assam and to the South and South-West by Bangladesh. The Index Map of the North Eastern Region covering the geographical location of Meghalya is shown at Fig-3.1(a). The relief of Meghalya varies from 1500 m to 1950 m above m.s.l. The state presents a picturesque landscape of plateau, ravines, brooks, rivulets, lakes and waterfalls, besides the magnificent gorges exceeding 600 m in depth in South Khasi Hills. Umiew watershed, the study area, is located on the south-west around 17 Km away from Shillong. The Project Index map, which covers the study area, is shown at Fig.-3.1(b). Shillong, the capital of the state, is located at an elevation of 1800 m in the central part of Khasi Hills.

The area is greener than the other parts of the world which are situated on the same transitional zones of tropical and sub-tropical climates. The extensive moisture availability is only because of direct effects of Northern and Eastern surroundings of the East arch of Himalya's folded mountains. These mountains control the hydrological processes and climatic conditions influencing directly or indirectly the micro landforms of Meghalaya plateau. The region experiences tropical monsoonic climate; the summer temperature is recorded as high as 25^0C

Fig. 3.1(a): **Index Map of North Eastern Region**

Fig. 3.1(b): **Project Index Map with Reference to Meghalaya State**

and the mean winter temperature falls down to 9^0 C with periodic deviation to below the freezing point marked by apperance of ground frost at night and morning over the higher elevations. The maximum annual average rainfall of 1143 cm has been recorded around Cherrapunji and Mawsynram, the world's rainiest spots. The average annual rainfall of the state is around 205 cm. The higher elevations over the plateau are clad with pine grooves. The outskirts of the plateau is marked by mixed forests including a few valuable trees. The main agri-horticultural products of the state are rice, jute, potato, orange and other citrus fruits, betel, banana, plum, pears and pineapple (Geological Survey of India 1987).

3.2 Physiography

The state of Meghalaya is geologically an extensive part of Chotanagpur plateau detached from the main Indian shield (the North Eastern parts of Deccan foreland) by the N-S trending Rajmahal-Garo lineament (Mazumdar 1976). It is a complete physiographic unit and its terrain features are emerging of gneissic complex of Shillong massif which is bounded on all the sides by the faults and lineaments forming a block uplifted to its present height of about 600 m to1800 m above the mean sea level (Agarwal 1994, Murthy *et al.* 1976, GSI 1987). Shillong peak, the highest spot over the plateau, is 1951 m above mean sea level.

The important aspect of study is to analyse interrelationships of the attributes of geo-ecological characteristics, landscape ecology with respect to evolving interaction patterns of these attributes. There are many and varied parameters of micro hierarchic orders of geo-ecological characteristics called elements which may be included in such studies of geo-ecological landscape. These elements of each and every lower level areal unit (i.e., watershed) must highly be associated with one another in the same matrix of geo-ecological elements for identifying geo-ecological zones in Meghalaya. There may be thus problem of co-linearity in the statistical exercise of given input matrix. Those elements will have to be removed because of co-linearity problem, but they may be more significant to be incorporated for present study. A correlation study for geomorphological parameters of micro-basins has been done by Agarwal (1994) in Umiam basin of Meghalya. The study area has been about 1,000 sq. km which is only 4.38 per cent of the total state area. This area has a significant geo-ecological variations and varieties of terrain evaluation processes. A matrix of 29 variables (parameters) with 120 observations (micro-basins as areal units) have been prepared for establishing correlations with one another. It has been observed that the correlation values are insignificant and weak in some cases. They do not have identical associations of geomorphological parameters to assess the risk and geo-hazard characteristics of the basin. The same question strikes while choosing the parameters for analysing their interaction patterns evolving on a diverse geo-ecological landscape.

The Geomorphic and metamorphic attributes are appropriate indicators of terrain which provide a strong base for understanding the emerging different features of geo-ecological landscape. The geomorphological attributes like Absolute Relief, Relative Relief, Drainge Texure, Drainge Density, Bifurcation Ratio and so on have great significance for terrain evaluation and land systems (Vink 1975). The hydrological characteristics of landscape are also part of geo-ecological studies. The hydrological study includes parameters related to runoff, sediment loss, permeability, intensity and amount of rainfall availability, temperature and humidity, etc.

3.3 Structure and Tectonics

In the southern fringe of Khasi Hills, the predominant structural lineament is the Dauki fault which comprises at least four E-W running normal faults and at places becoming reverse faults. The upthrown side of these faults is to the north and the system represents a major plane of dislocation. In the southern fringe of Jaintia Hills, one of these four faults continues further east to the North Cachar Hills and then joins the Disang Thrust.

In the western part of the plateau in the Garo Hills, the E-W lineaments are represented by monoclines and faults among which the Dapsi Reverse Fault at the base of the Tura Range is spectacular. The Tura Range, a horst, is bounded to the South by the Dapsi Fault (upthrust). In the Garo Hills, there is ample evidence to indicate activity along a number of E-W, N-S and NW-SE basement faults throughout the Tertiary period.

A rectilinear drainage pattern in NE-SW, NW-SE and E-W directions is a distinctive feature of the Shillong Plateau. Some of them appear to represent faults, many of them are master joints and fractures and the whole pattern has been developed due to uplift of this horst in the Tertiary period.

3.4 Relief Features and Slopes

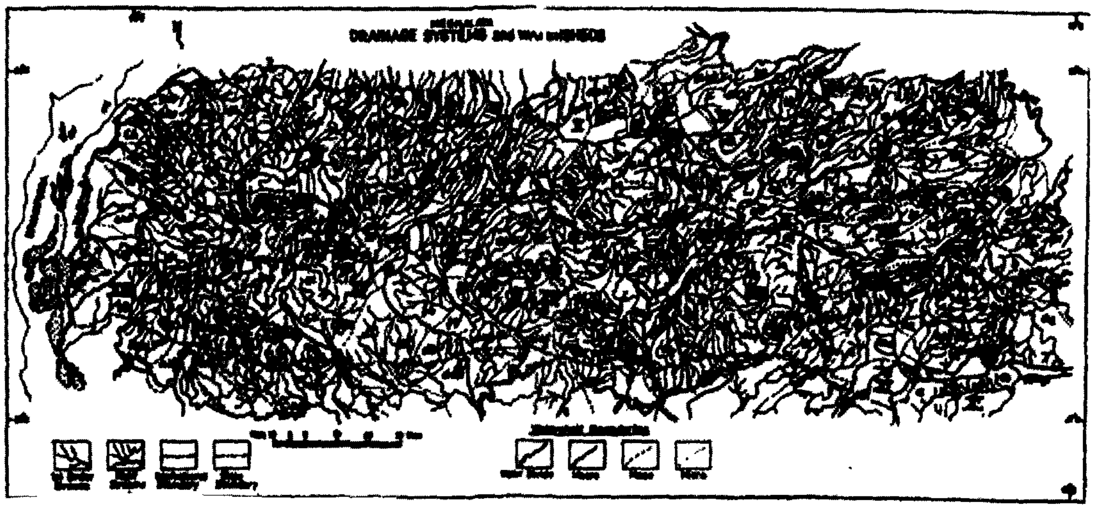
In general, the relief features and the slopes are the parts of land systems because they have direct bearings on hydrological attributes, micro-climatic conditions and landuse/land cover patterns of an area (Vink 1975). The slope map of Meghalya indicates the distribution of land slopes varying from extremely gentle and flat surface (0-2%) to cliffs and very steep slopes (above 35%) [Fig.-3.1(c)]. The gentle part of Meghalaya, i.e., Shillong massif is horst. The top of this horst is flat with the elevations ranging from 1,500 m to 2,000 m occupying most of the uplifted tracks of Khasi hills which have been dissected by the first order streams. Therefore, there is a variety of relief features of uplifted flat lands. Some of scarpments and eroded land features are noticeable. There are two major scarpments: the first one is the Milliam-Mawphlong scarp of about 30 kms with the highest point of 1960 m (Shillong peak) having steep slopes towards Umiam also called Barapani lake and the second one is Mautherrichau scarp of the West-Central parts of horst which covers longitudinally a distance of about 45 kms from Nongshillong to Mawlieh villages. The scarp-foot springs can be seen in this area. These scarps demarcate the boundaries of water divide of this area and separate drainage system of Meghalaya into two: the Brahmaputra system and the Surma system (Singh 1996) (Fig.-3.2).

There is another important fault-line escarpment along Dawki fault, which distinguishes the major relief features of flat lands of the central parts of Shillong massif from the sloppy areas of South Khasi and Jaintia hills. In addition, some micro-relief features of deep gorges, canyons, sharp hill ridges and funnel-like features of river valleys where creeps on debris and steep-slopes of free-faces of valleys can be observed. Such valley features in this severe erosion belt are

Legend : 1= Extremely Gentle and Flat Surface (0-2%), 2=Very Gentle (2-4%), 3=Gentle (4-8%), 4=Moderate (8-12%), 5=Moderatly Strong (12-15%) 6=Strong (15-20%), 7=Very Strong (20-25%), 8=Highly Strong (25-30%), 9=Steep Slopes (30-35%), 10=Cliffs and Very Steep Slopes (above 35%)

Source: Singh (1996).

Fig. 3.1(c): Average Slope Map of Meghalaya



Source: Singh (1996).

Fig. 3.2: Drainage System and Watersheds of Meghalaya

developing due to the steep slopes. In some of the areas of this belt, an average slope of more than 35% has been recorded.

3.5 Drainage System

The drainage pattern in the region represent a most spectacular feature revealing extraordinary straight courses of the rivers and streams evidently along joints and faults. The magnificent gorges scooped out by the rivers in the southern Khasi and Jaintia Hills are the result of massive headward erosion by antecedent streams along joints of the sedimentary rocks over the block, experiencing relatively greater uplift. Westward in the Garo Hills, the consequent streams are mostly controlled by the structures, faults and monoclines in the sedimentary rocks. The northern part of the plateau, devoid of any sedimentary cover, is marked by long, incisive valleys formed due to headward erosion along joints in the gneissic rocks and granites. The limestone covered over the southern Garo, Khashi and Jaintia hills represent a typical karst topography. The present physiographic configuration of the plateau has attained through different geological events since Mesozoic to present as indicated by the polycyclic erosional surfaces at various levels.

The evolution and development of drainage are the result of geological history of rock formations and tendency of residing confluences (Strahler 1963). The most commonly developed patterns are dendritic, trellis and radial. The dendritic patterns are developed in the most dissected parts of plateau (Fig-3.2). The river basins, which are situated on the central table lands and on the Southern steep slopes of the Shillong massif, are developed by following dendritic drainage patterns of Umiew, Umsohnyankew, Umngot, Soshympha and Umliehan rivers while the tributaries of Umiam and Umtrew (the N-E flowing rivers) are having the trellis drainage patterns. It may be because of granitic complex geological structure of these areas.

3.6 Hydrological Characteristics

Hydrology includes available water volume, its temporal changes, run off characteristics, discharge rates, sediment loss and water quality, while the hydrological processes are generally governed by the climatic conditions, terrain characteristics and physical properties of soils. In general, the entire Meghalaya comes under humid tropical climatic conditions with nearly 3,000 mm average annual monsoon rain along with its significant areal variation ranging from 1200 mm to 12,000 mm. The average annual rainfall of 12,000 mm occurs on the South-central slopes specially in Cherrapunjee and Mawsynram areas whereas, only 1200 mm of rainfall occurs on the North Eastern part of Meghalya plateau specially in the tributary areas of Kopili river.

More than 90 percent of the annual precipitation takes the shape of runoff on the southern slopes of Shillong massif due to shallow soils and poor vegetal cover. This leads to the conditions of seasonal floods in the south and south-west and southward flowing rivers. On the northern gentle slopes of massif where deep soils (more than 100 cm) are available, the monthly discharge rate of water is recorded lower even in the monsoon season.

It has been found in the upper portion of one of the micro watersheds, called Wah-Umium micro watershed of about 11.90 km^2 of area situated on the Northern slope of the plateau, that the average discharge of Wah-Umium during the month of January and February is even 20 times lower than the discharge observed during monsoon months (May-October). While studying the observed discharge of river Umiew for its geographical watershed area of 136.45 km^2 located on south-central slopes of Meghalya Plateau during monsoon months (May-October) from 1996-98, it has been found that the range of variation between the maximum and the minimum discharge continue from 1:227.5 (June,1996) to 1:3.29 (September,1996). The morphometric and physiographic characteristics, landuse pattern and temporal variation of intensity of rainfall occurring within the watershed may be attributed for influencing the variation in the flood discharge of the river. The effects of parameters related to the channel network like bifurcation ratio, stream orders that follow a law of its ordering system, called Horton's law of drainage system, and persuaded by Smart (1972), Chow, *et al.* (1988), are considered for the alteration of rainfall-runoff relationship through changing the basin's mean lag-time and giving different hydrologic responses (Rogers 1972, Rodriguez-Iturbe and Valdez 1979, Gupta, Waymire and Wang 1980). The detail hydrological processes would be analysed separately in the next chapter.

3.7 Soil Characteristics

Soil is the most important component of land through which an interaction of all geological factors is possible. On one hand, it is an interactive phenomenon of its natural factors like climate, geology and relief and, on the other hand, it characterises by its physical and chemical properties for its utilisation (Vink 1975, NBSS & LUP 1994). Therefore, there are two main approaches of the study on the basis of its parametric relationships : (a) Pedological – when soil is considered as natural phenomena and its relationships are established with climate, relief, parent material and living organisms and (b) Edaphological approach through which the study of plant growth and development of agriculture is considered with response to the physical and chemical properties of soils. In present context, soil characteristics of Meghalaya is described by pedological approach because it would be appropriate to interpret soil as a principal element of geo-ecological attributes rather than soil properties for agricultural development (Singh 1996).

Soils have been formed predominantly from the weathering of sedimentary and metamorphic rocks, quartizite, conglomerates, phyllite, shale, sand stone etc. The diversified characteristics of soil are mainly due to the continuous high intensity of denudation by jhum (shifting cultivation) which caused different erosional phases of soils. The crest and slope of hills and ridges are often steep and subjected to erosion. The soil materials removed continuously by erosion is deposited in the lower slopes, thus reducing the soils depth on the slopes and exposing rocks at places (Satapathy *et al.1996).*

Soil erosion is a dominant phenomena in Meghalaya. Besides, topographical factors of soil loss (slope gradient, slope length and rainfall effectiveness), the soil erodibility, which is directly related to permeability or hydraulic conductivity coefficient (K) and governed by the physical properties of soils specially of available organic matter, the soil particle size and its structure are important attributes of soil loss. When soil characteristics are considered here as product of geo-environmental attributes and soil has its direct bearings on hydrological processes, the terrain features and land cover/land use patterns, and the study of soil taxonomy and soil classification must be helpful in understanding its natural conditions, limitations and soil forming/eroding processes.

3.8 Vegetation and Land use System :

Vegetation is completely a part of ecosystem while land use is the result of combination of both the natural genesis of ecosystem and human influences but, the land use systems are concerned with the land resources which may lead to understand the problem of land degradation and appropriate land management (Vink 1975). Water (related to hydrological studies) and soil are two main stable resources of land with which intensity and extent of vegetative cover and land use systems are continuously concerned.

3.9 Land Evaluation

The soil resource map and the bulletin prepared for the state of Meghalya by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP 1994) in cooperation with the Department of Agriculture, Government of Meghalya, has identified the exact location of different types of soil degradation and also suggested proper ameliorative measures.

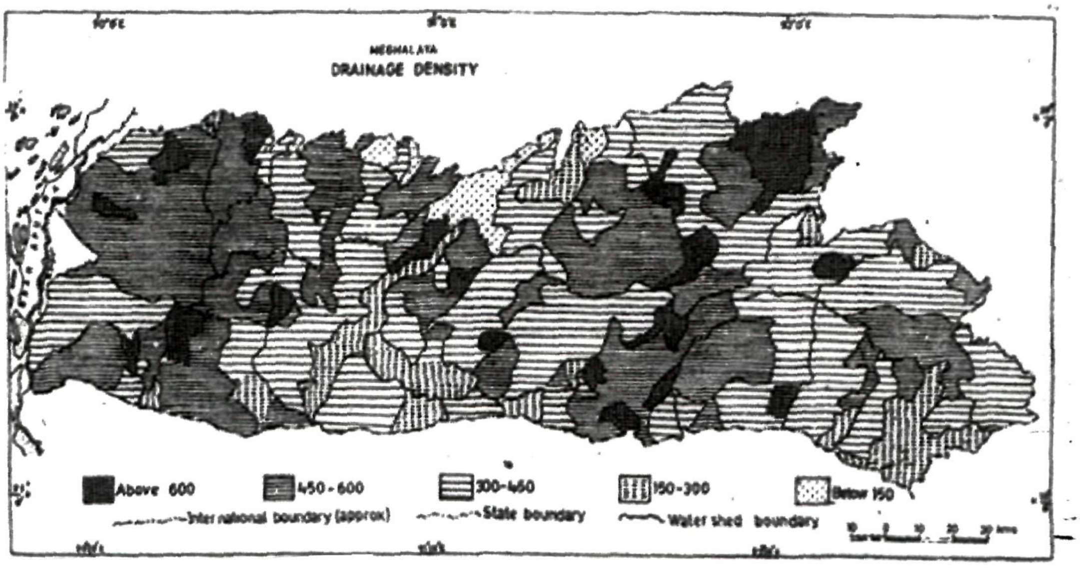
Soil resource interpretation for land evaluation proceeds to land use planning. Land evaluation is a process of evaluation of the soil site information with a view to assess its potential for alternative kind of uses. Based on the soil site characteristics and crop requirement criteria, soil suitability maps for different crops could be generated. The various thematic maps, related to soils of Meghalya like soil drainage, water holding capacity of the soils, soil reaction, soil depth, organic carbon, surface texture, erosion potential, which have been generated by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP 1994) have also been discussed in general and also with reference to the analysis of soil samples collected from different places in Umiew watershed. This analysis has included Organic Carbon, Soil Texture and Water Quality.

3.9.1 Soil Drainage : The soil drainage can form a limiting criteria for evaluating soil suitability for field crops, commercial crops and forest species. It is important for crop planning. It has been reported by (NBSS & LUP 1994) that excessively drained soil cover of around 90 % area of the state have no or little limitation for agricultural production. Poorly and very poorly drained soils constituting 6.5 % area of the state, have been observed in the valleys. These soils restrict their use for most of the field crops. The distribution patterns of drainage density and soil drainage status of different parts of Meghalya. These figures indicate that the drainage density of most of the areas of Umiew watershed lie between the range of 450 to 600 m/km^2 and soil drainage is excessive (Figs. - 3.3 & 3.4).

3.9.2 Available Water Holding Capacity : Available water holding capacity of the soils depends upon the soil texture, depth, stoniness and mineralogy of soils. This determines the total available water of the soils and helps in deciding length of growing period. This is essential parameter for crop planning in area where the crops are grown under rainfed conditions. The majority of soils in the state have medium available water holding capacity class combination which covers around 74 % of Total Geograpgical Area (TGA) of the state. The status of available water holding capacity of the soils of Meghalya suggests that the water holding capacity of major portion of Umiew watershed area lies between medium to medium-low range and some limited area of the watershed have low to very low water holding capacity (Fig.-3.5).

This textural class has been regrouped under medium soils. This regrouping of textural class has been done based on the relative ease of draught required to pull tillage equipment especially the plough.

3.9.3 Soil Reaction (pH) : Soil reaction govern the availability of several micro and macro nutrients along with micro organism population in a particular environment. Its measurement also help in suggesting ameliorative measures for



Source: Singh (1996).

Fig. 3.3: Distributional Patterns of Drainage Density in Meghalaya (in m/km^2)

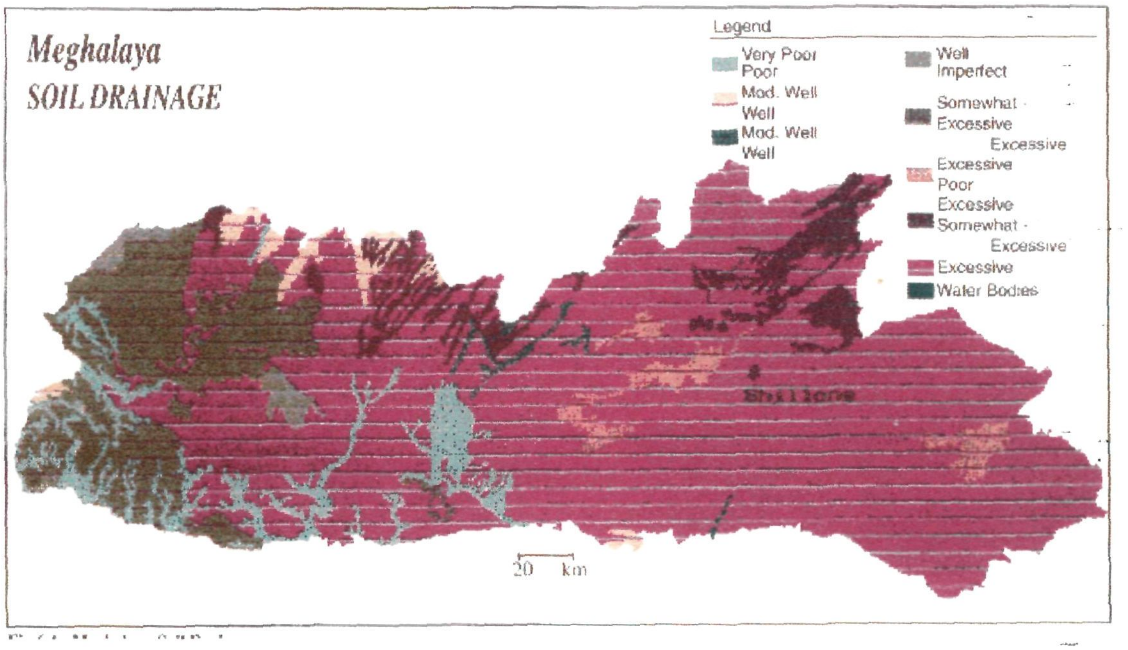


Fig. 3.4 : Soil Drainage Status of different parts of Meghalaya

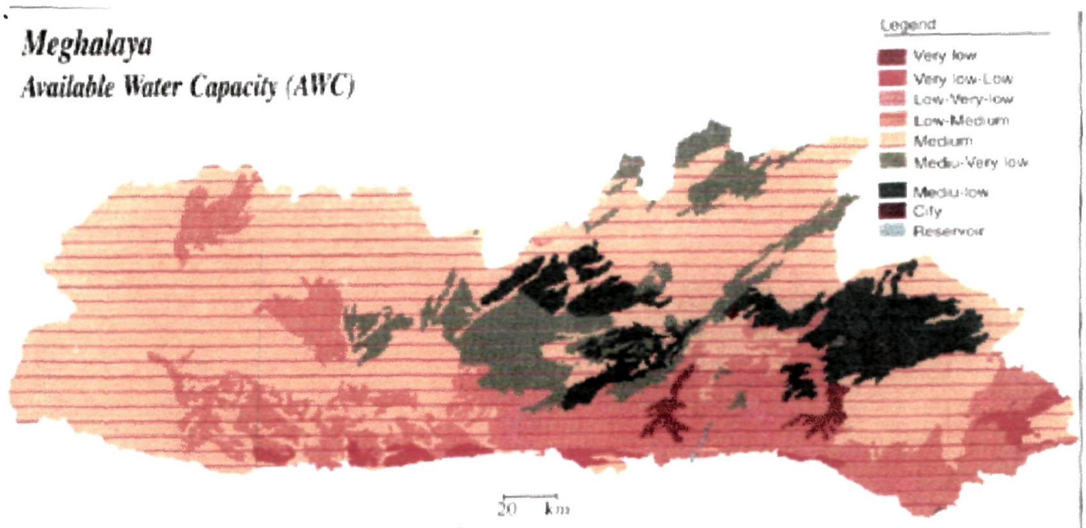
Source: NBSS & LUP (1994)

better land use. The soils of the state are acidic in reaction (pH 4.5-6.5). Majority of the soils (65 % of the TGA of the state) are moderately acidic and rest are under slight acidic category (Fig.-3.6). The soil samples collected during July,2001 from four different locations of Umiew watershed namely, Umsaw, Phuddingsong, Umtrigar and Mawngap are acidic. The range of pH vary between 4.5 to 5.3 (Table-3.1).

3.9.4 Organic Carbon : It is well known that the organic matter, measured through organic carbon estimation, has got immense influence in controlling physical and chemical properties of soil. It also accounts for much of cation exchange capacity, specially of the surface soil and is also responsible for the stability and structure of soil aggregrates. The organic carbon indicates the status of nitrogen in the soil. It helps in building up microorganisms population of the soil. The distribution of Organic Carbon in Meghalya suggests that the distribution of Organic Carbon in Umiew watershed varies from very high to medium low range (Fig-3.7).

3.9.5 Soil Depth : The soil depth refers to the volume of the soil which can be exploited by the roots of the plants in obtaining their nutrients and water for growth. Maximum per cent of total geographical area of the state is under combination of deep and moderately deep soils (56.99% of TGA) followed by deep soils (27.92%). Moderately shallow deep soils cover 11.3 % of the TGA (Fig.-3.8). The soils having moderately shallow depth classes are suitable for afforestation and agroforestry. These areas are preferred mainly for range, woodland, wildlife and recreation. Moderately deep to deep soils are suitable for climatically adapted crops. This figure suggests that the distribution of soil depth pertaining to the area of Umiew watershed lies between the range from deep to medium deep category.

3.9.6 Soil Texture : Soil texture governs plant growth either directly or indirectly by its influence on aeration, available water capacity, cation exchange, availability of nutrients, soil structure, workability, infiltration and drainage



Source: NBSS & LUP (1994)

Fig 3.5: Available water holding capacity of the soils of Meghalya

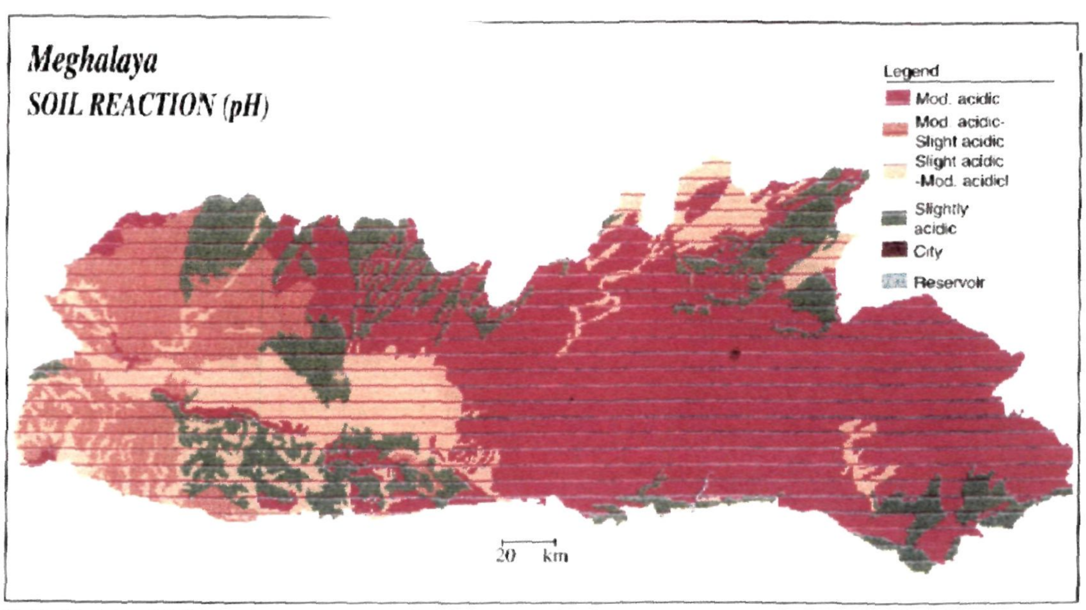
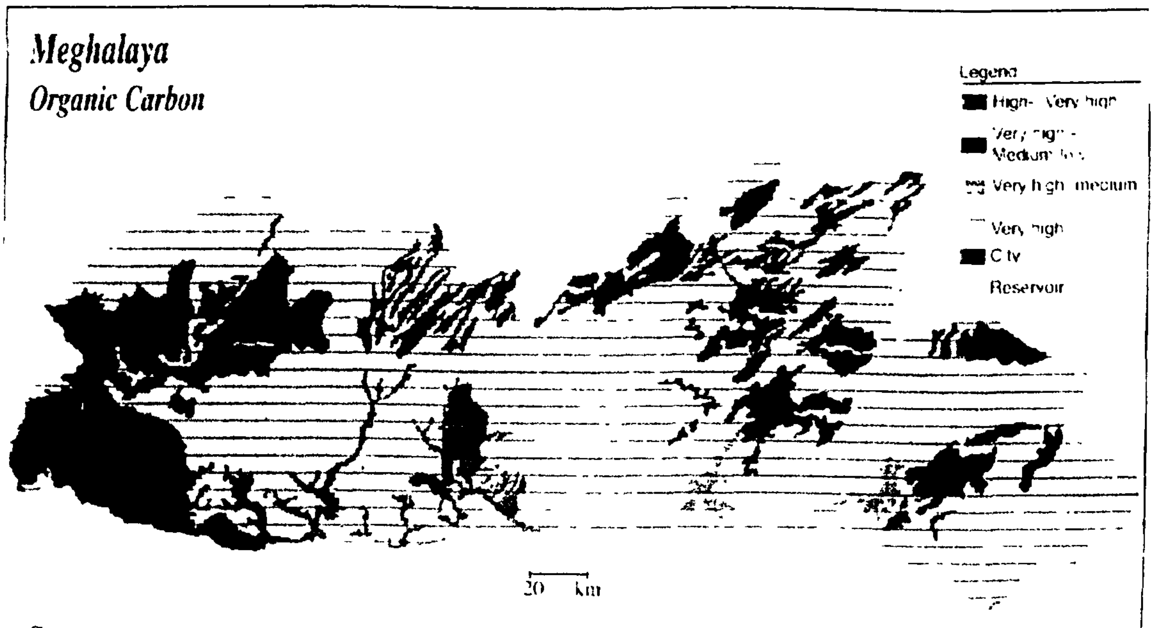


Fig 6.9: Meghalaya Soil Reaction (pH)

Fig 3.6: Soil Reaction of the soils of Meghalya

Source: NBSS & LUP (1994)



Source: NBSS & LUP (1994)

Fig 3.7 Distribution of Organic Carbon in the Soils of Meghalya

Source: NBSS & LUP (1994)

Fig.3.8: Distribution of Soil Depth of the Soils of Meghalya

conditions. Majority of the soils are loamy. Sandy loamy soils are normally present. The textural analysis of soil samples collected at 30 cm and 60 cm depths from four different places in Umiew watershed has revealed that the entire samples represent sandy clay loam (Table-3.1). The textural classification has been done according to the United States Department of Agriculture (USDA) System. Further, this textural class has been regrouped under medium soils. This regrouping of textural class has been done based on relative ease of draught required to pull tillage equipment especially the plough. This figure suggests that the major portion of Umiew watershed contains loamy soil followed by sandy loamy soil in the remaining area of the watershed (Fig.-3.9).

Table-3.1: Textural Analysis of Soil Samples from Umiew Watershed.

Sl.No.	Location	Depth of soil samples (cm)	Percentage distribution of sand silt and clay			Type of soil	Remarks
			Sand (%)	Silt (%)	Clay (%)		
1	Umsaw	30	78.5	0.01	21.49	Sandy clay Loam	Medium Soil
		60	78.5	0.01	21.49	Sandy clay Loam	Medium Soil
2	Phuddingsong	30	78.5	0.01	21.49	Sandy clay Loam	Medium Soil
		60	78.5	0.008	21.49	Sandy clay Loam	Medium Soil
3	Umtrigar	30	78.5	0.03	21.49	Sandy clay Loam	Medium Soil
		60	78.5	0.005	21.49	Sandy clay Loam	Medium Soil
4	Mawngap	30	78.51	0.005	21.49	Sandy clay Loam	Medium Soil
		60	78.51	0.005	21.49	Sandy clay Loam	Medium Soil

3.9.7 Soil Erosion : Soil erosion is a surface feature which refers to wearing away of the soil surface by the forces resulted due to water and wind. By this process, the surface layer is affected through the removal of soil from top thereby reducing nutrient status and also loss of organic matter. It is aggravated due to human intervention through indiscriminate felling of trees and reduced shifting cycles thus affecting the natural ecosystem. The soil erosion map, prepared by NBSS & LUP (1994) reveals that major area of Umiew watershed is susceptible to the erosion category of moderate very severe (Fig.-3.10). The class combinations of soil erosion have been done based on their extent and distribution. This soil erosion map indicates soil erosion potential of different parts of Meghalya. However, the influence of intensity of rainfall, drainage pattern, relative relief and

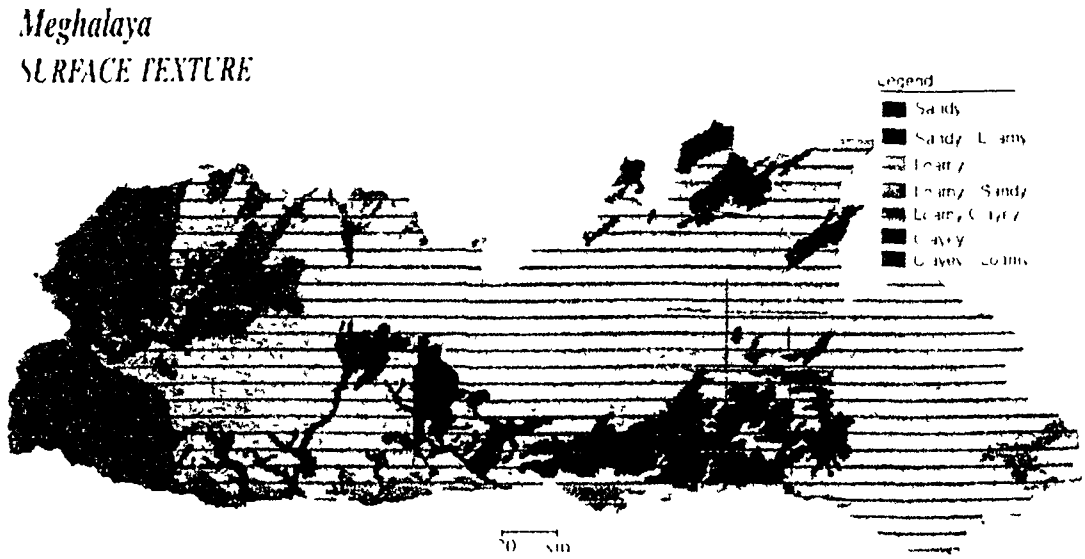
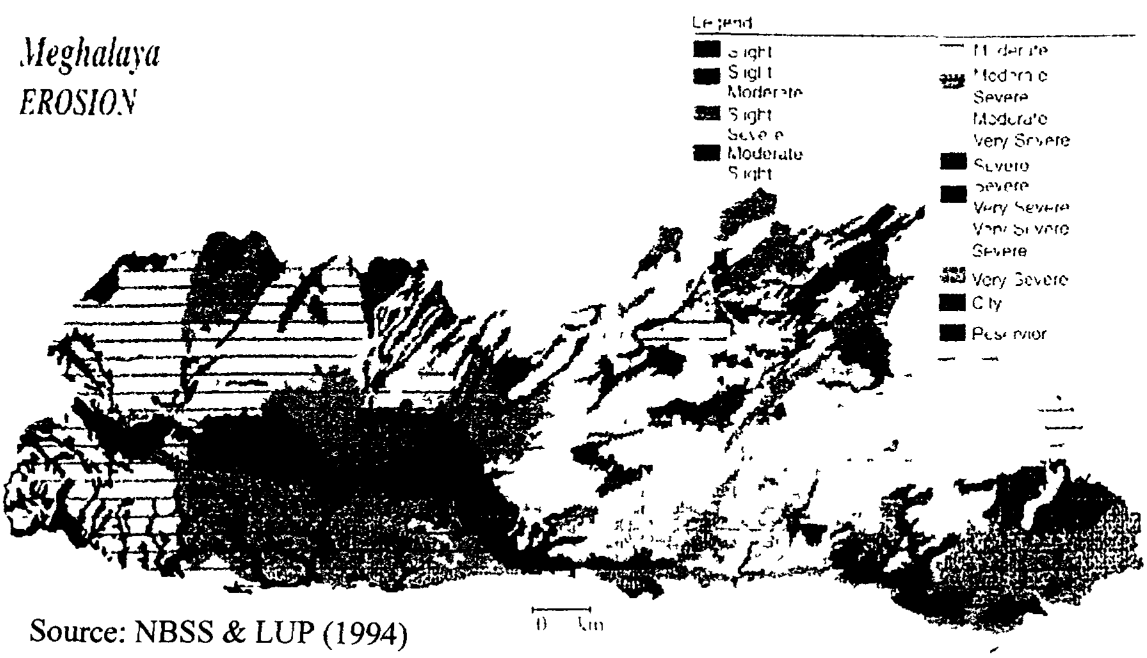


Fig.3.9: Surface texture of the Soils of Meghalaya

Source: NBSS & LUP (1994)



Source: NBSS & LUP (1994)

Fig.3.10: Erosion potential of different parts of Meghalaya

landuse cover on the erosion of soil in Umiew watershed has been covered in detail under chapter-6.

3.9.8 Water Quality : The analysis of water samples collected from the streams on 3rd July,2001 at four different places namely, Umrisani, Phuddingsong, Wasyana and Umtang in Umiew watershed have shown the range of pH varying from 5.4 to 7.1 whereas the iron concentration vary from 0.24 - 0.72 ppm (Table-3.2). The range of pH for providing safe irrigation vary from 6.0-7.5. Thus the pH value of the water samples of the streams are found well within the permissible limit. Similarly, the permissible limit of iron concentration in the water for safe drinking, as per Bureau of Indian Standards (BIS), is 0.3 ppm. The World Health Organisation (WHO) has recommended the permissible limit of 1.0 ppm. Therefore, the iron concentration in water samples of the streams are higher than the permissible limit given by BIS, except one water sample (pH=0.24) collected at Wasyana. The iron concentration of the entire water samples, when compared with the WHO standard, have been found within the permissible limit for safe drinking.

Table-3.2: Analysis of Water Samples Collected from the Streams of Umiew Watershed.

Sl.No.	Place of water sample collection	pH	Iron (ppm)
1.	Umrisani	7.1	0.64
2.	Phuddingsong	6.8	0.72
3.	Wasyna	5.4	0.24
4.	Umtang	5.5	0.47

3.10 Results and Interpretation

The thematic maps related to the soils of Meghalaya as described earlier may be utilized for the preparation of soil suitability maps for different crops planned to be grown in Umiew watershed. The analysis of soil samples collected at 30 cm and 60 cm depth from four different places under Umiew watershed on 3rd July,2001 have revealed that percentage of organic carbon varies from 0.70 % to 2.47%. Out of eight soil samples collected at 60 cm depth, only in one sample the organic carbon percentage has been found to be 0.70. This comes under medium class. The values of organic carbon in rest of the samples have been found higher varying between 0.85 % to 2.47%. This comes under high class category. The range of soil's pH, which varies between 4.5 to 5.3, comes under acidic range (Table-3.3).

Table-3.3: Status of pH, Organic Carbon, Potash and Phosphorus.

Sl.No.	Location	Depth of soil samples (cm)	pH	OC (%)	K (Kg/ha)	P (Kg.ha)
1	Umsaw	30	5.1	1.06	117.97	16.08
		60	5.2	0.7	69.56	13.25
2	Phuddingsong	30	4.5	2.47	182.33	62.46
		60	4.5	0.85	77.47	39.74
3	Umtrigar	30	4.7	1.70	171.60	37.85
		60	4.9	0.95	111.10	29.36
4	Mawngap	30	5.3	2.30	203.77	48.26
		60	5.1	1.15	89.66	43.53

The water quality test of the streams collected at different locations in Umiew watershed, has shown that water of the streams are suitable for providing safe drinking. The iron concentration in the water samples have been found slightly above the permissible limit prescribed for its potability for safe drinking, as per the norms of Bureau of Indian standards. However, these values are well within the recommended limit of World Health Organisation (WHO).

It is presumed that the areas which receive greater amount of rainfall must be characterised by the excellent drainage conditions and vice-versa. It is not, however, true in the case of Meghalaya. The areas of drainage basins situated in the central parts of Meghalaya have moderate to poor drainage density (below 4.5 km per sq km.). Most of the parts of Garo hills and the tributaries of Kopili river of the North-Eastern parts of the plateau have the excellent and extremely excellent drainage density of more than 4.5 km per sq km, though the precipitation is very less in these areas (Fig-3.3). But the basins situated on the Southern slopes of the Khasi hills between the flat lands of Shillong massif and Dawki fault have excellent drainage density (more than 4.5 km per sq km) with fast flowing water in the gorges and river valleys. Therefore, there may be the higher bifurcation ratio of first order streams. As a result, the time of concentration estimated from Synthetic Unit Hydrograph (SUH) has come to 8.35 hrs. The computational details may be seen at para-6.4.1, Equation- (3).

3.11 Concluding Remarks

The record rainfall intensity of about 77-68 mm/day in Cherrapunjee comparatively higher than the Western parts of the plateau, the Garo hills (30.36 mm/day in Tura) and the Central part of massif (19.70 mm/day in Shillong though it is close to Cherrapunjee a crow-fly distance of about 35 km) reveals that there are significant areal variations in the effectiveness of rainfall. The weather conditions of Shillong area are certainly different from the areas of Cherrapunjee-Mawsynram on account of 'rain shadow' effects. The iso-morphic attributes of geo-ecological elements (micro watersheds) located on the south-central slops of Meghalya plateau influence the hydrological processes. These hydrological processes are directly related to the effectiveness of rainfall, altitudinal variations and slope conditions.

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Chapter-4

Chapter 4

Geomorphological Characteristics

4.0 Introduction

When we aim at optimal use of land and water, it is essential to consider the entire land based activities in an integrated manner. The effort has been made to assess the geohydrological parameters responsible for the degradation of the natural resources and to suggest interventions required for the conservation of natural resources particularly the soil and water for the sustainable development of the entire watershed of Umiew. This study also acquires special significance in view of construction of a dam across river Umiew at Mawphlang site for maintaining the proposed life of the dam. This dam is envisaged for supplying water to urban and sub-urban population of Shillong for the domestic consumption. The views of Umiew river up-stream and down-stream of on-going works of dam are shown in Figs.- 4.01 and 4.02.

An attempt has been made to analyse geo-hydrological characteristics of Umiew watershed by delineating its geographical area of 136.45 km^2 into nine micro-watersheds. The area of these micro-watersheds varies between 5.59 km^2 and 44.04 km^2. Out of nine micro-watersheds, five of them namely, Mawphlang (short nomenclature as Um_1), Umgot (Um_2), Mawreng (Um_3), Nongkrem (Um_4) and Basio (Um_6) are located on the right bank of river Umiew and four of them namely, Nongkynrih (Um_5), Laitkroh (Um_7), Laitkynsew (Um_8) and Dympep (Um_9) are located on its left bank. The average slope map of Meghalaya {Fig.-3.1(c)}

Fig. 4.01 : View of Umiew River Up-Stream of On-Going Works of Dam Across the River

Fig. 4.02 : View of Umiew River Down-Stream of On-Going Works of Dam Across the River

indicates that the distribution of land slopes of Umiew watershed mostly varies from very gentle (2-4%) to moderate (8-12%). All the nine micro-watersheds, existing within the geographical area of Umiew watershed, are located on top of the horst of Shillong massif with elevations ranging from 1600 m to 2000 m.

4.0.1 Concept of Watershed: Watershed is a physical unit in which water from all over the area flows under gravity to a common drainage channel. In reference to management, watershed is most appropriate unit for efficient handling of rain water under different land use activities. The concept of watershed management involves optimal use of natural resources in terms of land and water within a natural physiographic unit (earth's surface), governed by ecology, topography, soil characteristics, present land use and socio-economic factors. In modern concept of planning and development, for enhancing and sustaining the land productivity, watershed unit, though varying in sizes up to micro level, is more permanent and natural. It has been accepted as most rational unit for planning and implementation of resource management programmes in integrated manner for optimal use of the prevailing resources within the watershed covering protective, curative, and ameliorative measures.

4.0.2 Location and Extent: The watershed of Umiew river is located in the East-Khasi Hills District of Meghalaya. The area of the watershed extends from 25^0-25' to 25^0-31' N latitudes and 91^0-45' to 91^0-52.7'E longitudes. The slope of drainage pattern of the upper most reach of the watershed moves towards Southern slope of the Shillong Peak. This is the highest peak in the East Khasi Hills having an altitude of 1964 m (6443.f ft). The Umiew River initially flows towards Eastern Side for about 10 Km and then towards the West upto confluence with its major tributaries namely Umtyngar and Umjyllieng. The boulder reaches of river Umtyngar, are shown in Figs.- 4.03 and 4.04. The river flows towards the South below the confluence along the Southern slope of Khasi Hills and enters into Bangladesh beyond Shella and there it joins with the river Surma.

4.0.3 Climate: The climatic conditions of the watershed experiences mild Summer and extreme cold during the winter. The Summer temperature varies

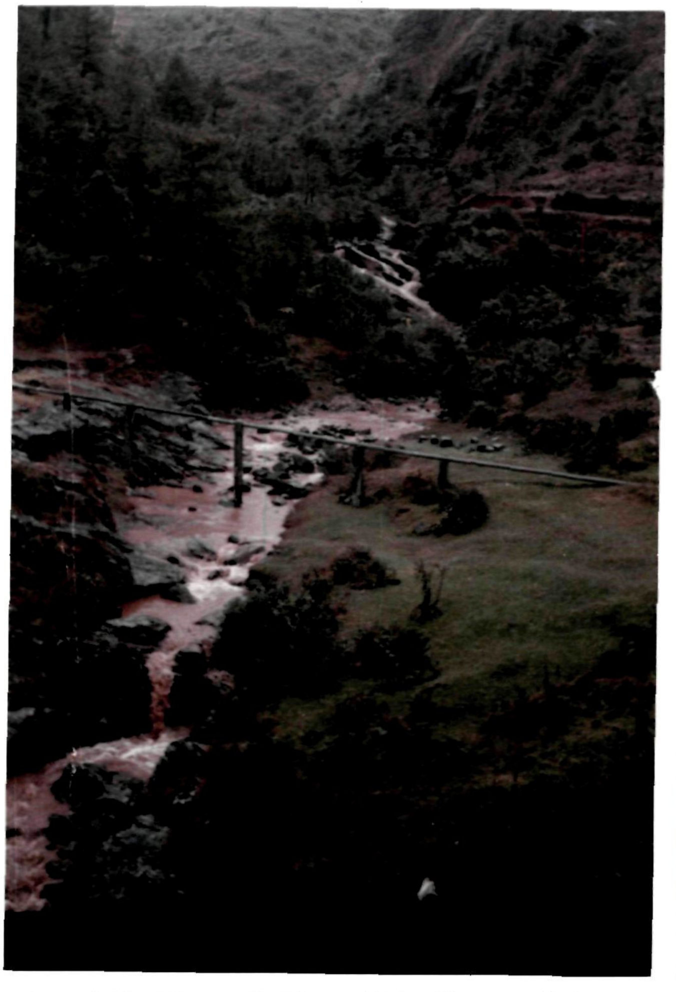


Fig.- 4.03 View of River Wah Umtong Syiem (Umtyngar)) one of the Tributaries of Umiew. Coming Under Micro Watershed Um_3

Fig. 4.04 : Down-Stream View of Wah Umtong Syiem

Fig. 4.05 : Stone Quarry by the Side of Shillong-Sohra Highway
and Along the Left Bank of River Umtyngar

from 14^0C to 24^0C whereas' the winter temperature touches upto 3^0C. The average annual rainfall has been registered to 3309 mm.

4.0.4 Vegetation: The forest cover in the upper part of the Umiew watershed has already disappeared. The lower part of this watershed is getting denuded rapidly. The existing green patches of forest are subjected to heavy grazing, cutting, lopping and incidence of fire leading to heavy degradation.

4.0.5. Settlements: The Umiew watershed comprises of four C.D. blocks namely Mawryngkheng, Mylliem, Mamphlang and Pynursla with altogether 63 villages lying in them. The Block wise distribution of the villages are:

(i) Mawryngkheng CD Block 17 villages

(ii) Mylliem CD Block 37 Villages

(iii) Mawphlang CD Block 7 Villages

(iv) Pynursla 2 Villages

The total population of these villages as per 1991 census has been recorded to 38,504 persons.

4.0.6 Land Use: In the upper part of the catchment, the agriculture is being followed as main activity by the farmers. More than one crop is grown in a year. This watershed area is one of the major potato belts of Meghalaya. In addition to potato, the paddy, maize, vegetable crops are also grown. The cultivation is mainly done along the steep slopes without adopting any conservation measures. This faulty practice of land use has given way to soil erosion leading to colossal losses of the top soil which is finally drained into river Umiew. The activity of such on-going faulty practice taking place along the hill slope towards right bank of river Umtingar, has been shown in Fig.-4.08. The main economic activities being practiced in the lower areas of the catchment, which include Mylliem and Mawreng areas, are both agriculture and mining. While paddy are being cultivated in the low lying areas. The massive stone and sand quarrying are going on in the areas lying at higher altitudes all along the road side and by the side of river Umtingar (Fig. 4.05, 4.06, 4.07). These activities are taking place around 3-4 Km down-stream of the boulder reaches of river Umtingar. In view of such massive sand and stone quarrying activities and the faulty agricultural

Fig. 4.06 : View Showing Sand Quarry Operation by the Excavator at the Right Bank of River Umtyngar Along Shillong- Sohra Highway

Fig. 4.07 : View Showing the Sediment Outflow From the Quarry Site into River Umtyngar. The Quarry Site is at the Right Bank of the River.

practices prevailing in the catchment area of river Umtyngar, the turbidity of this river has gone up very high. This can be visualised by the sediment laden water of river Umtyngar at its confluence with river Umsynteng (Fig.4.09). The spoils from the quarries, which are mechanically dumped by the side of the quarries' sites, are naturally drained into river Umtingar (Fig.-4.06).

4.1 Methods and Data collection

In order to understand the geo-hydrological characteristics of the watershed, and aggregated or composite picture of morphometric, land use and slope parameters of geomorphic features are needed. Design of the present chapter is prepared in such a way so that the parametric characteristics at micro-watershed level may be analysed and interpreted for the final synthesis of the results in the form of prioritisation mainly into three groups: slope, morphometry and land use. This analysis would be helpful in understanding the soil erosion risk pattern in the area. The major aspects of drainage network like shape, size, morphometric characteristics and relief features for the nine micro-watersheds have been studied from the Survey of India Toposheets. The measurement and mapping of morphometric parameters - relief ratio, drainage density, stream frequency, texture ratio, and basin shape parameters - form factor, circulatory ratio, elongation ratio etc. are made with the help of a Geographical Information System (GIS) based software called Integrated Land and Water Information System (ILWIS-3.1) version. The data related to stream pattern and the stream orders for the Umiew watershed as well as its all the nine micro-watersheds have been generated from the Toposheet of Survey of India at R.F. 1/50,000. The elevation maps, which give the areal distribution of relief of the micro-watersheds, are drawn by creating their Digital Terrain Model (DTM). The area and elevation data generated from the elevation maps have been used for the hypsometric analysis of the micro-watersheds. The slope maps of micro-watersheds, which indicate different slope categories, have been prepared by calculating the slope percentage in X an Y direction by using the Digital Elevation Model (DEM). The areal distribution of the land slopes under different land slope categories existing in the micro-watersheds, have been quatified and shown in

Fig. 4.08 : View Showing the Cultivation of Vegetable Crop Along the Hill Slope. The Cultivation is Lying at the Right Bank of River Umtyngar

Fig. 4.09 : View Showing the Sediment Laden Water of River Umtyngar. It is Confluencing With River Umsynteng, Which Carries Clean Water.

the form of bar charts. These parameters provide description of physical characteristics of the micro-watersheds of the basin which are useful for landuse planning, terrain evaluation, soil conservation and erosion studies. The laws of drainage basin development and shape factors can be arrived at by using conventional methods (Schumm 1956, Miller 1953, Taylor and Scwartz 1952, Strahler 1957, Melton 1958, Morisawa 1959, Hack 1957).

Peak runoff decreases as the catchment area increases due to higher time of concentration. A fan shaped catchment produces greater flood intensity than a fern shaped catchment (Knapp 1979). According to Viessman *et al.* (1977), the catchment characteristics affecting runoff are: geologic factors, morphometric parameters, and physiographic factors. The influence of geomorphic parameters on hydrology of Umiew watershed, particularly the estimation of sediment yield rate by the use of empirical relationship, have been studied in detail separately in chapter-4. However, the existing landuse of the entire Umiew watershed has been interpreted here to support the estimation of runoff and sediment yield conditions. It was pursuaded with the help of satellite data- IRS-ID, LISS-III for the scene acquired on 2nd November, 2000. This satellite data have been made available by the North Eastern Space Application Centre (NESAC), Barapani, Meghalya. The entire landuse of the micro-watersheds has been categorised into seven different categories of land uses. The visual interpretation of the thematic map, prepared with the help of digital satellite data, has also been done for the identification of different land use pattern of the mico-watersheds observed on 2nd November,2000. The cycle of shifting cultivation going on in the entire area of the micro-watersheds could not be studied due to non-availability of the satellite data for more number of years.

The combined prioritisation of the micro-watersheds has been worked out with the help of morphometric parameters, slope steepness and the landuse pattern existing during November,2000. This prioritisation has been done for detecting the soil erosion risk proneness of the micro-watersheds.

4.1.1 Delineation of Micro-watersheds

Spatial characteristics of watersheds are highly heterogeneous and anisotropic. In order to understand the hydrologic behaviour of the watershed, it is necessary to study the spatial characteristics of the watershed.

Delineation of the watersheds are essential before undertaking any activity related to planning and management of watersheds. A multitude of parameters are employed to study the geometrical and geomorphological characteristics of the watersheds. Different elements are used to represent a watershed geometry. Geomorphological characteristics can be employed to define flow paths in a watershed. Spatial geomorphological characteristics affect the flow of water in the watershed.

The boundary of a watershed is defined by all points that shed water to the outlet. The delineation of a watershed is important to hydrological design. It is necessary to decide which points in a watershed contribute water to the outlet. The most extreme of these points represent the boundary of a watershed. Therefore, delineation of boundary of the micro-watersheds has been accomplished by identifying the ridge lines from the toposheets of the Survey of India which covers the geographical area of Umiew Watershed. The ridge lines are the highest contour lines of the micro-watershed area that drains to the outlet.

The boundary line along a topographic ridge separating two adjacent micro-watersheds is called a micro-watershed divide. It has been observed that the drainage pattern of Umiew watershed has many small independent rivulets and some of them are forming upto second and third order of drainage network (Fig.-4.1). But, such drainage networks are widely spaced within smaller areal extent. In order to provide simplicity in the identification of erosion risk proneness of different portion of the umiew watershed, its area has been delineated into nine micro-watersheds areas by accommodating a set of small independent rivulets, and also in some cases, a combination of widely spaced second/third order network of the rivulets.

A distinct characteristic feature of the small watershed, from the hydrologic point of view, is that the effect of overland flow rather than the effect of channel

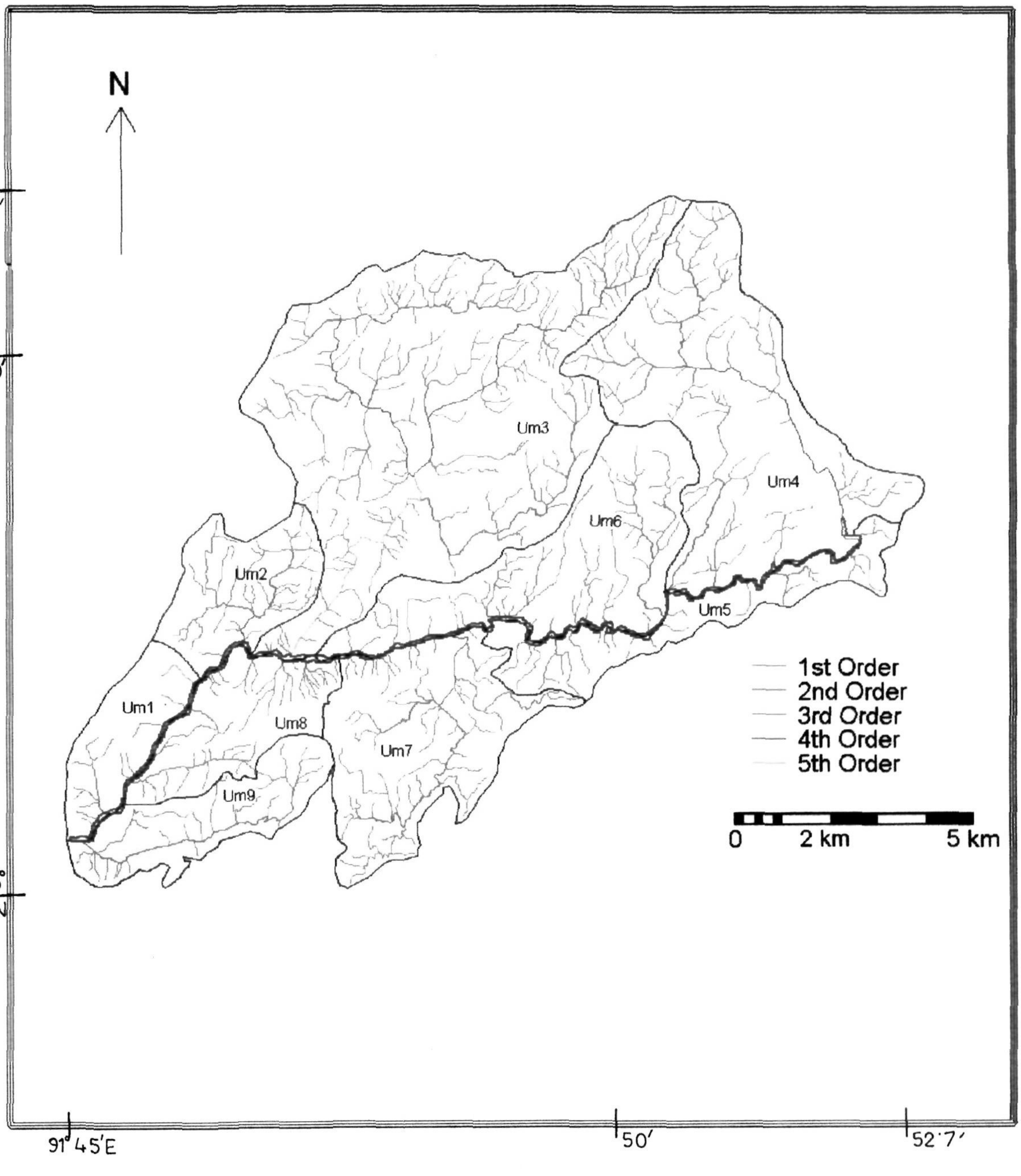


Fig.-4.1: Stream order and micro-watersheds

flow is a dominating factor affecting the peak runoff. Consequently, a small watershed is very sensitive to high intensity rainfalls of short duration and to land use. On larger watersheds, the effect of channel flow or the basin storage effect becomes very pronounced so that such sensitivities are greatly suppressed. Therefore, a small watershed may be defined as one that is so small that its sensitivities to high intensity rainfalls of short duration and to landuse are not suppressed by the storage characteristics (Chow 1964). By this definition, the size of a small watershed may be found from a few hectares to 1000 hectares. The upper limit of the area depends on the conditions at which the above mentioned sensitivities become practically lost due to channel storage.

4.1.2 Morphometric Analysis: The morphometric analysis has been done for detecting soil erosion risk proness of the micro-watersheds from the identified study area of Umiew Watershed. The analysis is used to prioritize the micro-watersheds by conducting Erosion Risk Assessment. The basic objective of this analysis is to generate data on morphometric parameters (physical characteristics) of the micro-watersheds which could be used to relate quantitatively the process of sediment yield taking place from the delineated micro-watersheds. The parameters required for this analysis are: stream length, bifurcation ratio, drainage density, stream frequency, texture ratio and basin shape parameters like form factor, circularity ratio, elongation ratio etc.

(a) Drainage Pattern: The drainage pattern of the micro-watersheds has basically been traced out from the toposheet of Survey of India. The analog data (in digital form) are transferred into vector format by means of digitizing program. The boundary of drainage catchment and the drainage networks of the delineated micro-watersheds have been digitized. The digitized map has been connected with the toposheet for any type of error pertaining to proper joining of streams, proper overlaying of the stream segments etc. The system then auto edits the coverage. The individual stream lengths are computed by default and stored in the order table along with the order of each stream. The area and perimeter of the micro watersheds are computed after converting their digitized maps into polygon forms. The different stream orders existing in the micro-watersheds and computation of length of each order of streams are then recorded (Table-4.1).

The drainage pattern of micro-watersheds namely, Mawphlang (Um1), Umgot (Um2), Mawreng (Um3), Nongkynrih (Um5), Basio (Um6), Laitkroh (um7) and Laitkynsew (Um8) have accommodated independent rivulets. These rivulets are distantly located within the micro-watersheds' boundary (Figs.-4.2 to 4.4, 4.6 to 4.9). In addition, Mawphlang micro-watershed (Um1) has the drainage network of 3rd order whereas, Umgot (Um2), Mawreng (Um3), Nongkynrih (Um5), Basio (Um6), Laitkroh (Um7) and Laitkynsew (Um8) have the drainage network of 4th, 5th, 3rd and 4th order respectively. The bifurcation ratio of Umgot (Um2), Nongkrem (Um4) and Basio (Um6) are in the range of 3.83 to 3.89 whereas, the bifurcation ratio of the remaining six micro-watersheds have been found to be in the range of 4.07 to 6.50. The drainage density of the above micro-watersheds are coming under the moderate range of 1.70 to 3.70 km/km^2 (Table-4.1).

(b) Relief Features: The land areas of different elevations (relief) of the micro-watersheds have been assessed. The distribution of such land areas have been shown in the elevation maps of the micro-watersheds (Figs.-4.11 to 4.19). The areal distribution of the area at different ranges of elevations have been analysed for the micro-watersheds.

This analysis, called the hypsometric analysis, has been carried out to develop the relationship between cumulative area (%) and their corresponding elevation. This relationship when plotted graphically depicts in the form of curve which shows the characteristics of micro-watersheds. The slope of the hypsometric curve indicates the existing stages of development of the micro-watersheds. The computations of cumulative area (%) and their corresponding elevations for all the nine micro-watersheds are given at Appendix-4.1.

The shape of hypsometric curves of five micro-watersheds namely, Mawphlang (Um1), Nongkynrih (Um5), Laitkynsew (Um8), Basio (Um6) and Umgot (Um2) micro-watersheds are found to be convex. The convex shape shows that these micro-watersheds are in equilibrium stage or young stage. This stage of the micro-watersheds shows that the developmental interventions may be undertaken for preventing the natural resources like soil and water

Table-4 1 Stream Orders and their Details

Micro Watershed	Sream Details											
	Order -1		Order - 2		Order - 3		Order - 4		Order - 5		Total	
	L	N	L	N	L	N	L	N	L	N	L	N
Um1	7935.94	13	1231.86	2	351.12	1	0	0	0	0	9518.92	16
Um2	18140.44	31	5823.29	8	3163.79	2	689.88	1	0	0	27817.4	42
Um3	88319.05	167	26031.4	41	14150.54	9	13399.42	2	6063.45	1	147964	220
Um4	36143.83	74	17277.13	19	7803.63	4	6609.79	1	0	0	67834.4	98
Um5	16080.04	25	2427.44	6	622.22	2	0	0	0	0	19129.7	33
Um6	32174.37	46	10111.72	12	2882.39	2	0	0	0	0	45168.5	60
Um7	32784 87	54	9985.69	11	7410.13	2	2082 39	1	0	0	52263.1	68
Um8	20657.39	38	6414.49	9	290.5	2	0	0	0	0	27362.4	49
Um9	14379.74	25	2854.87	5	6071.94	1	0	0	0	0	23306 6	31

NB· N = Number of Streams, and L = Stream length in metres

Table-4 2 Morphometric Parameters

Micro Watershed	Area, A (Km2)	Perimeter, P (Km)	Micro watershed length, Lb (Km)	Bifurcation ratio, R	Drainage density, Dd (Km/Km2)	Stream frequency, F (Number/ Km2)	Form factor,Rf	Circulatory ratio, Rc	Elongation ratio, Re	Texture ratio, T
Um1	5 59	11 43	1 99	6 50	1 70	2 86	1 41	0 54	1 34	1 41
Um2	7 43	12 87	4 07	3 87	3 74	5 65	0 45	0 56	0 76	2 41
Um3	44 04	36 50	16 20	4 07	3 36	4 99	0 17	0 42	0 46	4 58
Um4	25 87	30 12	11 17	3 89	2 62	3 79	0 21	0 36	0 51	2 46
Um5	7 68	26 55	1 83	4 16	2 52	4 35	2 26	0 13	1 70	0 94
Um6	15 91	24 42	4 65	3 83	2 84	3 77	0 74	0 34	0 96	1 88
Um7	14 75	21 99	9 24	4 90	3 54	4 61	0 17	0 38	0 47	2 46
Um8	7 66	14 42	3 34	4 22	3 57	6 40	0 69	0 47	0 93	2 63
Um9	7 52	16 79	7 16	5 00	3 10	4 12	0 15	0 34	0 43	1 49
Total	136 45									

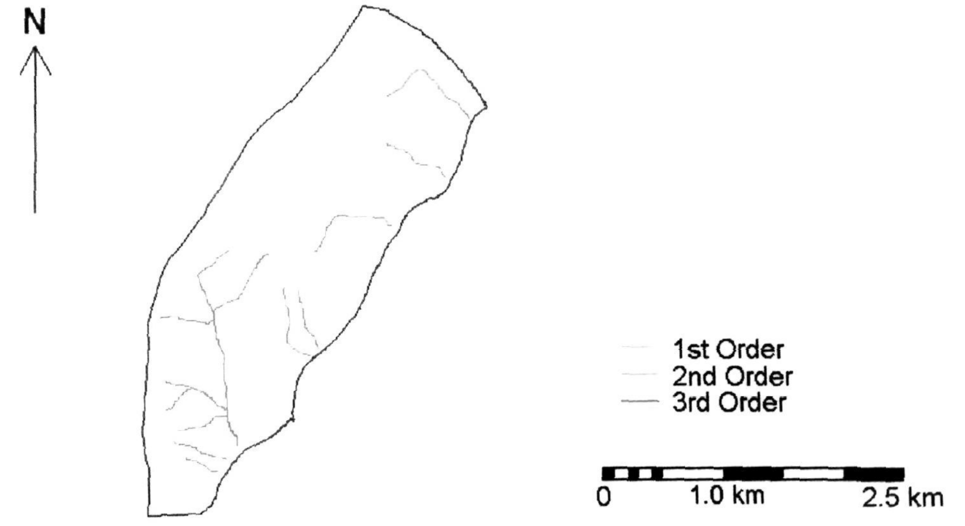


Fig. 4.2: Stream Order of Micro-Watershed Um1

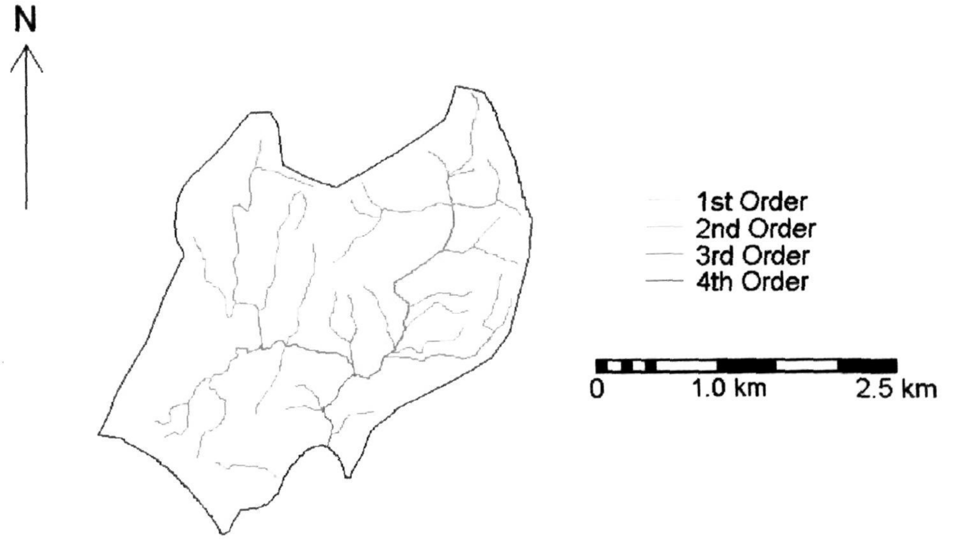


Fig. 4.3: Stream Order of Micro-Watershed Um2

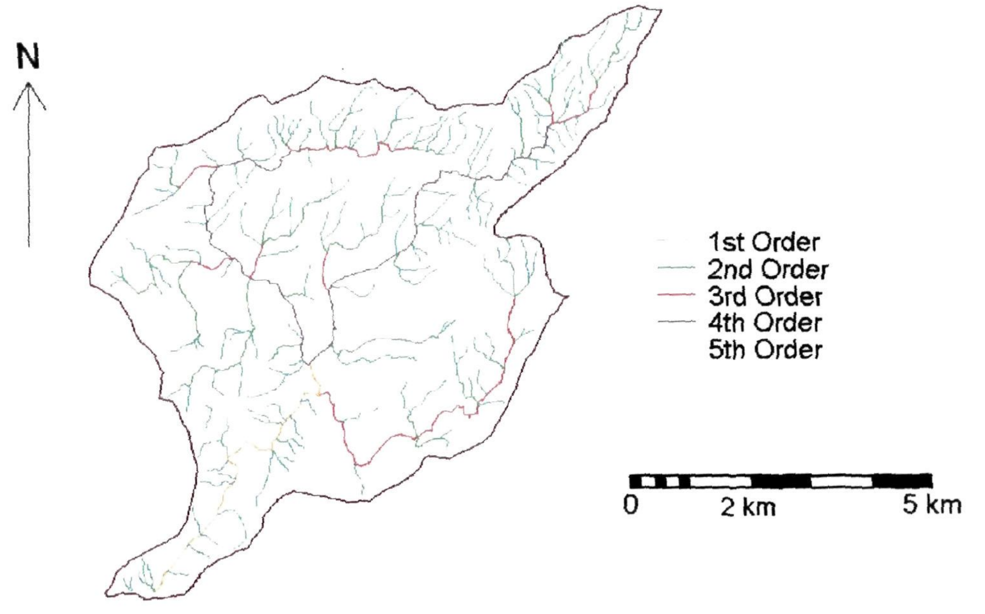


Fig. 4.4: Stream Order of Micro-Watershed Um3

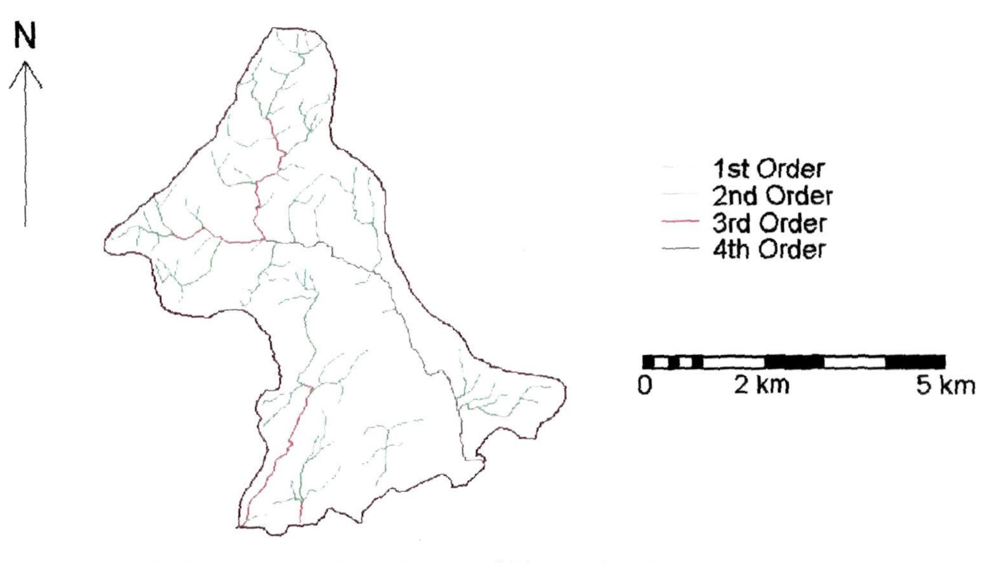


Fig. 4.5: Stream Order of Micro-Watershed Um4

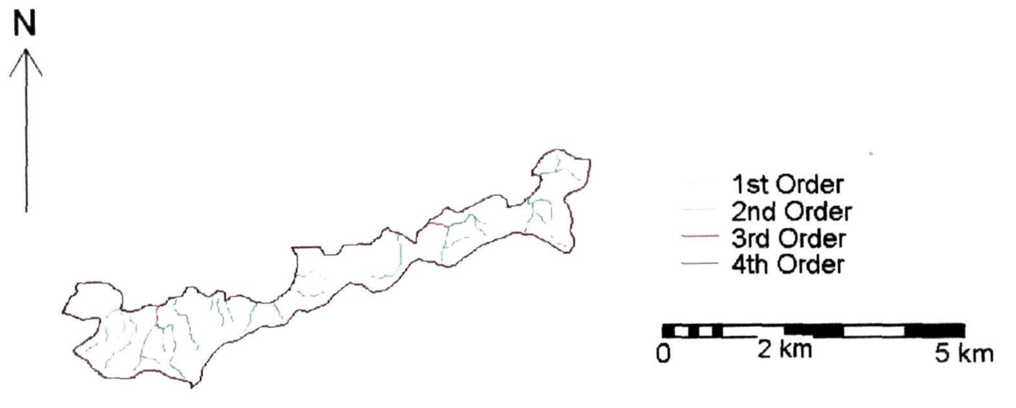


Fig. 4.6: Stream Order of Micro-Watershed Um5

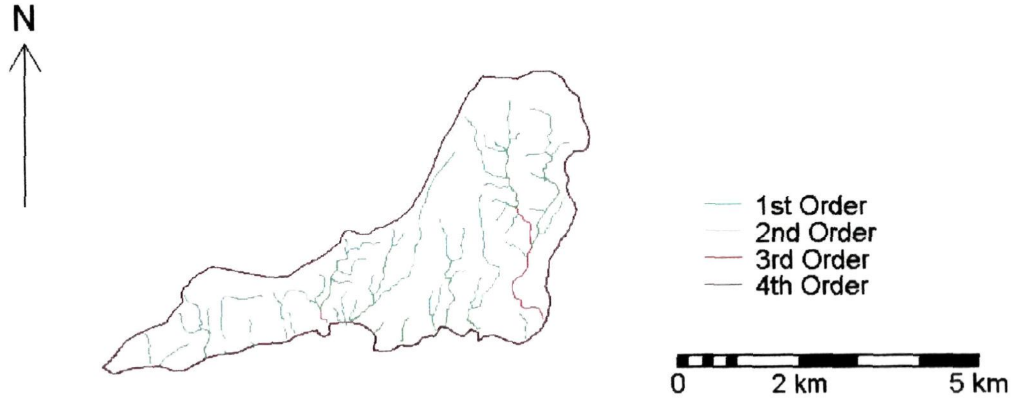


Fig. 4.7: Stream Order of Micro-Watershed Um6

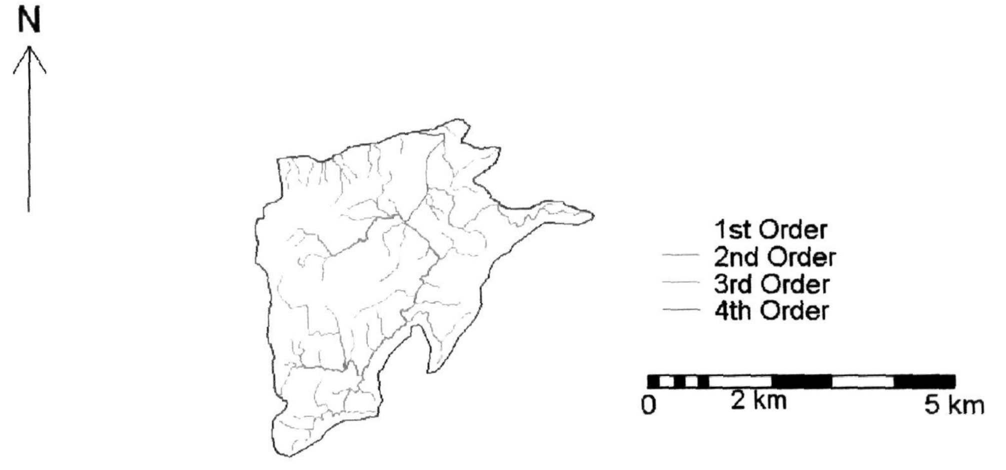


Fig. 4.8: Stream Order of Micro-Watershed Um7

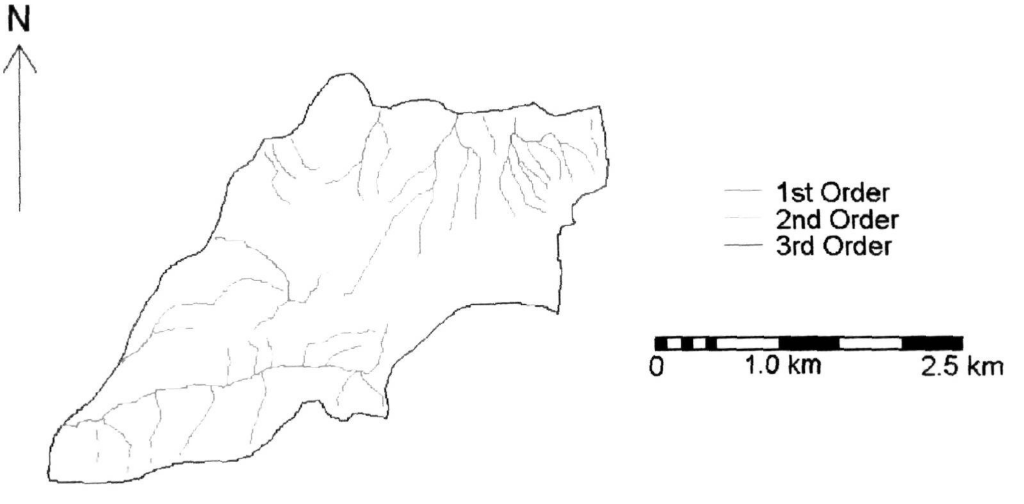


Fig. 4.9: Stream Order of Micro-Watershed Um8

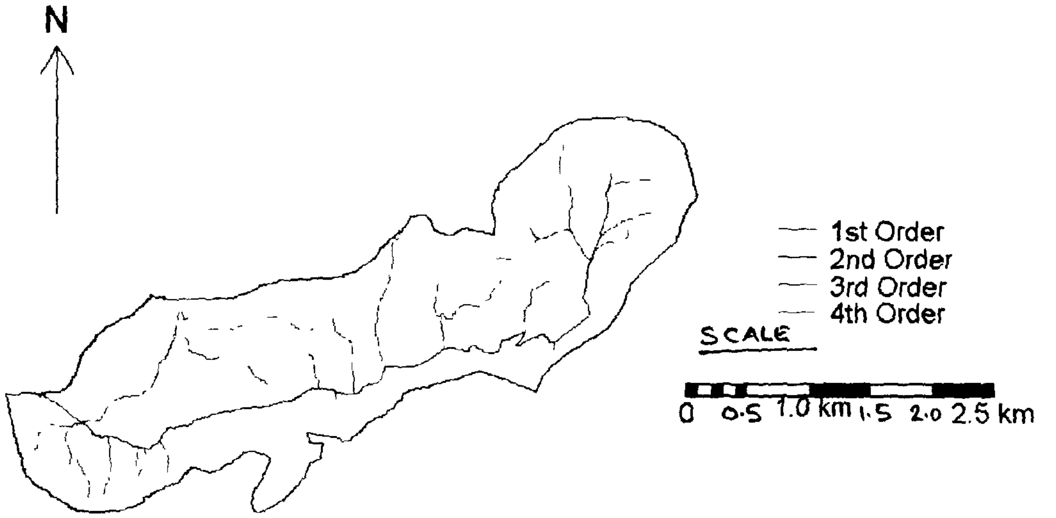


Fig. 4.10: Stream Order of Micro-Watershed Um9

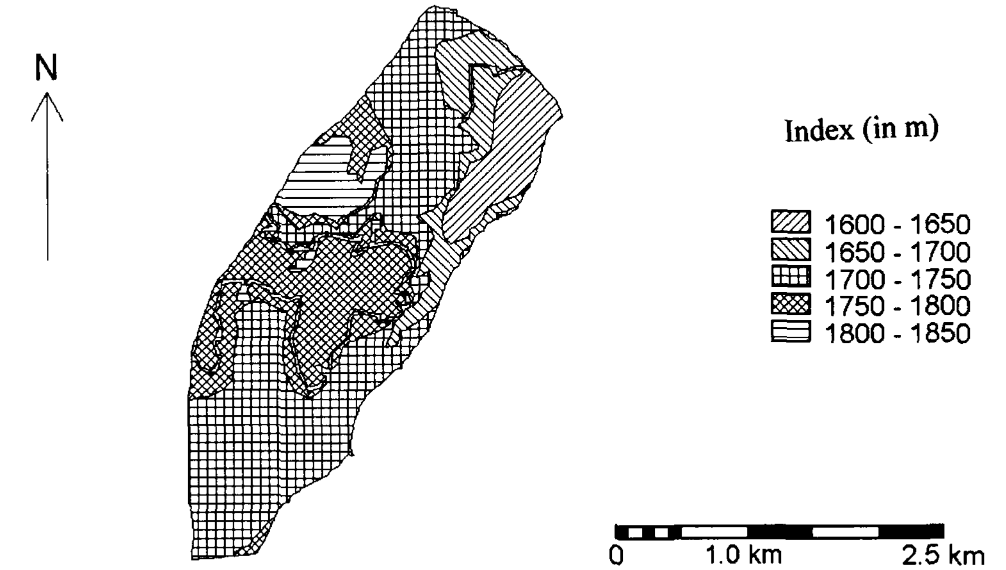


Fig. 4.11: Elevation Map of Micro-Watershed Um1

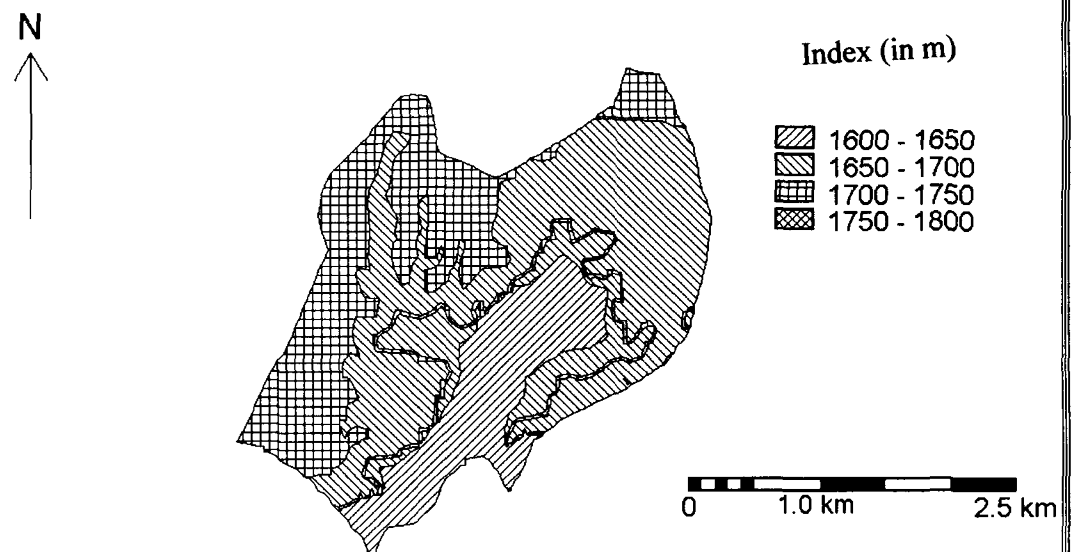


Fig. 4.12: Elevation Map of Micro-Watershed Um2

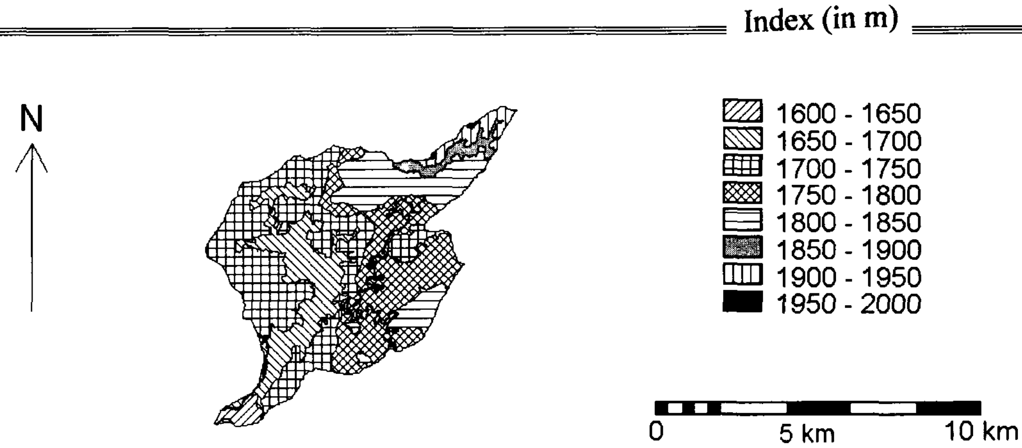


Fig. 4.13: Elevation Map of Micro-Watershed Um3

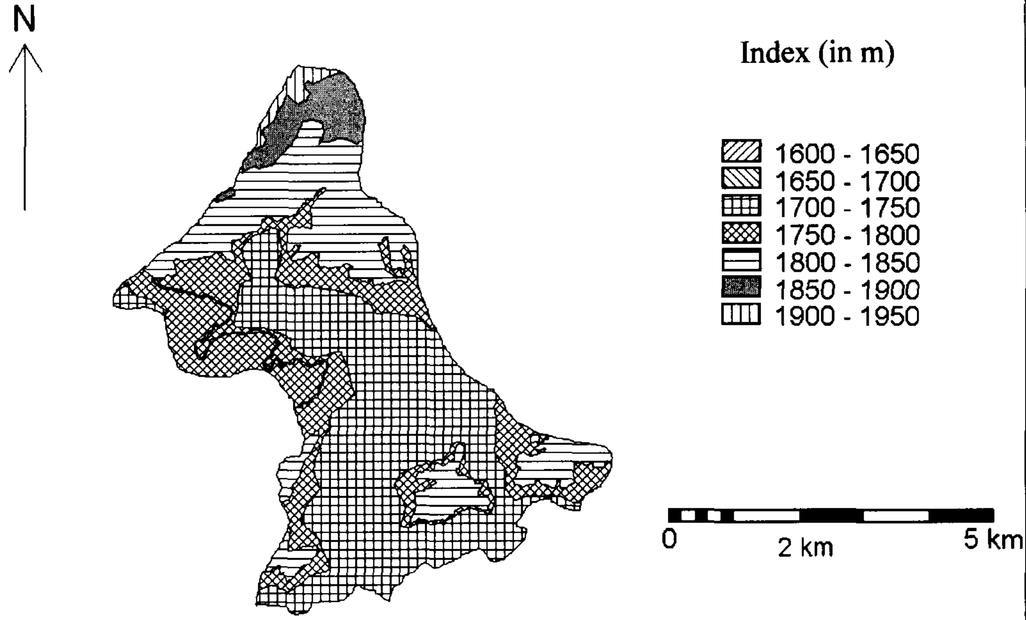


Fig. 4.14: Elevation Map of Micro-Watershed Um4

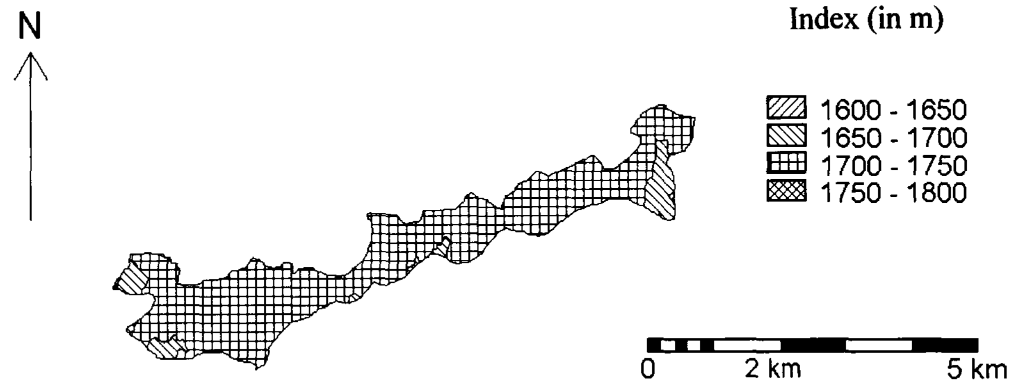


Fig. 4.15: Elevation Map of Micro-Watershed Um5

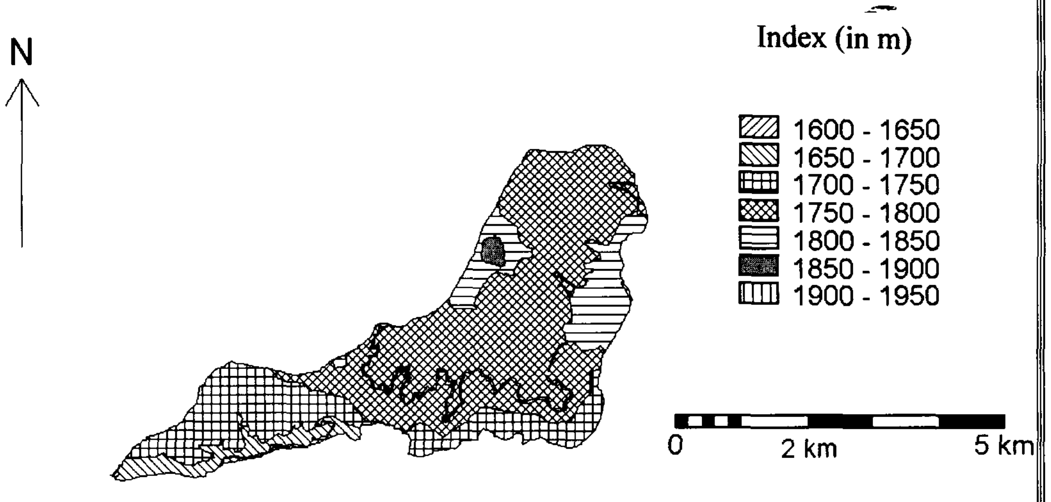


Fig. 4.16: Elevation Map of Micro-Watershed Um6

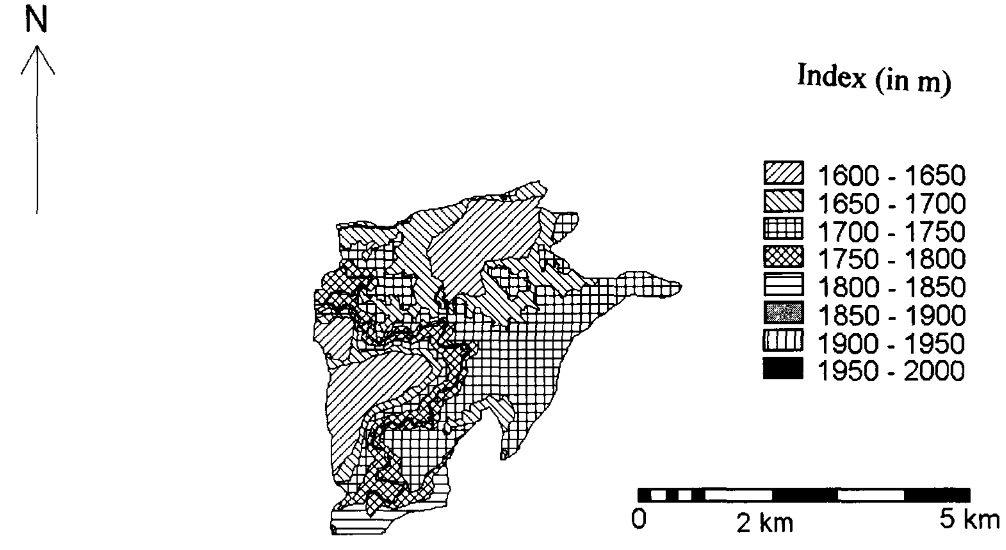


Fig. 4.17: Elevation Map of Micro-Watershed Um7

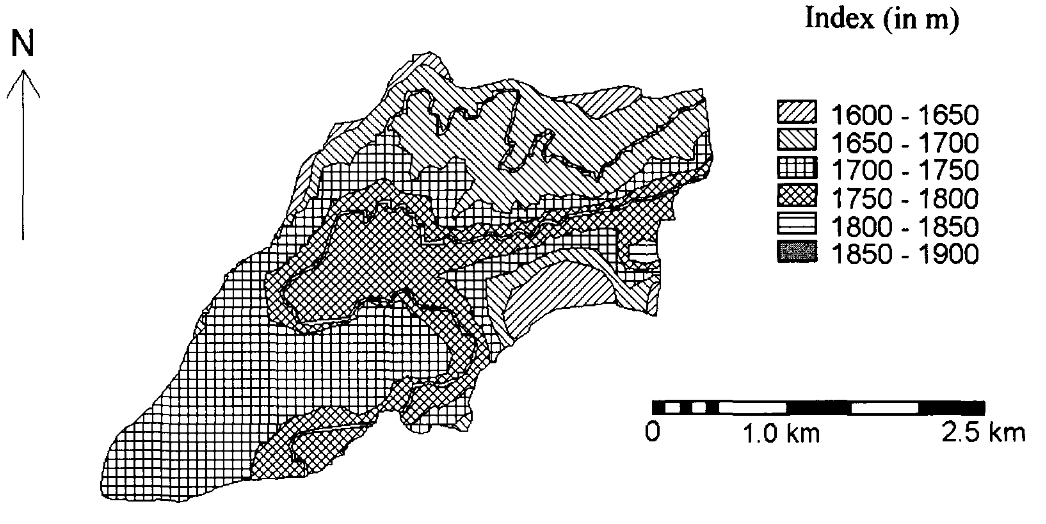


Fig. 4.18: Elevation Map of Micro-Watershed Um8

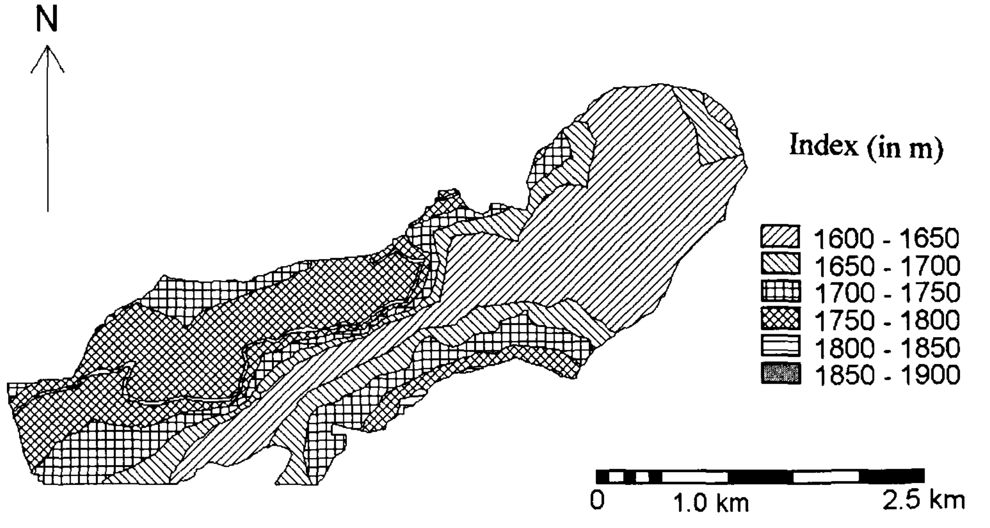


Fig. 4.19: Elevation Map of Micro-Watershed Um9

(Figs.- 4.41 to 4.43). In Laitkroh (Um7) and Mawreng (Um3) micro-watersheds, the shape of the upper part of the hypsometric curve has been found concave followed by convex shape to the lower part. This shape revels that the development of these micro-watersheds have reached at steady state condition under equilibrium stage of development (Figs.- 4.41 to 4.43). The shape of the hypsometric curve of the remaining two micro-watersheds namely, Nongkrem (Um4) and Dympep (Um9) has followed a concave shape. This shape reveals that the above micro-watersheds are under the Monadnock stage. This stage reveals that the isolated bodies of resistant rock from prominent hills have come above the subdued surface (Figs.- 4.42 to 4.43).

The land slopes existing in the micro-watersheds have been put under five different categories- Flat land (0-5 %), Moderate flat (5-10 %), Moderate slope (10-20 %), Steep slope (20-30 %) and Very steep slope (30-100 %). The areal distribution of the land slope under various land slope categories falling in different micro-watersheds are shown in the slope maps (Figs.-4.20 to 4.28).

Among right bank micro-watersheds, Mawphlang micro-watershed (Um1) contains 41 % of its geographical area by moderate slope to very steep slope followed by Nongkrem micro-watershed (Um4) and Umgot micro-watershed (Um2) with 28 % and 25 % of their geographical areas covered by moderate to very steep slopes. The right bank remaining two micro-watersheds – Mawreng (Um3) and Basio (Um6) have more dominance of moderate flat to moderate sloppy area of around 84 % and 92 % of their geographical areas respectively. Similarly, among the left bank micro-watersheds, Laitkynsew micro-watershed (Um8) possess 66 % of its geographical area by moderate slope to very steep slope followed by Laitkroh micro-watershed (Um7) and Dympep micro-watershed (Um9) with 59 % and 44 % of the geographical areas covered by moderate to very steep slopes. The left bank remaining one micro-watershed – Nongkynrih (Um5) have only dominance of moderate flat to moderate slopy area of around 81 % of its geographical area. The quantification of the area coverage by the different land slope categories in the micro-watersheds have been shown in the form of bar charts (Figs.-4.38 to 4.40).

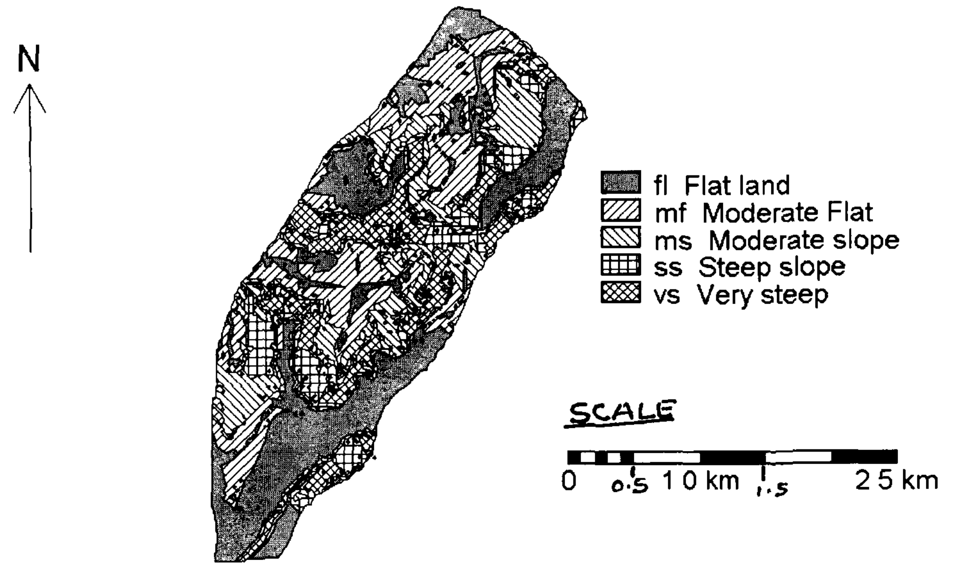


Fig. 4.20: Slope Map of Micro-Watershed Um1

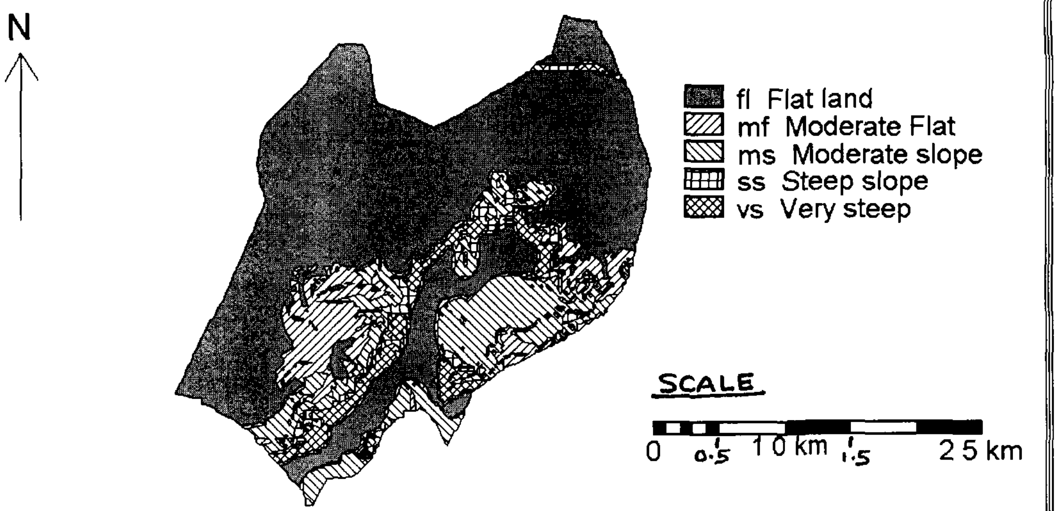


Fig. 4.21: Slope Map of Micro-Watershed Um2

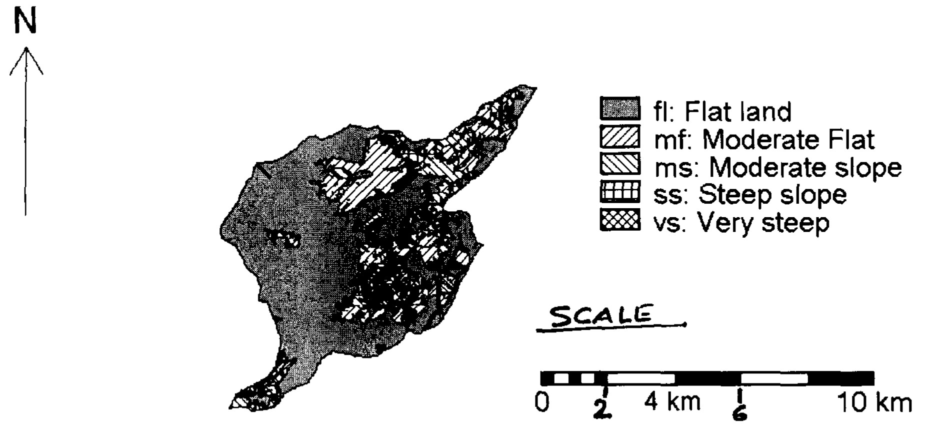


Fig. 4.22: Slope Map of
Micro-Watershed Um3

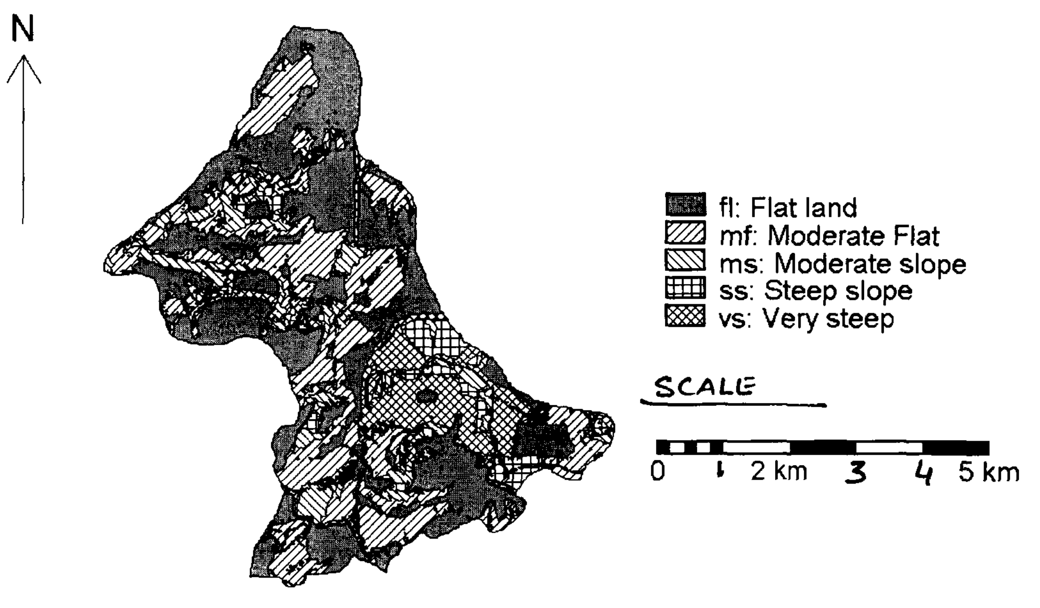


Fig. 4.23: Slope Map of
Micro-Watershed Um4

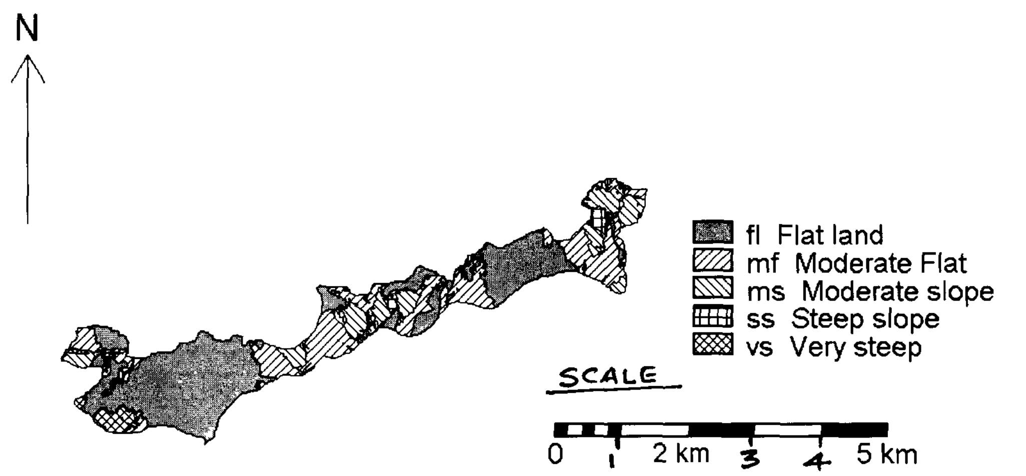


Fig. 4.24: Slope Map of Micro-Watershed Um5

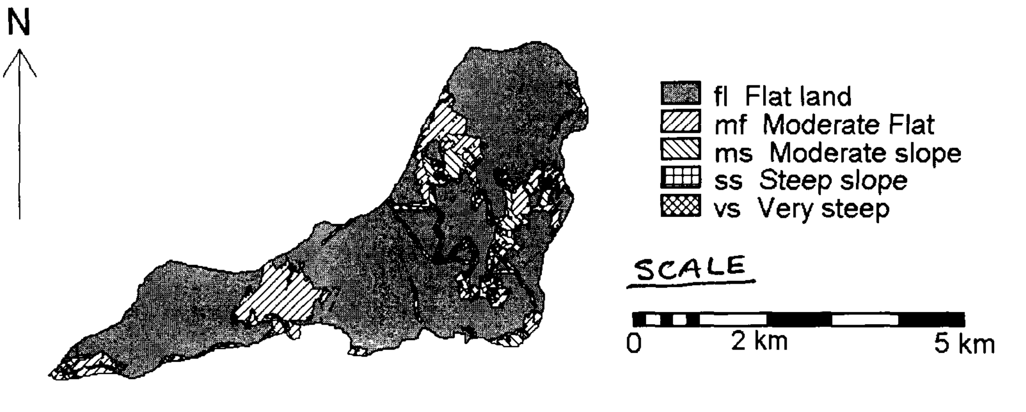


Fig. 4.25: Slope Map of Micro-Watershed Um6

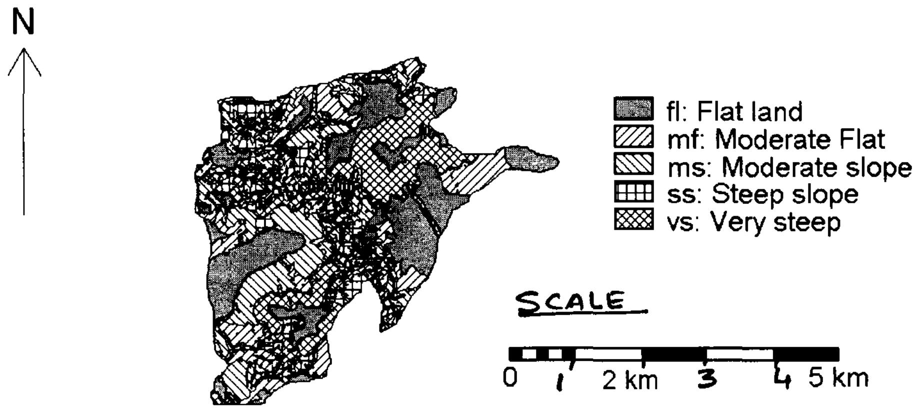


Fig. 4.26: Slope Map of Micro-Watershed Um7

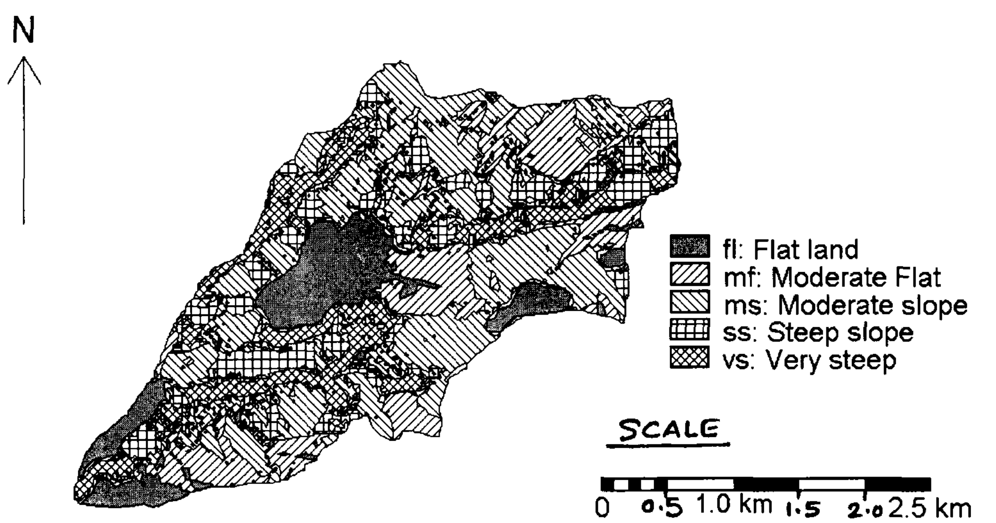


Fig. 4.27: Slope Map of Micro-Watershed Um8

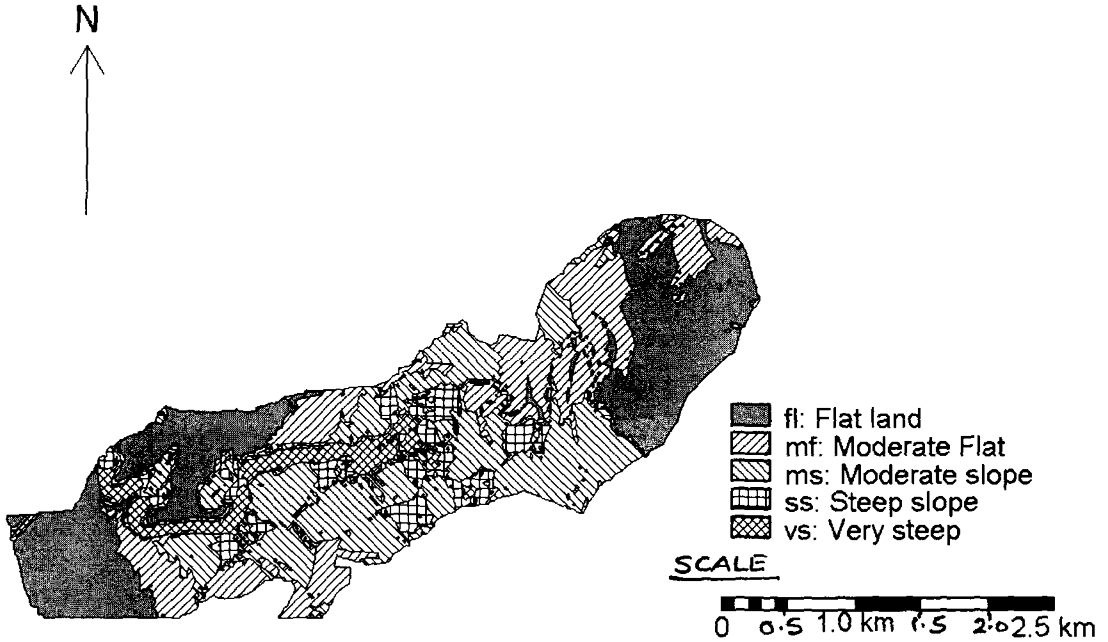


Fig. 4.28: Slope Map of Micro-Watershed Um9

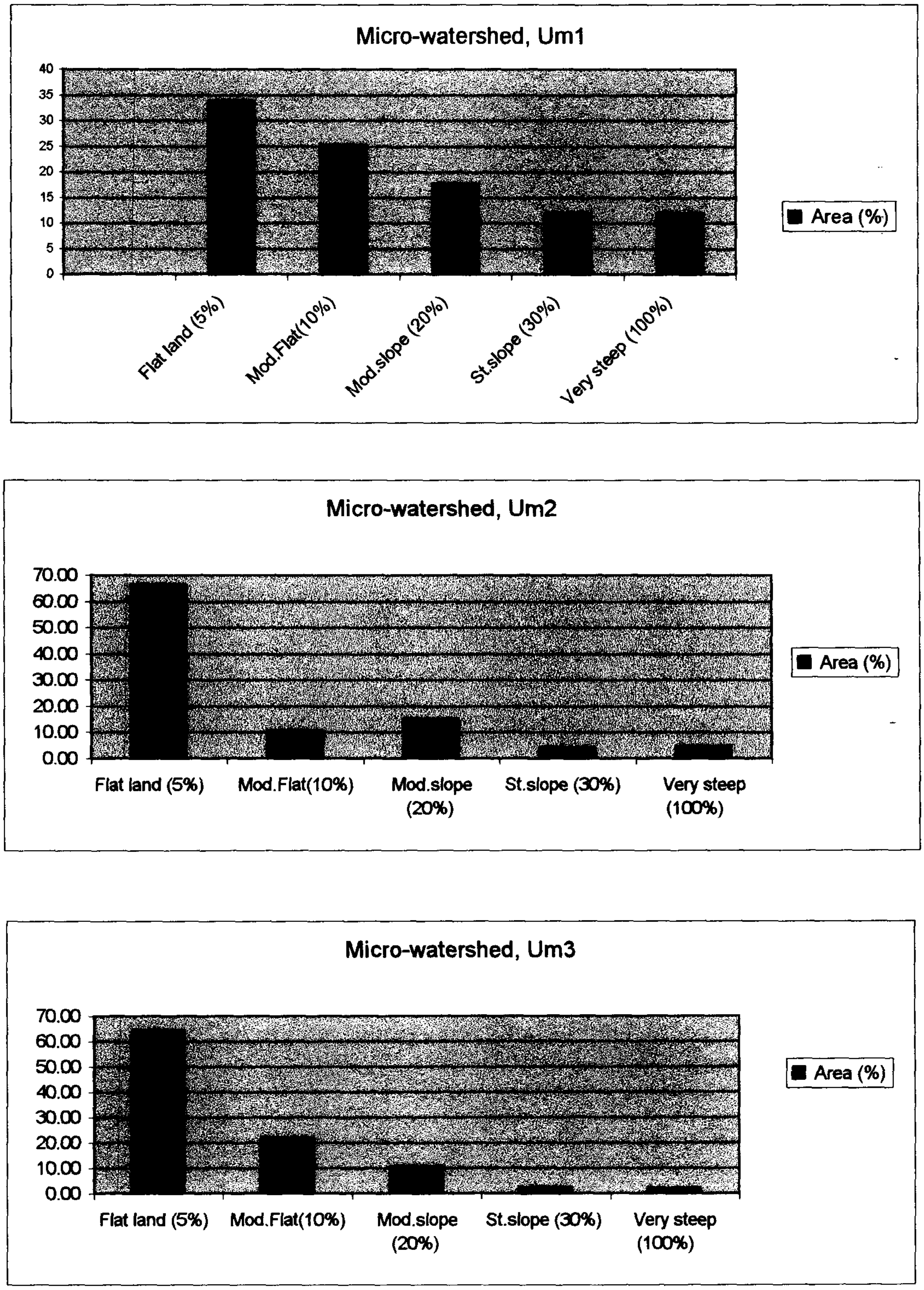
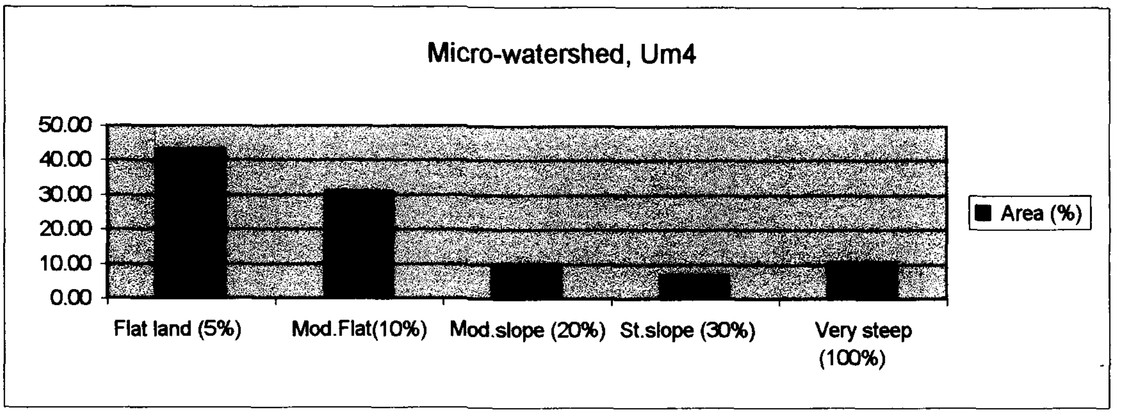
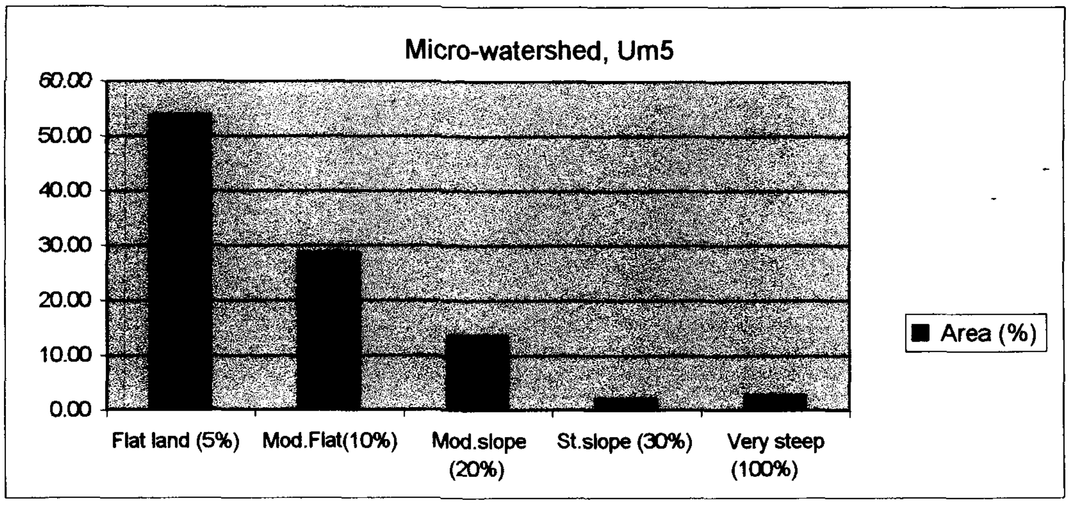


Fig.-4.38: Area of Different Land Slopes in Micro-Watersheds





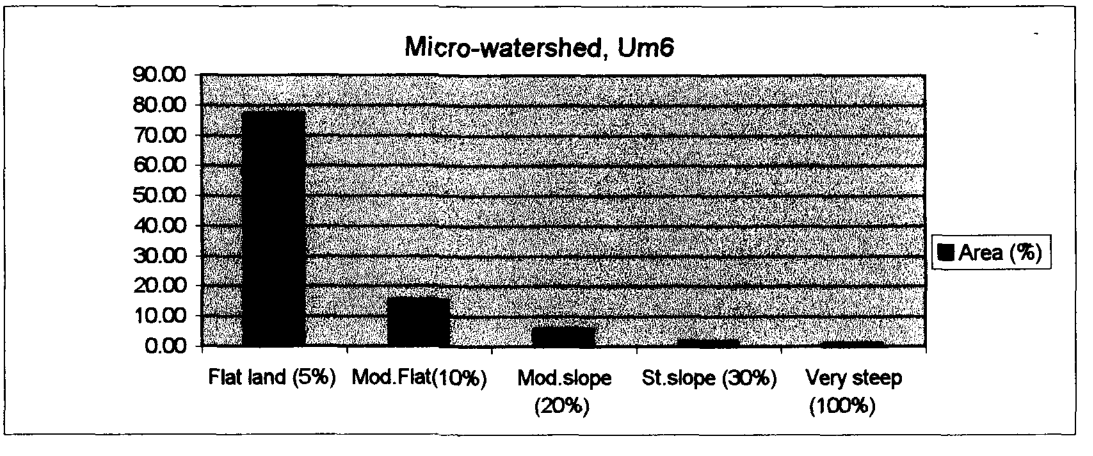
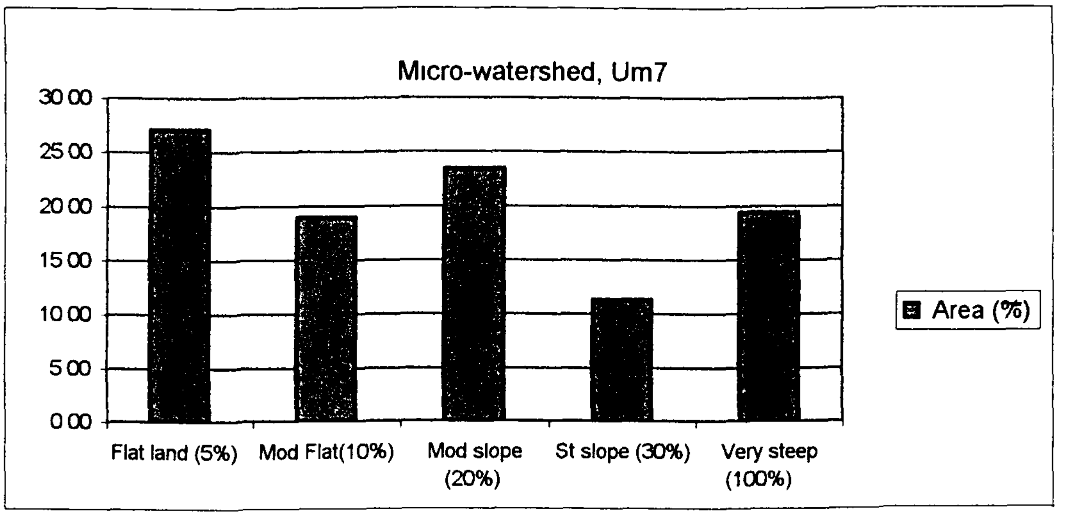
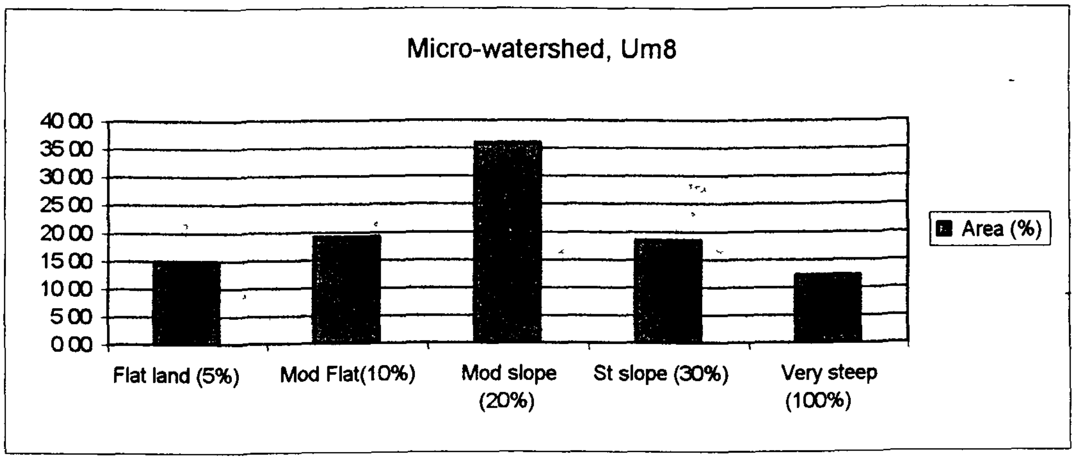


Fig.-4.39: Area of Different Land Slopes in Micro-Watersheds





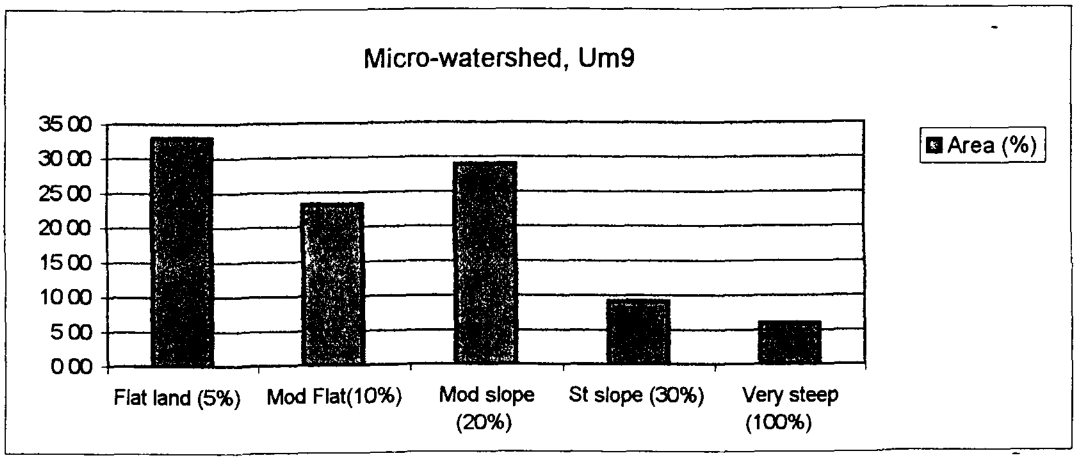


Fig.-4.40: Area of Different Land Slopes in Micro-Watersheds

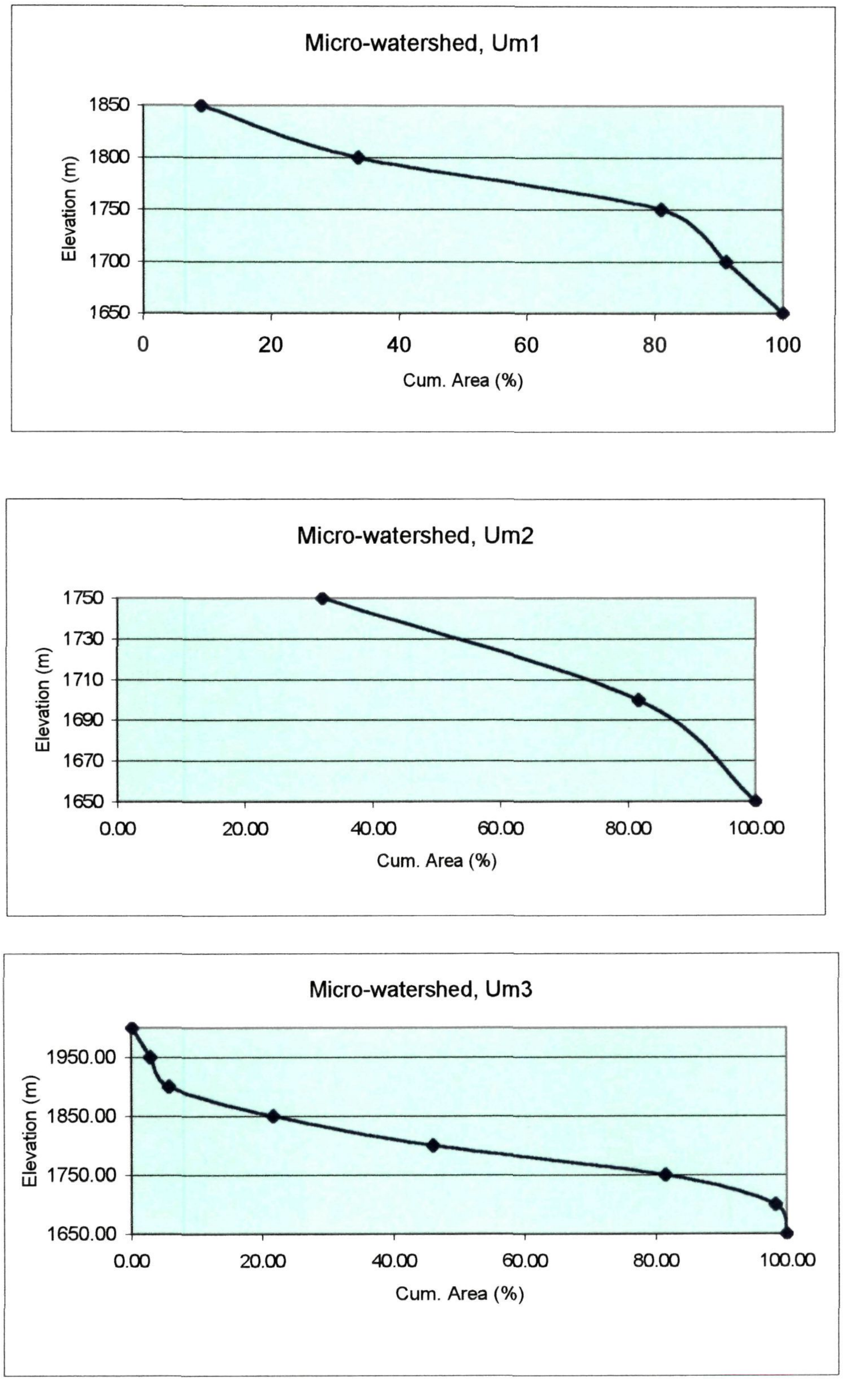
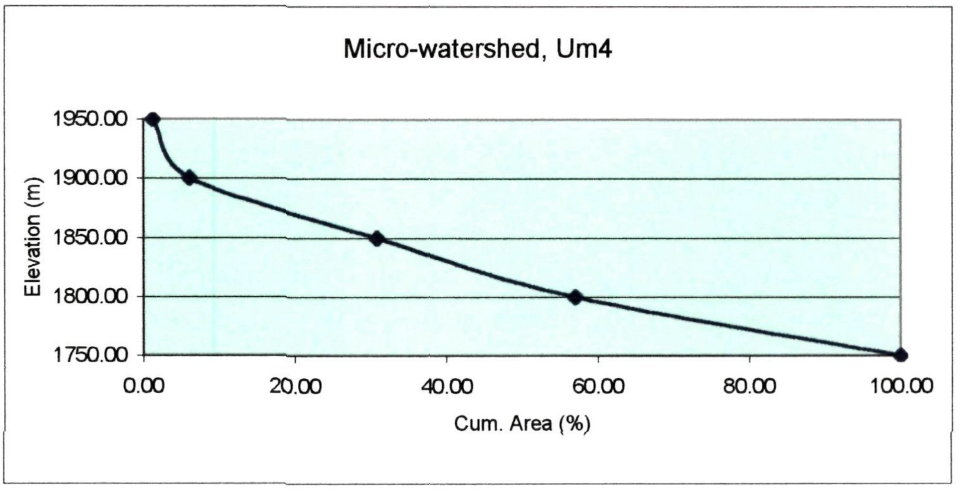
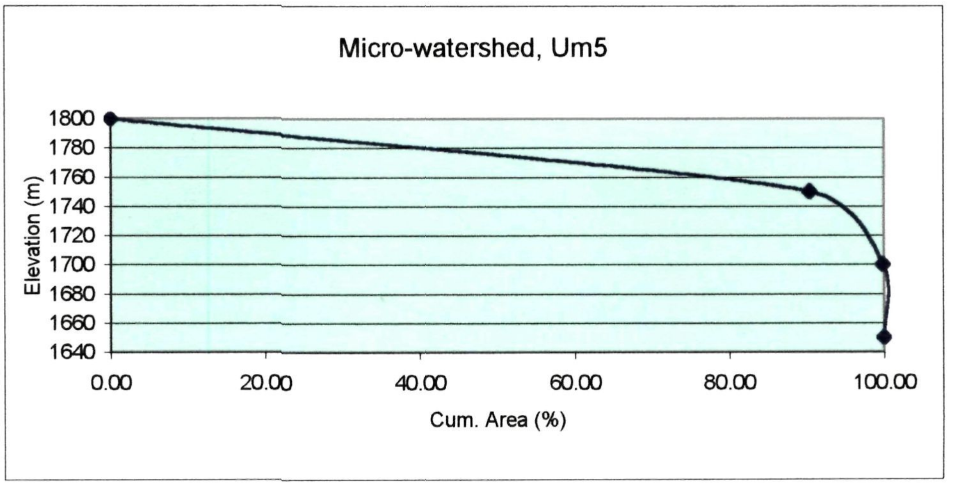


Fig.-4.41: Hypsometry Curve of Micro-Watersheds





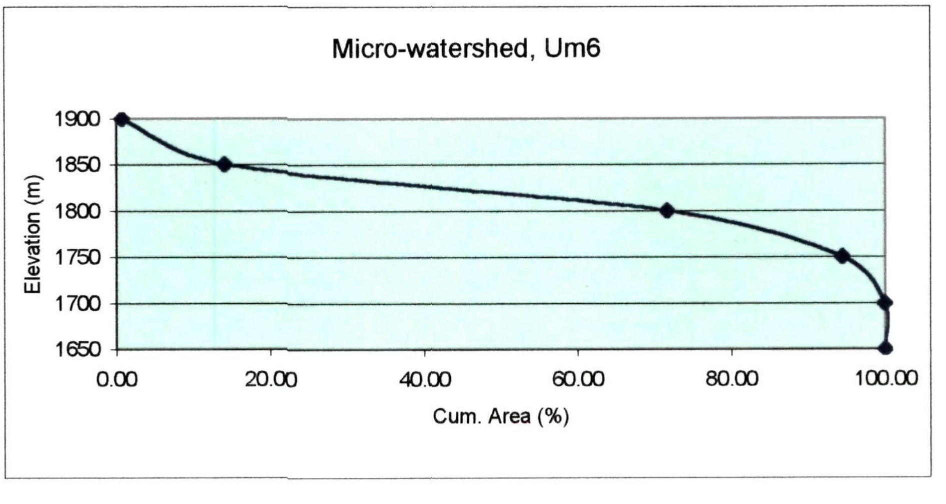
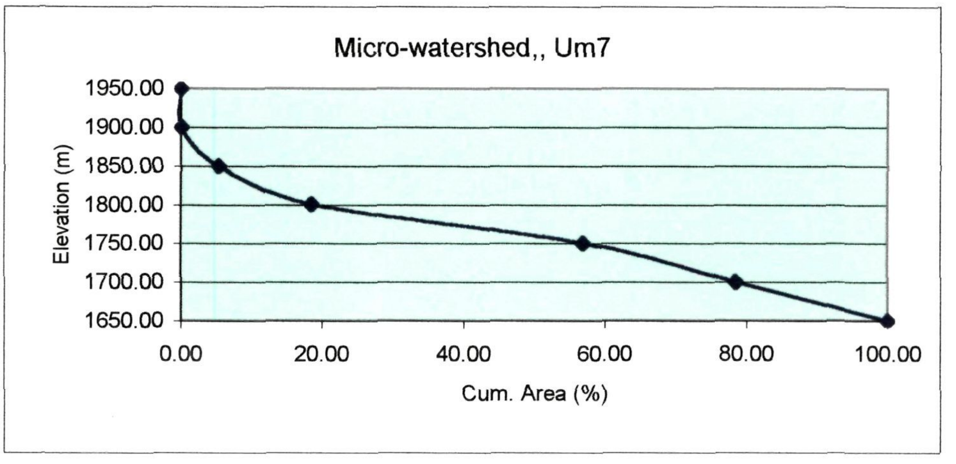
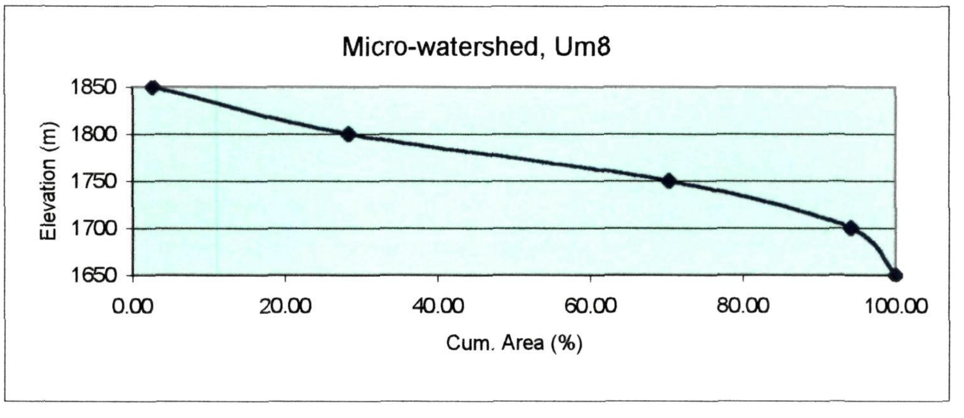


Fig.-4.42: Hypsometry Curve of Micro-Watersheds





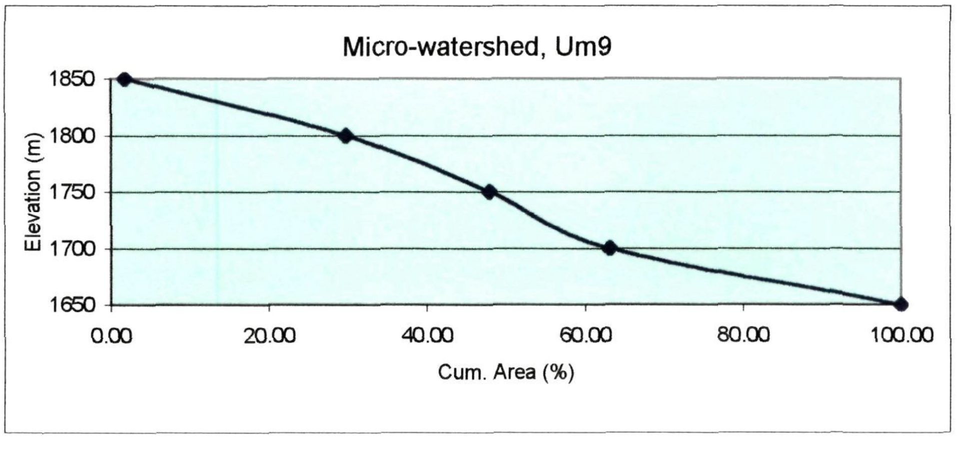


Fig.-4.43: Hypsometry Curve of Micro-Watersheds

4.1.3 Prioritization of Micro-watershed: The prioritization of micro-watersheds have been persuaded by quantifying the values of morphometric parameters, slope steepness and landuses influencing soil erosion. As regards to the ratings of the morphometric parameters, the higher bifurcation ratio indicate that the presence of number of streams of first order in the micro-watershed is high and hence will contribute more erosion. Similarly, higher drainage density, stream frequency and texture ratio also indicate the presence of more streams and hence will be responsible for contributing to more erosion. The lowest value of shape parameter indicate that the shape of micro-watershed would be of circular type. The elongated watershed having higher bifurcation ratio would result a lower but extended peak flow. The circular watershed with low bifurcation ratio produces sharp peak flow and hence accelerate the process of soil erosion. The sharp peak flow is responsible for doing more erosion. The micro-watersheds coming under rating number one has the highest values for the bifurcation ratio, drainage density, stream frequency, texture ratio and the lowest values for the shape parameters like form factor, circularity ratio and elongation ratio. The ratings are assigned for each value of the morphometric parameters indicated above. The assigned ratings are averaged out for each micro-watershed to determine its priority. The micro-watersheds which attain the least value of average rating comes under priority number one. Likewise, the other micro-watersheds which attain the highest value of average rating, has been assigned the last priority from the erosion risk assessment point of view.

The steep land and the status of prevailing landuse in the micro-watershed area like degraded forest, shifting cultivation, land mining, agriculture, exposed rock would be more sensitive to soil erosion and such areas have been given high priority to take up remedial interventions. The land covered by forest and dense forest shall restrict the rate of soil erosion and hence, the sensitivity of such areas from the soil erosion point of view would come comparatively under lower priority.

4.1.4 Land Use Characteristics: The land uses of the micro-watersheds have been put under eight different categories. These are: degraded forest, agricultural land, water bodies, shifting cultivation areas, land mining, light forest, exposed rock and dense forest. The quantification of different land uses prevailing in each micro-watershed has been done for working out the priority of the micro-watersheds from their sensitiveness to soil erosion. The land use pattern existing in the micro-watersheds on 2nd November, 2000 reveal that in Mawphlang micro-watershed (Um1) the percentage of forest degradation has been assessed to around 59.5 with respect to the total forest cover lying within the micro-watershed boundary. Whereas, the shifting cultivation area is limited only to 15% of the total micro-watershed area. This fact indicates that the forest degradation in this micro-watershed area is being affected by the other influencing factors like agricultural practices and the land mining activities followed along the steep hill slopes. In Nongkrem micro-watershed (Um4), the forest degradation of 46.6% comes next to Mawphlang micro-watershed. This micro-watershed is experiencing with 21% of its area by the exposed rock. The situation reflects that this micro-watershed is adversely affected by the adoption of shifting cultivation in along the steep land slopes. The quantifications of the different land uses are reflected under Table-4.4. However, the areal distribution of the land uses of the micro-watersheds have been shown in the land use maps of all the nine micro-watershed (Figs.-4.29 to 4.37).

4.2 Results and Interpretation

The delineation of the micro-watersheds has been done by taking into considerations about the accessibility of the existing villages in the micro-watersheds with the roads. The social factor of the house holds of the mocro-watersheds' villages has not been accounted for during dineation of the micro-watersheds. Though this factor is important, this has to be kept aside because the socio-economic data could not be collected during the study. The range of drainage density and bifurcation ratio of the micro-watersheds existing under Umiew watershed indicate that the drainage conditions of the micro-watersheds are moderate. The computation of morphometric parameter has indicated that Umngot (Um2), Mawreng (Um3), Nongkrem (Um4), Laitkroh (Um7) and Laitkynsew (Um8) micro-watersheds have higher values of drainage density (2.62-3.74 km/km^2) Stream frequency (3.79-6.40 number/ km^2), Texture ratio (2.41 to 2.63) and circulatory ratio (0.36 to 0.56) and hence more prone to soil

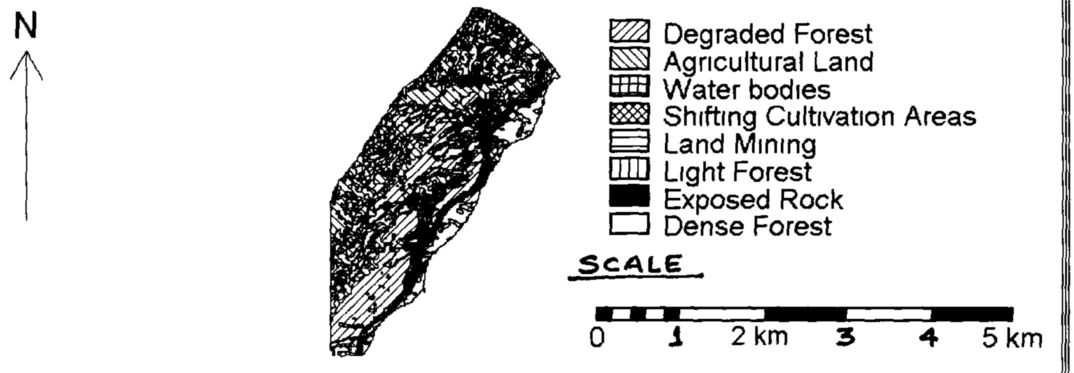


Fig. 4.29: Landuse Map of Micro-Watershed Um1

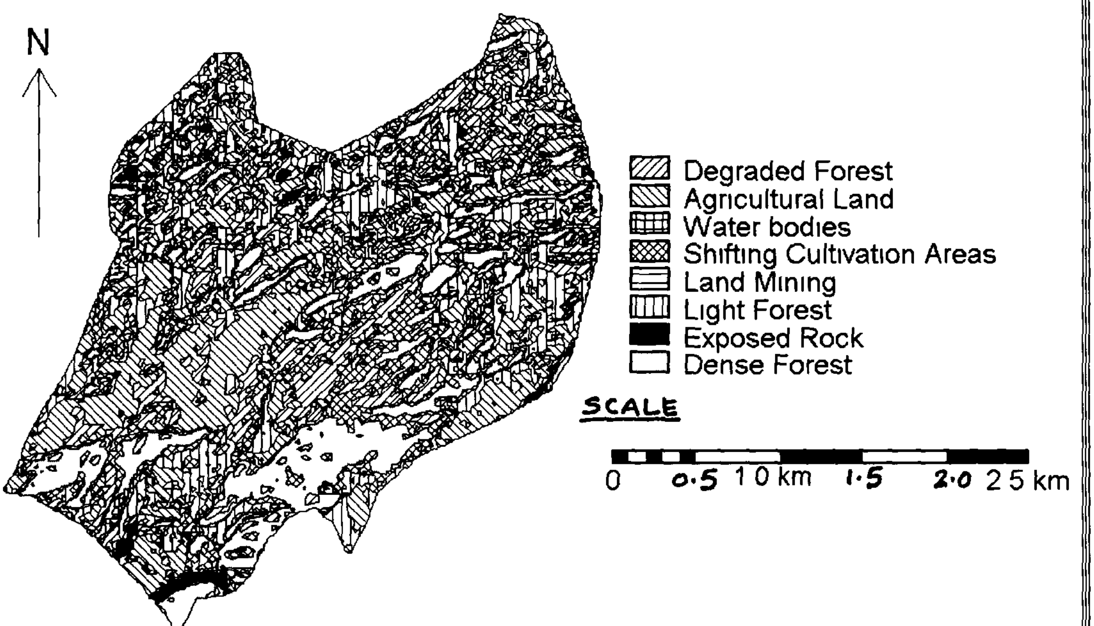


Fig. 4.30: Landuse Map of Micro-Watershed Um2

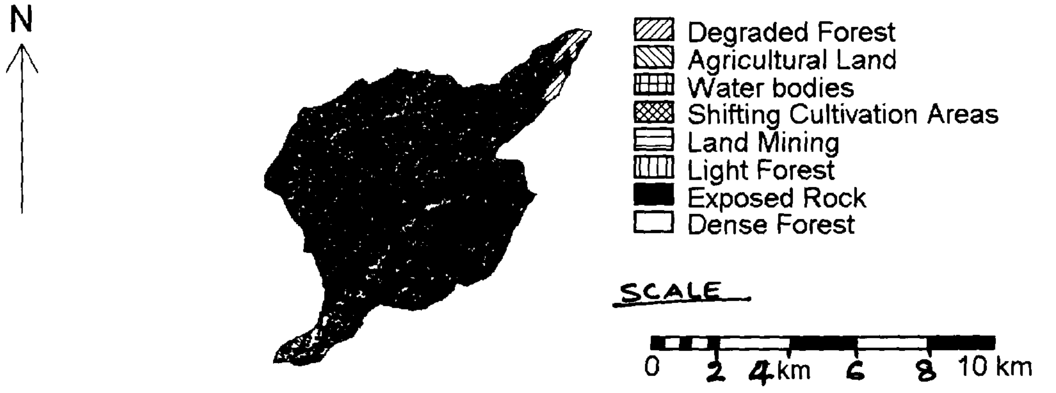


Fig. 4.31: Landuse Map of Micro-Watershed Um3

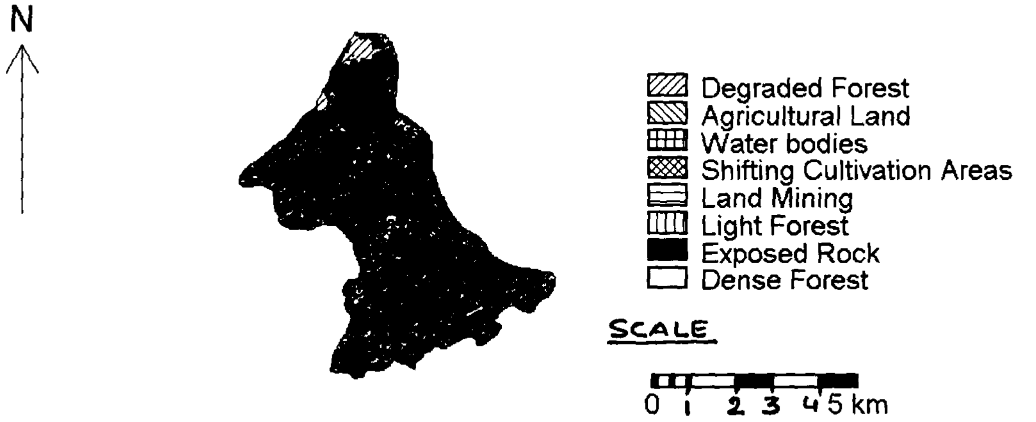


Fig. 4.32: Landuse Map of Micro-Watershed Um4

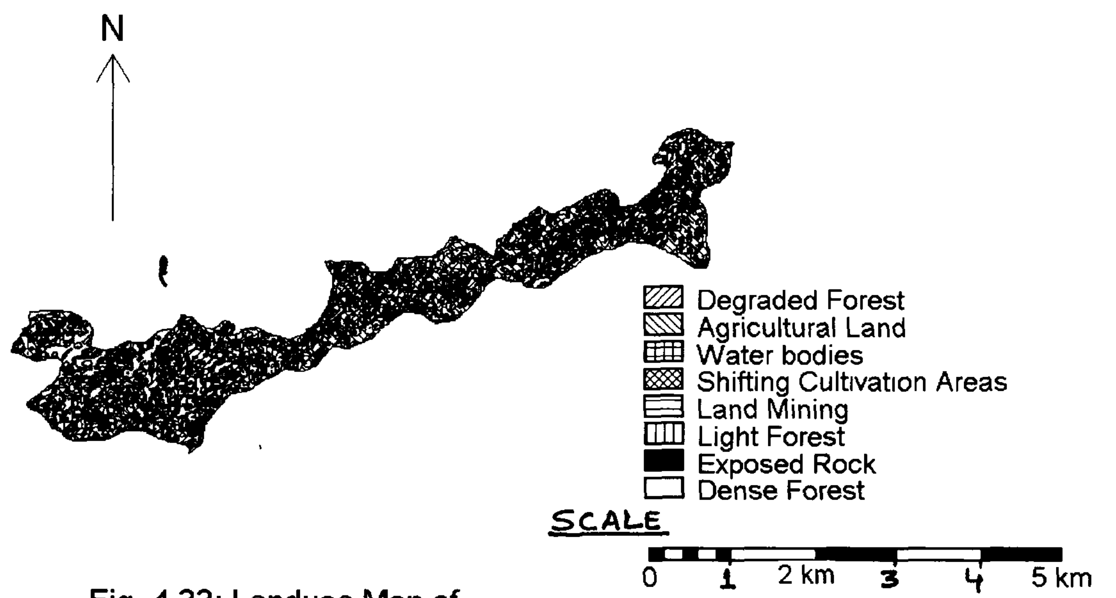


Fig. 4.33: Landuse Map of Micro-Watershed Um5

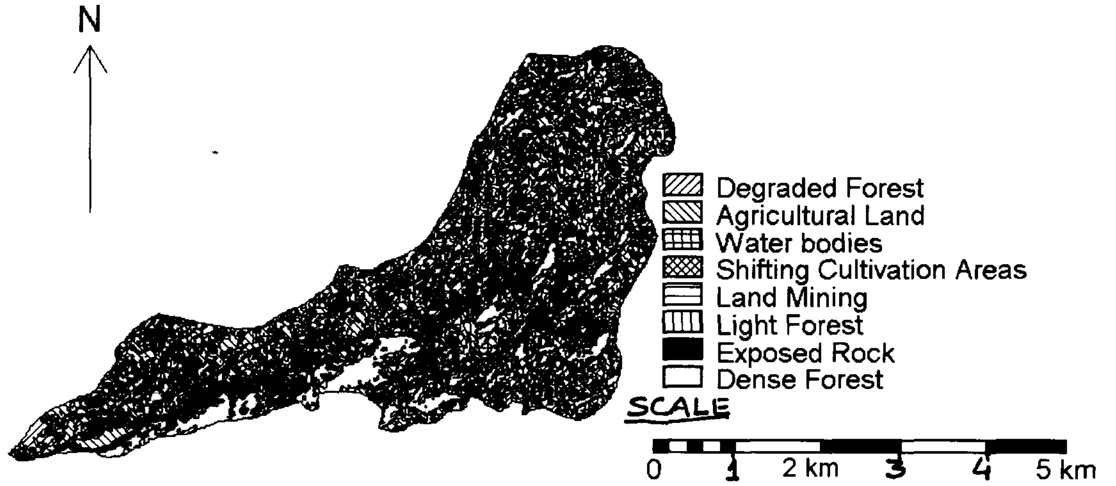


Fig. 4.34: Landuse Map of Micro-Watershed Um6

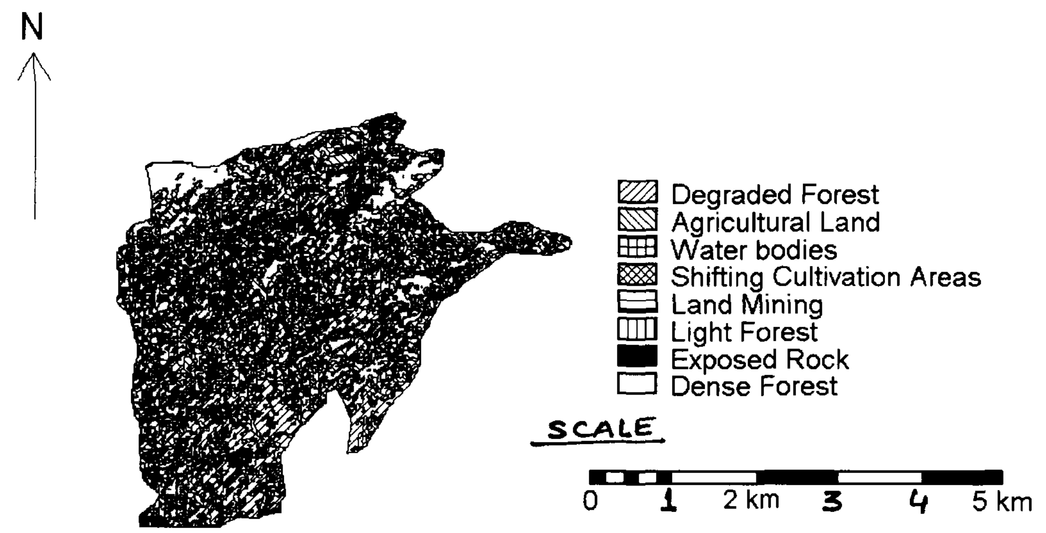


Fig. 4.35: Landuse Map of Micro-Watershed Um7

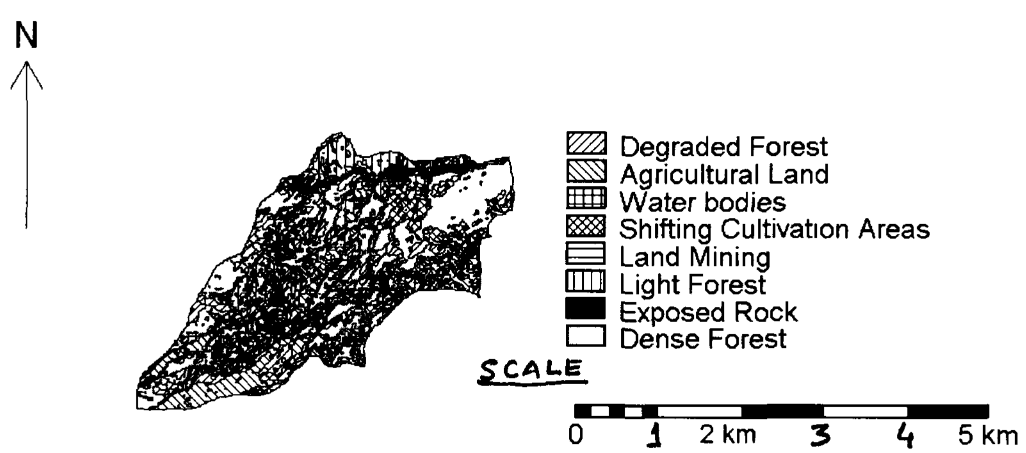


Fig. 4.36: Landuse Map of Micro-Watershed Um8

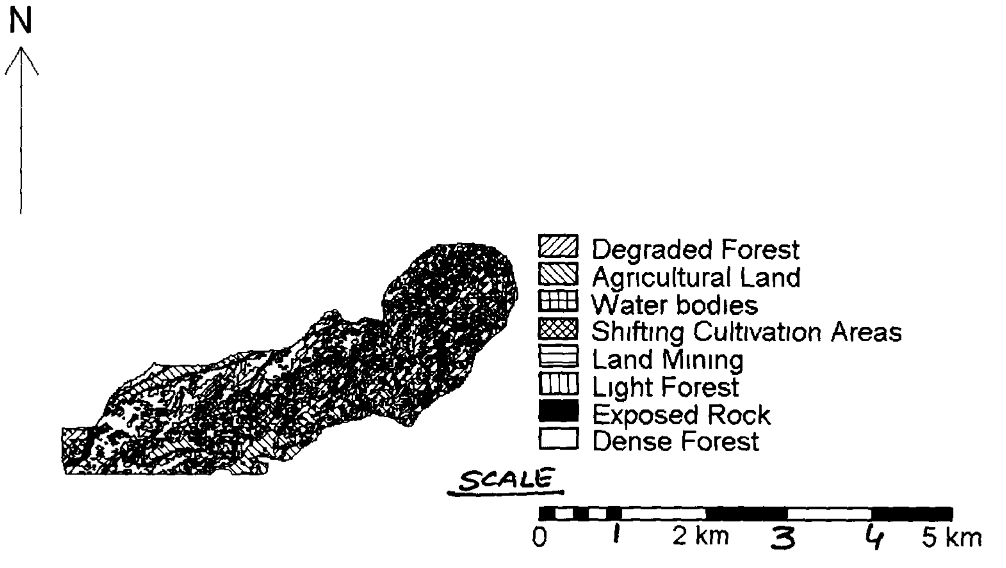


Fig. 4.37: Landuse Map of Micro-Watershed Um9

erosion. Nongkynrih (Um5) and Basio (Um6) micro-watersheds have lower values of circulatory ratio (0.13-0.34) and higher values of elongation ratio and, therefore, least prone to soil erosion (Table-4.2).

4.2.1 Morphometric Prioritization: In order to assess the soil-erosion sensitiveness of the micro-watersheds, the morphometric prioritization has been done by assigning the ratings of the morphometric parameters for each of the micro-watershed. It has been found in this prioritization that Laitkroh (Um7), Dympep (Um9), Mawreng (Um3) and Laitkynsew (Um8) micro-watersheds are more sensitive to soil erosion. The micro-watersheds which has been found least sensitive to soil erosion are Mawphlang (Um10, Nongkynrih (Um5) and Basio (Um6) [Table-4.3].

4.2.2 Slope Prioritization: While working out the soil erosion sensitivity of the micro-watersheds, the ratings have been assigned to the steep sloppy (slope more than 30 % to 100 %) areas. It has been assumed that the micro-watersheds which has more areal coverage of steep sloppy areas, would be more sensitive to soil erosion keeping other topographical and meteorological parameters the same. This assumption has been made for the sake of simplicity in arriving at some conclusion. It has been found in the land use prioritization that Laitkroh (Um7), Laitkynsew (Um8) and Mawphlang (Um1) micro-watersheds are more sensitive to soil erosion. The least sensitive micro-watersheds from the soil erosion are Basio (Um6), Mawreng (Um3) and Nongkynrih (Um5) [Table-4.6].

4.2.3 Land use Prioritization: The forest degradation in the micro-watersheds have been computed by the prevalence of different categories of forest covers existing as on 2nd November, 2000. These forest categories are: light forest, dense forest and degraded forest. Forest degradation is directly influenced with the activities of shifting cultivation and hence, sensitive to more soil erosion. Considering the status of forest degradation, Mawphlang (Um1), Nongkrem (Um4) and Nongkynrih (Um5) micro-watersheds are more sensitive to soil erosion. Laitkroh (Um7) and Laitkynsew (Um6) micro-watersheds have been found least sensitive to soil erosion (Table-4.4). Further to assess the soil-erosion sensitiveness of the micro-watersheds, the land use prioritization has been done by assigning the ratings of the existing land uses. It has been found

Table-4 3 Prioritisation based on Morphometric Parameters

Micro Watershed	Bifurcation Ratio	Drainage Density	Stream Frequency	Texture Ratio	Form Factor	Circulatory Ratio	Elongation Ratio	Avarage Ratings	Priority
Um1	1	9	9	7	7	7	8	6 86	8
Um2	8	1	2	4	4	8	5	4 57	4
Um3	6	4	3	1	2	5	2	3 29	2
Um4	7	7	7	3	3	3	4	5 14	5
Um5	5	8	5	8	8	1	9	6 29	7
Um6	9	6	8	5	6	2	7	6 14	6
Um7	3	3	4	3	2	4	3	3 14	1
Um8	4	2	1	2	5	6	6	3 71	3
Um9	2	5	6	6	1	2	1	3 29	2

Table-4.4: Landuses in Micro-watersheds

(Area in Ha)

Micro watershed	Degraded forest	Shifting cultivation	Land mining	Agriculture land	Exposed rock	Light forest	Dense forest	% of forest degradatio
Um1	179.74	83	2.49	114.81	39.94	49.76	72. 42	59.5
Um2	107.34	134.48	0.24	2.31	9.16	164.9	123.07	27.2
Um3	784.37	562.94	1.88	1032.74	292.86	1040	651.86	31.7
Um4	611.07	237.43	1.89	462.05	534.52	510.2	189.43	46.6
Um5	158.23	88.15	0	193.14	58.7	180.4	71.57	38.6
Um6	287.32	176.46	9.58	355.22	164.89	356	221.96	33.2
Um7	290.23	256.54	0.19	256.41	43.59	346.6	247.8	32.8
Um8	120.94	118.22	1.2	126.65	15.21	130.3	247.18	24.3
Um9	161.97	103.67	0.64	139.05	13.01	129	148.41	36.9

Table-4.5: Land use Prioritisation of Micro-watersheds

Micro watershed	Degraded forest	Shifting cultivation	Land mining	Agriculture land	Exposed rock	Light forest	Dense forest	Average rating	Priority
Um1	5	9	2	8	6	1	2	4.71	4
Um2	9	5	7	9	9	4	3	6.57	8
Um3	1	1	4	1	2	9	9	3.86	2
Um4	2	3	3	2	1	8	5	3.43	1
Um5	7	8	9	5	4	5	1	5.57	6
Um6	4	4	1	3	3	7	6	4	3
Um7	3	2	8	4	5	6	8	5.14	5
Um8	8	6	5	7	7	3	7	6.14	7
Um9	6	7	6	6	8	2	4	5.57	6

Table-4.6: Slope Prioritisation of Micro-Watersheds

Micro-Watershed	Very steep slope	Priority
Um1	11.88	3
Um2	4.40	6
Um3	1.82	8
Um4	10.23	4
Um5	2.56	7
Um6	0.82	9
Um7	19.37	1
Um8	12.09	2
Um9	5.91	5

that ongkrem (Um4), Mawreng (Um3) and Basio (Um6) micro- watersheds have been found to be more sensitive to soil erosion whereas, Umgot (Um2), Latkynsew (Um8) and Dympep (Um9) are found least sensitive to soil erosion (Table-4.5).

4.2.4 Combined Index of Prioritization: The combined influence of morphometric parameters, Land uses and slope of the micro-watersheds have been analyzed to identify their sensitiveness to soil erosion. It has been assessed during final prioritization of micro-watersheds that Laitkroh (Um7), Nongkrem (UM4), Mawreng (Um3) and Laitkynsew (Um8) micro-watersheds are more sensitive to soil erosion. On the other hand, Nongkynrih (Um5), Basio (Um6), Umgot (Um2), Mawphlang (Um1) and Dympep (Um9) micro-watersheds have been found least sensitive to soil erosion (Table-4.7). Therefore, two right bank micro-watersheds - Mawreng (Um3) and Nongkrem (UM4) and one left bank micro-watershed - Laitkroh (Um7) have been found sensitive to soil erosion and the remaining micro-watersheds found to be least sensitive to soil erosion.

4.3 Concluding Remarks

The prioritization of micro-watersheds with reference to their sensitiveness has indicated that the micro-watersheds would be soil erosion sensitive irrespective of the stages of development to which they have attained. Even after attaining the development activities in equilibrium stage, Laitkroh micro-watershed (Um7) has been found soil erosion sensitive. Similarly, Nongkrem micro-watershed (Um4) has become so sensitive to soil erosion that the isolated portion of hillocks lying in the micro-watershed area have come above the subdued surface. This status reflects the Monadnock stage of development. Laitkynsew (Um8), the third category of micro-watershed, where the developmental activities are yet to take place and hence, this has also become sensitive to soil erosion. Therefore, the soil erosion interventions has to be applied in the micro-watersheds irrespective of their stage of development. The nature and scale of soil erosion interventions may have to be applied depending upon the degree of severity under which the micro-watersheds are getting affected.

Table-4.7: Composite Index Prioritisation

Micro-Watershed	Morphometric priority	Landuse priority	Slope priority	Cumpound priority	Final priority
Um1	8	4	3	5.00	5
Um2	4	8	6	6.00	6
Um3	2	2	8	4.00	3
Um4	5	1	4	3.33	2
Um5	7	6	7	6.67	7
Um6	6	3	9	6.00	6
Um7	1	5	1	2.33	1
Um8	3	7	2	4.00	3
Um9	2	6	5	4.33	4

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Chapter-5

Chapter-5

Rainfall Characteristics

5.0. Introduction

The knowledge of rainfall characteristics is important for the estimation of runoff from the watersheds as well as for the analysis of erosion by water. It plays a pivotal role in hydrological cycle and alters the nature and characteristics of hydrograph. The quantitative estimates of runoff rates, volumes and its distribution are to be worked out for the adoption of water conservation measures. This may help in designing the hydrologic structures like small dams, weirs and channels which may be planned to carry maximum runoff expected in a specific recurrence interval.

Rainfall is major attribute of climate which has been defined differently by scientists of different disciplines such as meteorologists, hydrologists, soil scientists, agronomists, geographers, etc. The extreme rainfall conditions by way of influencing the evapotranspiration regimes, the soil moisture and sub-surface flow, the surface run off and the trends of base flow in the catchment are main determinants of hydrotopes of the catchment landscape. On the other hand, the amount, intensity and occurrences of precipitation are controlled by the atmospheric conditions at macro-areal scale and orographic effects at micro-regional levels of the monsoon climate of India (Starkel 1970, 1972). The shifting of Inter Tropical Convergence Zone is a broad atmospheric condition for prevailing monsoon climate which creates seasonal abnormalities in the distribution of rainfall (Ramdas 1968, O'Hare 1997).

Precipitation intensity influences both the rate and volume of run-off. In this reference, there are three main aspects of precipitation interpreted by the hydrologists and meteorologists as (a) the analysis of storm hyetograph (time-intensity relationship) and its cumulative intensity (i.e., called mass) curve which show the characteristics of rain storm; (b) the Depth-Area-Duration (DAD) curves, and (c) the Intensity-Duration-Frequency relationship. Hyetograph primarily reveals the precipitation intensity pattern within a specific storm duration. It may be uniform, advanced, intermediate or delayed as described by Horner and Jens (1942). The spatial characteristics of rainstorm are described by its preparing isohyetal pattern for its short duration (one-day) to long duration (even 5 to 10 days according to prevalence of rainstorm). Such homogenous zones of heavy rainfall of a specific duration establish DAD relationship (WMO 1969, 1986, Rakhecha *et al.* 1990). The rainstorm characteristics of Indian monsoon considering whole of India or part of it as domain of study was specially done by the team of Indian Institute of Tropical Meteorology (IITM Pune) and found that the past severe rainstorms over the monsoon regions of Gujarat and Punjab were not unprecedented in nature (Dhar and Rakhecha 1976, Dhar *et al.* 1981, IITM 1989, Dhar 1990, Rakhecha *et al.* 1990, Kulkarni 1992, Kulkarni *et al.* 1996). Thirdly, the important aspect of hydrometeorology is to predict recurrence interval and frequency of rainstorms. The rainfall frequency curve for predicting the probability of rainfall occurrences is a debatable subject and analysed by establishing semi-log relationship between annual rainfall and its frequencies (Ragunath 1985, Starkel and Basu 2000). Such predictions of Intensity-Duration-Return Period relationship are analysed by collecting rainfall statistics of more than 40 rainguage stations and calculating a specific kind of parameters/constants for the desired return period of rainfall in years and duration of rainfall in hours (Babu *et al.* 1979).

The description of hydrometeorological conditions prevailing in the Meghalaya plateau has not been made through detail investigation of meteorological statistics, inspite of available monthly as well as annual weather records for long series of time (nearly 100 years) in the office of Indian Meteorological Department, Pune. Only a few preliminary attempts have been made by the geographers, agricultural scientists and government agencies to interpret the atmospheric conditions, circulation of water and the orographic effects on rainfall distribution and, upto same extent, the water budget in connection with the interpretation of landuse, agronomic and climatic factors of the area (Starkel 1972, Gopalakrishnan 1996a, 1996b, Singh 1996). An investigation of rainstorm characteristics was done on the basis of 20 years monthly rainfall records and hourly records of significant rainstorms occurring in different seasons in the Cherrapunjee area (Singh and Syiemlieh 2001). Infact, meteorological statistics are used by ecologists, soil scientists, geographers, anthropologists as a background material of their work as to justify the causes of landuse variations, forest ecology, degraded ecosystem, etc (Ram and Ramakrishnan 1988, Umashankar 1991, Tripathi *et al.* 1995) rather than giving scientific explanation of the hydro-meteorological phenomena, which are relevant for the study of the characteristics of 'monsoon bursting' soil moisture, available water resource and to understand the nature of hydrographs and surface runoff.

5.0.1 Run-off - A Key Component of Hydrologic Cycle: A comprehensive review on rainfall-runoff relationship was prepared by Singh (2002) specially for the most humid areas around Cherrapunjee where the present study area is located. The following paragraphs are modified version of the same review.

Relaxation of some assumptions and application of some basic models for the estimation of run-off are the main tasks of the studies conducted on hydrotopes of any hydrological regime. Most of the studies of hydrological cycle revolve around the domain consisting two/three main parameters of estimation: the evaporation (that is atmospheric parameter), the infiltration (i.e., sub-surface parameter) and the ponding (a parameter of surface roughness). The surface available water is a function of precipitation (as input), evapotranspiration (as the loss of water) and infiltration (as water storage). Thus, the water balance sheet of a river catchment was made by using these parameters (Thornthwaite and Mathur 1957, Subramaniam 1982). The concept of water availability is described in wider perspective and is considered as it is dependent on the available vegetation cover and the soil properties as the ecotopic characteristics prevailing in the river catchment. Leaf diffusive conductance, leaf area size, aerodynamic conditions in and above the canopy, soil-water potential and saturation deficit are important factors that control the transpiration processes (Dirnbock and Grabherr 2000). However, a description of water assessment is also done by considering the hydrotopic characteristics in reference to available stream flow. Therefore, the direct run-off is the product of total stream flow minus the base flow and considered as excess or effective rain in the catchment.

The assessment of direct run-off at the watershed outlet under the assumption of Hortonian over land flow was made by describing the base flow curve and separate it from the total rain hyetograph. There are two methods of run-off assessment namely, the separation of base flow and the abstractions using infiltration rate. The master base flow recession curve for the base flow separation in general hydrologic system of constant rate of water storage in sub-surface soil follows a semi-logarithmic exponential expression of K decay constant of base flow recession ($Q(t) = Q_0e^{-(\Delta t/k)}$) (Horton 1933).

The loss of available water through infiltration is a major source of sub-surface storage, which is helpful in assessing run-off by abstraction method. The hydraulic conductivity of soil, the wetting front capillary pressure head and the difference between initial and final soil moisture contents are main factors of determining infiltration rate that have been considered in the Green-Ampt equation, in Horton's equation as well as in the Philip's method of measuring the infiltration rate (Chow, *et al.* 1988).

The abstraction of direct run-off is also assessed by considering the different conditions of landuses and soil types by the Soil Conservation Service (SCS 1972) following an assumption that the ratios of (i) the continuing abstraction, Fa, with potential maximum retention (ii) the two potential quantities, that are rainfall excess, Pe, with the difference of total rain and initial abstraction, (P-Ia), are equal as (Fa/S) = [Pe/(P-Ia)]. This parametric method of run-off assessment is based on geomorphologic and landuse/landcover characteristics of river catchment. The effects of their variations on the rainfall-run-off relationship have been shown by way of different Curve Number (CN) (SCS 1972). Therefore, this method of run-off estimation was used in various ecological and hydrological conditions. For example, it is used by Tripathi and Singh (1993) for variety of Indian hydrological conditions and by Prokop (1996) specially for the extreme rainfall conditions of Cherrapunjee area.

5.1 Rainfall Distribution Characteristics

The daily rainfall data for the monsoon period (May-October) during 1996-2001 have been collected from Shillong IMD Station and are plotted to analyze the distribution characteristics of the rainfall (Figs.-5.1 and 5.2). The mean values of the monsoon rainfall for each year are plotted on the daily rainfall data. The upper range of rainfall which are lower than the mean rainfall values has been restricted to 20 mm to blow up the rainfall values. This has been done to clearly visualize the qualitative distribution of the daily rainfall values with reference to the mean rainfall values (Figs.-5.3 and 5.4).

The observed weekly rainfall series for the monsoon period from 1996-2001 have been tabulated to analyse the distributional characteristics of rainfall. This weekly rainfall series is represented by 26-weeks rainfall data pertaining to each monsoon year. The mean, standard deviation, co-efficient of variation and skewness of the weekly series has been computed to analyse the distribution pattern of the weekly rainfall (Table-5.1).

5.1.1 Rainfall-Intensity-Duration-Frequency Analysis : The maximum rainfall that is expected depends upon the period which is taken into consideration. The selection of a particular statistical distribution function to predict the extreme event is important and it depends upon experience and verification. The relationship between frequency, intensity and storm duration vary sufficiently from place to place and, hence, the daily rainfall data of IMD station, shillong recorded for seven years (1996-2002) during the monsoon period only has been used for the analysis purpose. The selection of IMD station, Shillong has primarily due to its locational proximity with the rain gauge site established in Umiew Watershed at Mawphlang. Secondly, the rainfall data of only three years

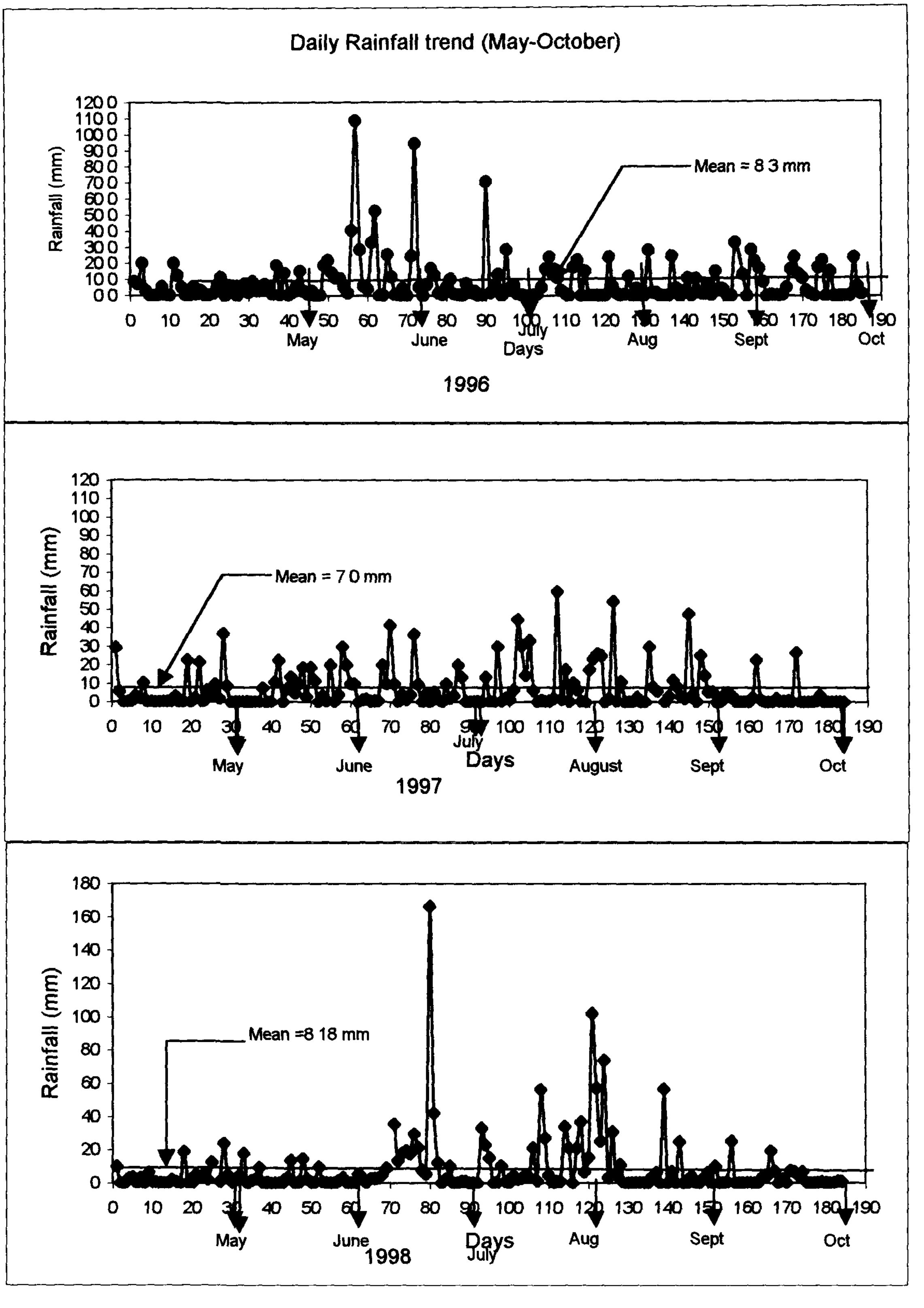

Daily Rainfall trend (May-October)
Rainfall (mm)
Mean = 8 3 mm
May
June
July
Days
Aug
Sept
Oct
1996
Mean = 7 0 mm
August
1997
Mean =8 18 mm
1998

Fig.-5.1

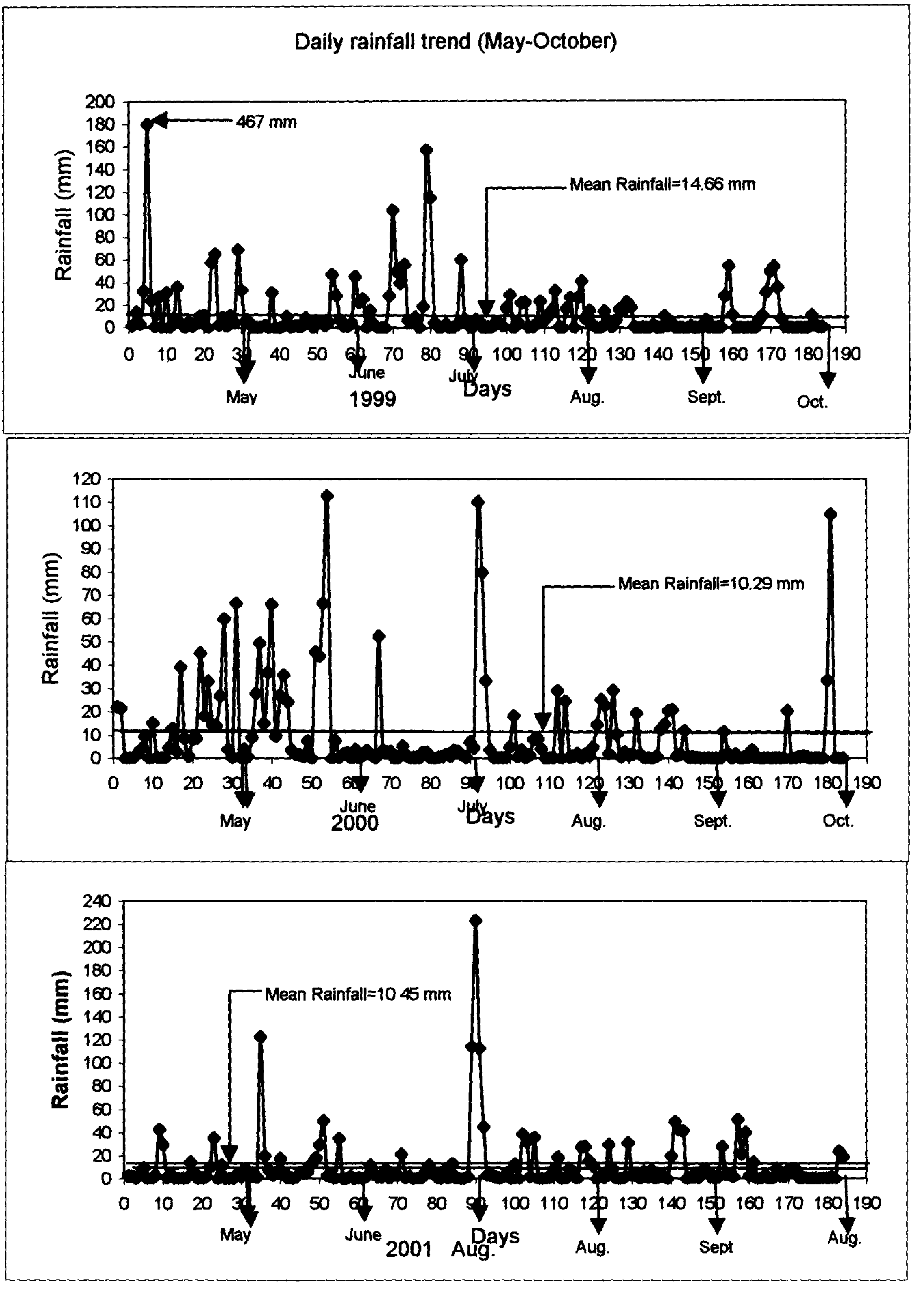
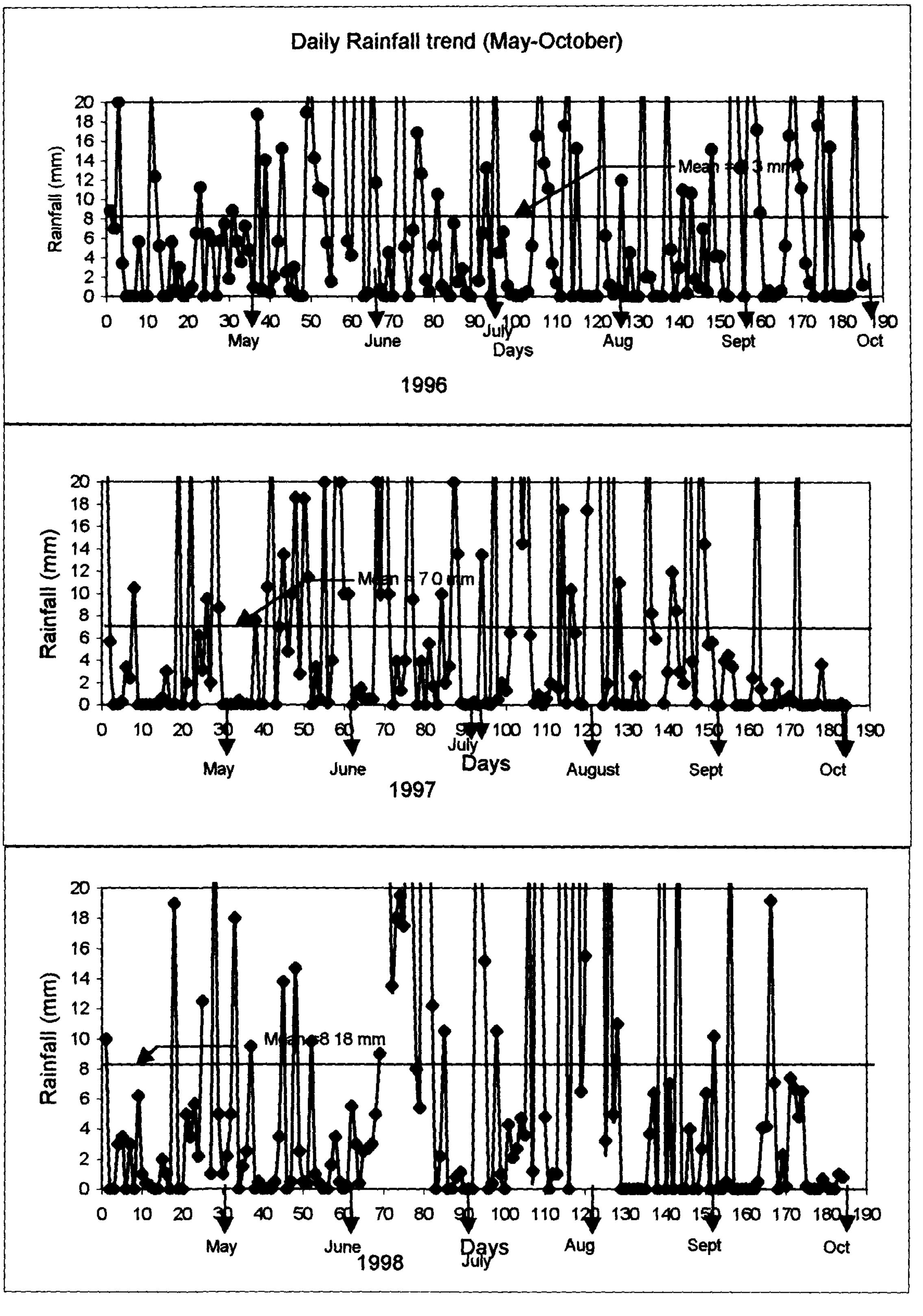
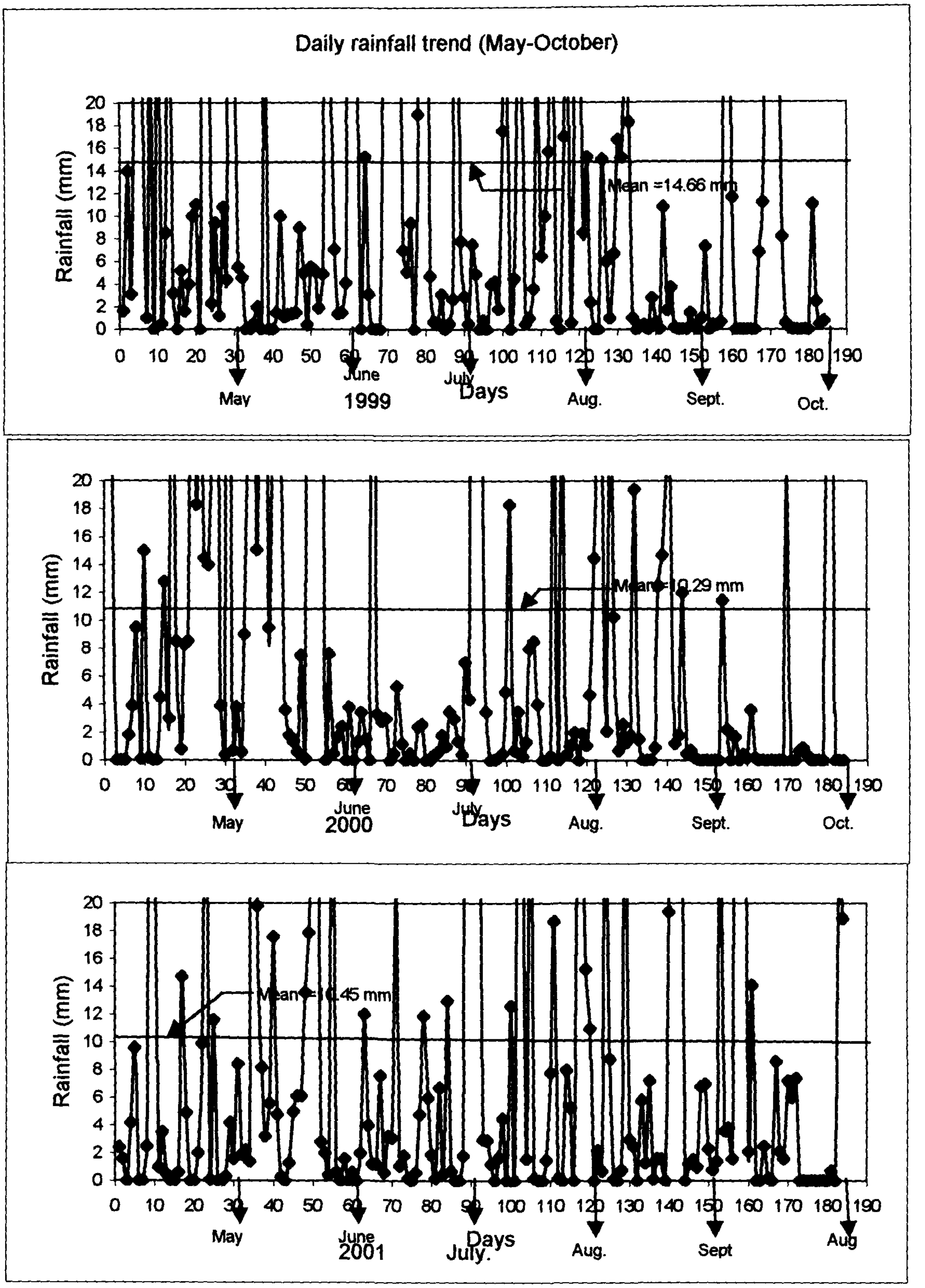

Daily rainfall trend (May-October)
Rainfall (mm)
467 mm
Mean Rainfall=14.66 mm
May
June
July
Aug.
Sept.
Oct.
1999
Days
Rainfall (mm)
Mean Rainfall=10.29 mm
May
June
July
Aug.
Sept.
Oct.
2000
Days
Rainfall (mm)
Mean Rainfall=10.45 mm
May
June
2001
Aug.
Days
Aug.
Sept
Aug.

Fig.-5.2



Daily Rainfall trend (May-October)
Rainfall (mm)
May
June
July
Days
Aug
Sept
Oct
1996
Rainfall (mm)
May
June
July
Days
August
Sept
Oct
1997
Rainfall (mm)
May
June
July
Days
Aug
Sept
Oct
1998

Fig.-5.3



Daily rainfall trend (May-October)
Rainfall (mm)
Mean =14.66 mm
Days
1999
May
June
July
Aug.
Sept.
Oct.
Rainfall (mm)
Mean=10.29 mm
Days
2000
May
June
July
Aug.
Sept.
Oct.
Rainfall (mm)
Mean=10.45 mm
Days
2001
May
June
July.
Aug.
Sept
Aug

Fig.5.4

Table-5.1: Distribution Characteristics of Weekly Rainfall During May-Oct., 1996-2001

Week	Mean	Std. Dev.	CV(%)	Co-eff. of Skewness	Week	Mean	Std. Dev.	CV(%)	Co-eff. of Skewness
1	120.49	190.47	158.08	2.43	14	82.08	73.78	89.89	2.05
2	49.63	37.09	74.73	0.34	15	70.23	52.48	74.73	0.16
3	33.76	22.28	65.99	1.92	16	65.17	27.53	42.24	0.65
4	88.16	67.61	76.69	1.34	17	68.35	39.70	58.08	0.30
5	64.36	49.66	77.16	0.65	18	117.37	86.76	73.92	1.56
6	73.01	73.14	100.18	2.23	19	38.83	26.45	68.12	1.38
7	79.41	89.65	112.90	2.44	20	38.57	20.89	54.16	-0.47
8	135.56	104.05	76.76	0.69	21	55.83	44.16	79.10	1.52
9	68.61	80.03	116.64	1.78	22	35.88	25.47	70.99	0.23
10	64.19	44.08	68.67	1.29	23	58.42	51.74	88.57	0.48
11	88.57	69.59	78.57	0.17	24	23.32	16.45	70.54	0.05
12	107.2	118.02	110.10	0.95	25	56.15	62.07	110.54	2.25
13	126.07	157.03	124.56	1.91	26	32.87	53.84	163.80	2.08

(May,96 to October,98) was available at Mawphlang site during the data collection in 1999. The rainfall charts for each storm event have been prepared and analysed for computing maximum intensities of rainfall for the duration of 15, 45, 60, 75, 90, 105 and 120 minutes. The monsoon series of observed maximum rainfall intensity data of different duration have been prepared by selecting the maximum observed value of each monsoon year of record (Table-5.2). The observed maximum rainfall intensity series in ascending order for *different durations have been subjected to the frequency analysis* by applying Normal, Log-Normal, Gumbel EV Type-I and Log-Pearson Type-III probability distribution functions (Table- 5.3). The predicted values of maximum rainfall intensity of different durations at 20%, 50% and 80% probability levels have been computed by applying Normal, Log-Normal, Gumbel EV Type-I and Log-Pearson Type-III. The computations are enclosed at Appendix-5.1 (a) and Appendix-5.1 (b). The Weibul's formula has been used to compute the rainfall intensity at 80 %, 50 % and 20 % probability levels. These predicted rainfall intensity values have been compared with the computed values taken from the recorded rainfall intensity series. The Chi-Square test has been conducted to the predicted values of rainfall intensity under each probabilty distribution function to check the best fit of the distribution functions applied for. The Chi-Square values obtained under each distribution function have been compared to 5 % significance level and degree of freedom 2. This table value has been estimated to 5.99.

5.1.2 Results and Interpretation : It has been observed from the rainfall plot for the month of May that the daily rainfall is densely distributed from 1996 to 1999 and in 2001. It has seen that the distribution of rainfall values higher than the mean monsoon values are changing from year to year. It has also been observed that such distribution during 1996, 1999 and 2001 is found to vary between beginning of May to later part of October. But, in 1997 and 1998 , the distribution of higher rainfall is found to vary between mid of May to mid of October. It is only observed during 2000 that the distribution of higher rainfall has spread over from May to early part of July and again from the beginning of August to the later part of September. It means that out of six monsoon years (1996-2001), the

Table-5.2: Observed Maximum Rainfall Intensity of Different Durations during Monsoon from 1996-2002

Duration in minutes	Observed maximum intensity of rainfall (mm/hr)						
	1996	1997	1998	1999	2000	2001	2002
15 min.	100.0	40.0	40.0	98.0	40.0	120.0	56.0
30 min.	50.0	20.0	80.0	26.6	20.0	20.0	66.8
45 min.	23.3	24.7	13.3	33.1	18.7	14.7	13.3
1 hr.	20.0	11.0	10.0	10.0	10.0	10.0	10.0
1.25 hr.	13.2	10.4	8.0	8.0	9.6	8.0	8.0
1.50 hr.	6.7	6.7	6.7	6.7	2.6	2.7	6.7
1.75 hr.	8.6	5.7	5.7	5.7	5.7	5.7	5.7
2.00 hr.	3.6	5.0	5.0	5.0	5.0	5.0	2.2

Table-5.3: Observed Maximum Rainfall Intensity Series of Different Durations during Monsoon from 1996-2002

Sl.No.	15 min.	30 min.	45 min.	60 min.	75 min.	90 min.	105 min.	120 min.
1	40.0	20.0	13.3	10.0	8.0	2.6	5.7	2.2
2	40.0	20.0	13.3	10.0	8.0	2.7	5.7	3.6
3	40.0	20.0	14.7	10.0	8.0	6.7	5.7	5.0
4	56.0	26.6	18.7	10.0	8.0	6.7	5.7	5.0
5	98.0	50.0	23.3	10.0	9.6	6.7	5.7	5.0
6	100.0	66.8	24.7	11.0	10.4	6.7	5.7	5.0
7	120.0	80.0	33.1	20.0	13.2	6.7	8.6	5.0
Std. Dev.	34.35	25.15	7.35	3.74	1.97	1.98	1.10	1.10
Mean	70.57	40.49	20.16	11.57	9.31	5.54	6.11	4.40
Skew	0.45	0.77	0.87	2.59	1.55	-1.23	2.65	-1.76
CV (%)	48.67	62.13	36.45	32.28	21.14	35.66	17.93	25.03

Table-5.4: Predicted Rainfall Intensities of Different Durations and Return Periods

Duration in minutes	Return Period				Duration in minutes	Return Period			
	5 years	10 years	25 years	50 years		5 years	10 years	25 years	50 years
15	95.58	120.30	157.59	188.67	75	10.49	11.82	13.74	15.18
30	56.26	76.71	109.95	141.17	90	7.54	8.41	9.12	9.58
45	25.53	30.27	36.97	42.10	105	6.55	7.39	8.67	9.87
60	12.68	15.49	20.09	24.78	120	5.42	5.58	5.7	5.75

N.B. : Predicted values of rainfall intensities have been estimated by Log-Pearson Type-III

Table-5.5: Estimated Rainfall Intensities by Intensity Duration Frequency Chart developed by ICAR.

Duration in minutes	Return Period				Duration in minutes	Return Period			
	5 years	10 years	25 years	50 years		5 years	10 years	25 years	50 years
15	95.98	100.47	106.73	111.73	75	43.50	45.54	48.38	50.64
30	72.15	75.53	80.24	83.99	90	38.79	40.61	43.14	45.16
45	58.62	61.36	65.19	68.24	105	35.11	36.75	39.04	40.87
60	49.78	52.11	55.36	57.95	120	32.14	33.65	35.74	37.42

distribution of higher rainfall has spread over to entire monsoon period during five monsoon years from 1996 to 1999 and 2001.

The values of the Co-efficient of Variation (CV in %) reveal that the variation in the weekly rainfall values with respect to the mean value of the concerned week is found highest in the last week of October followed by first week of May and the last but one week of October. It is also observed that the deviation in the weekly rainfall values from the mean weekly during four monsoon months - May, June, July and October are found to be high (more than 100 %) at least in one of the weeks of these months. The values of Co-efficient of Variation also indicate that two weeks in each month of June and October, the deviations in the weekly rainfall values from the mean weekly value have been found more than 100 % (Table- 5.1).

It is observed that the 6^{th},7^{th},14^{th},25^{th} and 26th weeks have been found highly skewed towards the positive side i.e. the tail of the weely rainfall distribution is lying to the right of the maximum point. Out of 26 weeks rainfall data set, only 20^{th} week falling in the month of September, has got weekly rainfall distribution negatively skewed. In this week, the tail of the weekly rainfall distribution is lying left to the maximum point. This distibution of the weekly rainfall indicates that the distribution pattern of weekly rainfall during three consecutive weeks-19, 20 and 21 in the month of September is highly uneven (Table-5.1).

The probability analysis of rainfall intensity has shown that no probability model fits into the rainfall intensity of all the storm durations. It is observed that, out of eight different storm durations starting from 15 minutes to 120 minutes, the storm duration of 60 minutes fits into Gumbel EV Type-I distribution. Similarly, the storm duration of 45 minutes fits into Normal distribution. The remaining six storm durations of 15 minutes, 30 minutes, 75 minutes, 90 minutes, 105 minutes and 120 minutes fit into Log-Pearson Type-III distribution. Out of eight different storm durations, the maximum rainfall intensity of six different duration computed at 20 %, 50 % and 80 % probability levels are fitting into Log-Pearson Type-III distribution function (Table-5.6). That is why, the observed maximum rainfall intensity series of different durations have been subjected to frequency Analysis by Log-Pearson

Table-5.6:Observed and Predicted Maximum Rainfall Intensity at Different Probability Levels

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E) Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Sigma (O-E)2/E Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
Storm duration = 15 min										
1.0	20.00	108.00	99.42	93.58	95.29	95.58	0.74	2.22	1.70	1.61
2.0	50.00	56.00	70.57	63.36	65.02	62.18	3.01	0.85	1.25	0.61
3.0	80.00	40.00	41.72	43.09	42.24	41.68	0.07	0.22	0.12	0.07
						Sigma	3.82	3.30	3.07	**2.30**
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 30 min										
1.0	20.00	72.10	61.62	55.58	58.59	56.26	1.78	4.91	3.12	4.46
2.0	50.00	26.60	40.49	34.45	36.43	32.79	4.76	1.79	2.65	1.17
3.0	80.00	20.00	19.36	21.38	19.75	20.49	0.02	0.09	0.00	0.01
						Sigma	6.57	6.79	5.77	**5.64**
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 45 min										
1.0	20.00	28.10	26.33	25.53	25.45	25.53	0.12	0.26	0.28	0.26
2.0	50.00	18.70	20.16	18.98	18.97	18.73	0.11	0.00	0.00	0.00
3.0	80.00	13.30	13.99	14.06	14.10	14.15	0.03	0.04	0.05	0.05
						Sigma	**0.26**	0.30	0.33	0.31
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 1 hr.										
1.0	20.00	14.60	14.71	14.38	14.26	12.68	0.00	0.00	0.01	0.29
2.0	50.00	10.00	11.57	11.01	10.97	9.97	0.21	0.09	0.09	0.00
3.0	80.00	10.00	8.43	8.43	8.49	9.03	0.29	0.29	0.27	0.10
						Sigma	0.51	0.39	**0.36**	0.40
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 1.25 hr.										
1.0	20.00	11.50	10.96	10.87	10.73	10.49	0.03	0.04	0.06	0.10
2.0	50.00	8.00	9.31	9.11	8.99	8.76	0.18	0.14	0.11	0.07
3.0	80.00	8.00	7.66	7.64	7.69	7.85	0.02	0.02	0.01	0.00
						Sigma	0.23	0.19	0.18	**0.17**
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 1.50 hr.										
1.0	20.00	6.70	7.20	6.99	6.97	7.54	0.035	0.01	0.01	0.09
2.0	50.00	6.70	5.54	5.22	5.22	5.58	0.243	0.42	0.42	0.22
3.0	80.00	2.70	3.88	3.90	3.91	3.71	0.359	0.37	0.37	0.27
						Sigma	0.64	0.80	0.80	**0.59**
							5.99	**5.99**	**5.99**	**5.99**

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E)				Sigma (O-E)2/E			
			Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
Storm duration = 1.75 hr.										
1.0	20.00	6.90	7.03	6.98	6.90	6.55	0.00	0.00	0.00	0.02
2.0	50.00	5.70	6.11	6.00	5.93	5.70	0.03	0.02	0.01	0.00
3.0	80.00	5.70	5.19	5.18	5.20	5.42	0.05	0.05	0.05	0.01
						Sigma	0.08	0.07	0.06	**0.03**
							5.99	**5.99**	**5.99**	**5.99**
Storm duration = 2.00 hr.										
1.0	20.00	5.00	5.32	5.25	5.19	5.42	0.02	0.01	0.01	0.03
2.0	50.00	5.00	4.40	4.26	4.22	4.66	0.08	0.13	0.14	0.02
3.0	80.00	3.00	3.48	3.48	3.49	3.53	0.07	0.48	0.07	0.08
						Sigma	0.17	0.62	0.22	**0.14**
							5.99	**5.99**	**5.99**	**5.99**

Type-III distribution function (Table-5.3). The predicted values of rainfall intensity of durations varying from 15 minutes to 120 minutes (15 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, 90 minutes, 105 minutes and 120 minutes) and for the return periods varying from 5 years to 50 years (5 years, 10 years, 25 years and 50 years) have been computed by Log-Pearson Type-III (Table 5.4). The sample computation showing frequency analysis of maximum rainfall intensity by Log-Pearson Type-III distribution function has been shown at Appendix-5.2.

The probability of occurrences of maximum rainfall intensity of different durations and return periods based on the observed rainfall data has been compared with the estimated values obtained by using the Intensity Duration Frequency (IDF) relationship developed by ICAR (Table-5.5). This relationship has been developed for the micro-watersheds located at Barapani, around 22 km away from Shillong. This relationship is :

$$I = k\,T^{a}/(t+b)^{d}$$

$$I = 128.74\,T^{0.066}/(t+18.44)^{0.77} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

(r = 0.99),

where, I = rainfall intensity (cm/hr),

T = return period (years),

t = duration of rainfall intensity (minutes),

r = correlation co-efficient,

k,a,b,d are the equation parameters reflecting the physiographic and climatic conditions of the area.

While comparing these two sets of values, it has been found that percentage variation between the predicted and the estimated values of rainfall intensity of 15 minutes duration and 5 years return period has been found minimum to the extent of 0.41 %. This variation has gone up from 22.02 % to 83.14 % as the duration of rainfall intensity has increased from 30 minutes to 120 minutes. The estimated values of rainfall intensity have been found higher in the range of 38 % to 84 % w.r.t. the predicted values of rainfall for the storm duration from 45 minutes to 120 minutes and for the return periods varying from 5 years to 50 years. In case of rainfall intensity of duration 15 minutes to 30 minutes and the return periods varying from 10 years to 50 years, the predicted values of rainfall intensity are higher than the estimated values. The percentage variation between these two values for the said rainfall duration and return periods has been found in the range of 1.57 % to 68.87 % (Table-5.7).

The predicted values of rainfall intensity of different durations and return periods have been computed by applying two IDF charts as (a) the IDF relationship developed by ICAR (Fig.-5.5) and by log-Pearson Type-III distribution function (Fig.-5.6). This chart indicates that the variation in the values of rainfall intensity for the storm duration ranging from 15 minutes to 45 minutes for the return period of 5 to 50 years are getting high w.r.t. the variation observed for the same storm duration in Fig-5.6. This variation starts reducing down progressively as the storm duration increases beyond 45 minutes and the curves become asymtotic to X-axis. The same trend has also been observed in Fig.-5.6. The chart shown at Fig.5.5 may facilitate in finding out the theoretical value of the rainfall intensity for any duration from 15 minutes to 120 minutes and for the return periods of 5 years to 50 years. Table-5.4 shows that the maximum rainfall intensity of 15 minutes duration varies from 95.58 mm/hr to 188.67 mm/hr for the return periods of 5 years to 50 years. The chart indicated at Fig.-5.5 may also be used in the rational method for estimating peak runoff from small watersheds. The rainfall intensity for the desired frequency can be computed from these curves for the duration equal to the time of concentration of the watersheds. The frequency chosen may reflect the economics of flood damage reduction (Satapathy 1996).

5.2 Prediction of Monsoon Rainfall

The characterization of rainfall which provides basic tools for adopting better cropping system and crop management practices for sustainable crop planning, the rainfall is characterized in terms of its variability and probability distribution by many researchers (Rana and Thakur 1998, Sharma *et al.* 1979, Prakash and Rao 1986, Sharma and Thakur 1995, Mohanty *et al.* 2000, Singh 1991, Kumar *et al.* 1998).

Table-5.7: Estimated and Predicted Maximum Rainfall Intensity of Different Durations and Return Periods

Rainfall Intensity (mm)

Storm duration (min)	5 years return period			10 years return period			25 years return period			50 years return period		
	Estimated	Predicted	% variation	Estimated	Predicted	% variation	Estimated	Predicted	% variation	Estimated	Predicted	% variation
15	95.98	95.58	0.41	100.47	120.30	-19.74	106.73	157.59	-47.65	111.73	188.67	-68.87
30	72.15	56.26	22.02	75.53	76.71	-1.57	80.24	109.95	-37.03	83.99	141.17	-68.08
45	58.62	25.53	56.45	61.36	30.27	50.67	65.19	36.97	43.29	68.24	42.10	38.30
60	49.78	12.68	74.53	52.11	15.49	70.27	55.36	20.09	63.71	57.95	24.78	57.24
75	43.50	10.49	75.89	45.54	11.82	74.05	48.38	13.74	71.60	50.64	15.18	70.03
90	38.79	7.54	80.56	40.61	8.41	79.29	43.14	9.12	78.86	45.16	9.58	78.79
105	35.11	6.55	81.34	36.75	7.39	79.89	39.04	8.67	77.79	40.87	9.87	75.85
120	32.14	5.42	83.14	33.65	5.58	83.42	35.74	5.7	84.05	37.42	5.75	84.63

Note 1. - sign shown under % variation column indicate that the estimated value is smaller than the predicted value.

2. + sign shown under % variation column indicate that the estimated value is larger than the predicted value.

3. % variation has been worked out w.r.t. estimated value of rainfall intensity

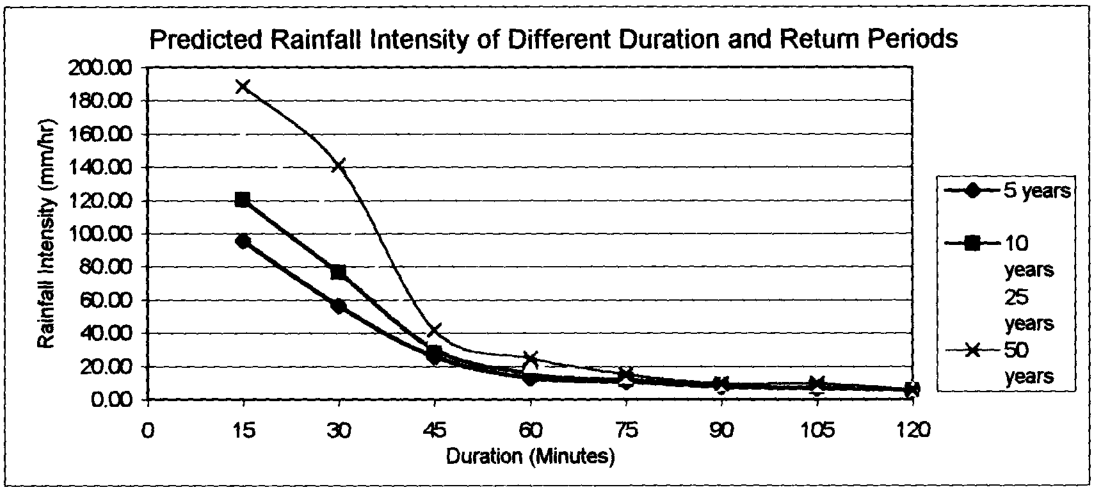

Predicted Rainfall Intensity of Different Duration and Return Periods
Rainfall Intensity (mm/hr)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
15
30
45
60
75
90
105
120
Duration (Minutes)
5 years
10 years
25 years
50 years

Fig.-5.5

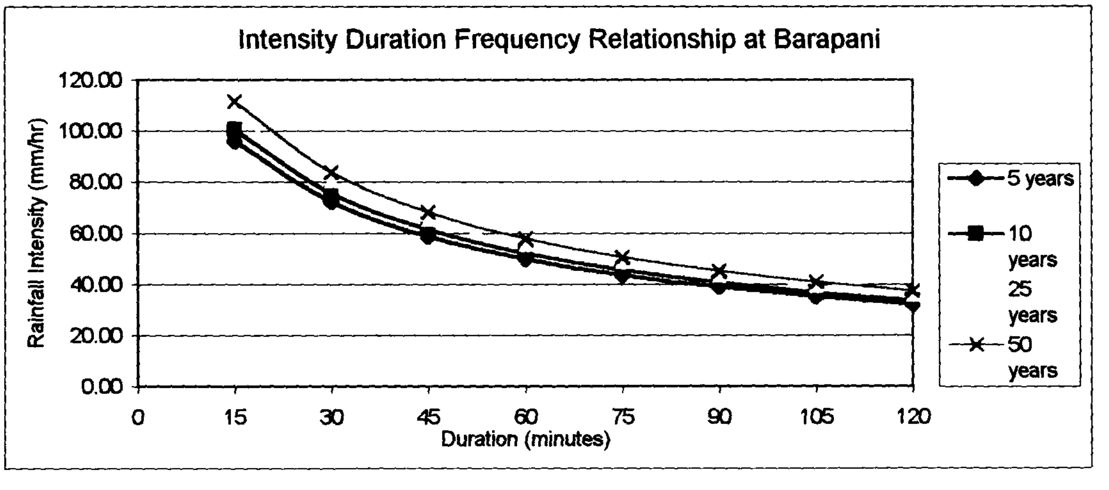

Intensity Duration Frequency Relationship at Barapani
Rainfall Intensity (mm/hr)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
15
30
45
60
75
90
105
120
Duration (minutes)
5 years
10 years
25 years
50 years

Fig.-5.6

The monsoon rainfall data for the period from 1996-2002 (May-October) have been analysed for predicting the rainfall values on weekly basis by applying Normal, log-normal, Gumbel Extreme Value (EV) Type-I and log-Pearson Type-III as desired earlier. The probability distribution function which best fit into the rainfall values computed from the observed values corresponding to the probability levels of 10 %, 20 %, 50 % and 80 %, is taken for predicting weekly rainfall values. The planning for the crop diversification and substitution in upland for agricultural activities in micro-watersheds of Umiew river basin is suggested on the basis of availability of monthly rainfall at 80 % probability level during monsoon months. The predicted weekly rainfall values are compared with the rainfall values computed from the observed value by applying Weibul's formula. The Weibul's formula is as:

$P = (m/N+1) * 100$

Where, m = rank number,

N = total number of years of record, and

P = Plotting position

These four probability distribution functions are given below (Chow,1964) :

(a) Normal Distribution

The Normal distribution arises from the central limit theorem where sequence of random variables X_i are independently and identically distributed with mean μ and variance σ^2.

Normal, $f(x) = 1/\sigma\ (\sqrt{2\pi}) * e\ [-(x-\mu)^2/2\sigma^2]$

Range: $- \propto \leq x \propto$

Where μ , σ and σ^2 are mean, standard deviation and variance respectively

(b) Log-normal Distribution

$f(x) = 1/x\sigma(\sqrt{2\pi}) * e\ [-(y-\mu_y)^2/2\sigma_y^2]$

where, y = log x; μ_y and σ_y are the mean and standard deviation respectively for the variate y.

(c) Log-Pearson Type-III Distribution

$f(x) = \lambda^{n} x^{n-1} e\text{-}\lambda x / \Gamma(\eta)$

where $y = \ln x$ *, Mean =* η/λ *and variance =* η/λ^2

(d) Gumbel Extreme Value Distribution Type-I

$f(x) = e(-y-e^{-y})$

where $y = (\ln x - \beta)/\alpha$

α and β are the parameters of distribution

Mean = $\beta + 0.5772\,\alpha$ and variance = $1.645\,\alpha^2$

The Chi-Square test of goodness of fit is given by the equation $=\Sigma(O-E)^2/E$ Where, O is the observed value obtained by Weibul's method and E is the estimated value by different probability distribution functions.The computed and predicted weekly rainfall values at different probability levels are presented in Table-5.8. The Chai-Square test has been conducted to the predicted values of weekly rainfall under each distribution function to check the best fit of the distribution functions applied for following the method of Mohanty *et al.* (2000). The Chi-Square value obtained under each distribution function has been compared to 5 % significance level and degree of freedom 2. This table value has been estimated to 5.99. The model having least Chi-square value has been selected as best fit probability distribution function.

5.2.1 Results and Interpretation: The daily rainfall data during monsoon period (May-October) has been put under weekly rainfall for 26 weeks. The probability analysis of weekly rainfall has indicated that no single probability model fit into weekly rainfall for all the 26-weeks. It is revealed from the table-5.8 that out of 26 weeks, 13-weeks (week-2,5,6,8,9,11,12,17,19,22,23,25 and 26) best fit into log-Pearson distribution. The other 5-weeks (week-1,3,4,14 and 21) fit into Gumbel EV type-I, 7-weeks (week-10,13,15,16,18,20 and 24) fit into Normal Distribution and the remaining one week (week-7) fit into log-Normal distribution. The predicted values computed by the selected distribution functions and computation of Chai-Square value under each distribution function are shown in

Table-5.8:Observed and Predicted Weekly Rainfall During Monsoon at Different Probability Levels

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E)				Sigma (O-E)2/E			
			Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
1	2	3	4	5	6	7	8	9	10	11
Week-1										
1	20	297.30	280.48		257.58	137.00	1.01		6.13	187.56
2	50	41.10	120.49		89.71	45.20	52.31		26.34	0.37
3	80	18.82	39.50		-36.57	20.90	10.83		-83.90	0.21
							64.15		**-51.43**	**188.14**
							5.99		5.99	5.99
Week-2										
1	20	89.92	78.48	69.17	74.35	84.80	1.67	6.22	3.26	0.31
2	50	43.30	49.63	40.70	44.08	49.40	0.81	0.17	0.01	0.75
3	80	9.42	20.78	24.22	21.31	17.30	6.21	9.04	6.63	3.59
							8.69	**15.43**	**9.91**	**4.65**
							5.99	5.99	5.99	5.99
Week-3										
1	20	53.58	51.11	46.24	48.63	62.20	0.12	1.17	0.50	1.19
2	50	28.30	33.78	28.83	30.45	37.70	0.89	0.01	0.15	2.34
3	80	17.60	16.45	18.02	16.72	15.60	0.08	0.01	0.05	0.26
							1.09	**1.18**	**0.70**	**3.79**
							5.99	5.99	5.99	5.99
Week-4										
1	20	175.78	144.98	124.37	136.86	113.30	6.54	21.25	11.07	34.45
2	50	57.10	88.20	69.95	77.28	57.40	10.97	2.36	5.27	0.00
3	80	36.34	31.42	39.53	32.46	39.60	0.77	0.26	0.46	0.27
							18.28	**23.87**	**16.80**	**34.72**
							5.99	5.99	5.99	5.99
Week-5										
1	20	124.68	106.07	90.83	100.10	104.60	3.27	12.62	6.04	3.85
2	50	39.00	64.36	50.95	56.33	58.00	9.99	2.80	5.33	6.22
3	80	21.28	22.65	28.60	23.41	23.30	0.08	1.87	0.19	0.18
							13.34	**17.29**	**11.56**	**10.25**
							5.99	5.99	5.99	5.99
Week-6										
1	20	140.54	134.44	103.65	125.65	111.10	0.28	13.13	1.76	7.80
2	50	44.40	73.00	51.13	61.18	54.60	11.20	0.89	4.60	1.91
3	80	29.42	11.56	25.53	12.69	25.30	27.59	0.59	22.06	0.67
							39.08	**14.61**	**28.42**	**10.38**
							5.99	5.99	5.99	5.99

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E)				Sigma (O-E)2/E			
			Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
1	2	3	4	5	6	7	8	9	10	11
Week-7										
1	20	156.44	154.72	131.21	143.94	102.50	0.02	4.85	1.09	28.39
2	50	50.00	79.41	52.52	64.92	47.90	10.89	0.12	3.43	0.09
3	80	29.18	4.10	23.50	5.48	27.70	153.42	1.37	102.50	0.08
							164.33	**6.35**	**107.01**	**28.56**
							5.99	5.99	5.99	5.99
Week-8										
1	20	277.92	220.96	188.60	208.45	242.00	14.68	42.30	23.15	5.33
2	50	105.70	133.56	105.47	116.74	81.40	5.81	0.00	1.04	7.25
3	80	37.18	46.16	58.75	47.76	34.40	1.75	7.92	2.34	0.22
							22.24	**50.22**	**26.54**	**12.81**
							5.99	5.99	5.99	5.99
Week-9										
1	20	153.30	135.48	98.22	126.21	112.17	2.34	30.89	5.81	15.08
2	50	33.00	68.61	44.60	55.68	46.56	18.48	3.02	9.24	3.95
3	80	12.46	1.38	18.99	2.62	14.73	88.96	2.25	36.96	0.35
							109.79	**36.15**	**52.01**	**19.38**
							5.99	5.99	5.99	5.99
Week-10										
1	20	104.86	101.22	89.40	95.92	96.54	0.13	2.67	0.83	0.72
2	50	63.50	64.19	52.82	57.07	56.26	0.01	2.16	0.72	0.93
3	80	21.92	27.16	31.48	27.84	29.67	1.01	2.90	1.26	2.02
							1.15	**7.74**	**2.82**	**3.67**
							5.99	5.99	5.99	5.99
Week-11										
1	20	162.86	147.03	125.17	138.66	154.57	1.70	11.35	4.22	0.44
2	50	65.30	88.57	107.36	77.32	67.36	6.11	16.48	1.87	0.06
3	80	20.88	30.11	38.74	31.18	23.57	2.83	8.23	3.40	0.31
							10.65	**36.06**	**9.49**	**0.81**
							5.99	5.99	5.99	5.99
Week-12										
1	20	261.70	206.34	152.52	192.15	172.43	14.85	78.16	25.17	46.22
2	50	40.20	107.20	71.79	88.13	55.15	41.88	13.90	26.07	4.05
3	80	14.82	8.06	33.56	9.88	16.61	5.67	10.46	2.47	0.19
							62.40	**102.52**	**53.71**	**50.46**
							5.99	5.99	5.99	5.99
Week-13										
1	20	300.22	257.98		239.10	179.47	6.92		15.62	81.24
2	50	70.4	126.07		100.69	57.40	24.58		9.11	2.94
3	80	17.38	-5.84		-3.42	22.42	-92.32		-126.50	1.13
							-60.82		**-101.77**	**85.32**
							5.99		5.99	5.99

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E) Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Sigma (O-E)2/E Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
1	2	3	4	5	6	7	8	9	10	11
Week-14										
1	20	169.30	144.06	116.68	135.19	112.17	4.42	23.73	8.61	29.10
2	50	58.70	82.08	60.68	70.16	54.60	6.66	0.06	1.87	0.31
3	80	30.60	20.10	31.98	21.24	32.46	5.49	0.06	4.12	0.11
							16.57	**23.85**	**14.60**	**29.51**
							5.99	5.99	5.99	5.99
Week-15										
1	20	127.70	114.31	98.78	108.00	265.07	1.57	8.47	3.59	71.19
2	50	63.41	70.23	56.90	61.75	62.80	0.66	0.74	0.04	0.01
3	80	20.10	26.15	32.23	26.95	25.03	1.40	4.57	1.74	0.97
							3.63	**13.78**	**5.38**	**72.17**
							5.99	5.99	5.99	5.99
Week-16										
1	20	95.30	88.30	84.50	84.99	88.23	0.55	1.22	1.25	0.57
2	50	65.10	65.17	59.99	60.72	60.34	0.00	0.40	0.32	0.38
3	80	36.90	42.04	42.82	42.47	41.26	0.63	0.95	0.73	0.46
							1.18	**2.57**	**2.30**	**1.40**
							5.99	5.99	5.99	5.99
Week-17										
1	20	114.20	101.70	93.04	96.93	98.49	1.54	4.81	3.08	2.51
2	50	60.30	68.35	58.90	61.93	57.40	0.95	0.03	0.04	0.15
3	80	31.20	35.00	37.70	35.61	34.12	0.41	1.12	0.55	0.25
							2.90	**5.97**	**3.67**	**2.90**
							5.99	5.99	5.99	5.99
Week-18										
1	20	225.90	190.25	164.91	179.82	159.17	6.68	22.56	11.81	27.98
2	50	92.80	117.37	94.64	103.35	71.52	5.14	0.04	1.08	6.33
3	80	47.40	44.49	54.21	45.83	49.40	0.19	0.86	0.05	0.08
							12.01	**23.45**	**12.94**	**34.39**
							5.99	5.99	5.99	5.99
Week-19										
1	20	69.50	61.05	54.01	57.87	66.69	1.17	4.44	2.34	0.12
2	50	36.50	38.83	32.06	34.56	42.10	0.14	0.61	0.11	0.74
3	80	14.80	16.61	19.15	17.02	17.99	0.20	0.99	0.29	0.57
							1.51	**6.05**	**2.74**	**1.43**
							5.99	5.99	5.99	5.99
Week-20										
1	20	59.50	56.02	51.86	53.51	64.72	0.22	1.13	0.67	0.42
2	50	39.90	38.47	33.87	35.09	47.47	0.05	1.07	0.66	1.21
3	80	15.50	20.92	22.15	21.24	18.36	1.40	2.00	1.55	0.45
							1.67	**4.20**	**2.88**	**2.07**
							5.99	5.99	5.99	5.99

Sl.No.	Probability levels (%)	Observed value (O)	Predicted value (E) Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III	Sigma (O-E)2/E Normal	Log-Normal	Gumbel EV type-I	Log-Pearson type-III
1	2	3	4	5	6	7	8	9	10	11
Week-21										
1	20	112.60	92.92	78.93	87.62	86.49	4.17	14.36	7.12	7.88
2	50	36.55	55.83	43.91	48.69	50.40	6.66	1.23	3.03	3.81
3	80	22.70	18.74	24.34	19.41	24.29	0.84	0.11	0.56	0.10
							11.66	**15.71**	**10.71**	**11.79**
Week-22							5.99	5.99	5.99	5.99
1	20	64.00	57.39	51.09	54.46	68.03	0.76	3.26	1.67	0.24
2	50	34.30	36.86	30.78	32.93	39.25	0.18	0.40	0.06	0.62
3	80	13.00	16.37	18.52	16.74	13.46	0.69	1.65	0.84	0.02
							1.63	**5.31**	**2.56**	**0.88**
Week-23							5.99	5.99	5.99	5.99
1	20	118.90	101.88	83.00	95.66	102.51	2.84	15.53	5.65	2.62
2	50	50.90	58.42	43.16	50.06	50.91	0.97	1.39	0.01	0.00
3	80	9.10	14.96	23.50	15.75	15.18	2.30	8.82	2.81	2.44
							6.11	**25.74**	**8.47**	**5.06**
Week-24							5.99	5.99	5.99	5.99
1	20	42.00	37.14	32.58	35.16	65.37	0.64	2.72	1.33	8.35
2	50	22.30	23.32	19.04	20.66	32.46	0.04	0.56	0.13	3.18
3	80	5.50	9.50	11.15	9.76	3.46	1.68	2.86	1.86	1.20
							2.36	**6.14**	**3.32**	**12.74**
Week-25							5.99	5.99	5.99	5.99
1	20	130.60	108.29	79.92	100.83	86.49	4.60	32.14	8.79	22.50
2	50	28.30	56.15	37.53	46.12	42.10	13.81	2.27	6.89	4.52
3	80	22.30	4.01	17.48	4.97	29.67	83.42	1.33	60.43	1.83
							101.83	**35.74**	**76.10**	**28.85**
Week-26							5.99	5.99	5.99	5.99
1	20	99.00	78.10		71.62	83.93	5.59		2.71	2.71
2	50	8.70	32.87		24.17	18.54	17.77		5.22	5.22
3	80	0.80	-12.36		-11.53	1.10	-14.01		0.08	0.08
							9.35		**8.01**	**8.01**

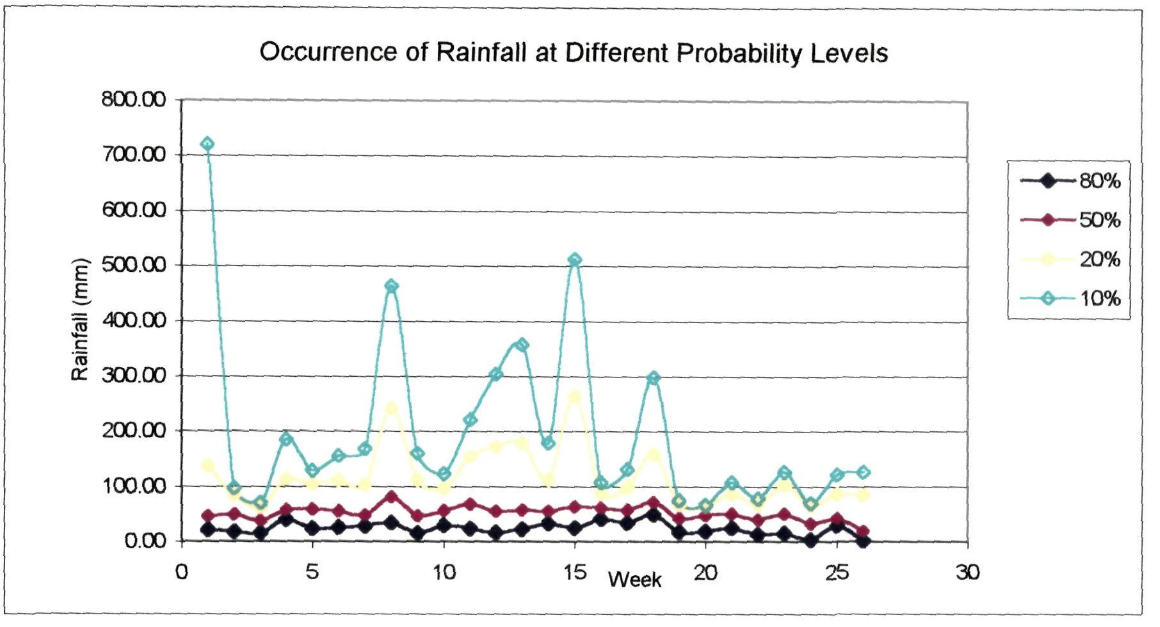
Table-5.8. The sample computations of the selected probability distribution functions are enclosed at Appendices-5.3, 5.4 and 5.5. It has also been observed that weekly rainfall under week-1,4,7,13,14,15,16,18,20,21 and 24 though fitting into Normal, log-Normal and Gumbel EV type-I distributions, but weekly rainfall of these weeks predicted by log-Pearson type-III at 80 % probability level are found almost comparable to the weekly rainfall compared with the observed weekly rainfall values at the same probability levels. Therefore, except 2-weeks (week-3 and week-10), the predicted weekly rainfall values computed by log-Pearson Type-III for the remaining 24-weeks at 80 % probability levels may be taken reasonably well for upland crop planning (Kar and Singh, 2002). The highest monthly rainfall computed from the observed rainfall at 80 % probability level has been obtained in August (168.78 mm) followed by June (106.42 mm) and may (105.25 mm). The least rainfall computed from the observed rainfall at 80% probability level has been found in October {(56.4 mm) (Table-5.9)}. The probability of occurrence of weekly rainfall at 80 %, 50 %, 20 % and 10 % levels as computed by log-Pearson Type-III distribution has been plotted (Fig.-5.7). The probability of occurrence has been found the minimum as its 80% level and is maximum at its 10% level. The blown up view of occurrence of weekly rainfall at different probability levels are shown by the Fig.-5.8. The weekly rainfall assessment made at 80 % probability levels could be used for providing supplemental irrigation to the agricultural crops during dry spell of monsoon and lean period and also during abrupt withdrawals of monsoon in October. Satapathi (1996) has also conducted similar study in the micro-watersheds developed at Barapani, Meghalaya and highlighted the need for such analysis for developing integrated water management plan.

The variation of size and frequency of occurrences of rainfall have caused high variability in the monsoon discharge of the river. The range of variation between the observed ratio of minimum and maximum discharge during the monsoon months in 1996 are found to be in the ratio of 1:227.5 to 1:3.29. Variation in the minimum and maximum monsoon discharge in 1996 is observed highest during June and October and the least variation has been during August and September. This variation in the minimum and maximum monsoon discharge

Table 5.9 : Occurrence of Rainfall at Different Probability Levels

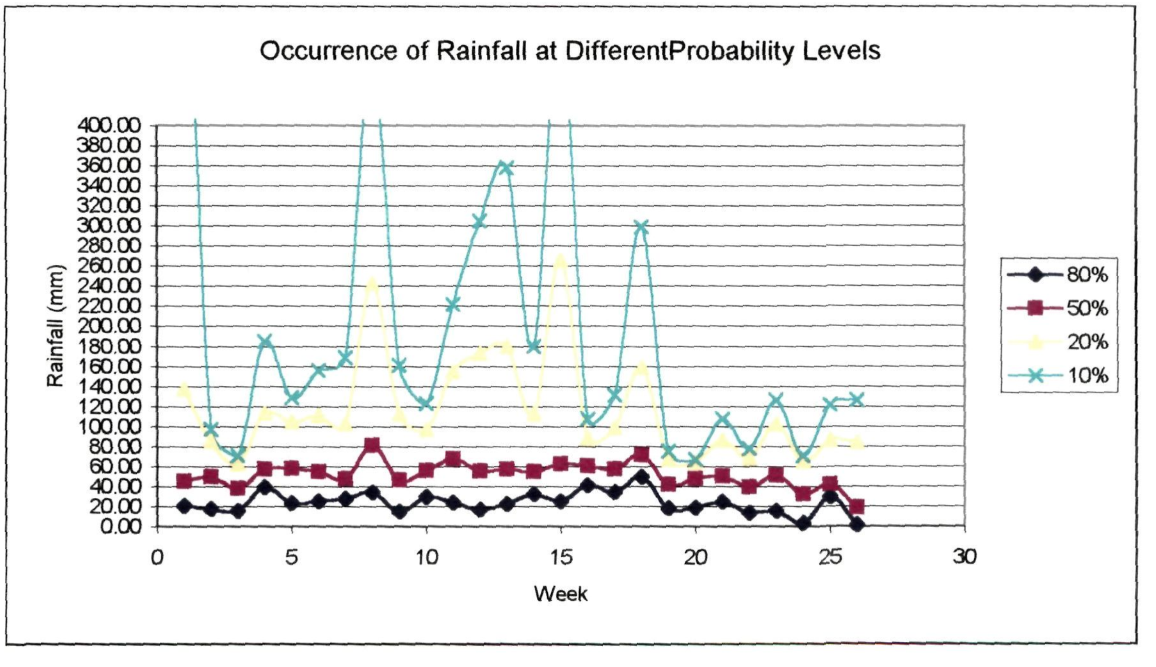
Rainfall in mm

Week	Probability levels of occurrence of rainfall				Month	Monthly rainfall at 80 % probability level
	80%	50%	20%	10%		
1	20.90	45.20	137.00	720.50		
2	17.30	49.40	84.80	97.50		
3	15.60	37.70	62.20	70.80		
4	39.60	57.40	113.30	184.90		
5	23.30	58.00	104.60	129.00	May	105.25
6	25.30	54.60	111.10	156.00		
7	27.70	47.90	102.50	169.00		
8	34.40	81.40	242.00	464.10		
9	14.73	46.53	112.17	160.77	June	106.42
10	29.67	56.26	96.54	122.73		
11	23.57	67.36	154.57	221.41		
12	16.61	55.15	172.43	304.90		
13	22.42	57.40	179.47	357.81	July	88.43
14	32.46	54.60	112.17	179.47		
15	25.03	62.80	265.07	512.86		
16	41.26	60.34	88.23	107.77		
17	34.12	57.40	98.49	131.63	August	168.78
18	49.40	71.52	159.17	298.87		
19	17.99	42.10	66.69	75.19		
20	18.36	47.47	64.72	66.69		
21	24.29	50.40	86.49	107.77		
22	13.46	39.25	68.03	78.26	September	92.07
23	15.18	50.91	102.51	126.47		
24	3.46	32.46	65.37	70.81		
25	29.67	42.1	86.49	121.51		
26	1.10	18.54	83.93	126.47	October	56.14



Occurrence of Rainfall at Different Probability Levels
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Rainfall (mm)
0
5
10
15
Week
20
25
30
80%
50%
20%
10%

Fig.-5.7



Occurrence of Rainfall at DifferentProbability Levels
400.00
380.00
360.00
340.00
320.00
300.00
280.00
260.00
240.00
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Rainfall (mm)
0
5
10
15
20
25
30
Week
80%
50%
20%
10%

Fig.-5.8

in 1997 has become highest during June and July and the least variation has been observed during May and October. Similarly, during 1998, the variation in the minimum and maximum monsoon discharge ratio is observed highest during July and August and the least variation is registered during June and September (Table-5.10). Therefore, the maximum and minimum variations between the maximum and minimum monsoon discharges of river Umiew have been found to be changing from year to year between May to October.

A three tier system for the conservation and utilization of rain water in the micro-watersheds of river Umiew could be introduced with certain modifications over the system of conservation suggested by Gupta and Narayan (1974) and Narayan and Pandey (1976). These modified features are:

A series of dugout storage ponds with adequate capacity, estimated on the basis of water availability study, may be panned at different elevation of the lands under all the nine micro-watersheds of river Umiew. These dugout storage ponds may be connected suitably by the drainage channels. The impounded water from the dugout ponds located at higher elevation, after getting utilised by the crop, the excess drainage water may be collected by the dugout ponds located at next lower elevation. This way the rain water tapped at higher altitude of the micro-watershed area may be utilized optimally by the lands located at different elevations. The remaining excess water may then be discharged into the regional drainage system.

5.3 Concluding Remarks

The morphometric and physiographic characteristics, landuse pattern and temporal variation of intensity of rainfall occurring within the watershed may be attributed for influencing the variation in the flood discharge of the river.

The analysis of Intensity-Duration-Frequency(IDF) chart, prepared by applying Log-Pearson Type-III distribution function, when compared with Intensity-Duration-Frequency chart by using IDF relationship developed by ICAR, indicate that the higher degree of variation in the spatial distribution of rainfall intensity of lesser duration have been observed and vice-versa.

Table-5.10 : Monthly Average, Maximum and Minimum Discharge of River Umiew

During Monsoon (May -Oct.) from 1996 - 1998

Month

Discharge (Cumecs)	May	June	July	August	September	October
1996						
1. Max.discharge	4.48	464.09	72.22	30.16	14.10	488.55
2. Min. discharge	0.36	2.04	9.22	7.49	4.39	2.97
3. Ratio between minimum and maximum discharge	1/12.44	1/227.5	1/7.83	1/4.03	1/3.29	1/164.49
4. Monthly average discharge	2.23	108.12	35.70			101.34
1997						
1.Max. discharge	5.73	229.47	476.68	103.75	93.33	16.50
2. Min. discharge	1.94	1.94	12.73	12.24	13.53	4.76
3 Ratio between minimum and maximum discharge	1/2.95	1/118.28	1/37.45	1/8.48	1/6.9	1/3.47
4. Monthly average discharge	3.73					10.47
1998						
1. Max.	27.56	21.82	463.04	315.63	67.13	110.89
2. Min.	0.71	1.62	5.90	7.60	7.91	4.30
3. Ratio between minimum and maximum discharge	1/38.82	1/13.47	1/78.48	1/41.53	1/8.49	1/25.79
4. Monthly average discharge	5.05	5.95	46.08	45.97	18.36	7.40

Since the values of monthly rainfall computed from the observed rainfall values at 80 % probability level especially for the months of May and June, has been predicted significantly higher as 105.25 mm and 106.42 mm respectively, the month of May itself can be utilized for the seedling and transplantation of kharif paddy. The rainfall during the months of July to September has suitable moisture for meeting the requirement of the paddy by making a provision of supplemental irrigation, when the values of monthly rainfall at 80 % probability level are computed 88.43 mm and 92.07 mm respectively (Table-5.9). The probability analysis for the occurrence of weekly rainfall at 80 % probability levels at annual scale would be helpful in realistic planning for the optimal conservation of rain water.

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Chapter-6

Chapter-6

Soil Erosion and Discharge

6.0 Introduction

Though erosion is known to be related to the degree of slope and the potential capacity of the rain, there are several factors such as soil and rainfall characteristics which are specific for the location and not necessary the same under all conditions. It thus becomes necessary to quantify the relationships under a set of given conditions. It also indicates the need for carrying out studies which may be location specific. The degree of steepness of slope and rainfall erosivity are two important factors among others affecting soil erosion. Erosivity which is the property of rainfall has been evaluated quantitatively in relation to the potential capacity of the rain.

Application of mulch to soil surface especially for the sloppy lands, prevents to some extent the soil erosion. The fall of raindrops at high velocity directly on the surface of land is mitigated because of the intervening mulch layer. The detachability of the soil particles is also reduced and, thus, soil erosion to a greater extent is prevented. When rain drops hit a bare soil, they have dispersive action (Ellsion 1944 and 1947) These rain drops are responsible for sealing the surface which prevents infiltration and storage of moisture and thereby causing runoff and soil loss (Duley 1939, Mc Intyre1958). The correlation of soil loss with an amount of rain in individual storm as well as with maximum amount falling in 5, 15 or 30 minutes intervals has been poor. However, the product of the kinetic energy and the 30 minute intensity is most significantly correlated with soil loss (Wischmeier *et al.*1958).

The soil detachment hazard is found to be inversely proportional to the resistance factor of surface cover and mulches in reducing runoff velocity (Ellision 1947). Mulching is an effective means to protect the soil surface from sealing under the impact of rain drops (Schaller and Evans1954, Meyer *et al.*1975). The runoff and soil loss are found to be reduced by the application of mulch materials over the soil surface (Meyer *et al.* 1970, Lattanzi *et al.* 1974, Singer and Blackard 1978).

It has been observed that nearly 75-98 % of the total Erosion Index (EI) values have been concentrated during rainy months except Southern Zone of India (Ram Babu *et al.* 1978). In the North Eastern Region particularly in Meghalya, where the study area is located, the monsoon period continues from May to October. Taking these facts into consideration, an attempt has been made in this chapter to compute the rainfall erosivity index by analyzing the daily rainfall data for the monsoon period from 1996-2002 and to study its influence on the sediment yield rate. The relationship between the monthly flow of river Umiew and its sediment yield and also between the monthly erosivity index and sediment yield during monsoon months have been established by carrying out logarithmic regression analysis. The discharge and erosivity index have been taken as independent variables and that of sediment yield being the dependent variable. The correlation test has been done to find out the best possible relationship between them. Analysis of the observed discharge and sediment yield rate data of river Umiew and the computed maximum single storm erosion index have been done to assess the impact of erosion index on the sediment yield rate.

In the absence of long term rainfall and observed discharge data of river Umiew, one-hour modified Synthetic Unit Hydrograph (SUH) has been developed to infer the results for the Umiew watershed. This Unit Hydrograph is developed by using the relationship established by the Central Water Commission (CWC) for estimating one-hour Synthetic Unit Hydrograph parameters for an ungauged catchments for the South Bank of river Brahmaputra (Flood Estimation Report for South Brahmaputra Sub-zone-2(b), Revised,CWC,2000). The catchment of river Umiew is lying on the

South Bank of river Brahmaputra. The peak discharge of river Umiew has been computed with the help of modified one-hour Synthetic Unit Hydrograph by taking the rainfall corresponding to the date of occurrence of observed maximum discharge of the river. The discharge computed by this process has been compared with the observed maximum discharge of the river related to the specified date on which the rainfall has been taken for discharge computation. This has been done to check the applicability of Synthetic Unit Hydrograph for the estimation of peak discharge of river for the specific return period. These peak discharges may be used in estimating the expected sediment loss.

6.1 Assessment of Rainfall Erosion Potential

The Universal Soil Loss Equation (USLE) was developed to enable planners to predict the average annual rate of soil erosion for alternative crop systems and management practices at a specific site. Erosion is a process for which the energy is supplied partly by falling raindrops. The energy of a rainfall event is a function of the amount of rain and all the intensity components of the event. The erosion index concept is used in the USLE as a numerical description of the potential of the rainfall to erode soil.

Based on the kinetic energy of the storm, Wischmeier (1959) showed that if all factors other than rainfall are held constant, annual erosion losses from cultivated areas are directly proportional to the yearly values of the erosion index. The quantification of this parameter has a great significance for soil erosion control.

6.1.1. Estimation of Erosion Index: The rainfall charts from self-recording raingauge have been used for the computation of kinetic energy and erosion index. The rainfall data of Shillong for the years 1996 to 2002 are used for the estimation of Erosion Index (EI) ofe Umiew watershed on the assumption that IMD station Shillong and the dam site of Umiew watershed are lying within the closer proximity of around 20 Km. The method suggested by Wischmeir (1959) has been used for estimating the erosion index value of each storm.

The seasonal erosion index i.e. erosion index during each year of monsoon has been computed by summing up monthly erosion index occurred during monsoon months. Similarly, the monthly erosion index is computed by adding all single storm erosion index for each monsoon months. The maximum single storm erosion index on monthly basis is obtained by selecting the largest value of the single storm erosion index which has occurred during the monsoon months of each year. The monthly, seasonal and maximum single storm erosion index and the observed values of rainfall for the monsoon period (May-October) from 1996 to 2002 have been computed (Tables-6.1, 6.2 and 6.3. The computed values of Erosion Index (EI) for the different storms occurred during the monsoon from 1996 to 2002 are shown separately in Appendix-6.1.

The frequency analysis has been performed on the computed data series of the erosion index for the monsoon period as well as maximum single storm by applying the Gumbel E.V.Type-I and Log-Pearson Type-III distribution functions. The computed data series are shown in Table-6.4. The predicted values of the monsoon and maximum single storm erosion indices for the different return periods, namely-2 years, 5 years, 10 years and 20 years are obtained by these two distributions (Tables-6.6 and 6.7). The Goodness of Fit by D-Index Test is applied for the predicted values. It is found that the predicted values of maximum single storm erosion index fits well with the Gumbel E.V. Type-I distribution.

6.1.2. Results and Interpretation: The computed values of monthly and monsoon erosion indices, maximum single storm erosion index and the observed values of rainfall for the monsoon period (May-October) from 1996 to 2002 reveal that they vary substantially from month to month and year to year (Tables-6.1, 6.2 and 6.3). The ICAR (1996) while making the assessment of rainfall erosion potential at Barapani in Meghalya has also observed that the values of monthly, seasonal and maximum single storm erosion indices vary monthwise as well as yearwise. It has been observed that the monthly erosion index, which varies from (9.48 to 569.70 metre-ton-cm/ha-hr) in June, is recorded as the highest (Table-6.1). The standard deviation in the values of monthly erosion index in June, 1999 has also been observed highest. The monthly erosion index is found highest (569.70) in June, 2002 but, the average monthly erosion index is found highest (204.12)

Table-6.1: Monthly Erosion Index during Monsoon (May-Oct) from 1996 -2002

Year	Erosion Index (metre-ton-cm/ha-hr)						Erosion Index
	May	June	July	Aug	Sept.	Oct.	during monsoon
1996	84.58	381.06	128.53	46.15	56.38	182.29	878.99
1997	54.28	18.30	29.42	101.37	40.68	34.22	278.27
1998	15.38	9.48	197.10	196.44	206.10	17.00	641.50
1999	176.93	48.61	413.80	60.20	71.73	256.88	1028.15
2000	42.23	225.34	21.35	103.11	31.36	12.90	436.29
2001	23.06	85.36	443.57	235.07	70.59	108.99	966.64
2002	133.68	569.70	195.10	*	*	*	898.48
Mean	75.73	191.12	204.12	123.72	79.47	102.05	732.62
Std.dev.	60.11	214.06	168.85	75.71	64.07	100.24	265.54
C.V. (%)	191.37	112.00	82.72	61.20	80.62	98.23	36.25

Table-6.2: Maximum Single Storm Erosion Index (metre-ton-cm/ha-hr) during Monsoon

Year	Maximum single storm indices					
	May	June	July	August	Sept.	Oct.
1996	34.06	155.28	63.39	9.97	19.49	114.21
1997	36.94	7.16	24.05	47.09	22.21	24.23
1998	10.83	3.86	160.73	83.62	111.36	17.00
1999	37.64	16.88	140.85	11.77	28.12	109.71
2000	17.82	61.73	18.83	58.88	10.52	9.48
2001	14.23	47.91	274.44	193.00	23.20	70.30
2002	39.83	233.05	94.06	*	*	*
Mean	27.34	75.12	110.91	67.39	35.82	57.49
Std. dev.	12.48	86.96	90.08	67.70	37.46	47.24
C.V. (%)	45.65	115.76	81.22	100.46	104.59	82.18

Table-6.3: Monthly Rainfall during Monsoon (May-Oct) from 1996- 2002

Year	Rainfall (mm)						Rainfall during
	May	June	July	August	Sept.	Oct.	monsoon
1996	146.70	389.40	366.30	216.60	170.60	252.10	1541.70
1997	167.80	225.90	201.60	375.20	246.60	73.60	1290.70
1998	111.40	90.40	434.80	532.10	245.40	91.40	1505.50
1999	940.50	244.80	723.80	344.90	133.80	308.90	2696.70
2000	442.30	606.50	213.80	271.70	177.70	180.80	1892.80
2001	190.50	360.20	602.50	259.30	294.30	216.50	1923.30
2002	292.10	766.20	486.80	*	*	*	1545.10
Mean	327.33	383.34	432.80	333.30	211.40	187.22	1770.83
Std. dev.	292.65	233.36	192.46	113.40	60.15	91.66	430.90
C.V. (%)	89.41	60.88	44.47	34.02	28.45	48.96	24.33

Note: (1) * Rainfall data were collected in August,2002

Table-6.4: Maximum Single Storm Erosion Index and Rainfall during Monsoon (May to Oct.) from 1996-2002

Year	Rainfall during (Monsoon (mm)	Monsoon Erosion index	Maximum single storm erosion index during Monsoon	Ln of Monsoon Erosion Index	Ln of max. single storm Erosion Index
1996	1541.70	878.99	155.28	6.78	5.05
1997	1290.70	278.27	47.09	5.63	3.85
1998	1505.50	641.50	160.73	6.46	5.08
1999	2696.70	1028.15	140.85	6.94	4.95
2000	1829.80	436.29	61.73	6.08	4.12
2001	1923.30	966.64	274.44	6.87	5.61
2002	1545.10	898.48	233.05	6.80	5.45
Mean	1770.83	732.62	153.31	6.51	4.87
Std. dev.	430.90	265.54	76.45	0.59	0.65

Note :(1) Values of monsoon erosion index and maximum single storm erosion index during 2002 habe been computed from the rainfall data of May,02 to July,02. (2) Erosion Index is in meter-ton-cm/ha.-hr. and rainfall in mm.

Table-6.5: Monthly Average Rainfall, Erosion Index and Maximum Single Storm Erosion Index

Month	Average rainfall	Standard deviation in rainfall	Average monthly erosion index	Standard deviation in monthly erosion index	Average single storm erosion index	Standard deviation in single storm erosion index
May	327.33	292.65	75.13	60.11	27.34	12.48
June	383.34	233.36	191.12	214.06	75.12	86.96
July	432.80	192.46	204.12	168.85	110.91	90.08
August	333.30	113.40	123.72	75.71	67.39	67.70
Sept.	211.40	60.15	79.47	64.07	35.82	37.46
Oct.	187.22	91.66	102.05	100.24	57.49	47.24

Table-6.6 . Predicted Monsoon Erosion Index for different Return Periods

Statistical Distribution	Erosion Index (metre-ton -cm /ha.-hr.) 2 years	5 years	10 years	20 years	Statistical Distribution	Erosion Index (metre-ton -cm./ha.-hr) 2 years	5 years	10 years	20 years
Gunbel EV Type-I	689.74	923.6	1078 82	1227.83	Log Pearson Type-III	742 48	1012 32	1141 39	1224.15

Table-6 7· Predicted Maximum Single Storm Erosion Index during Monsoon for different Return Periods

Statistical Distribution	Erosion Index (metre-ton.-cm./ha.-hr.) 2 years	5 years	10 years	20 years	Statistical Distribution	Erosion Index (metre-ton -cm./ha.-hr) 2 years	5 years	10 years	20 years
Gunbel EV Type-I	140.96	208.32	253.02	295 94	Log Pearson Type-III	141 17	228.15	218 17	320.9

in July, 2002 (Table-6.1). The monsoon erosion index is found highest (1028.15 metre-ton-cm/ha-hr) in 1999 (Table-6.1). The maximum single storm erosion index has been observed highest (274.44 metre-ton-cm/ha-hr) in July, 2001. This single storm has got the capability to generate 61.87 % of the monthly erosion potential observed in July,2001. The monthly rainfall of 602.50 mm is recorded during the said period. The maximum rainfall month and maximum rainfall monsoon year are observed in May,1999 and 1999 respectively. The maximum rainfall of 2696.70 mm is precipitated during the monsoon (May-October) in 1999. It has been observed that the highest monthly rainfall (940.50 mm) is noticed in May 1999 (Table-6.3) whereas, the monthly erosion index is found highest (569.70 metre-ton-cm/ha-hr in June 2002 (Table-6.1). This means that the value of erosion index is influenced more by the higher intensity of rainfall than its overall magnitude. That is why higher intensity of rainfall has larger value of the erosion index and ,hence, carries more erosion potential. It is a coincidence that the maximum value of the monsoon erosion index and occurrence of maximum rainfall have been recorded in the same year i.e.1999.

The average values of the monthly erosion index computed during the monsoon from 1996-2002, show that the month of June, July, August and October have considerable erosion potential (Table-6.2). It has been found that during October, the field has little crop canopy and remains barren. It is therefore suggested that adoption of proper crop management and soil conservation measures are essential to minimize the effects of rain storm. Similar suggestion has also been offered by the Indian Council of Agricultural Research (ICAR) for its model micro-watersheds developed at Barapani (Satapathy, 1996).

In order to estimate the average annual soil loss from a particular watershed area, Satapathi (1996) has suggested that the value of R (average annual erosion index) in the Universal Soil Loss Equation must be taken the average annual erosion index value of that area. Ram Babu *et al.* (1978) has reported that except southern zone of India, nearly 75-98 % of the total EI values are concentrated during June-September (rainy months). It is ,therefore, more realistic to estimate the average soil loss separately for the monsoon and non-monsoon periods. For this, the value of R may be substituted separately for the value of average monsoon and non-monsoon erosion index of the concerned area in the Universal Soil Loss Equation.

The values of monsoon erosion index and the maximum single storm erosion index are predicted at 80 %, 50 % and 20 % probability levels by applying Normal, Log-normal, Gumbel EV Type-I and Log-Pearson type-III distribution functions (Tables-6.8 and 6.9). These predicted values have been subjecd to Chi-square test with 5 % significance level and degree of freedom 2 to obtain the best fit probability distribution functions following the method of Mohanti *et al.* (2000). The Chi-square values in all the four distribution functions have been found higher than the tabular value of 5.99. The Chi-square value has been found least in Log-Pearson Type-III distribution. Therefore, Log-Pearson Type-III distribution may be used for estimating the monsoon erosion index and maximum single storm erosion index for a specific return period. The estimated value of the Erosivity Index R are used in the Universal Soil Equation for predicting the value of soil loss from a specific micro-watershed area during monsoon against the specific return period for which the predicted value of the monsoon erosion index has been taken. The predicted values of monsoon erosion index and maximum single storm erosion index give an appreciation of erosion risks involved with the concerned micro-watershed.

6.2. Sediment Yield Rate

It has been seen in the review of the literature Chapter-2 that the complex phenomena of soil erosion depend on a large number of variables which is not amenable to analytical solution and hence, has forced the researchers to evolve empirical relations. The empirical relationships developed by Garde *et al.* (1983) and Garde and Kothyari (1987) for estimating annual sediment yield from the catchments have been used to estimate the sediment load from Umiew Watershed during monsoon.

6.2.1. Results and Interpretation: Umiew watershed is located between the average altitude of 1650 m to 2000 m with the average annual rainfall of 2000.54 mm. The sediment load observed from Umiew watershed during monsoon (May-October) in 1997 and 1998 has been found to vary from

Table-6.8: Observed and Predicted Monsoon Erosion Index at different Probability Levels

Sl.No.	Return Period (years)	Probability (%)	Observed value (O)	Predicted value (E)				(O-E)2/E			
				Normal	Log-Normal	Gumbel EV Type-I	Log Pearson Type-III	Normal	Log-Normal	Gumbel EV Type-I	Log Pearson Type-III
1	1.25	80	373.08	509.57	497.43	513.82	468.72	36.559	31.086	38.55	19.51
2	2.00	50	878.99	732.62	683.89	689.74	742.48	29.243	55.658	51.93	25.10
3	5.00	20	991.24	955.67	939.13	923.60	1012.32	1.3239	2.8915	4.95	0.44
								67.126	89.635	95.43	45.05
								5.99	**5.99**	**5.99**	**5.99**

Table-6.9: Observed and Predicted Maximum Single Storm Erosion Index at different Probability Levels

Sl.No.	Return Period (years)	Probability (%)	Observed value (O)	Predicted value (E)				(O-E)2/E			
				Normal	Log-Normal	Gumbel EV Type-I	Log Pearson Type-III	Normal	Log-Normal	Gumbel EV Type-I	Log Pearson Type-III
1	1.25	80	55.87	89.09	88.90	90.28	74.44	12.39	12.27	13.12	4.63
2	2.00	50	155.28	153.31	135.14	140.96	141.17	0.03	3.00	1.45	1.41
3	5.00	20	249.61	89.09	206.16	208.32	320.90	289.22	9.16	8.18	15.84
								301.63	24.43	22.75	21.88
								5.99	**5.99**	**5.99**	**5.99**

Note: (1) The numerical figure 5.99 mentioned in bold indicates tabular value of Chai-square at 5 % significance level and degree of freedom 2. (2) Monsoon erosion index and Maximum single storm erosion index are in metre-ton-cm/ha-hr

2588.97 ton to 25,364 ton. The maximum sediment yield rate obtained during this period, has been found to the tune of 1.86 ton/ha. The maximum sediment yield rate observed from nine micro-watersheds with different land use systems developed by ICAR at Barapani during 1976-1983 and 1983-90 has been found to 0.33 $ton.ha.^{-1}yr.^{-1}$ (Borthakur *et al.* 1978; Singh *et al.* 1981). These micro-watersheds located at Barapani are lying between the altitude of 952 m to1082 m and subjected to maximum annual rainfall of 2232 mm. The sediment yield rates estimated by using empirical relationships developed by the researchers, have been compared with the sediment yield rate observed from Umiew watershed. It is found that the sediment yield estimated by the method adopted by Garde *et al.* (1983) is 52.63 % lower than the observed sediment yield rate of Umiew river during 1996. The sediment yield rate estimated by Garde and Kothyari (1987) has been found 552.7 % higher than the observed sediment yield rate of river Umiew during 1997 (Table-6.10). The computational details, related to the estimation of sediment yield rate by using the empirical relationships, are given at Appendix-6.3. The maximum sediment yield rate of 0.33 ton/ha from the micro-watersheds at Barapani *has come within the limit of sediment yield rate* (0.19–1.86 *ton/ha*) *of* river Umiew observed during 1997-98(Table-6.10). The closer proximity in the value of the sediment yield rates observed from both the watersheds may be attributed to the physiographic and climatic similarity.

6.3. Discharge-Sediment-Erosivity Index

In India, many studies on run-off plots related to the effect of length of slope on soil loss have been conducted earlier at different places by various researchers but, their results are not found conducive. These studies have been conducted on runoff plots of 18 m, 37 m and 57 m lengths on 5 % slope at Rehmankhera, Lucknow. The data collected over a period of fifteen years has shown that soil loss decreased consistently with the increase in slope length. The study conducted at Chandigarh also showed that the soil loss decreased consistently throughout the years in the study area with the increase in slope length 90-120 m and 150 m (Singh *et al.*1981). These are quite contrary to the relationship suggested by Wischmeier and Smith (1978). The studies conducted on plots of 25, 37.5, 50 and 60 m length

Table-6.10: Observed and Estimated Sediment Load for Umiew Watershed during Monsoon (May-Oct.)

Sediment load observed		Sediment load estimated		
Umiew Watershed		Micro-watershed developed by ICAR	Garde et al. (1983)	Garde et al. (1987)
1997	1998			
25,364 ton (1.86 ton/ha)	2,588.97 ton (0.19 ton/ha)	0.33 (ton/ha)	1,275.85 ton (0.09 ton/ha)	1,65,600 ton (12.14 ton/ha)

with 2 % slope in Kharagpur has shown that the soil loss has increased with the increase in length upto 50 m but, at 60m length the soil loss did not exactly follow the same pattern (Rao 1981). The studies conducted at Vasad on plots of 11 m, 22 m, 44 m and 66 m lengths on 2 % slope revealed that the magnitude of soil erosion does not seem to increase appreciably with increase in slope length (Chandra and Rao 1983). The results show that the soil loss has increased with the increase in slope length upto 44 m but, it does not follow the same pattern at 66 m slope length.These results seem similar to the equation suggested by Wischmeier and Smith (1978).

These run-off plots and the USLE give estimates of total soil detached and displaced over short distances, but do not indicate the sediment delivered to the reservoir. Much of the deposition and reduction in sediment yield occurs between the sediment sources and reservoirs. The sediment data of 21 rivers of the Himalayan region and 15 of the non-Himalyan regions along with the data on catchment areas, average annual discharge and rainfall are reported by Gupta (1975), Rao (1975) and Chaturvedi (1978). Ram Babu *et al.* (1978) computed the average annual erosion index values, EI for various regions of the country and prepared an Iso-erodent map. Based on these data, the following statistical relationship are established for the sediment loads of rivers:

$$Y = f(x), \quad --- \quad --- \quad --- \qquad (1)$$

where, y = sediment in millions of tones, and x = annual total run-off in millions of hectare-metres

However, this equation does not have any parameter representing the watershed characteristics. A weighted independent variable Xw, which takes into account the silt-producing characteristics, has been accounted for in equation (1). The modified regression equation is :Y = f (Xw)

6.3.1. Discharge-Sediment Relationship: The run-off and soil loss studies from many of the country's 20 land resource regions have been conducted since 1955 by the Central Soil and Water Conservation Research and Training Institute, Dehradun and its regional stations (Gupta *et al.* 1970). Other organizations like Forest Research Institute, Dehradun, Damodar Valley Corporation and Soil Conservation Departments of various states have also reported data on this aspect. Narayana and Ram Babu (1983) estimated the soil loss for each of the 20 land resource regions of India. It has been reported that the maximum annual soil loss of 64.5 tonnes/ha has taken place from the cultivated areas of black soil region followed by North Eastern Region to 41 tonnes/ha, ravine region to 33 tonnes/ha and Assam valley to 28 tonnes/ha. The observed daily discharge and sediment data of river Umiew, which have been collected during monsoon (May-October) from 1996-1998, has shown that the maximum soil loss has invariably taken place at high discharge. Some exception to this has also been observed at low discharge during October,98 i.e. at low discharge the soil loss has become high. In some cases, there has been some time lag between the occurrence of maximum soil loss and the peak discharge. The time of observation of maximum soil loss has been preceded by the occurrence of peak discharge.

6.3.2. Discharge-Erosion Index Relationship: While analysing the single storm erosion index data with that of the sediment yield rate during 1996-98, it has been observed that single storm erosion index has influenced positively in enhancing the sediment yield rate of river Umiew.

6.3.3. Results and Interpretation: It has been observed from the discharge and sediment data during 1996-98 that discharge and sediment relationship can be put under three categories (Table-6.11). In the first category, high discharge of river has yielded high sediment yield rate. This has occurred during 14th and 31st August,97, 13th September,97 and 21st October,98 (Table-6.11). While analysing the chart of daily sediment load and the flood hydrograph plotted from August,96 to October,98 (excluding the lean period from November to April), it has been found during August,96 that the peak discharge of 30.16 cumecs and the maximum sediment load 171.99 ton/day has been observed on the same day i.e. on 15 th of August. In the same month, corresponding to the lower discharge of 8.11 cumecs, the maximum sediment load of 237.48 ton/day has been observed on August 30th. In other months like May,97, June,97 to October,97 and again from May,98 to September,98 , the peak discharge and the peak sediment load have taken place on the same day. The peak discharge and the peak sediment load though have occurred on the same day but these days vary from month to

Table-6.11: Discharge-Sediment-Erosivity Index

Period	Maximum observed discharge (cumecs)	Maximum observed sediment load (ton/day)	Single storm erosion Index on date of occurrence of maximum observed discharge	Single storm erosion Index on previous date of occurrence of maximum observed discharge	Maximum single storm erosion Index and date of its occurrence
15/8/96	30.16	171.99	1.87	1.12	9.26 (01/08/96)
30/8/96	8.11	237.48	5.45	4.54	18.08 (30/08/96)
1/9/96	14.10	24.36	Insignificant	Insignificant	
2/9/96	8.69	26.28	Insignificant	Insignificant	
30/10/96	488.55	33.77	Insignificant	6.58	19.98 (4/10/96)
9/5/97	5.73	201.67	Insignificant	Insignificant	36.96 (28/5/97)
29-06-97	154.41	1307.39			
30/06/97	229.47	2496.77	Insignificant		7.16 (27/6/97)
14/8/97	103.75	464.00	9.52	2.34	47.09 (20/8/97)
31/8/97	100.24	649.54	1.88	6.31	
13/9/97	93.33	959.69	8.04	22.21 (3/9/97)	22.21 (3/9/97)
4/10/97	16.50	15.68	Insignificant	Insignificant	9.99 (9/10/97)
24/5/98	27.56	5.47	Insignificant	4.55 (18/5/97)	
22/6/98	21.82	4.34	Insignificant	1.26 (18/6/98)	
20/7/98	463.04	152.00	8.71	160.47 (19/7/98)	160.47 (19/7/98)
31/8/98	315.63	299.47	6.4	21.89 (29/8/98)	83.71 (28/8/98)
1/9/98	67.13	34.80	70.24	6.4	110.42 (16/9/98)
4/9/98	64.47	38.99	Insignificant	2.25	
21/10/98	110.89	229.94	Insignificant	17.00 (3/10/98)	17.00 (3/10/98)

Note: Erosion Index in metre-ton-cm/ha-hr month. In some of the months during 1996 i.e. September and October, the occurrence of peak discharge has preceded the occurrence of the peak sediment load. In September,96 the peak discharge of 9.43 cumecs has preceded the occurrence of peak sediment load of 21.28 ton/day by one day. Similarly, during the month of October,96, the peak discharge of 10.29 cumecs has preceded the occurrence of peak sediment load of 9.43 ton/day by two days (Figs.-6.1 to 6.8). It has also been observed that the river has carried abnormally very high sediment load of 2496.77 ton/day and 1307.39 ton/day during two consecutive days on 29th and 30th June,97 corresponding to the discharge of 154.407 cumecs and 229.47 cumecs. The extreme value of the sediment load could be manifested with the occurrence of heavy land slides in the land mining areas of Umiew river catchment (Table-6.11).

In the second category, the low discharge of river has carried high sediment load. This has occurred during 30th August,96, 9th May,97 and 10th of October,98. Under the falling trend of discharge at 4.30 cumecs, the rising trend of sediment load of 13.93 ton/day has been observed on 10th of October,98 (Fig.6.8).

In the third category, it has been found that with the increase in river discharge, the rate of sediment yield has gone down. This has occurred during 20th July,98 and 31st August,98. This could be due to delay in the detachment of soil particles and transportation of the same at the observation site (Table-6.11).

In order to establish the relationship between the discharge and sediment load (soil loss) falling under the three categories indicated above, the regression analysis has been done between sediment load (dependent variable) and surface runoff (independent variable) for the month of August, September and October with the data set of sediment yield rate and the discharge of river Umiew available for the years 1996-98.

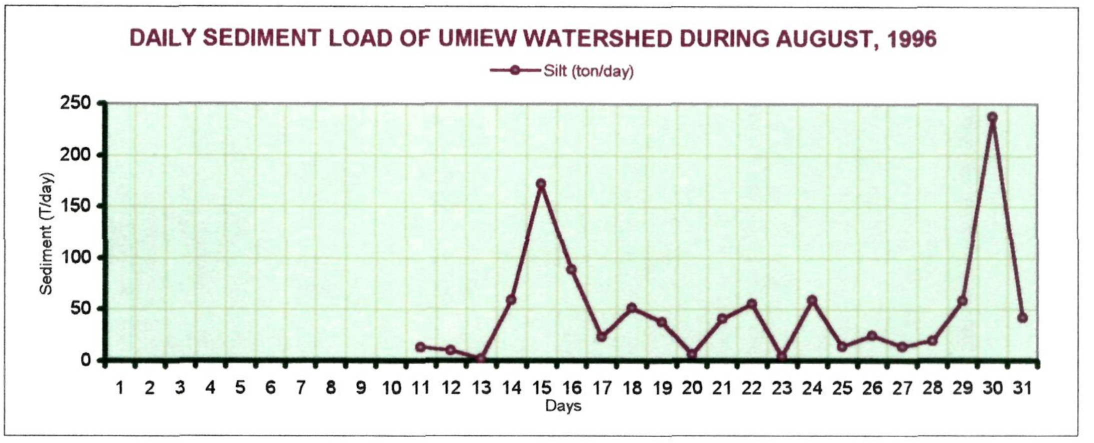
The relationship between the discharge and the sediment load has been assumed logarithmic and indicated by the following power function:

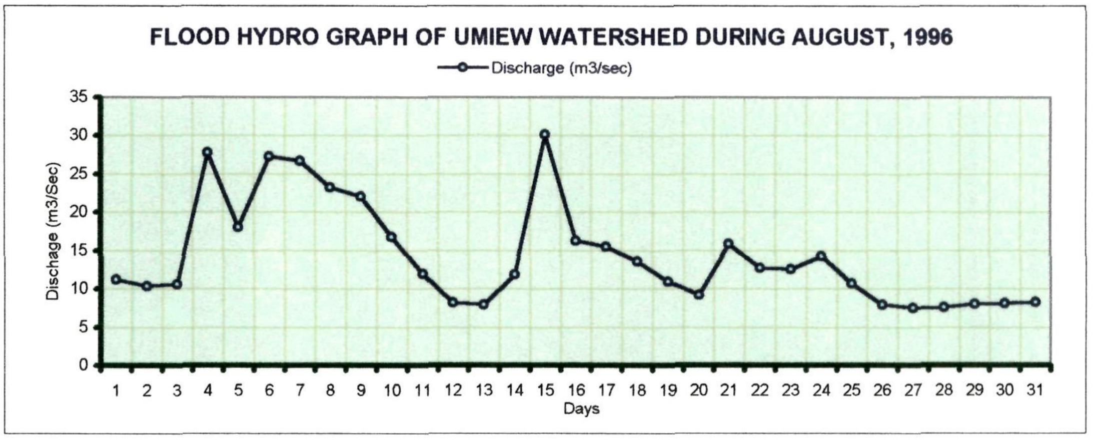
$$S = A * Q^{B}, \qquad \text{-----} \qquad \text{-----} \qquad \text{----} \qquad (2)$$

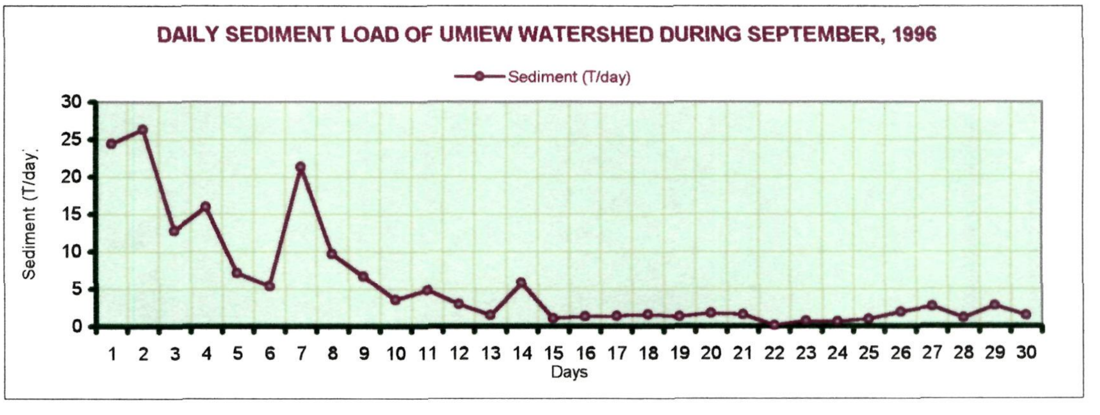
where, S = Monthly sediment load in ton

A = constant reflecting the physiography of the catchment,

B = exponent


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING AUGUST, 1996
Silt (ton/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING AUGUST, 1996
Discharge (m3/sec)
Dischage (m3/Sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING SEPTEMBER, 1996
Sediment (T/day)
Sediment (T/day)
Days

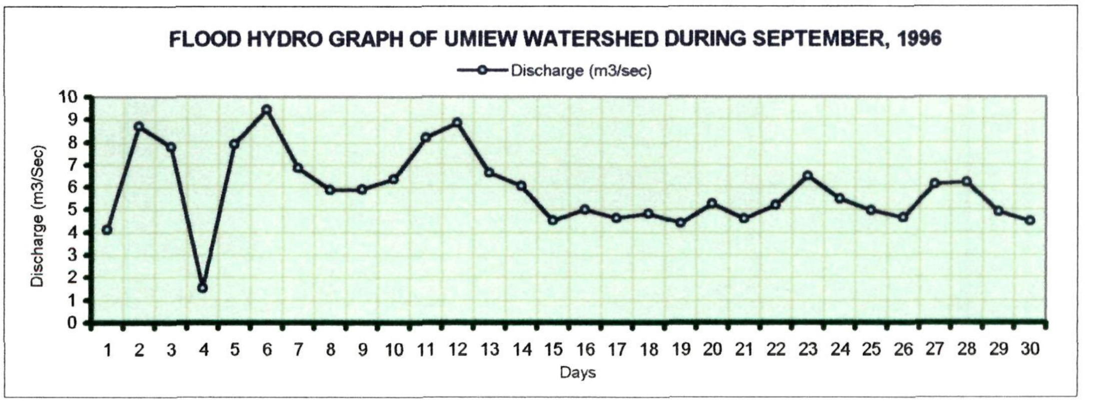
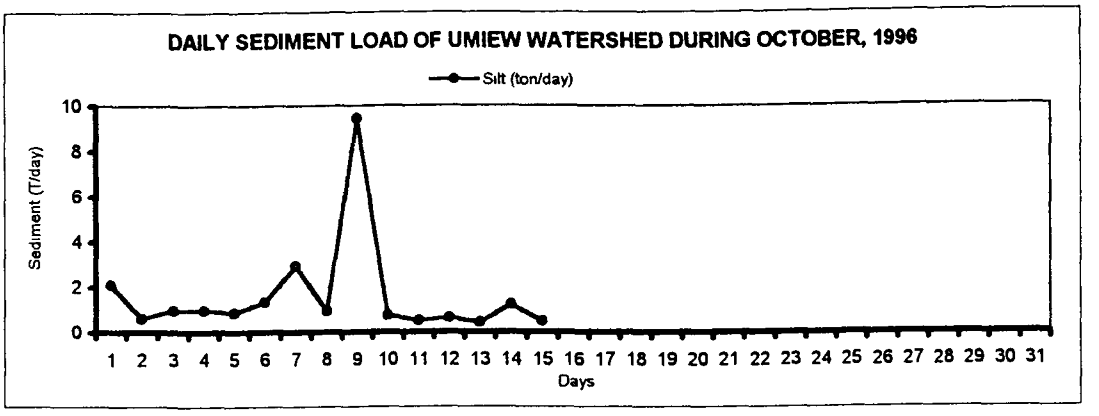
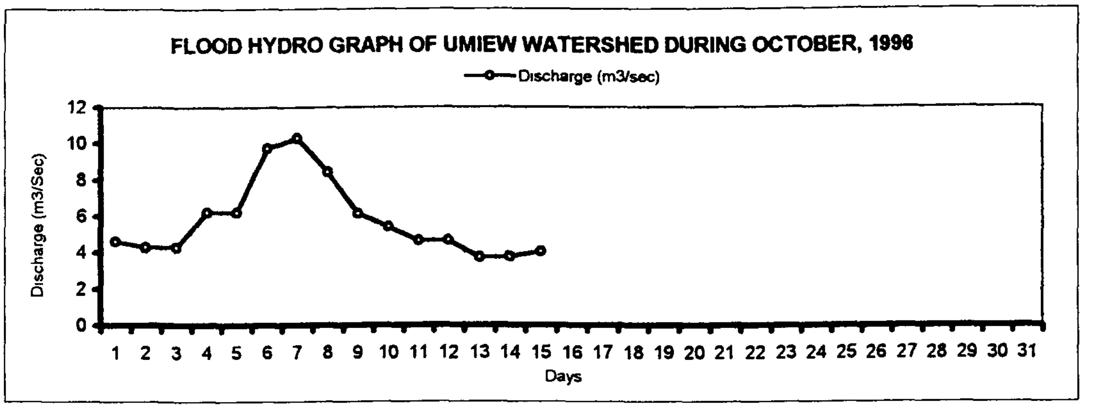
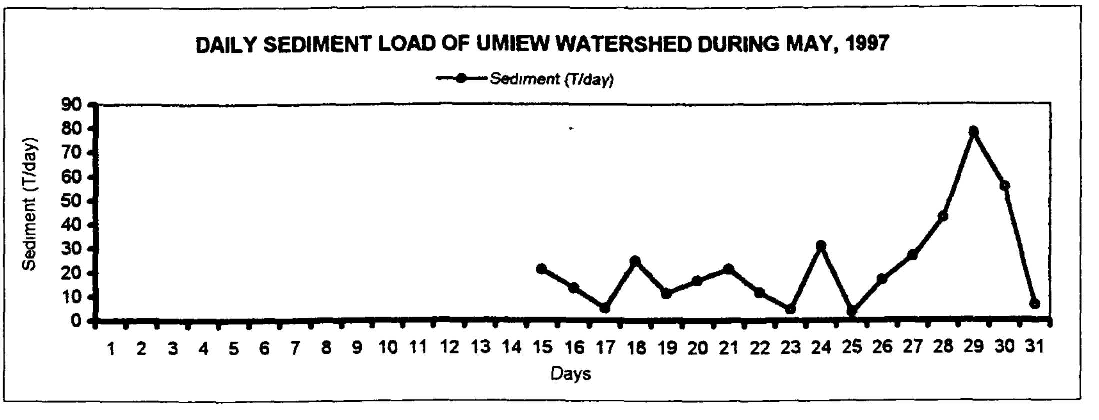

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING SEPTEMBER, 1996
Discharge (m3/sec)
Discharge (m3/Sec)
Days

Fig.-6.1


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1996
Silt (ton/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING OCTOBER, 1996
Discharge (m3/sec)
Discharge (m3/Sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING MAY, 1997
Sediment (T/day)
Sediment (T/day)
Days

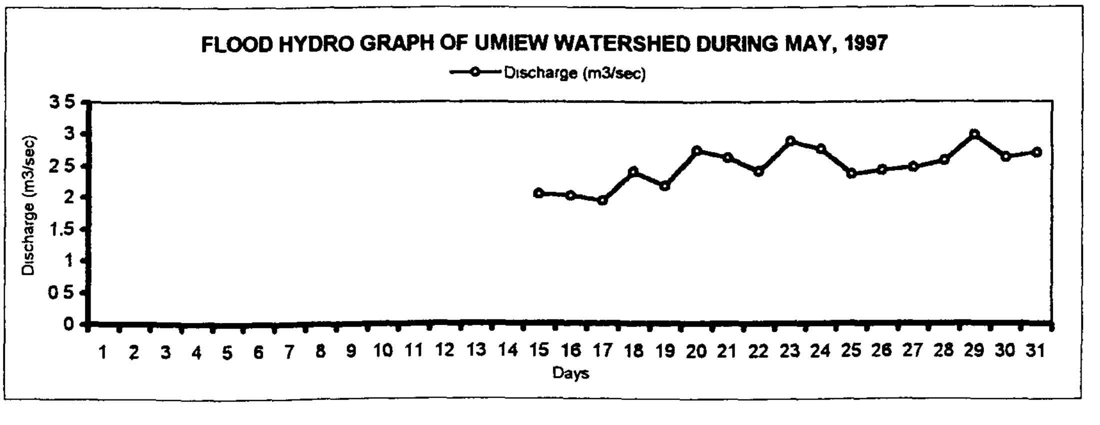

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING MAY, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig-6.2

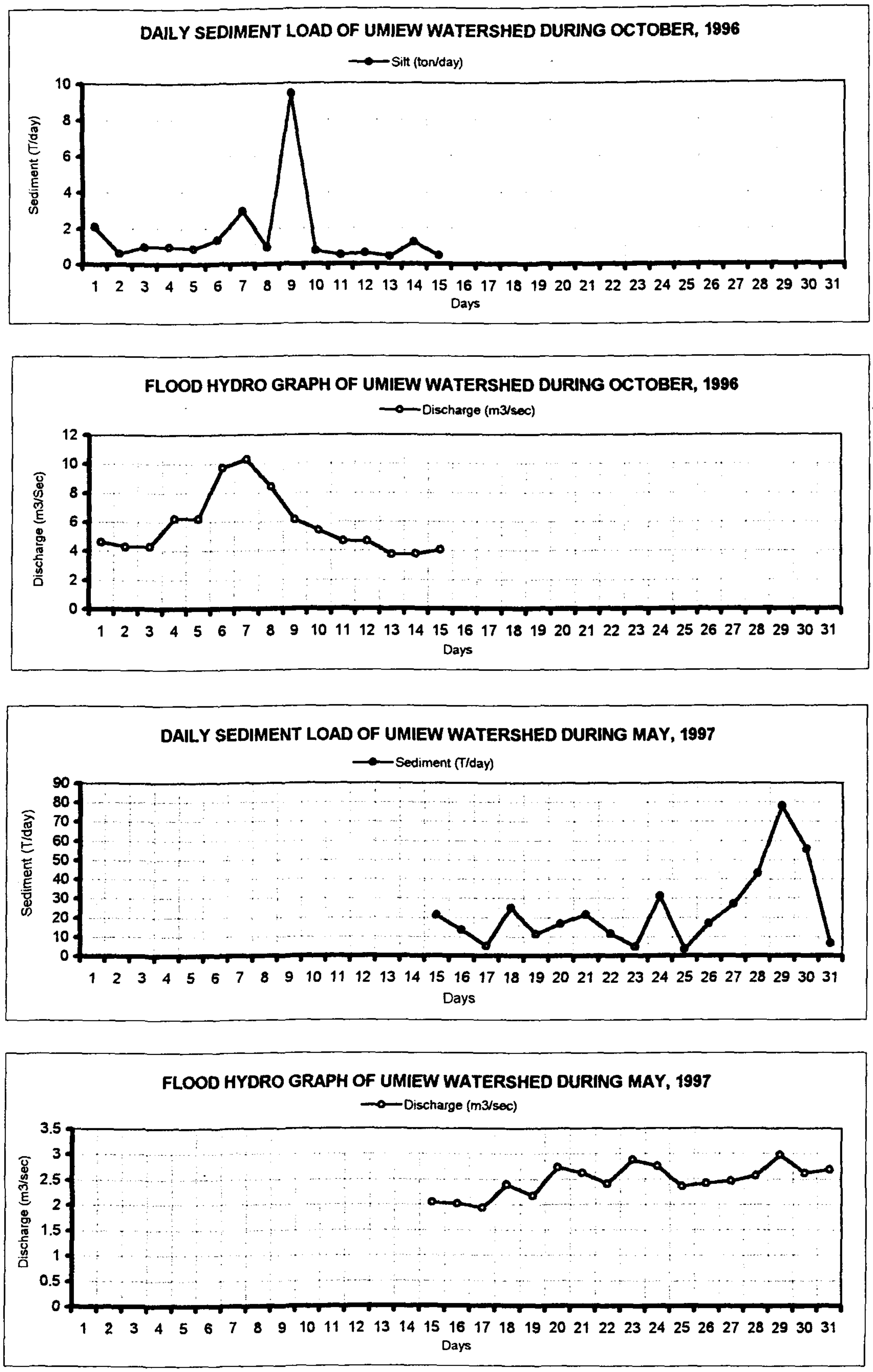
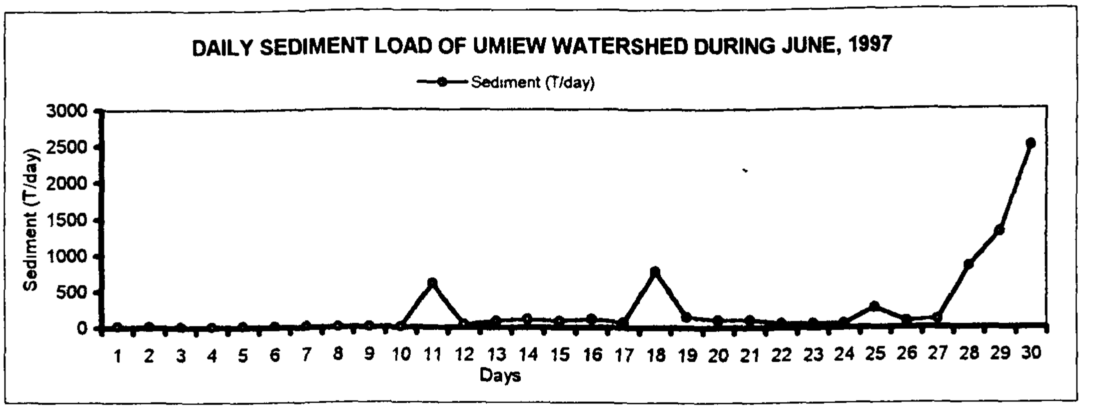
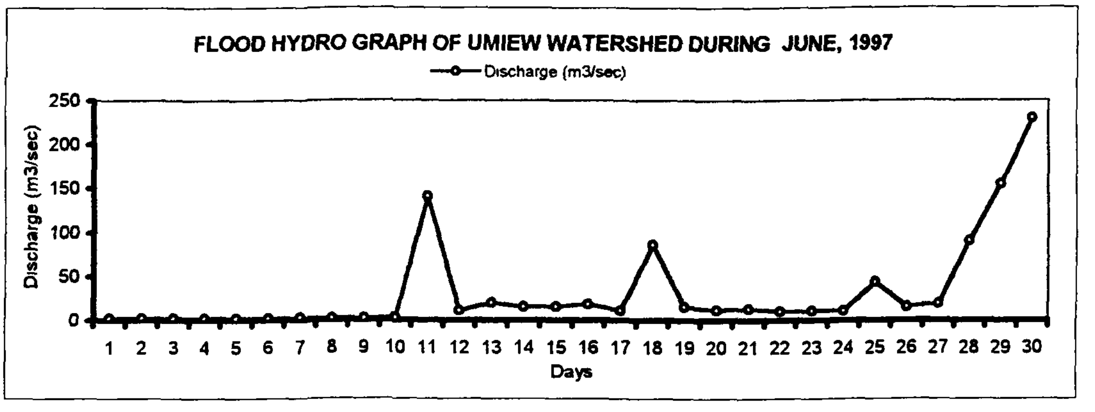
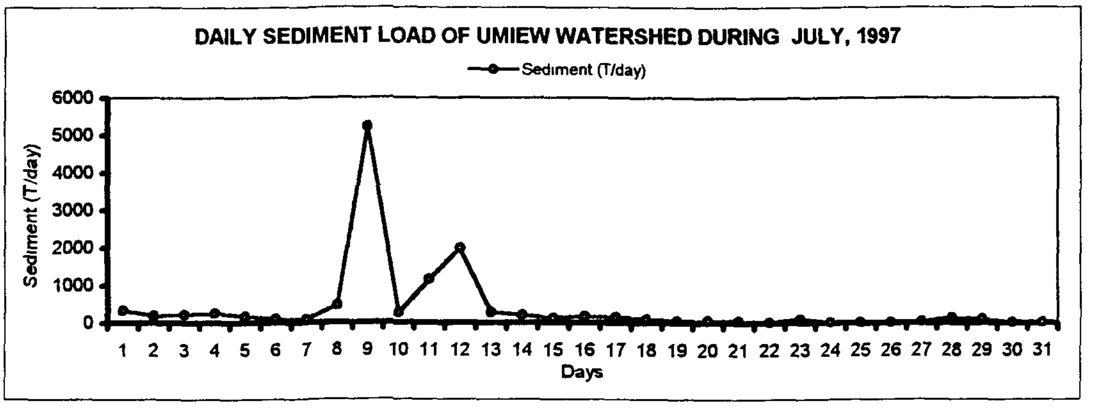

DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1996
Silt (ton/day)
Sediment (T/day)
Days
FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING OCTOBER, 1996
Discharge (m3/sec)
Discharge (m3/Sec)
Days
DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING MAY, 1997
Sediment (T/day)
Sediment (T/day)
Days
FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING MAY, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig-6.2


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JUNE, 1997
Sediment (T/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNE, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JULY, 1997
Sediment (T/day)
Sediment (T/day)
Days

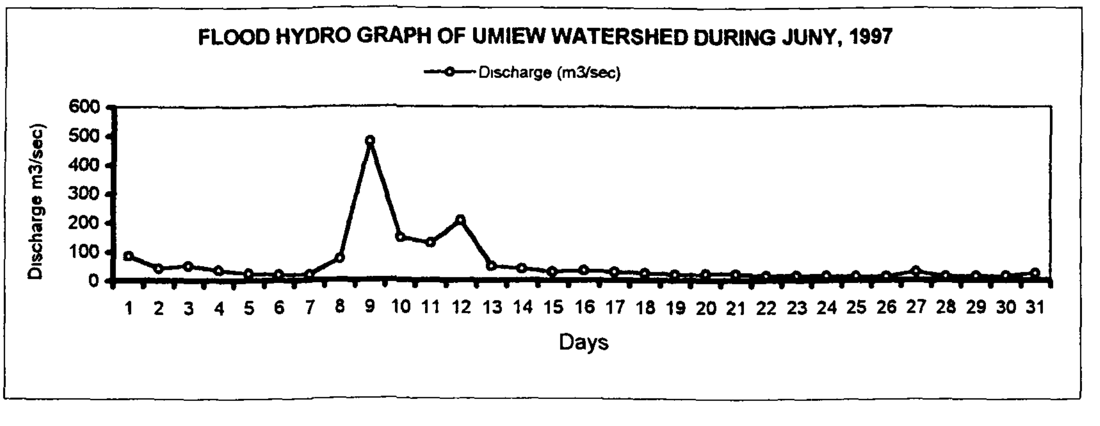
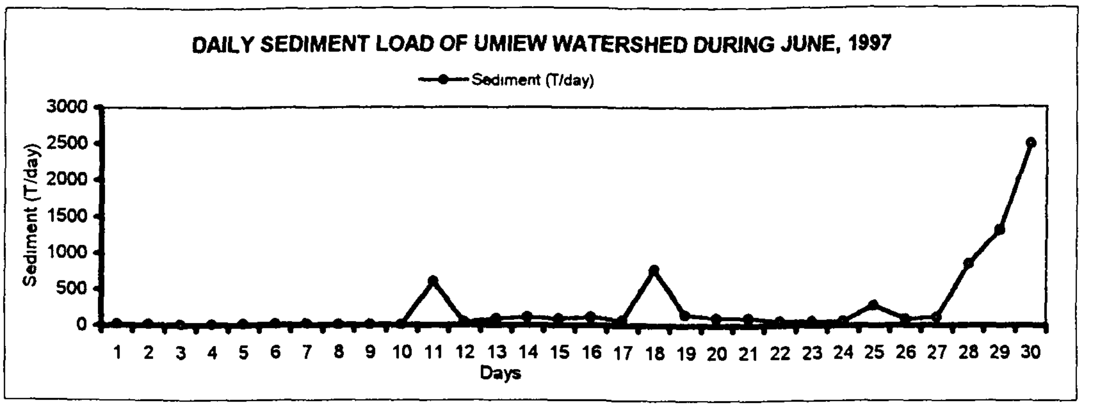
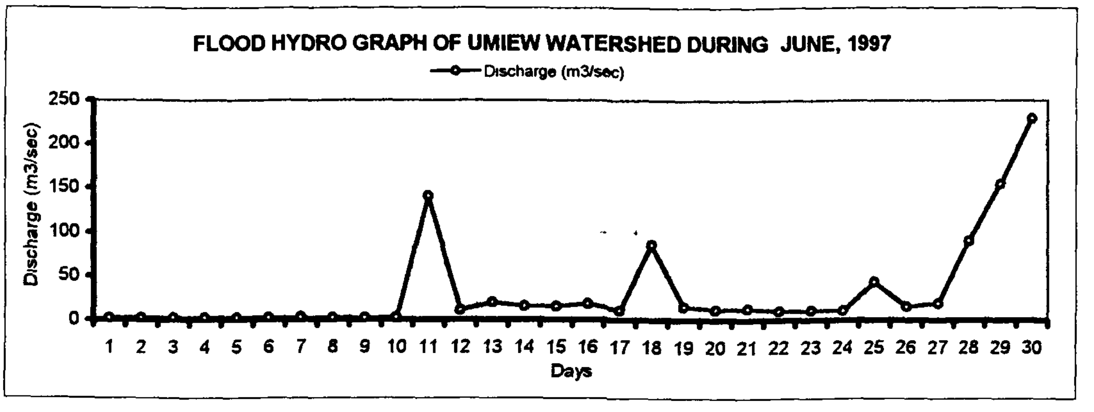
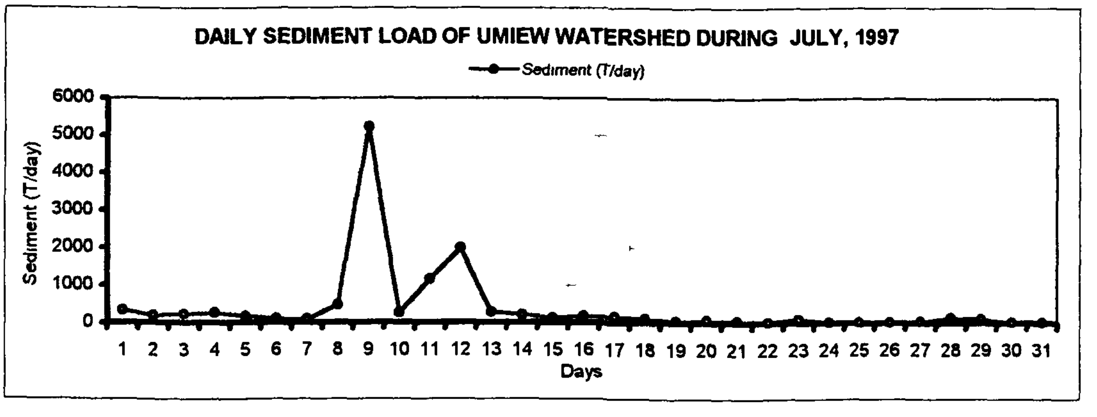

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNY, 1997
Discharge (m3/sec)
Discharge m3/sec)
Days

Fig-6.3


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JUNE, 1997
Sediment (T/day)
Sediment (T/day)
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNE, 1997
Discharge (m3/sec)
Discharge (m3/sec)
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JULY, 1997
Sediment (T/day)
Sediment (T/day)
6000
5000
4000
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

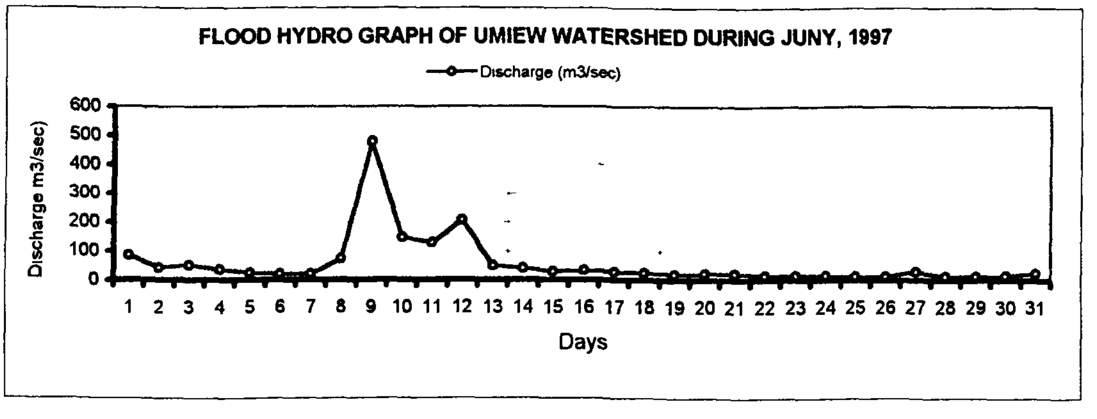
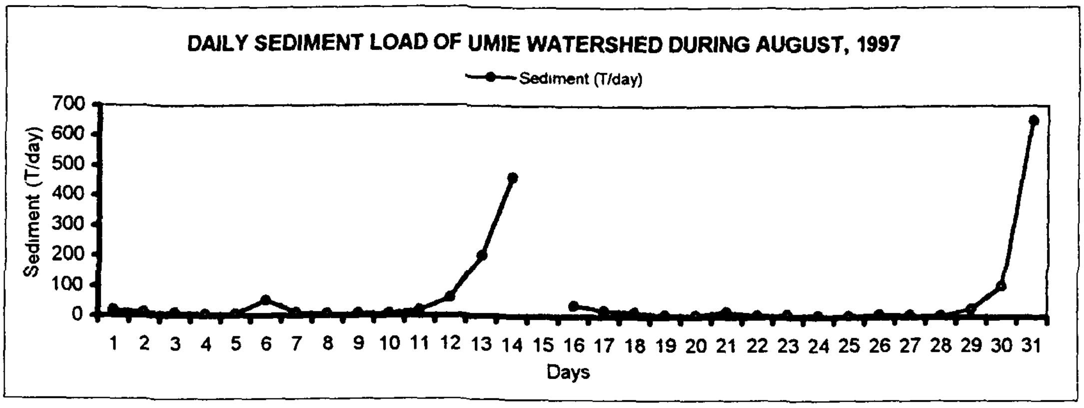
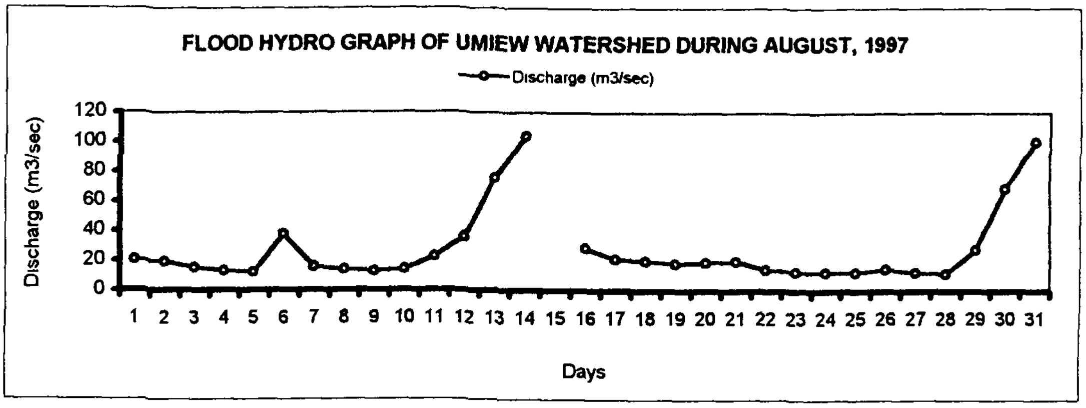

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNY, 1997
Discharge (m3/sec)
Discharge m3/sec)
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

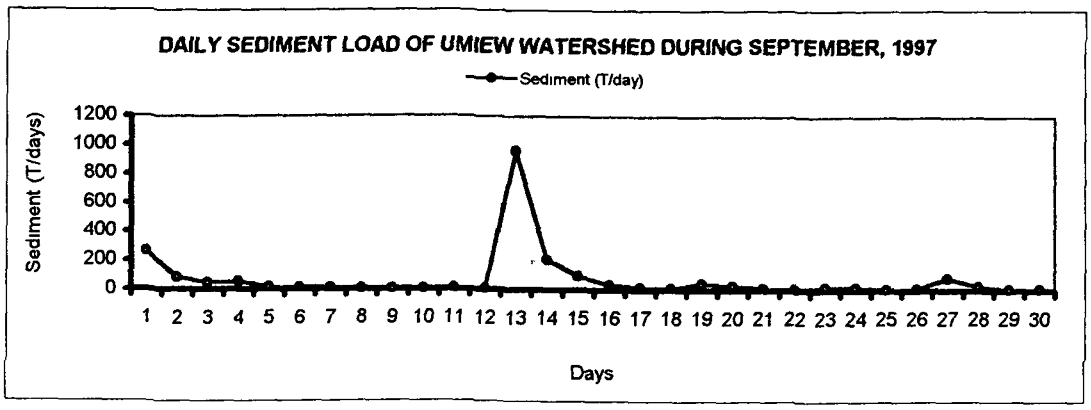
Fig-6.3



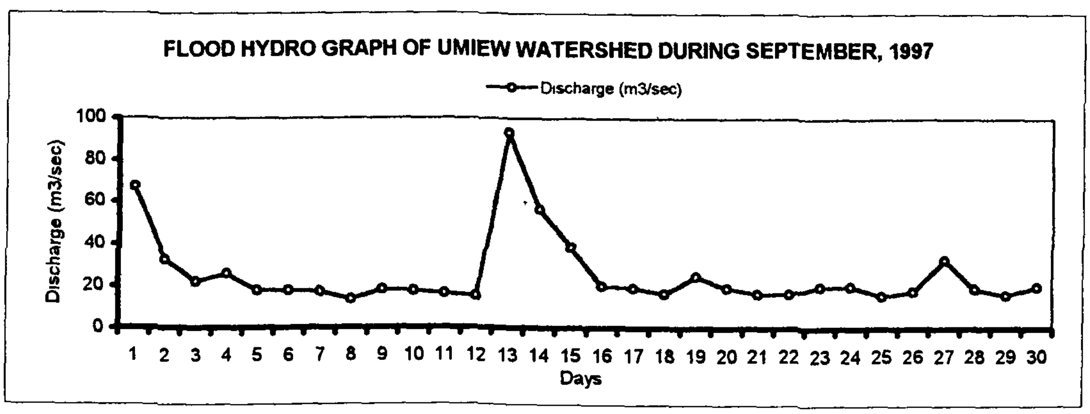
DAILY SEDIMENT LOAD OF UMIE WATERSHED DURING AUGUST, 1997
Sediment (T/day)
Sediment (T/day)
0 100 200 300 400 500 600 700
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days



FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING AUGUST, 1997
Discharge (m3/sec)
Discharge (m3/sec)
0 20 40 60 80 100 120
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

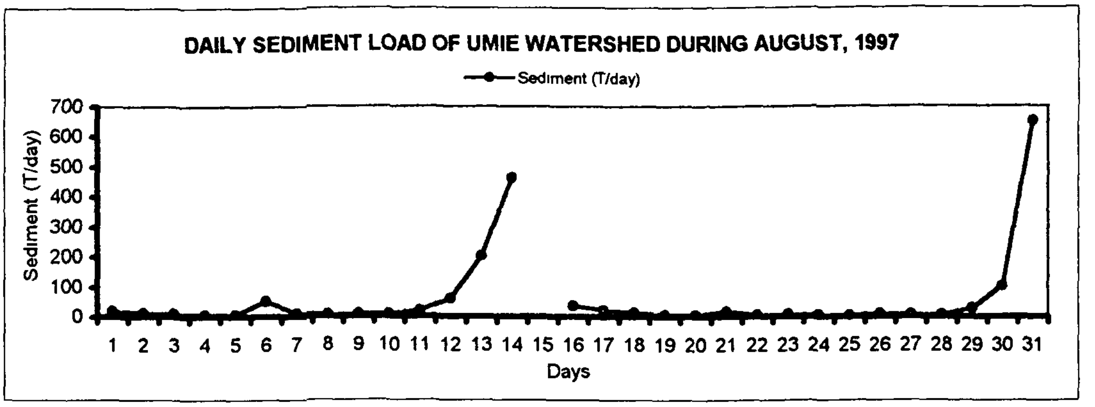


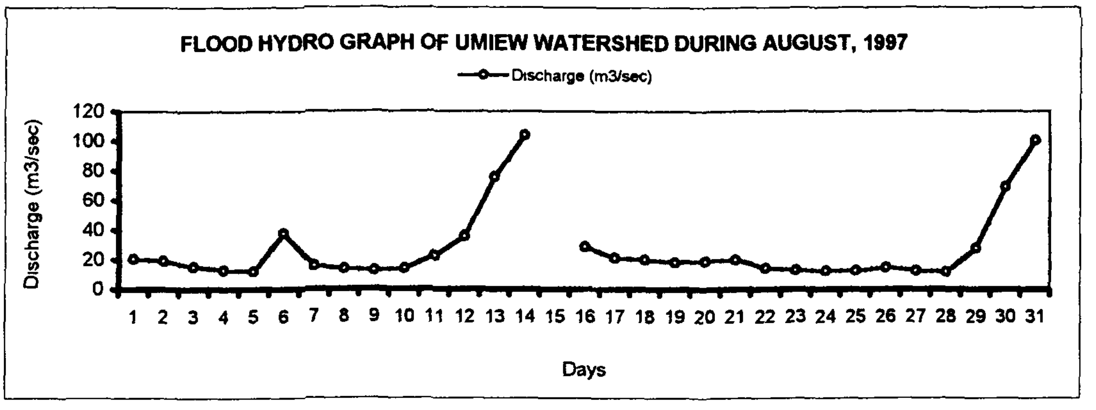
DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING SEPTEMBER, 1997
Sediment (T/day)
Sediment (T/days)
0 200 400 600 800 1000 1200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

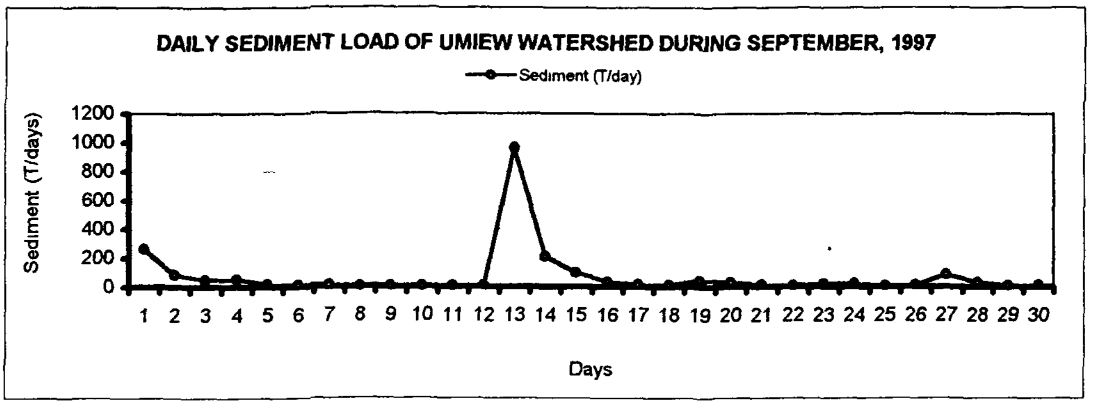


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING SEPTEMBER, 1997
Discharge (m3/sec)
Discharge (m3/sec)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

Fig.-6.4


DAILY SEDIMENT LOAD OF UMIE WATERSHED DURING AUGUST, 1997
Sediment (T/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING AUGUST, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING SEPTEMBER, 1997
Sediment (T/day)
Sediment (T/days)
Days

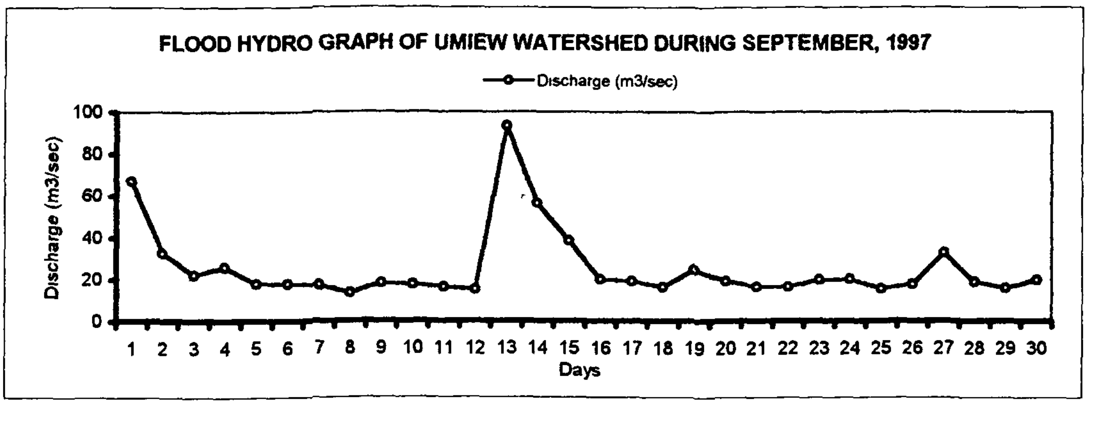
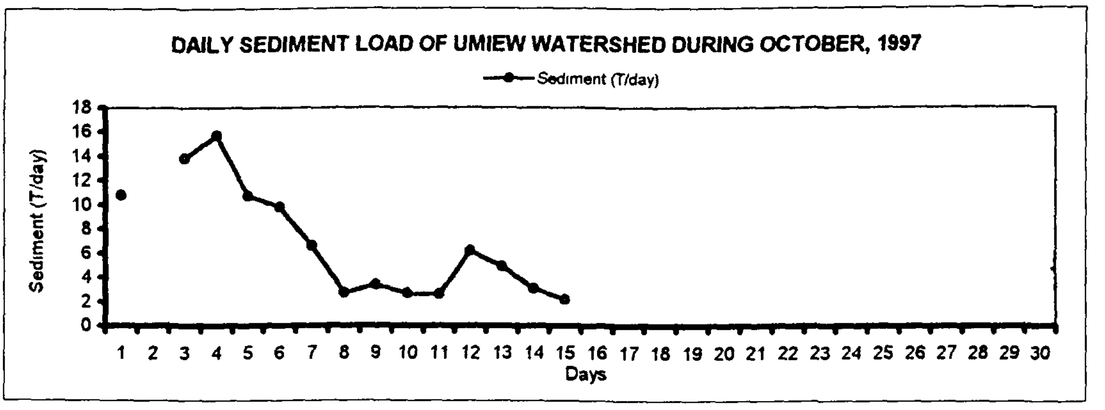
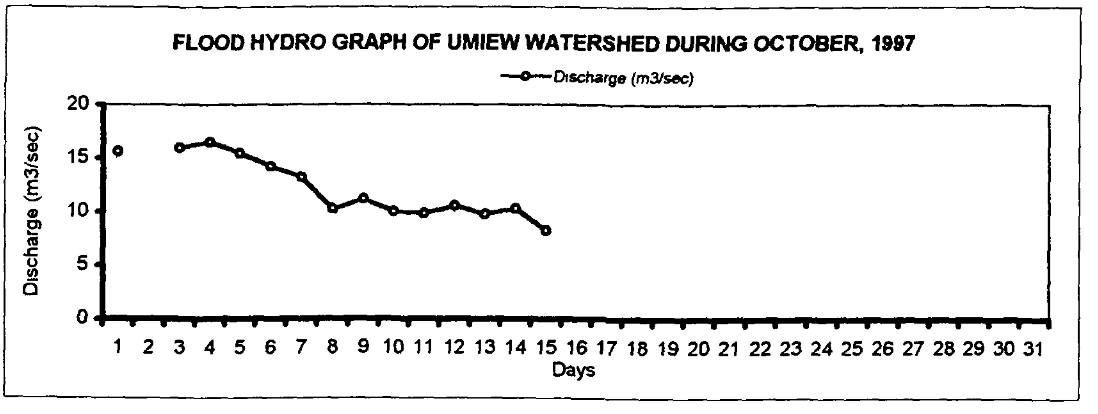
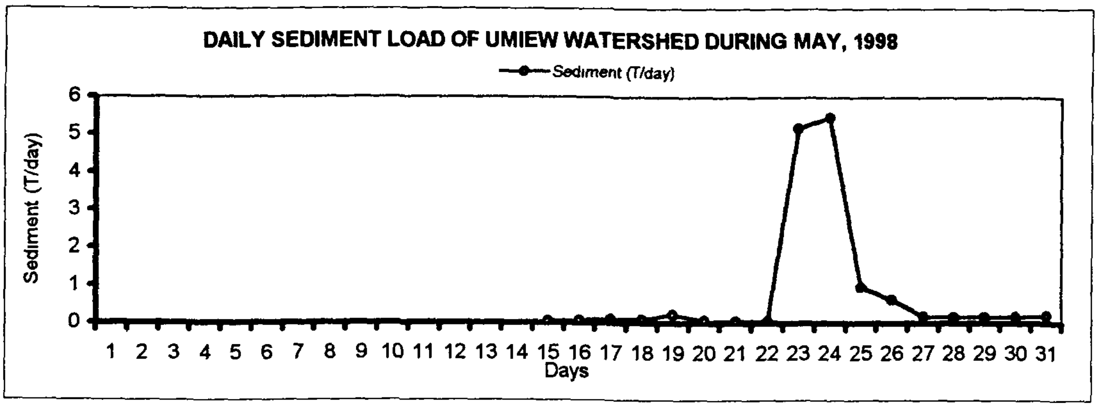

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING SEPTEMBER, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig.-6.4


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1997
Sediment (T/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING OCTOBER, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING MAY, 1998
Sediment (T/day)
Sediment (T/day)
Days

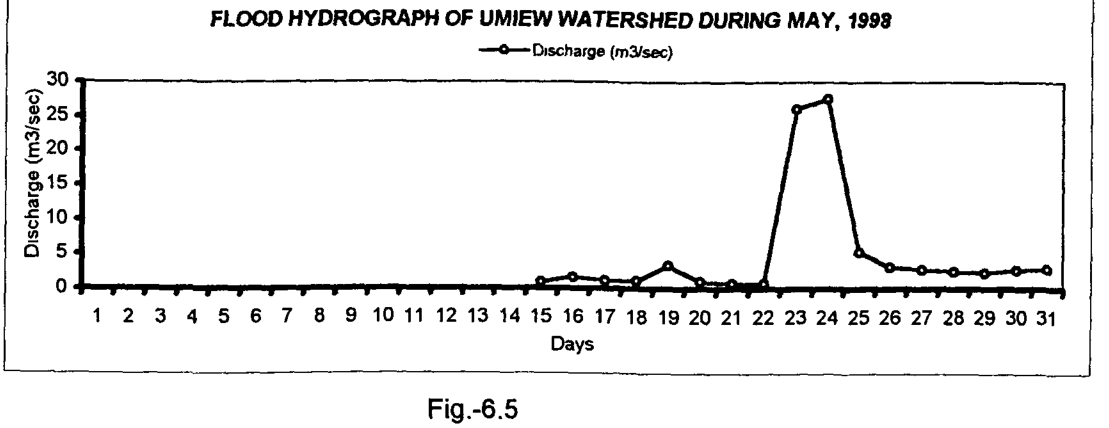
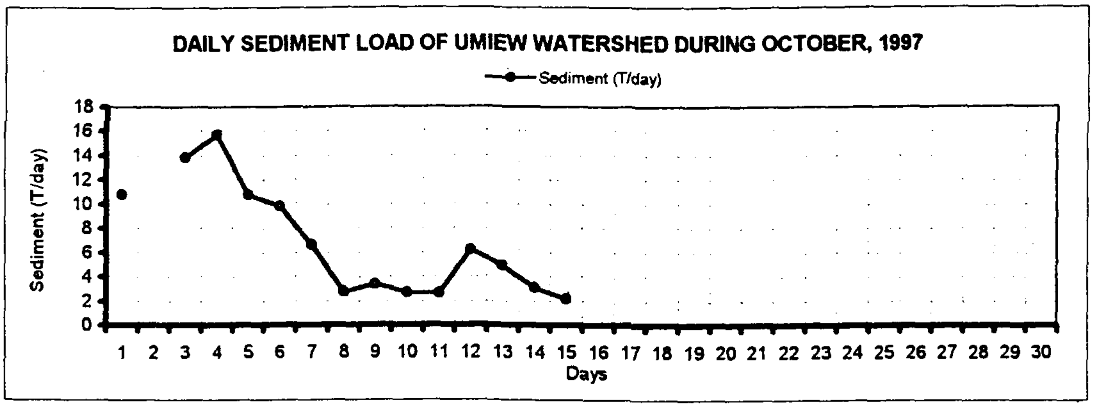
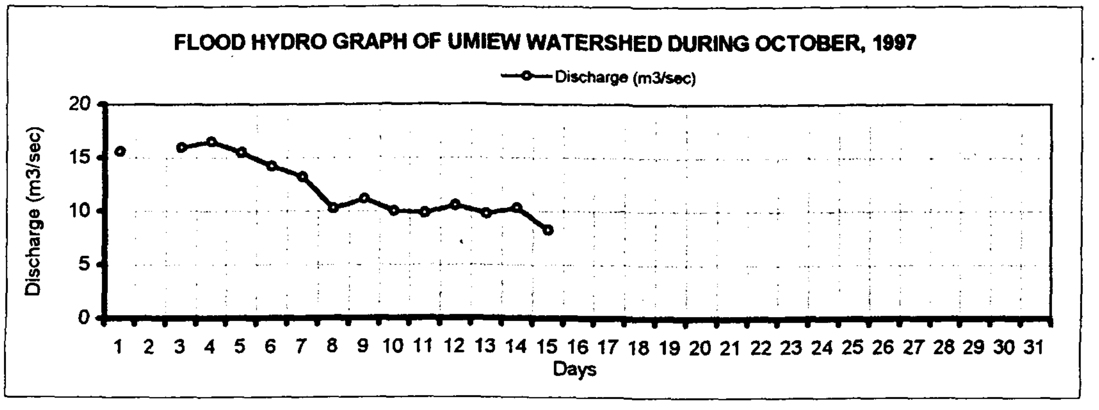
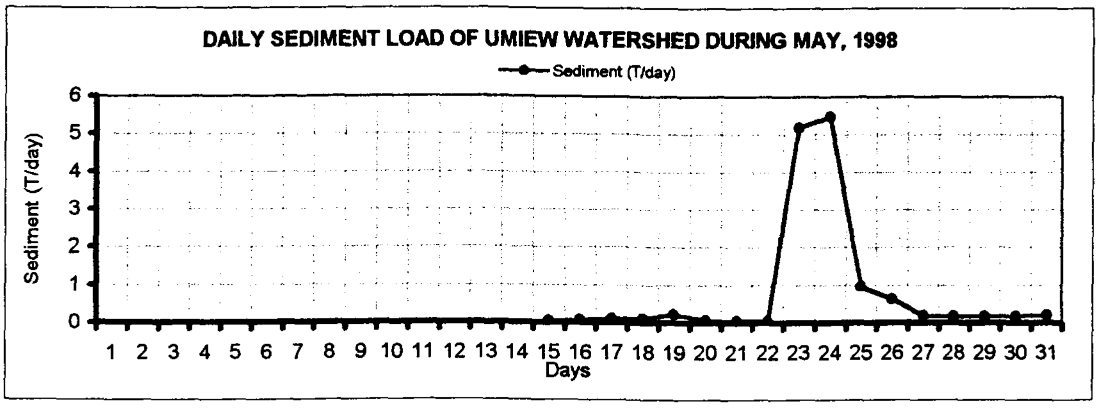

FLOOD HYDROGRAPH OF UMIEW WATERSHED DURING MAY, 1998
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig.-6.5


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1997
Sediment (T/day)
Sediment (T/day)
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING OCTOBER, 1997
Discharge (m3/sec)
Discharge (m3/sec)
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING MAY, 1998
Sediment (T/day)
Sediment (T/day)
Days

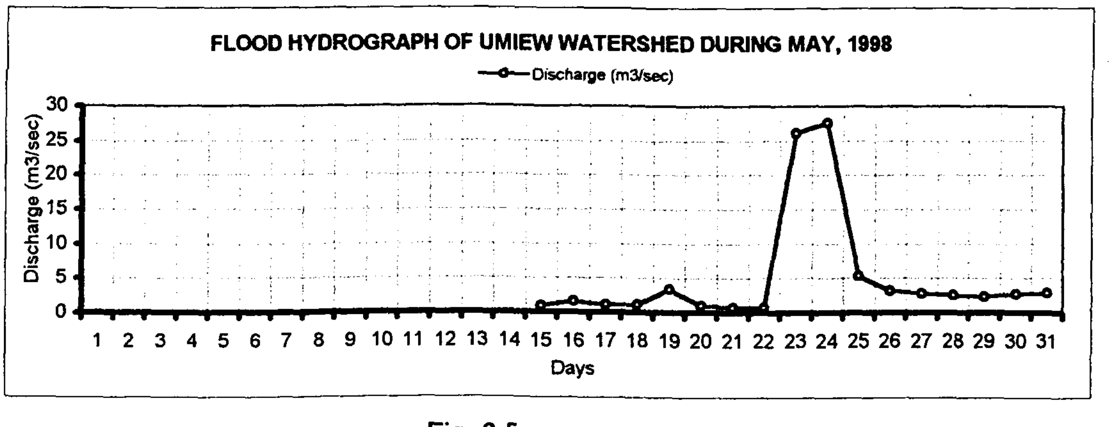
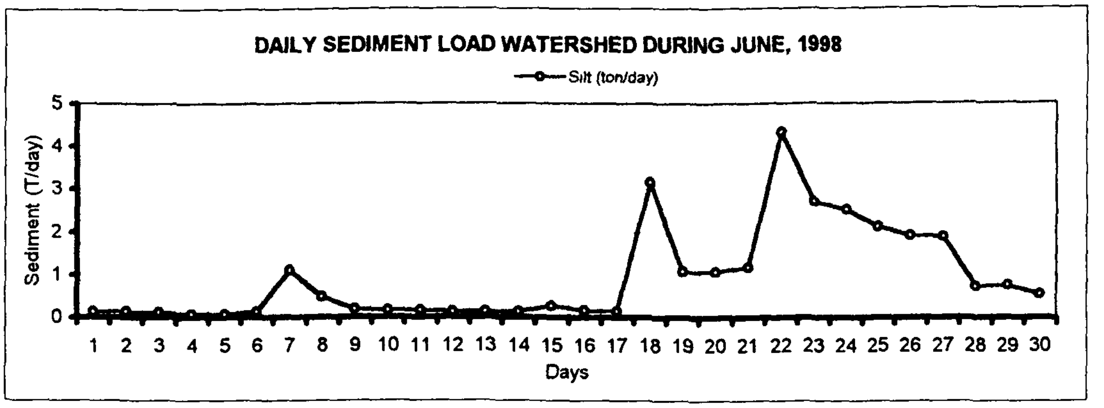
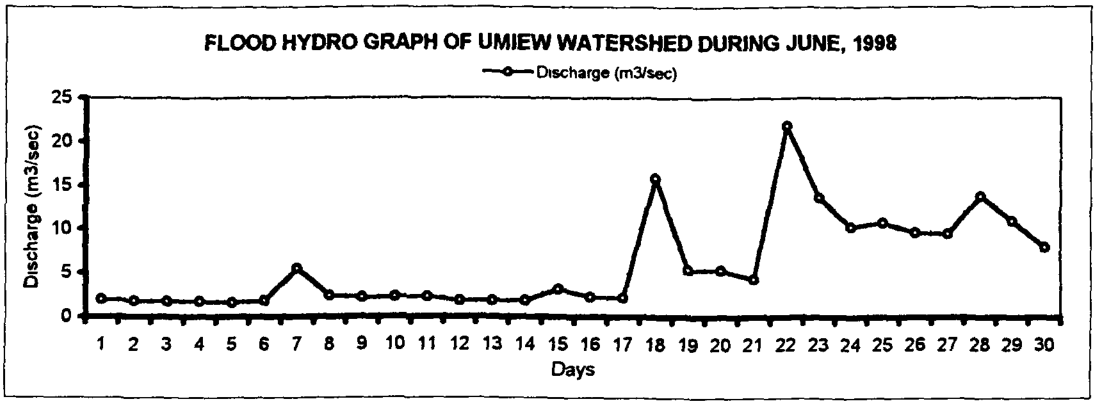
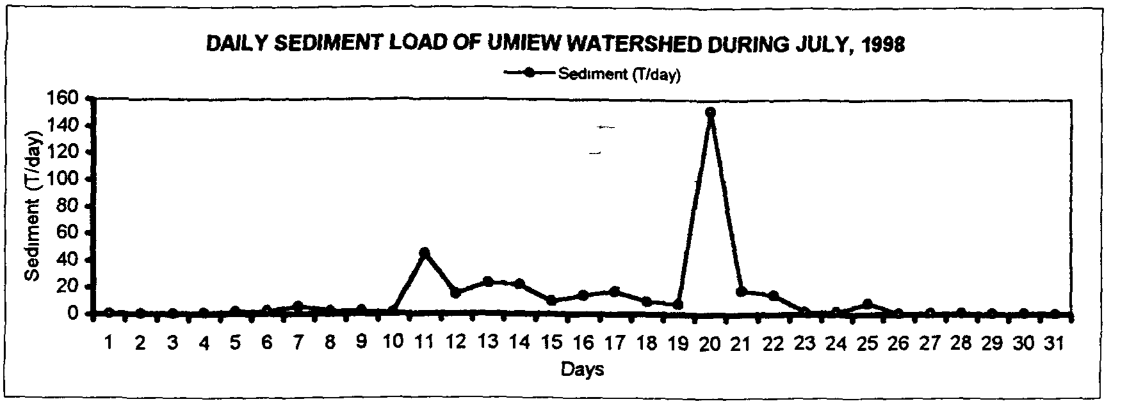

FLOOD HYDROGRAPH OF UMIEW WATERSHED DURING MAY, 1998
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig.-6.5


DAILY SEDIMENT LOAD WATERSHED DURING JUNE, 1998
Silt (ton/day)
Sediment (T/day)
0
1
2
3
4
5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNE, 1998
Discharge (m3/sec)
Discharge (m3/sec)
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JULY, 1998
Sediment (T/day)
Sediment (T/day)
0
20
40
60
80
100
120
140
160
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

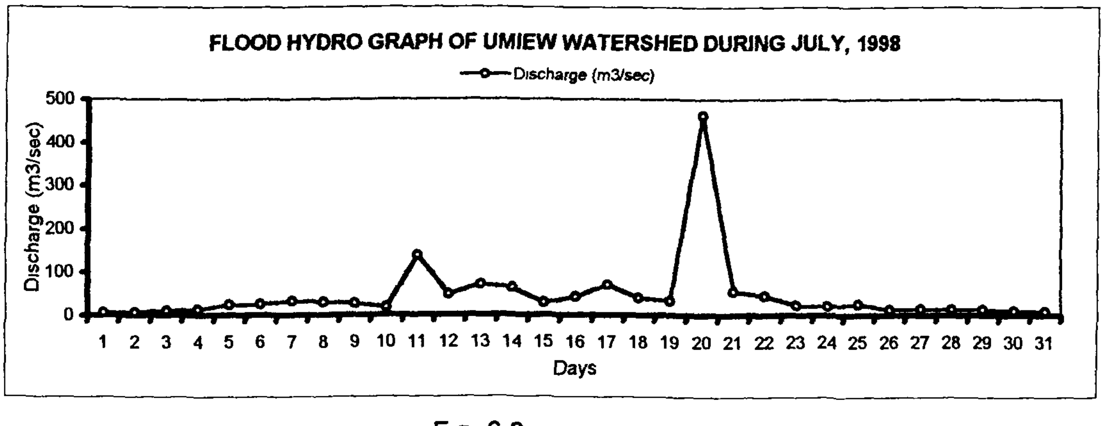
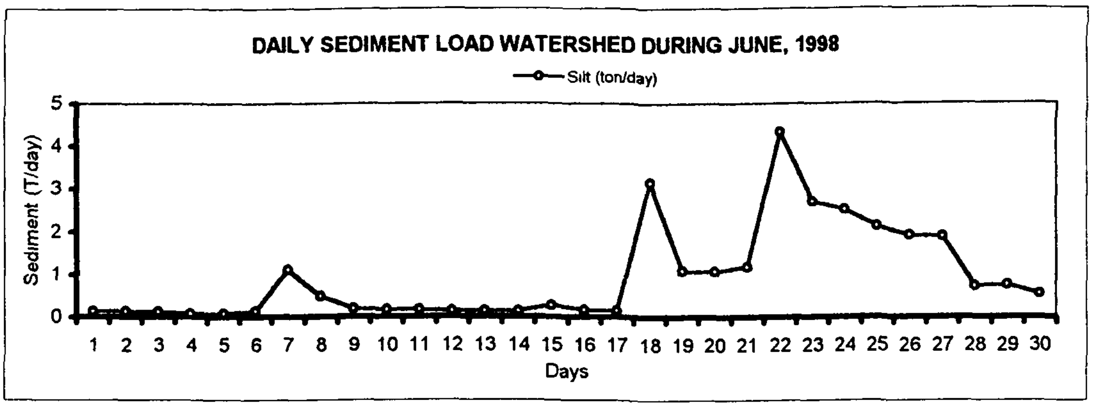
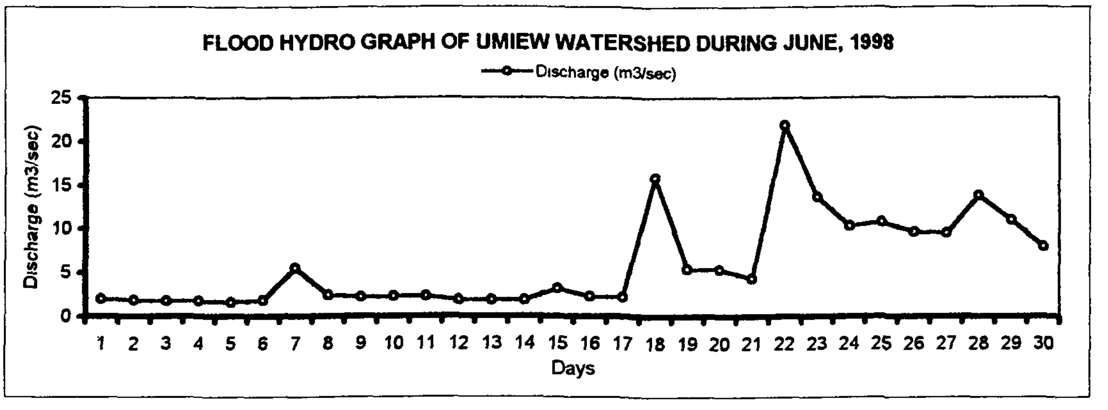

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JULY, 1998
Discharge (m3/sec)
Discharge (m3/sec)
0
100
200
300
400
500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

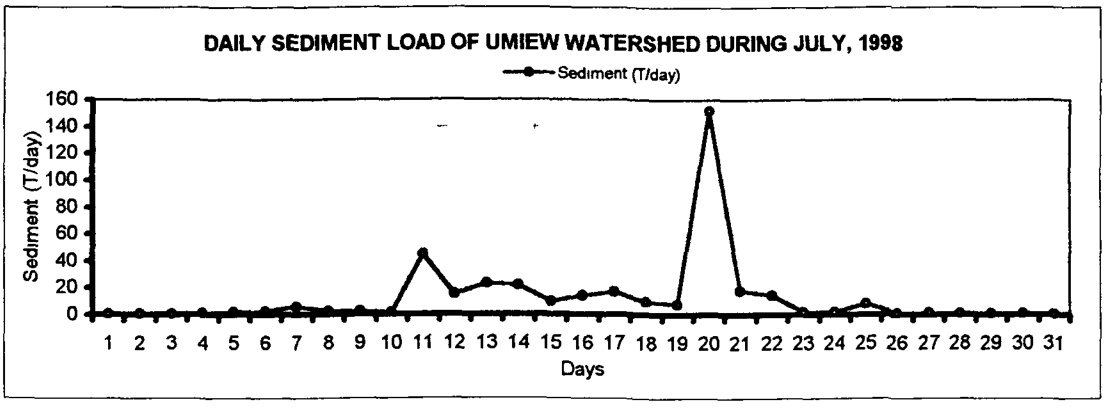
Fig -6 6



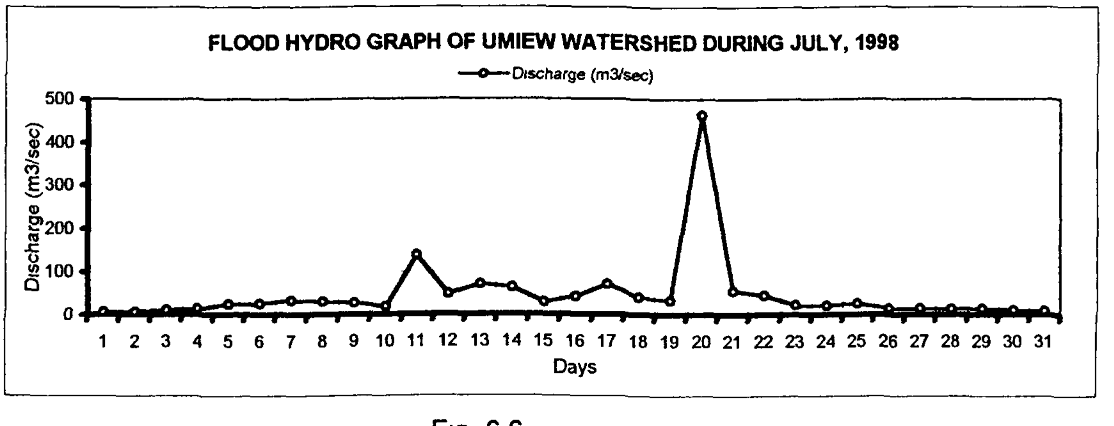
DAILY SEDIMENT LOAD WATERSHED DURING JUNE, 1998
Silt (ton/day)
Sediment (T/day)
Days



FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JUNE, 1998
Discharge (m3/sec)
Discharge (m3/sec)
Days

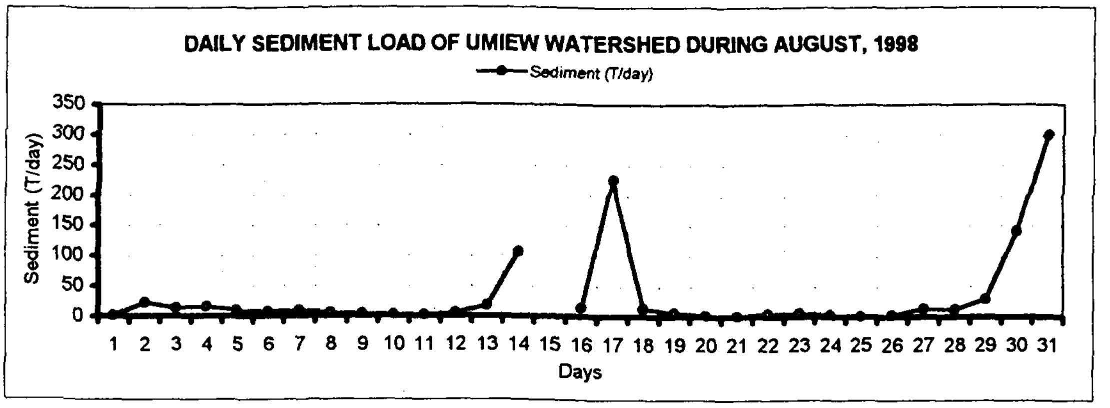


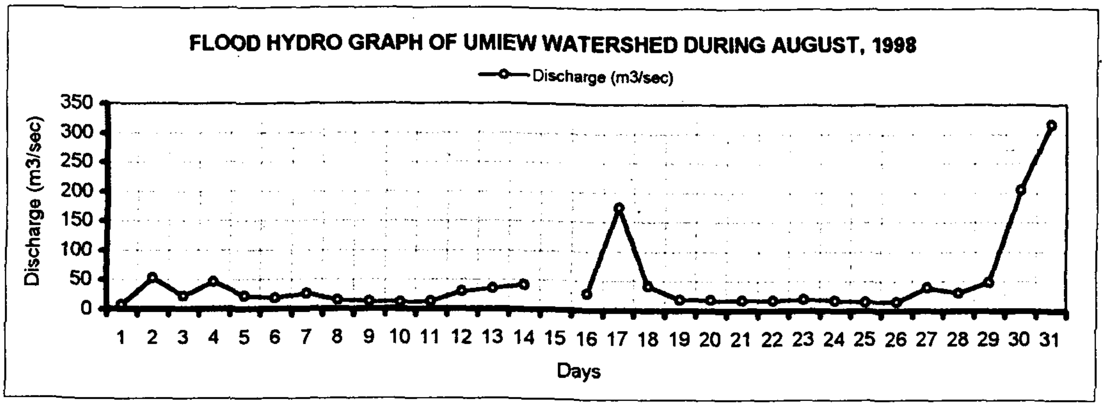
DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING JULY, 1998
Sediment (T/day)
Sediment (T/day)
Days

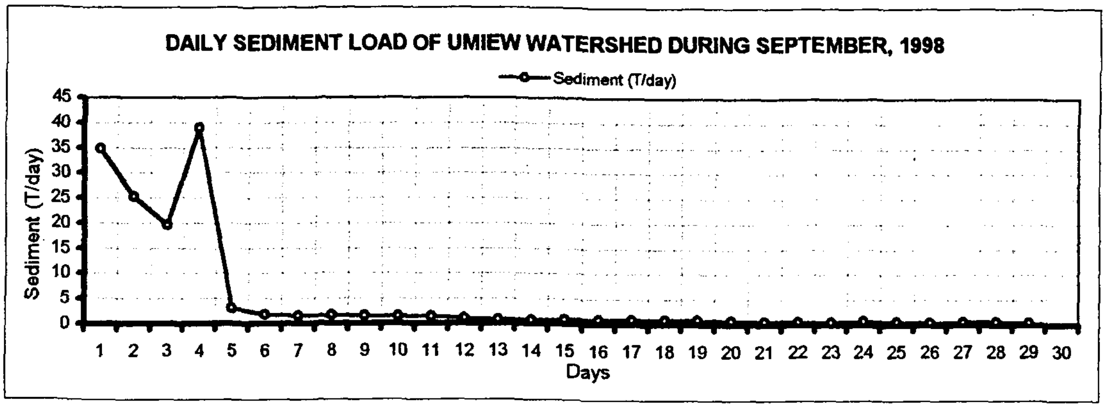


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING JULY, 1998
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig -6.6


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING AUGUST, 1998
Sediment (T/day)
Sediment (T/day)
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING AUGUST, 1998
Discharge (m3/sec)
Discharge (m3/sec)
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING SEPTEMBER, 1998
Sediment (T/day)
Sediment (T/day)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

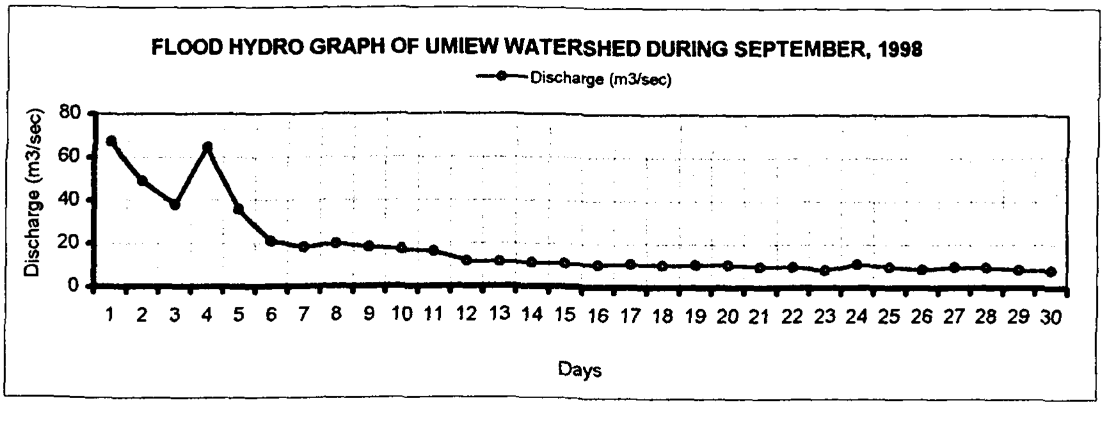
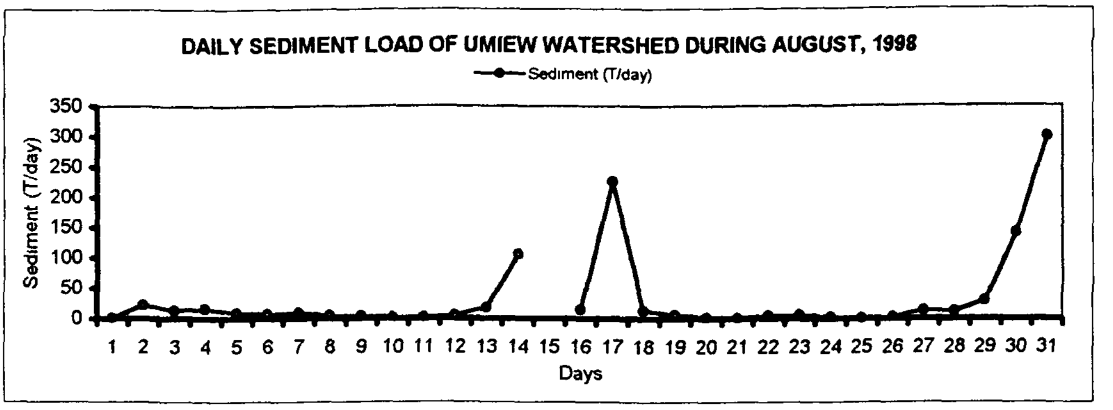
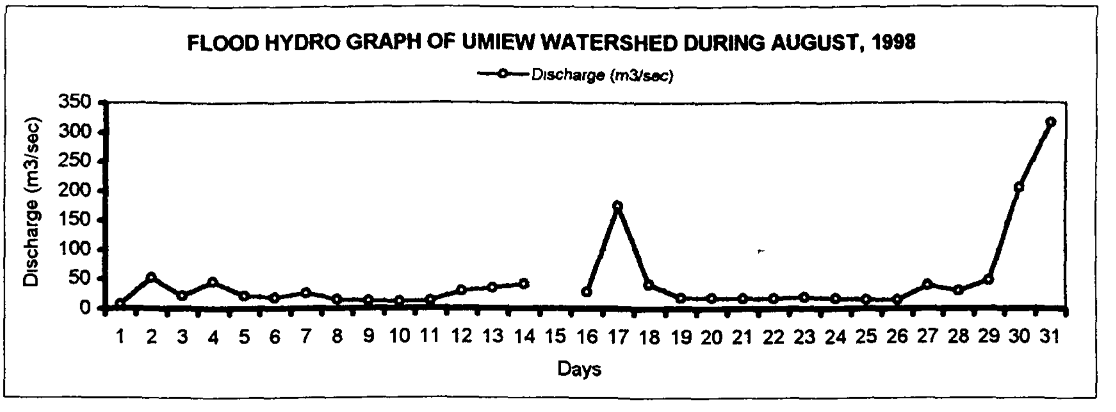
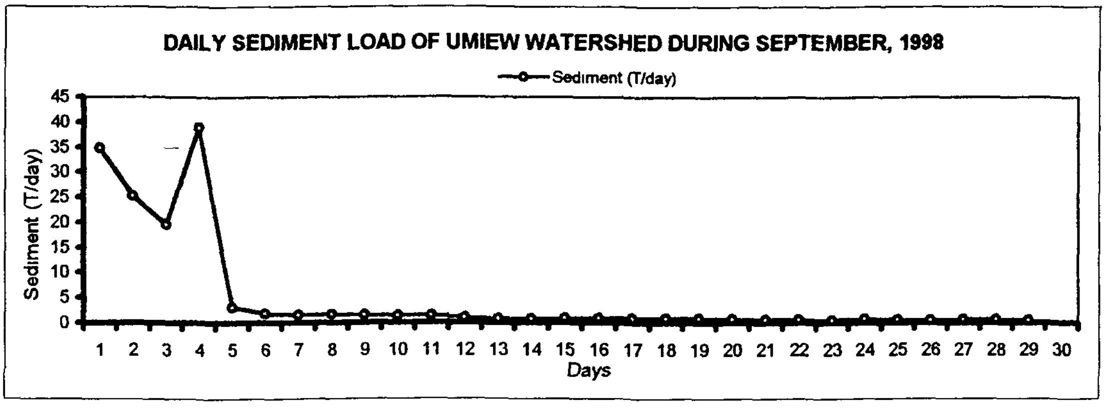

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING SEPTEMBER, 1998
Discharge (m3/sec)
Discharge (m3/sec)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

Fig.-6.7


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING AUGUST, 1998
Sediment (T/day)
Sediment (T/day)
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days


FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING AUGUST, 1998
Discharge (m3/sec)
Discharge (m3/sec)
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING SEPTEMBER, 1998
Sediment (T/day)
Sediment (T/day)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

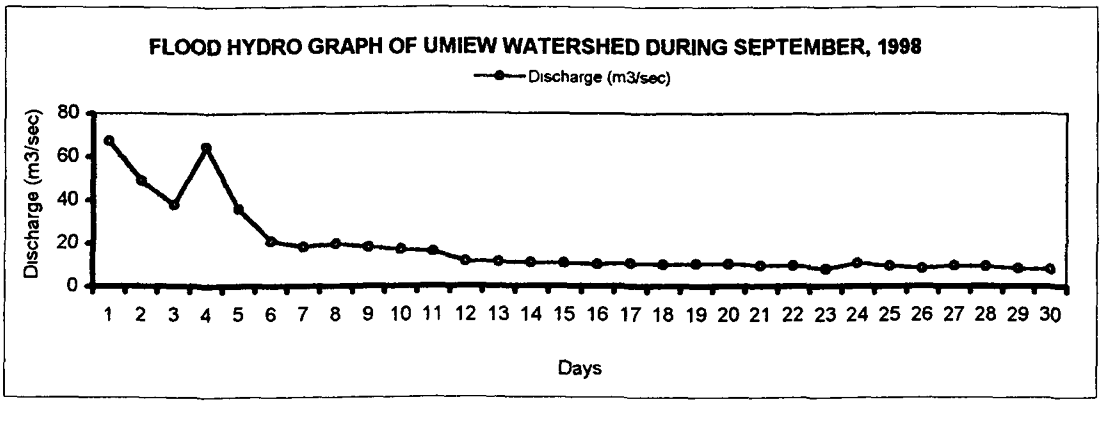
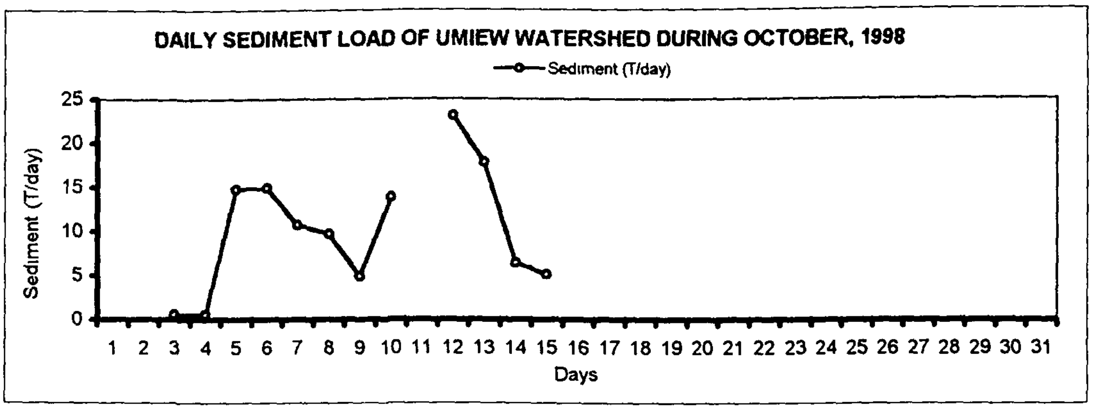

FLOOD HYDRO GRAPH OF UMIEW WATERSHED DURING SEPTEMBER, 1998
Discharge (m3/sec)
Discharge (m3/sec)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days

Fig -6 7


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1998
Sediment (T/day)
Sediment (T/day)
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

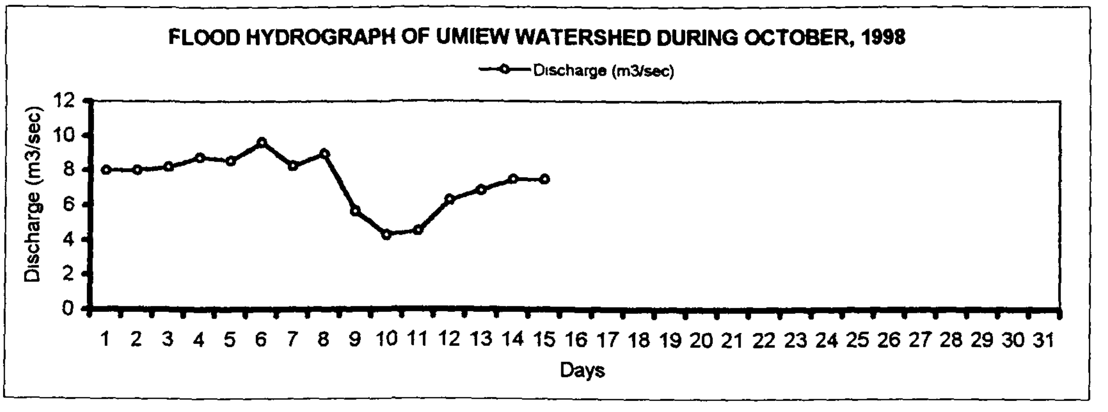
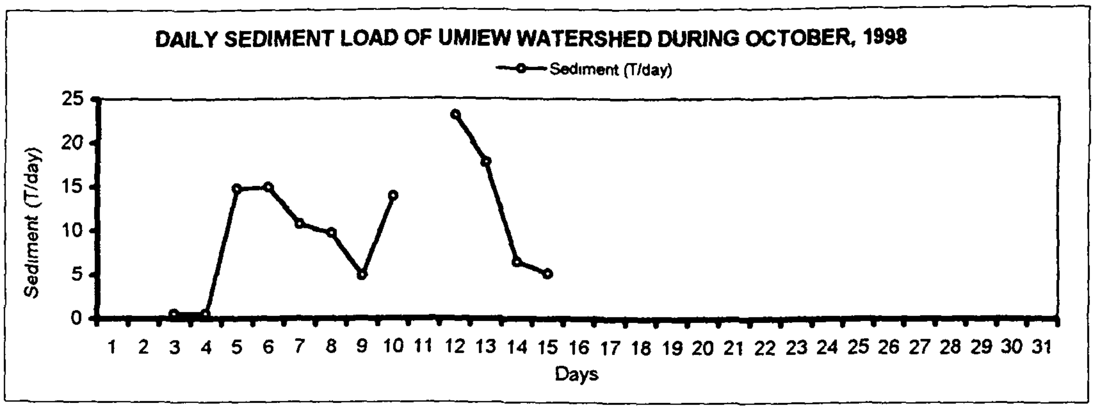

FLOOD HYDROGRAPH OF UMIEW WATERSHED DURING OCTOBER, 1998
Discharge (m3/sec)
Discharge (m3/sec)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days

Fig.-6.8


DAILY SEDIMENT LOAD OF UMIEW WATERSHED DURING OCTOBER, 1998
Sediment (T/day)
Sediment (T/day)
Days

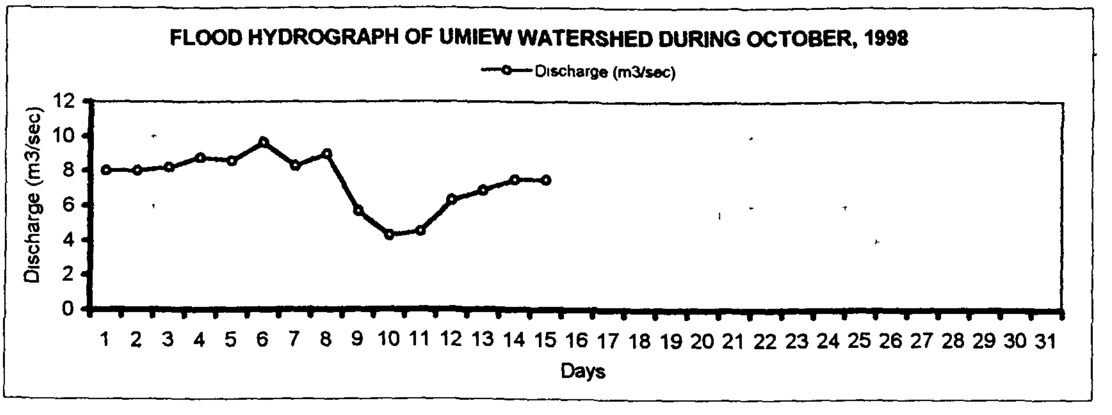

FLOOD HYDROGRAPH OF UMIEW WATERSHED DURING OCTOBER, 1998
Discharge (m3/sec)
Discharge (m3/sec)
Days

Fig.-6.8

Q= discharge of the river in ha.m

The logarithmic relationship has been developed between the river yield(independent variable) and sediment load (dependent variable) for the month of August, September and October by carrying out regression analysis (Fig.-6.9). The relationships developed are:

$S = 0.99 * Q^{0.465}$ (August) ----- ----- ------ (3)

$S = 1.22 * Q^{0.375}$ (September) ----- ----- ------ (4)

$S = 2.17 * Q^{-0.465}$ (October) ----- ----- ------ (5)

While establishing the correlation between the observed and the estimated sediment load in Equation (3), (4) and (5), a significant positive correlation of 0.63 has been found in Equation-(4). It means that this equation may reasonably represent the variation of discharge and the sediment outflow taking place from the river during September month. The other two equations (3) and (5), have got poor correlation to the tune of 0.12 and 0.33 respectively (Table-6.12).

It has been observed from the single storm erosion index and sediment yield rate data during 1996-98 that the erosion index influences in enhancing the sediment yield rate (Table-6.11). Wischmeier (1957) has also showed that *if all factors other than rainfall are held constant, annual erosion losses from cultivated areas are directly proportional to the yearly values of the erosion* index. The impact of rainfall intensity, which is measured in terms of erosion index, on the sediment yield rate has been found positive. The soil particles which are detached by the impact of falling drop of rain may take some time to get transported by the surface runoff and finally goes back to the river by moving through connecting streams of different orders. The sediment yield rate corresponding to the maximum single storm erosion index (18.08 metre-ton-cm/ha-hr), has been found to 237.48 ton/day on 30th August,96. A small discharge of 8.11 cumecs has been observed on this date. Similarly, the sediment yield rates corresponding to the discharge of 30.16 cumecs and 14.10 cumecs are, 171.99 ton/day and 24.36 ton/day respectively on 15th August and 1st September, 96. The sediment yield rates compared to the discharges have been found substantially lower than the sediment yield rate of 237.48 ton/day and that to the discharge of 8.11 cumecs on 30th August,96. It means that the sediment yield rate goes up even at lower discharge. This

Table-6.12: Regression Analysis of Observed Sediment Load vs. Surface Runoff

August

Sl.No.	Q,surface runoff (ha.m)	S, Sediment load (ton)	x=ln Q	y=ln S	x2	xy	x=ln Q	y'	Correlation between y and y'
1	3827	940.50	8.25	6.85	68.06	56.48	8.25	6.3359	0.12
2	7161	1822.54	8.88	7.51	78.79	66.64	8.88	6.3417	
3	12703	1006.06	9.45	6.91	89.29	65.33	9.45	6.3469	
		Σ	26.58 706.27	21.27	236.15	188.46			

September

Sl.No.	Q,surface runoff (ha.m)	S, Sediment load (ton)	x=ln Q	y=ln S	x2	xy	x=ln Q	y'	Correlation between y and y'
1	1689	170.38	7.43	5.14	55.23	38.19	7.43	4.51	0.63
2	6426	2164.02	8.77	7.68	76.88	67.34	8.77	6.34	
3	4755	144.74	8.47	4.97	71.69	42.12	8.47	5.93	
		Σ	24.67 608.46	17.79	203.80	147.64			

October

Sl.No.	Q,surface runoff (ha.m)	S, Sediment load (ton)	x=ln Q	y=ln S	x2	xy	x=ln Q	y'	Correlation between y and y'
1	6595	84.11	8.79	4.43	77.34	38.98	8.79	5.12	0.33
2	2383	118.25	7.78	4.77	60.47	37.11	7.78	5.71	
3	3505	429.11	8.16	6.06	66.62	49.48	8.16	5.49	
		Σ	24.73 611.68	15.27	204.42	125.57			

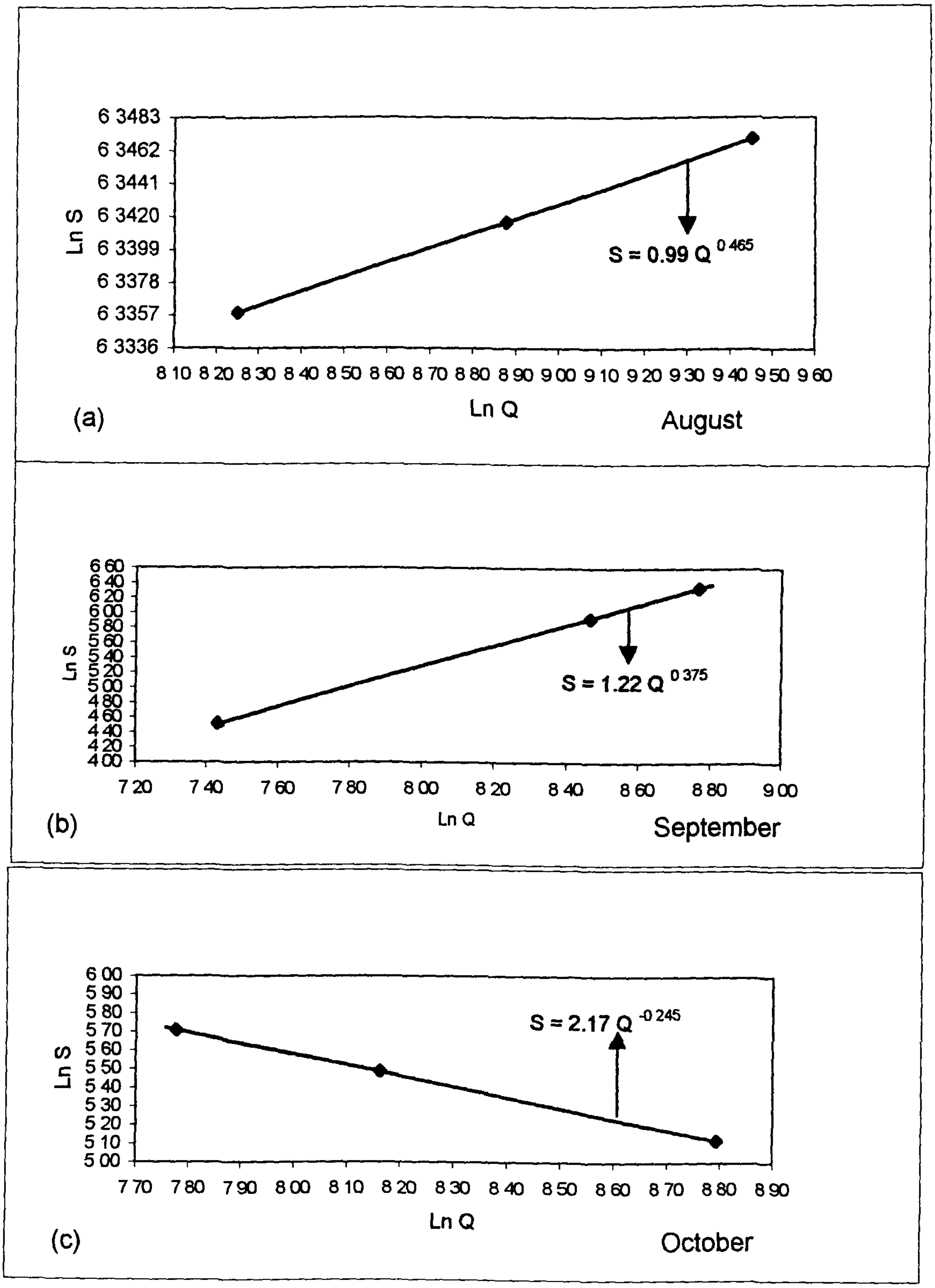


Fig.-6.9: Sediment (S) vs. Runoff (Q)

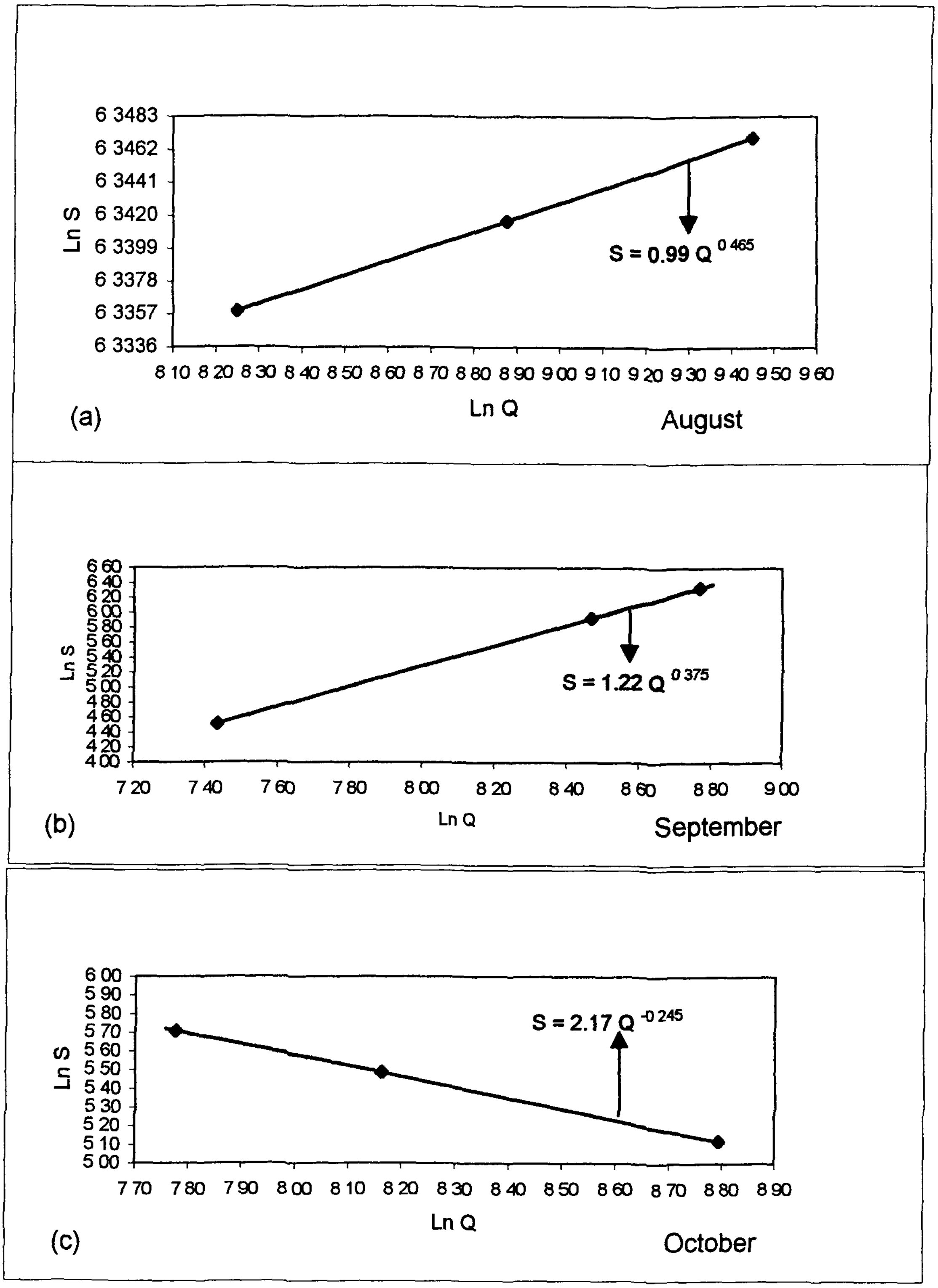


Fig.-6 9: Sediment (S) vs. Runoff (Q)

could mainly because of the high impact of the rain drops, which is measured in terms of maximum single erosion index, on the soil. The maximum single storm erosion index of 47.09 metre-ton-cm/ha-hr, as occurred on 20th August,97, could have influenced more in mobilising 649.54 ton/day of sediment yield obtained on 31st August,97 corresponding to the river discharge of 100.24 cumecs than the single storm erosion index of 6.31 metre-ton-cm/ha-hr occurred on previous day of the above observed discharge. This erosion index has been computed on 31st August,97. The time lag of 11 days has been observed between the occurrence of maximum single storm erosion index and the sediment yield. This is due to the fact that the soil particles are gradually getting detached by the continuous impact of rain drop and thereby transported from the source to the streams.

The relationship between the monthly erosion index and the sediment load has also been assumed logarithmic and indicated by the following power function:

$S = A * E^{B}$, ------- ------ ------- (6)

where, S = Monthly sediment load in ton

A = co-efficient reflecting the physiography of the catchment,

B = exponent of best fit

E= Monthly Erosion Index in metre-ton-cm/ha-hr

A relationship has been developed between monthly erosion index and sediment load (soil loss). The regression analysis has been done between sediment load (dependent variable) and the monthly erosion index (independent variable) for the month of August, September and October with the data set of sediment yield rate and the monthly erosion index available for the years 1996-98(Fig.-6.10).

The constraints and co-efficients of logarithmic relationship for the month of August, September and October as shown in Table-6.13 and Fig.-6.10, are given below:

$S = 1.04 * E^{0.075}$ (August), ---- ----- ----- (7)

$S = 16.44 * E^{-1.11}$ (September), and --- ---- ---- (8)

$S = 6.30 * E^{-0.65}$ (October). ---- ---- ---- (9)

While calculating the correlation between the observed and the estimated sediment load for the equations (7), (8) and (9), a significant

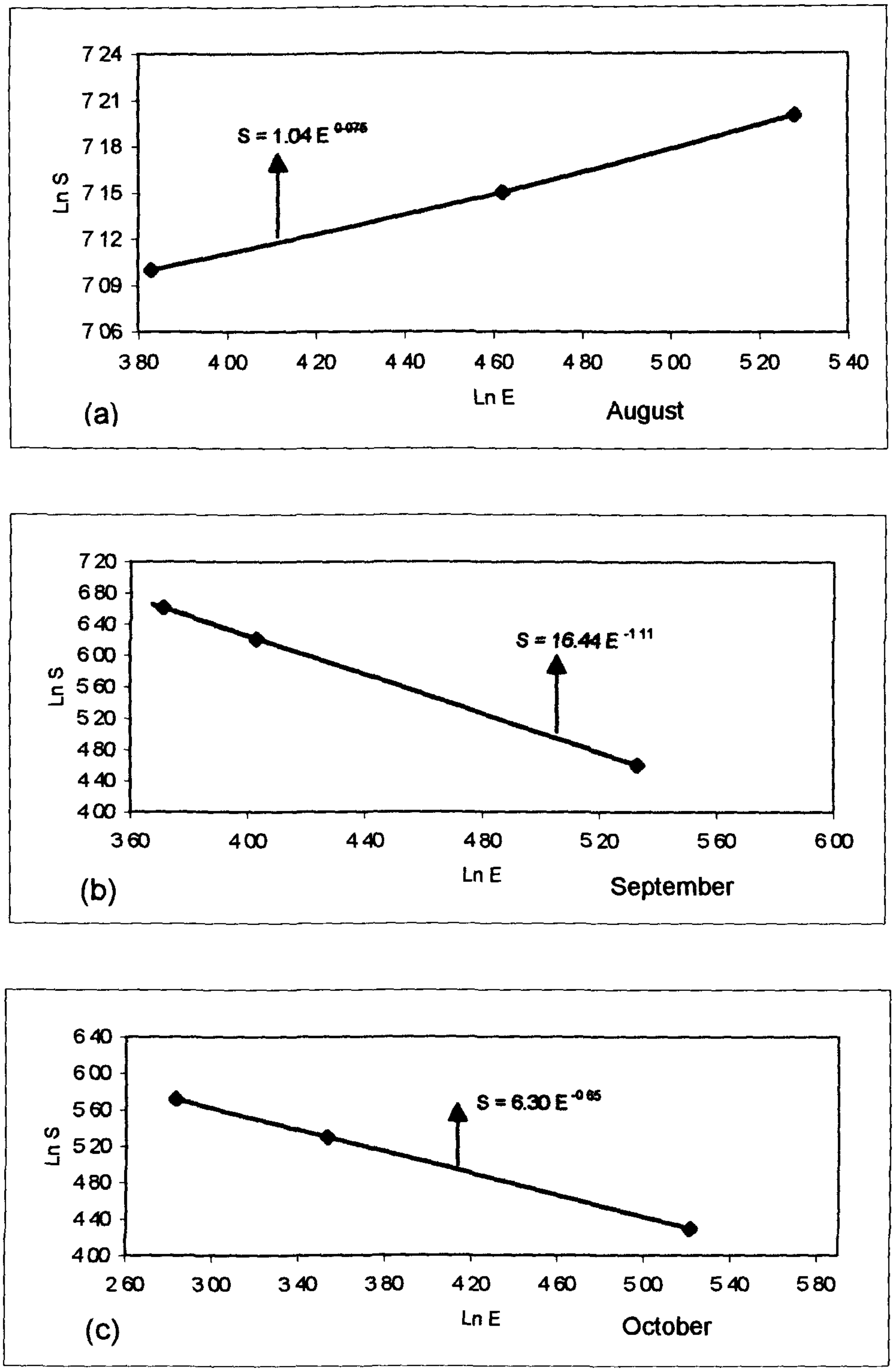


Fig.-6.10: Sediment (S) vs. Erosivity Index (E)

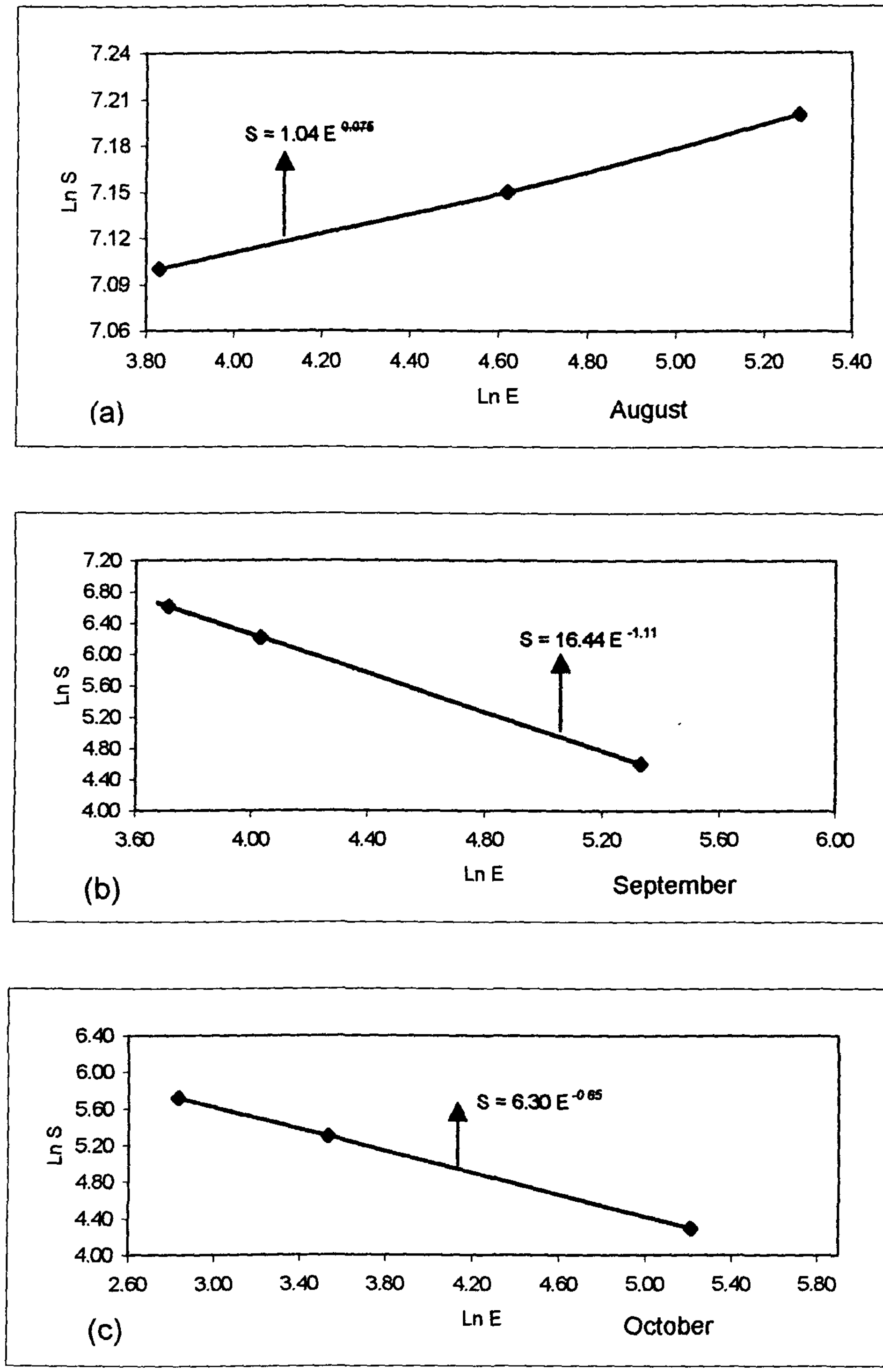


Fig.-6.10: Sediment (S) vs. Erosivity Index (E)

Table-6.13: Regression Analysis of Observed Sediment Load vs. Erosivity Index

August

Sl.No.	S, Sediment load	E, Erosivity index	x=ln E	y=ln S	x2	xy	x=ln E	y'	Correlation between y and y'
1	940.50	46.15	3.83	6.85	14.68	26.23	3.83	7.10	0.09
2	1822.54	101.37	4.62	7.51	21.33	34.68	4.62	7.15	
3	1006.06	196.44	5.28	6.91	27.88	36.51	5.28	7.20	
			13.73	21.27	63.90	97.42			
			188.54						

Regression Analysis of Observed Sediment Load vs. Erosivity Index

September

Sl.No.	S, Sediment load	E, Erosivity index	x=ln E	y=ln S	x2	xy	x=ln E	y'	Correlation between y and y'
1	170.38	56.38	4.03	5.14	16.26	20.72	4.03	6.21	0.69
2	2164.22	40.68	3.71	7.68	13.73	28.46	3.71	6.61	
3	144.74	206.10	5.33	4.97	28.39	26.51	5.33	4.60	
			13.07	17.79	58.38	75.68			
			170.73						

Regression Analysis of Observed Sediment Load vs. Erosivity Index

October

Sl.No.	S, Sediment load	E, Erosivity index	x=ln E	y=ln S	x2	xy	x=ln E	y'	Correlation between y and y'
1	84.11	182.29	5.21	4.43	27.10	23.07	5.21	4.29	0.85
2	118.25	34.22	3.53	4.77	12.48	16.86	3.53	5.30	
3	429.11	17.00	2.83	6.06	8.03	17.17	2.83	5.72	
			11.57	15.27	47.61	57.11			
			133.90						

Note: Sediment load is measured in ton and Erosivity Index in metre-ton-cm/ha-hr coefficient of correlation (as r= 0.85) has been found for the Equation (9) followed by 0.69 for the Equation (8). The Equation (7) has weak correlation to the tune of only 0.09. Though Equations (8) and (9) give better correlation but may not be explaining the reason for occurrence of high sediment load corresponding to lower value of monthly erosion index.

6.4 Estimation of Flood Peaks by Synthetic Unit Hydrograph

In the absence of long-term rainfall and observed flow data, no conceptual model could be developed or extended. The synthetic monthly flow (yield) series may be generated by Thomas-Fiering Model by using the limited period (1996-98) observed monthly flow data of river Umiew provided the data covers the monsoon and the non-monsoon period. The method of Thomas Fiering Model implicitly allows for the non-stationarity observed in the monthly discharge data. In its simplest form, the method consists of use of the twelve linear regression equations. If say three years of monthly flows are available, the three January and December flows are abstracted and January flows are regressed upon December flows. Similarly, February flows are regressed upon January flows and so on for each month of the year. Using the Thomas-Fiering notation, the model may be written as :

$$q_{i+1} = q_{j+1} + b_j (q_i - q_j) + z_i s_{j+1} (l - r_j^2)^{0.5} \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (1)$$

In equation, q_i and q_{i+1} are the volumes of discharges during ith and (i+1)th months respectively, q_j and q_{j+1} are the mean monthly discharges during the jth and (j+1)th months respectively within a repetitive annual cycle of 12 months. z_i is a random normal deviate with zero mean and unit variance, s_{j+1} and s_j are the standard deviations of discharges in the (j+1)th and jth months and r_j is the correlation coefficient between flows in the jth and (j+1)th months; b_j is the regression co-efficient for estimating volume of discharge in the (j+1)th month from the j th month and is given by :

$$b_j = r_j (s_{j+1}/s_j) \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (2)$$

Since the discharge and rainfall data pertaining to Umiew watershed from 1996-1998 are only available during monsoon period, Thomas-Fiering Model can not be applied for the generation of synthetic series of monthly flow.

Whenever sufficient records on stream flow and rainfall are not available in the small river catchments, the unit hydrograph for such catchments may be estimated by Regional Unit Hydrograph Analysis. In this analysis, the data on climatological, physiographic and other factors of the catchments are being used. The procedure involved in regional unit hydrograph analysis requires the evaluation of representative unit hydrograph parameters and pertinent physical characteristics for the gauged catchments in the region. The multiple linear regression analysis is performed considering one of the unit hydrograph parameters at a time as a dependent variable and various catchment characteristics as independent variables in order to develop the regional relationship for the unit hydrograph derivation. Knowing the catchment characteristics from the available toposheet and climatological data, the unit hydrograph for that catchment can be derived by using the relationship developed for the region.

An attempt has been made to estimate peak discharge of river Umiew, which is falling in South Brahmaputra Sub-zone-2(b), for the different different return periods with the help of recommended relations given by CWC (Flood Estimation Report for South Brahmaputra Sub-zone-2(b)–Revised, March,2000, CWC). These relations are used for representing one-hour unit hydrograph parameters for an ungauged catchment in the Sub-zone–2(b). The relationship has been developed by first establishing the relationship between Representative Unit Hydrograph (RUG) parameters and physiographic parameters of 14 catchments for South Brahmaputra Basin. Non-linear equations are tried for the relationship because it is found to be the best fit. The mathematical form of the equations is written as:

$Y = A * X^B$,

where Y = dependent variable (RUG parameters),

X = independent variable (physiographic parameters of the catchment)

A = a constant, and

B = an exponent.

In view of insufficient records on the flow of river Umiew and rainfall in Umiew watershed (1996-1998 and limited to monsoon period only) available with the CWC during data collection in 1999, the peak discharge of river Umiew has been estimated corresponding to the observed rainfall on date of occurrence of observed maximum discharge by applying the relationship of Synthetic one-hour Unit Hydrograph parameters recommended by CWC. The peak discharge thus estimated has been compared with the observed maximum discharge of the river to obtain the variation between the two values. This has been done to ascertain the efficacy of applying the Synthetic Unit Hydrograph approach for the estimation of peak discharge from small river catchment where sufficient data of stream flow and rainfall are not available.

6.4.1. One-Hour Synthetic Unit Hydrograph (SUH) Parameters: The relationship developed by the CWC for estimating one-hour Synthetic Unit Hydrograph (SUH) parameters for an ungauged catchments lying towards the South Bank of river Bramaputra has been used for developing the Synthetic Unit Hydrograph for the Watershed area of river Umiew. The relationships are :

$$Q_p = 0.905\,(A)^{0.758}, \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where, Q_p = Peak discharge of synthetic unit hydrograph in Cumecs

A = Catchment Area in km^2

$$Q_p = 0.905 * (136.45)^{0.758}$$

$$= 37.58 \text{ Cumecs}$$

$$Q_p = 38.00 \text{ Cumecs (Say)}$$

$$q_p = \frac{Q_p}{A} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where, q_p = Peak discharge of SUH per unit area in Cumecs/ Km^2

$$q_p = \frac{Q_p}{A} = \frac{38.00}{136.45} = 0.28 \text{ Cumecs/ km}^2$$

$$t_p = \frac{2.87}{(q_p)^{0.839}} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where, t_p = time to peak i.e time lag from centre of unit rainfall duration to the peak of unit hydrograph in hrs.

$t_p = \frac{2.87}{(0.28)^{0.839}}$ = 8.35 hrs adjusted to 8.50 hrs when t_r (Unit rainfall duration) is 1 hr.

$$W_{50} = \frac{2.304}{(q_p)^{1.035}} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where, W_{50} = Width of unit hydrograph measured at 50% of maximum peak discharge (Q_p) in hours.

$$W_{50} = \frac{2.304}{(0.28)^{1.035}} = 8.60 \text{ hrs.}$$

$$W_{75} = \frac{1.339}{(q_p)^{0.978}} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

where, W_{75} = width of unit hydrograph measured at 75% of peak discharge (Q_p) in hours.

$$W_{75} = \frac{1.339}{(0.28)^{0.978}} = 4.65 hrs.$$

$$W_{R_{50}} = \frac{0.814}{(q_p)^{1.018}} \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

where, $W_{R_{50}}$ = Width of hydrograph at 50% of peak discharge (Q_p) between the rising limb and (Q_p) ordinate in hours.

$$W_{R_{50}} = \frac{0.814}{(0.28)^{1.018}} = 2.97 \text{ hours.}$$

$$W_{R_{75}} = \frac{0.494}{(q_p)^{0.966}} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where, W_{R75} = Width of hydrigraph at 75 % of peak discharge (Q_p) between the rising limb and (Q_p) ordinate in hours.

$$W_{R_{75}} = \frac{0.494}{(0.28)^{0.966}} = 1.69 \text{ hours}$$

$$T_B = 2.447(t_p)^{1.157} \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

where, T_B = Base period of unit hydrograph in hours

$$T_B = 2.447(8.5)^{1.157}$$

$$T_B = 29.11 \quad \text{rounded off to } 29.00 \text{ hours}$$

$$T_m = t_p + t_{r/2} \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (9)$$

where, T_m = Time from start of rise to the peak of unit hydrograph

$$T_m = 8.5 + \tfrac{1}{2} = 9.00 hrs.$$

The synthetic hydrograph parameters as computed above have been plotted to draw synthetic hydrograph. One-hour Synthetic hydrograph of river Umiew is shown in Fig- 6.11.The discharge ordinates of synthetic hydrograph at $t_r = 1$ hr interval have been summed up and multiplied by $t_r = 1$.The discharge obtained by this has been compared with the theoretical volume of 1.00 cm direct runoff depth over the catchment computed from the formula,

$$Q = (A * d)/t_r * 0.36, \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

where, Q = Discharge in cumces

A = Catchment Area in km ^{2}

d = direct runoff depth over the catchment in cm

0.36 cm/hr. = A modal value of design loss rate recommended by the CWC for computing the loss rate values for the ungauged catchments falling under sub zone 2 (b). (Ref. – Flood Estimation Report for South Brhamaputra , Sub-Zone 2 (b) Revised, CWC, 2000, pp.18)

$$Q = \frac{136.45 * 1}{0.36 * 1} = 379 \text{ Cumecs,}$$

$$= \frac{379x3600x100}{136.45x10^6} = 1.00 \text{ cm direct rum off depth over the catchment}$$

ΣQ_i x t_i for the SUH plotted has been estimated to 435.1 cumecs. This has become higher than the volume of 1 cm direct runoff depth over the catchment i.e. 379 cumecs. The falling limb of one-hour SUH is suitably modified such that discharge ordinates get reduced without altering the points of synthetic unit hydrograph and the summation of modified discharge ordinates at t_r = 1 hr duration under the modified SUH has become 376.1 cumecs (Fig-6.12). This value is almost equal to the theoretical value of 379 cumecs (Appendix-6.5).

6.4.2 Computation of Flood Peak Corresponding to Observed Rainfall: The daily rainfall of 160.4 mm is observed on 20th July,1998 near Mawphlang gauge and discharge site of river Umiew corrsponding to the observed maximum river discharge of 463.04 cumecs. It has been studied that the critical storm duration which causes severe floods in small and medium catchments, has the value of 1.1 tp (CWC, 2000, pp. 25). Therefore, the

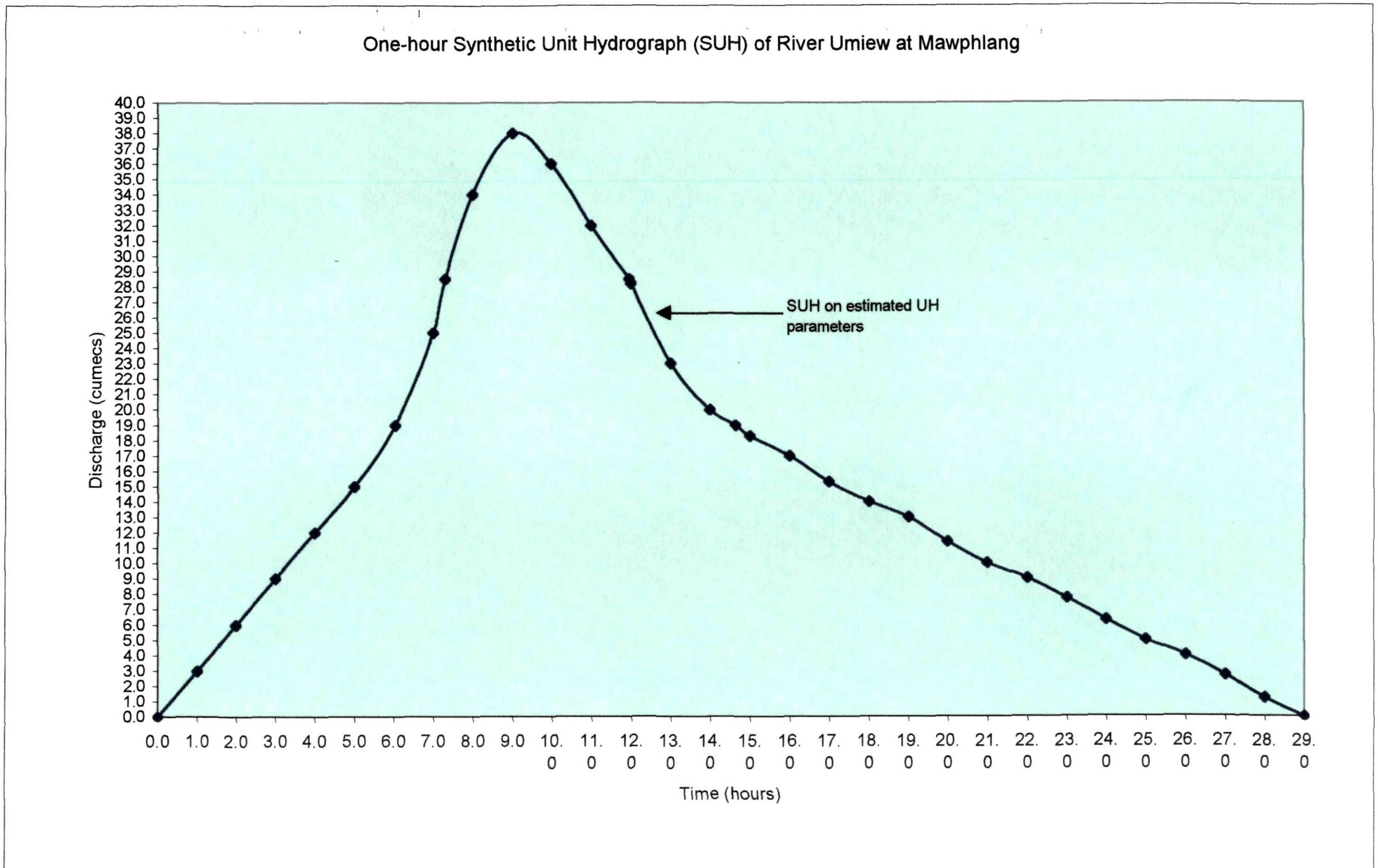

One-hour Synthetic Unit Hydrograph (SUH) of River Umiew at Mawphlang
Discharge (cumecs)
Time (hours)
SUH on estimated UH parameters

FIG. 5.11

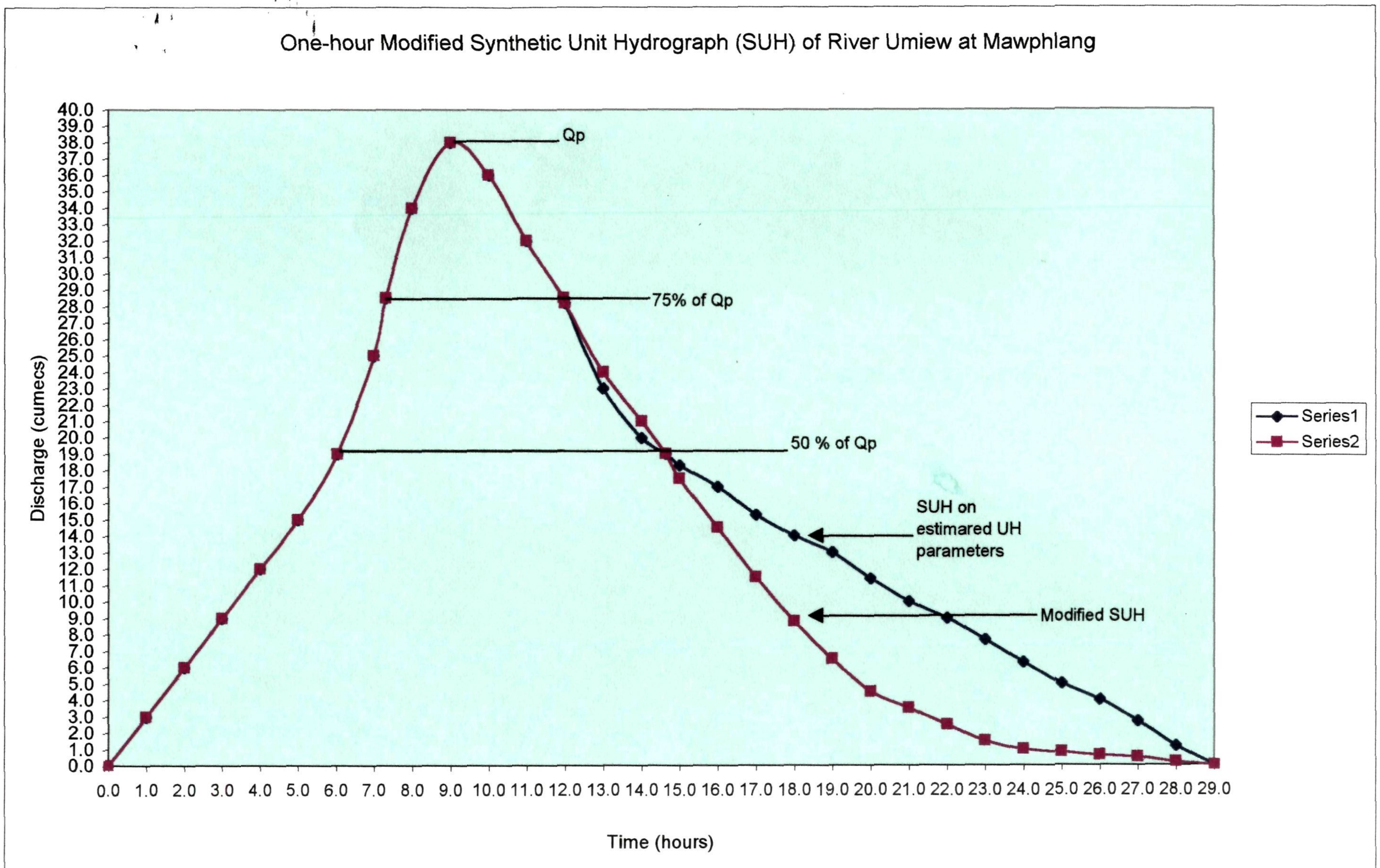

One-hour Modified Synthetic Unit Hydrograph (SUH) of River Umiew at Mawphlang
Discharge (cumecs)
Time (hours)
Qp
75% of Qp
50 % of Qp
SUH on estimared UH parameters
Modified SUH
Series1
Series2

FIG. 6.12

computation of flood peak has been done corresponding to the point rainfall of 160.4 mm.

The design strom duration, $T_D = 1.1\ t_p$

$= 1.1 \times 8.5 = 9.35$ hrs

$= 9.00$ hrs (Rounded off to nearest full hours)

6.4.3. Estimation of Point Rainfall and Areal Rainfall for Design Storm Duration : The 24-hour point rainfall for Mawphlong site of river Umiew has firstly been converted into point rainfall of 9.00 hrs storm duration by the conversion curve prepared by IMD. So, 160.4 mm point rainfall has been worked out to 131.53 mm (= 0.82 x 160.4) point rainfall of 9.00-hr duration. The areal reduction factor of 0.91 correspnding to the catchment area of 136.45 Km^2 and for storm duration of 9 hours has been interploted from the areal reduction table. The point rainfall of 9 hours has been converted into 9-hr areal rainfall by applying the conversion factor of 0.91. Thus 9 hours areal rainfall has been found to 119.69 mm (=0.91*131.53). Now, 9 hours areal rainfall has been split into 1-hour rainfall increment by using time distribution co-efficients. The effective hourly rainfall during storm duration of 9 hours has been computed in Table 6.14

Table - 6.14 : Hourly Effective Rainfall Increments

Duration (hr)	Destribution co-efficient	Strom Rainfall (cm)	Rainfall Increments	Loss rate / hr (cm)	Effective hourly rainfall (cm)
1	0.38	4.55	4.55	0.35	4.20
2	0.59	7.06	2.51	0.35	2.16
3	0.71	8.50	1.44	0.35	1.09
4	0.80	9.60	1.10	0.35	0.75
5	0.86	10.29	0.69	0.35	0.34
6	0.91	10.89	0.60	0.35	0.25
7	0.95	11.37	0.48	0.35	0.13
8	0.98	11.73	0.36	0.35	0.01
9	1.00	11.97	0.24	0.35	-

6.4.4 Computation of Flood Peak: In order to compute flood peak discharge, the effective rainfall increments have been rearranged against the ordinate of SUH such that maximum value of one-hour effective rainfall is placed against the maximum ordinate of modified SUH, next lower value of effective rainfall against next lower value of ordinate of modified SUH and so on. The modified ordinates of SUH are shown in Appendix-6.4. The flood peak computation has been shown in Table-6.15. The sum of the product of SUH ordinates and effective hourly rainfall gives total direct surface runoff to which the base flow has been added to get total peak discharge.

The average base flow rate of 0.05 cumecs/km2 has been recommended by the Central Water Commission (CWC) for estimating base flow for the river catchment falling in South Brahmaputra sub-zone-2(b). Therefore, the base flow for the entire watershed of river Umiew has been *estimated to be 6.82 cumecs (=0.05 * 136.45)*

The total flood peak discharge corresponding to maximum 24 hr observed rainfall of 160.4 mm, has been computed to 324.51 cumecs (Table-6.15).

Table - 6.15 : Design Flood Peak Corresponding to 24-hr Observed Rainfall on 24th July, 1998

Time (hr)	SUH modified ordinate (cumecs)	1-hour effective rainfall (cm)	Direct runoff (cumecs)
7	*25.0*	*0.25*	*6.25*
8	34.0	1.09	37.06
9	38.0	4.20	159.60
10	36.0	2.16	77.76
11	32.0	0.75	24.00
12	28.5	0.34	9.69
13	24.0	0.13	3.12
14	21.0	0.01	0.21
		Total	317.69
		Base Flow	6.82
		Design Flood Peak	324.51

6.4.5 Results and Interpretation : The maximum observed discharge of river Umiew recorded on 20th July, 1998 is 463.04 cumecs. Therefore, the percentage reduction in the design flood peak w.r.t. the observed max^{m} discharge of river Umiew = $\frac{463.4-324.51}{463.04}$ = 30%

This reduction of 30% in the computed design flood peak w.r.t the observed maximum discharge of river Umiew may be attributed to the following reasons :

1. The daily rainfall of 160.4 mm as observed on 20th July, 98 near to Mawphlang gauge and discharge site of river Umiew, has been assumed to occur uniformly over the entire river catchment of 136.45 km^2. But, there could be the possibility of occurrence of higher and also lesser rainfall than this observed rainfall in some of the micro-watersheds of the catchment of Umiew.
2. The topographical variations also affect the variation of rainfall. This has been revealed by observing daily rainfall data to be 42.0 mm. The difference of 118.4 mm of rainfall observed in one day between IMD station Shillong and gauge and discharge site at Mawphlang are occurring within a distance of 20 Km.

   The average elevation of Shillong IMD station is higher than the elevation of gauge and discharge site at Mawphlang. The Indian Council of Agricultural Research (ICAR) for North Eastern Region at Barapani, Meghalaya has also observed while conducting studies related to the topographical effect on the variation of rainfall that the annual rainfall decreases with the increase of elevation due to the combined effect of wind and topography (Satapathy 1996).

   Therefore, SUH developed by CWC may be used for estimating the design flood peak for the river Umiew and its tributaries. The design flood peak for the specified return periods (25-year, 50-year) and 24-hr rainfall may be used for the design of water conservation structures in the micro watersheds of river Umiew. The CWC's criteria of 1968 specify that the diversion weirs should be designed for flood frequency of 50-100 years (CWC, 2000 pp. 23-24). The diversion-cum-impounding weirs may be constructed across 3rd, 4th and 5th order streams of the micro-watersheds for the conservation and utilisation of water for drinking as well as for providing irrigation to the agricultural fields. In hilly micro-watersheds, the need is often being felt for ensuring efficient drainage arrangement to avoid flood congestion during the monsoon periods. Such congestion may be avoided by the construction of cross drainage works across the main and subsidiary natural drainage channels at suitable locations in micro-watershed areas. These cross drainage works may be designed for a 25-year return period flood (IS:7784,part-I, 1975). The computational details of design flood peak for 25-year and 50-year return period are shown in Appendix-6.5. But, in case of design of check dams required for soil conservation purpose, lower storm duration may be taken for estimating design flood of a particular return period. In this regard, Orgrosky and Mockus (1987) have suggested the use of 6-hour rainfall for the design frequency for small watersheds which are within the provision of soil conservation.

6.5. Concluding Remarks

The analysis of rainfall and erosion index has indicated that erosion index is influenced more by the higher intensity of rainfall than its overall magnitude. The single storm erosion index and sediment yield rate data of river Umiew for the period 1996-98 reveal that erosion index contributes significantly in enhancing the sediment yield rate. Wischmeier (1957) has also substantiated this finding that, if all factors other than rainfall are held constant, the annual erosion losses from cultivated areas are directly proportional to the yearly values of the erosion index. The analysis of monthly erosion index data for the period 1996-2002 shows that the month of October has considerable erosion potential (102.05 metre-ton-cm/ha-hr). It has been observed that micro-watershed areas of Umiew during October have little crop canopy and most of the portion remains barren. In order to minimize the effects of rain storm on the soil erosion, adoption of proper crop management and soil conservation measures are essential. The analysis of discharge-sediment-erosivity index has revealed that there is a noticeable time lag between the rain drop striking the soil surface and its effect in the form of sediment yield. The reason for this time lag could be attributed to the time consumed right from the soil particles getting detached by the impact of rain drop upto getting these particles transported by overland flow through the connecting streams of different orders and finally coming into the main stem of river Umiew.

In view of getting the concentration of 75-98 % of total EI values during June-September in different zones of India except the Southern Zone (Ram Babu et al.,1978), it may be more realistic to estimate the average soil loss separately for the monsoon and non-monsoon periods. For this, the value of R may be substituted separately for the average monsoon and non-monsoon erosion index of the concerned area in the Universal Soil Loss Equation. The prediction of soil loss from Umiew watershed may also be tried by substituting R by the predicted value of monsoon erosion index for a specific return period in the Universal Soil Loss Equation. The predicted values of monsoon erosion index done by log-Pearson Type-III may be tried as this distribution fits well in the series of the monsoon erosion index computed for the rainfall period from 1996-2002.

In the absence of long-term rainfall and observed flow data, no empirical model can be developed or extended. However, the Regional Unit Hydrograph (RUH) relationship developed by CWC may be used with a fair degree of accuracy in computing the Peak-discharge of river Umiew.

The peak discharge of river Umiew computed by Synthetic Unit Hydrograph (SUH) when compared with the maximum observed discharge of this river, it has been found that there is reduction of 30% in the computed design flood peak w.r.t. the observed maximum river discharge. This variation in the discharge could be attributed to non-uniform distribution of rainfall over the river catchment. The area of the river catchment which is located at higher elevation are getting less rainfall than the area located at comparatively lower elevation. This has also been substantiated by the Indian Council of Agricultural Research (ICAR) for North Eastern Region at Barapani, Meghalaya while conducting studies related to the topographical effect on the variation of rainfall. It has been observed by the ICAR that the annual rainfall decreases with the increase of elevation due to the combined effect of wind and topography (Satapathy 1996). Therefore, SUH developed by CWC may be used for estimating the design flood peak for the river Umiew and its tributaries.

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Chapter-7

Chapter-7

Conclusions and Findings

7.0 Conclusions

The natural landscape of Meghalya Plateau, especially its southern slopes, have been subjected to intensive acceleration of hydrological processes The areal variations in the annual rainfall of the state, especially its southern slopes, are observed magnificently higher ranging from 1,200 mm to 12,000 mm. The occurrences of 90 % of the annual precipitation over the shallow soils and poor vegetal cover of the southern slopes create seasonal floods during monsoon and at the same time, this area reels under acute shortage of drinking water during the lean season. In addition, the increased human interference in terms of land mining and quarrying and faulty agricultural practices being resorted to along the hilly slopes, has degraded the land resources through heavy soil loss. In fact, against 55.83 % of the geographical area of Meghalya being affected by different types of land degradation, 52 % land of the total geographical area of the state, is affected by soil erosion.

In order to understand the natural intricacies of Meghalya Plateau, the watershed area of river Umiew, located on its southern slopes, has been selected for detail study. There are many aspects of integrated watershed management. However, the main processes of land forms and human interferance are related to water circulation and its impact on surface as well as sub-surface soils. Main emphasis has been thus given to hydrological aspects of watershed in the present study. The influence of geo-hydrological characteristics on soil erosion and water conservation, has been analyzed by delineating this watershed area into nine micro-watersheds namely, Mawphlang (Um1), Umgot (Um2), Mawreng (Um3), Nongkrem (Um4), Nongkynrih (Um5), Basio (Um6), Laitkroh (Um7), Laitkynsew (Um8) and Dympep (Um9) with the sizes varying from 5.59 km^2 to 44.04 km^2. The index of soil erosion sensitiveness of these micro-watersheds has been done through their prioritization.

It has been found during prioritization analysis that four micro-watersheds namely, Laitkroh (Um7), Nongkrem (Um4), Mawreng (Um3) and Laitkynsew (Um8) are more sensitive to soil erosion. The remaining five micro-watersheds namely, Nongkynrih (Um5), Basio (Um6), Umgot (Um2), Mawphlang (Um1) and Dympep (Um9) are less sensitive to soil erosion. The hypsometric curve has indicated that Laitkroh micro-watershed (Um7) has obtained equilibrium stage of development. The area of Nongkrem micro-watershed (Um4), where the developmental activities have exceeded the balanced limit whereas, in Laitkynsew micro-watershed (Um8), the developmental activities are yet to take place. Even then the area of these micro-watersheds are soil erosion sensitive.

The degree of soil erosion sensitiveness of the micro-watershed will further depend upon the areal variation of rainfall, intensity of rainfall and the storm durations to which it is subjected to. The rainfall intensity and storm durations have been analyzed for computing monthly erosivity index and its impact on the soil loss taking place from the Umiew watershed during the monsoon period. The influence of over land flow in terms of stream discharge on soil loss has also been studied. It has been observed that the intensity and duration of rainfall create more influence in detaching the soil particles due it containing high kinetic energy than merely the magnitude of rainfall. The rainfall containing higher rainfall erosivity index yields higher sediment load. These are highly positively related to each other.

The areal variation of rainfall over the micro-watersheds with different soil erosion sensitiveness plays more important role in deciding the overall yield of soil loss taking place from Umiew watershed. It has been observed that the rainfall of lower erosivity index has yielded high sediment load (soil loss) from Umiew watershed during August, September and October (Table-6.13). This result indicates that there would be much more occurrences of rainfall over the micro-watersheds' areas of Laitkroh, Nongkrem, Mawreng and Laitkynsew, which are more erosion sensitive rather than the less soil erosion sensitive micro-watersheds' areas.

The probability analysis of rainfall intensity has shown that no probability model fits into the rainfall intensity of all the storm durations except to a great extent by log-Pearson Type-III distribution function. While comparing the predicted value of maximum rainfall intensity of different durations and return periods computed by log-Pearson Type-II distribution function with that of the estimated values obtained by using the Intensity Duration Frequency (IDF) relationship developed by ICAR, it has been found that percentage variation between the predicted and the estimated values of rainfall intensity of 15 minutes duration and 5 years return period is minimum to the extent of 0.41 %. This variation has gone up from 22.02 % to 83.14 % as the duration of rainfall intensity has increased from 30 minutes to 120 minutes. It means that there are occurrences of high intensity of rainfall at shorter duration with more frequent in the watershed area and vice-versa.

The Intensity-Duration-Frequency chart prepared by the predicted values of rainfall intensity of different durations and return periods indicates that there are significant variations in the values of rainfall intensity for the storm duration ranging from 15 minutes to 45 minutes and for the return period of 5 to 50 years. Such variations get reduced as the storm duration increases beyond 45 minutes.

The daily rainfall data has been put under weekly rainfall for 26 weeks. The probability analysis of weekly rainfall during monsoon period (May-October) from 1996-2002 has indicated that no single probability model fit into the observed weekly rainfall for all the 26-weeks. The weekly rainfall predictions found out by log-Pearson type-III at 80 % probability level, are almost comparable to the observed weekly rainfall values at the same probability levels.

The highest monthly rainfall of 168.78 mm has been computed in August computed from the observed rainfall at 80 % probability level for the month of August which is followed by 106.42 mm for June and 105.25 mm for May. The least rainfall of 56.4 mm has been predicted for the month of October. The weekly rainfall assessment made at 80 % probability levels could be used for providing supplemental irrigation to the agricultural crops during dry spell of monsoon, lean period and also during abrupt withdrawals of monsoon in October. The Satapathi (1996) has also conducted similar study in the micro-watersheds developed at Barapani in Meghalaya and highlighted the need for such analysis for developing integrated water management plan.

The log-Pearson Type-III distribution function gives better performance for the prediction of monsoon erosion index and the maximum single storm erosion index. This function has thus been used for estimating the monsoon erosion index and maximum single storm erosion index for a specific return period. The value of the Erosivity Index (R) is used in the Universal Soil Equation for predicting the value of soil loss from a specific micro-watershed area during monsoon against the specific return period for which the predicted value of the monsoon erosivity index has been taken. It is found that the maximum sediment yield rate obtained during this period (in monsoon 1997 & 1998) is obtained to the tune of 1.86 ton/ha. The empirical relationships developed by varoius researchers for the estimation of sediment yield rates are also comparable with the results observed from Umiew watershed. The sediment yield index as estimated by Garde *et al.* (1983) is noticed 52.63 % lower than the observed sediment yield rate of Umiew river. It shows that the rate of sediment yield is higher in the southern parts of Meghalya Plateu.

The discharge and sediment relationship has been put under three different combinations of these two attributes as: (a) the high discharge with high sediment yield, (b) the high discharge with low yield, and (c) the low but increasing discharge with very low yield. This relationship is logarithmic9(as has been shown by double-log graphs) and significant for the month of September as r = 0.63. It means that the rate of erosion increases fast subject to increasing discharge in the month of September because the soils are in the state of full saturation during this time and even slow increase in the discharge rate increases soil erosion fast.

A strong relationship between the observed and estimated sediment load have been found for the month of September & October. However, the weak correlations are not explainable for the reason of occurrence of high sediment load corresponding to lower value of monthly erosion index.

In view of insufficient data on the flow of river and rainfall in Umiew watershed, an attempt has been made to estimate peak discharge of river Umiew corresponding to the observed rainfall on date of occurrence of observed maximum discharge by applying the relationship of Synthetic one-hour Unit Hydrograph parameters recommended by CWC. The peak discharge thus estimated has been compared with the observed maximum discharge of the river and found that the percentage reduction in the design flood peak w.r.t. the observed max^m discharge of river Umiew to be 30%.

This reduction of 30% in the computed design flood peak may be attributed to the following reasons: (i) Uneven spatial distribution of rainfall, and (ii) The topographical variations of the watershed.

7.1 Findings

The main findings of the present study are arranged in the following manner.

(1) Prioritization of the micro-watershed which is done by considering geo-morphic and land use characteristics of the study area, clearly reveals that the micro-watersheds, irrespective of their various stages of landscape evaluation has become soil erosion sensitive. The soil erosion interventions may be applied to the micro-watersheds depending upon the degree of sensitivity with which the micro-watersheds are affected to.

(2) The IDF chart prepared by applying log-Pearson Type-III distribution function is applicable to find out the theoretical values of rainfall intensity for any duration from 15 minutes to 120 minutes and for the return periods of 5 years to 50 years.

(3) The rainfall intensity for the desired frequency has been can be computed from this chart for the duration equal to the time of concentration of the watersheds and the same has been may be used in the rational method for estimating peak runoff from small watersheds. Thus, log-Pearson Type-III is the ideal distribution for showing the rainfall pattern of the southern slopes of Meghalya.

(4) While comparing the Intensity-Duration-Frequency (IDF) chart, prepared by applying log-Pearson Type-III distribution function with IDF relationship developed by ICAR, Barapani, Shillong, it is obvious from analysis that the variation in the distribution of rainfall intensity of lower duration storms are recorded higher and vice-versa. It shows that the lower duration rainstroms are more fluctuating with frequent occurrences in the area.

(5) The log-Pearson Type-III distribution function is also found best fitted function as compared with others for the prediction of soil loss through the Universal Soil Loss Equation.

(6) Since the monthly rainfall computed from the observed rainfall values at 80 % probability level has been fairly higher to the tune of 105.25 mm and 106.42 mm respectively. The month of May itself can be utilized for the seedling and transplantation of kharif paddy. The rainfall during the months of July to September may be utilized for meeting the requirement of the paddy by making a provision of supplemental irrigation during this period.

The variations in the size and frequency of occurrences of rainfall in the micro-watershed areas have caused high variability in the monsoon discharge of the river Umiew. The range of variation between the observed minimum and maximum discharge during the monsoon months in 1996 has been found to be in the ratio of 1:227.5 to 1:3.29. For providing the supplemental irrigation under the scenario of high seasonal variability in the monsoon discharge of Umiew river, a three tier system for the conservation and utilization of rain water in the micro-watersheds of river Umiew could be introduced with certain modifications over the system of conservation suggested by Gupta and Narayan (1974) and Narayan and Pandey (1976). The modified features of suggested design are as:

A series of dugout storage ponds with adequate capacity, estimated on the basis of water availability study, may be panned at different elevation of the lands under all the nine micro-watersheds of river Umiew. These dugout storage ponds may be connected suitably by the drainage channels. The impounded water from the dugout ponds located at higher elevation, after getting utilised by the crop, the excess drainage water may be collected by the dugout ponds located at next lower elevation. This way the rain water tapped at higher altitude of the micro-watershed area may be utilized optimally by the lands located at different elevations. The remaining excess water may then be discharged into the regional drainage system.

(7) It has been found from the average values of the monthly erosion index that the month of June, July, August and October have considerable erosion potential (Table-6.2). The agricultural field used to have crop canopy during October and remains almost barren. In order to safe guard the agricultural field from soil erosion adoption of proper crop management and soil conservation measures are essential to minimize the effects of rain storm. Similar suggestions have also been offered by the Indian Council of Agricultural Research (ICAR) for its model micro-watersheds developed at Barapani (Satapathy, 1996).

(8) The analysis of rainfall and erosion index has indicated that erosion index is influenced more by the higher intensity of rainfall than its overall magnitude. The single storm erosion index and sediment yield rate data of river Umiew for the period 1996-98 reveal that erosion index contributes significantly in enhancing the sediment yield rate. Wischmeier (1957) has also substantiated this finding that, if all factors other than rainfall are held constant, the annual erosion losses from cultivated areas are directly proportional to the yearly values of the erosion index.

(9) The analysis of discharge and sediment-erosivity index has revealed that there is a noticeable time lag between the rain drop striking the soil surface and its effect in the form of sediment yield. The reason for this time lag could be attributed to the time consumed right from the soil particles getting detached by the impact of rain drop upto getting these particles transported by overland flow through the connecting streams of different orders and finally coming into the main stem of river Umiew.

(10) In the absence of long-term rainfall and observed flow data, no empirical model can be developed or extended. However, the Regional Unit Hydrograph (RUH) relationship developed by CWC is the suitable may be

used with a fair degree of accuracy in computing the Peak-discharge of river Umiew.

7.2 Further Study

(1) In this study, the micro-watershed wise soil properties have not been done comprehensively except limited collection and analysis of soil and water samples from few locations of Umiew watershed area. Therefore, soil mapping of micro-watersheds, which covers existing landforms, vegetation and the soil properties, could not have been done. In fact, such mapping provides a sound base for making land use and soil loss recommendations (Sehgal, *et al.* 1987).

(2) The observations of one rainfall station data have been used in the present study for the computation of erosivity index and the river discharge for the entire Umiew watershed. The analysis of the relationship between the sediment yield and discharge and also between the sediment yield and erosivity index have done in an integrated manner for the entire Umiew watershed. In order to know the realistic contribution of the sediment yield from the soil erosion sensitive and non-sensitive micro-watersheds and the influence of discharge and erosivity index on the soil loss, the detail observations of sediment load and comprehensive hourly data sheet of rainfall are needed for the detail study of runoff and soil loss in these areas.

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Appendices

Appendix-4.1

Area-Elevation Relationship (Hypsometry)

Micro-watershed	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
Um1					
	1850-1800	50.47	9.04	9.04	1850
	1800-1750	137.12	24.57	33.61	1800
	1750-1700	264.13	47.33	80.94	1750
	1700-1650	56.81	10.18	91.12	1700
	1650-1600	49.57	8.88	100.00	1650
		558.10			
Um5	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1800-1750	0.21	0.03	0.03	1800
	1750-1700	686.43	90.33	90.36	1750
	1700-1650	71.84	9.45	99.81	1700
	1650-1600	1.43	0.19	100.00	1650
		759.91			
Um7	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1950 - 1900	0.21	0.01	0.01	1950.00
	1900 - 1850	0.63	0.04	0.06	1900.00
	1850 - 1800	78.24	5.33	5.39	1850.00
	1800 - 1750	192.40	13.12	18.51	1800.00
	1750 - 1700	562.49	38.35	56.86	1750.00
	1700 - 1650	317.45	21.64	78.50	1700.00
	1650 - 1600	315.18	21.49	99.99	1650.00
		1466.71			
Um8	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1850-1800	20.42	2.66	2.66	1850
	1800-1750	196.68	25.67	28.33	1800
	1750-1700	322.16	42.04	70.38	1750
	1700-1650	181.71	23.71	94.09	1700
	1650-1600	45.28	5.91	100.00	1650
		766.26			

Um6	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1900-1850	12.54	0.79	0.79	1900
	1850-1800	211.81	13.34	14.13	1850
	1800-1750	912.9	57.50	71.63	1800
	1750-1700	362.1	22.81	94.44	1750
	1700-1650	87.44	5.51	99.94	1700
	1650-1600	0.9	0.06	100.00	1650
		1587.69			

Um2	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1750-1700	239.32	32.18	32.18	1750
	1700-1650	368.24	49.52	81.70	1700
	1650-1600	136.06	18.30	100.00	1650
		743.62			

Um3	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	2000-1950	6.93	0.16	0.16	2000.00
	1950-1900	123.73	2.81	2.97	1950.00
	1900-1850	122.46	2.78	5.75	1900.00
	1850-1800	702.99	15.96	21.71	1850.00
	1800-1750	1070.22	24.30	46.01	1800.00
	1750-1700	1563.88	35.51	81.52	1750.00
	1700-1650	740.18	16.81	98.32	1700.00
	1650-1600	73.80	1.68	100.00	1650.00
		4404.19			

Um4	Elevation (m)	Area (ha)	Area (%)	Cum. Area (%)	Elevation (m)
	1950-1900	33.49	1.30	1.30	1950.00
	1900-1850	123.31	4.77	6.06	1900.00
	1850-1800	640.20	24.76	30.82	1850.00
	1800-1750	677.81	26.21	57.03	1800.00
	1750-1700	1111.06	42.97	100.00	1750.00
		2585.86			

Um9

Elevation (m)	Area (ha)	Area (%)	Cum. Area	Elevation (m)
1850-1800	13.33	1.81	1.81	1850
1800-1750	205.30	27.89	29.70	1800
1750-1700	134.26	18.24	47.94	1750
1700-1650	111.41	15.14	63.08	1700
1650-1600	271.75	36.92	100.00	1650
	736.05			

Appendix-5.1(a)

Observed and Predicted Maximum Rainfall Intensity by Normal Distribution

Rainfall Intensity in mm/hr

Storm duration (minutes)	Observed maximum rainfall intensity (O) at 20 %, 50 % and 80 % probability levels			**Mean of rainfall intensity**	**Standard Deviation**	Predicted maximum rainfall intensity (E) at 20 %, 50 % and 80 % probability levels by **Normal distribution**			alpha = 0.78*Std. Dev.	u=I-0.5772* alpha
	I 0.2	I 0.5	I 0.8			I 0.2	I 0.5	I 0.8		
15	108.0	56.0	40.0	70.57	34.35	99.42	70.57	41.72	26.79	55.11
30	72.1	26.6	20.0	40.49	25.15	61.62	40.49	19.36	19.62	29.17
45	28.1	18.7	13.3	20.16	7.35	26.33	20.16	13.99	5.73	16.85
60	14.6	10.0	10.0	11.57	3.74	14.71	11.57	8.43	2.92	9.89
75	11.5	8.0	8.0	9.31	1.97	10.96	9.31	7.66	1.54	8.42
90	6.7	6.7	2.7	5.54	1.98	7.20	5.54	3.88	1.54	4.65
105	6.9	5.7	5.7	6.11	1.10	7.03	6.11	5.19	0.86	5.61
120	5.0	5.0	3.0	4.40	1.10	5.32	4.40	3.48	0.86	3.90

Appendix-5.1(b)

Predicted Maximum Rainfall Intensity by Gumbel's EV and Log Normal Distribution

Rainfall intensity in mm/hr

Predicted rainfall intensity by **Gumbel EV distribution (E)**			Co-eff. of variation=SD/Mean	Co-efficient of skew	K= Log-Probability frequency factor			Predicted rainfall intensity by **Log-Normal distribution**		
I 0.2	I 0.5	I 0.8			K 0.2	K 0.5	K 0.8	I 0.2	I 0.5	I 0.8
95.29	65.02	42.24	0.49	1.58	0.67	-0.21	-0.8	93.58	63.36	43.09
58.59	36.43	19.75	0.62	2.10	0.60	-0.24	-0.76	55.58	34.45	21.38
25.45	18.97	14.10	0.36	1.14	0.73	-0.16	-0.83	25.53	18.98	14.06
14.26	10.97	8.49	0.32	1.00	0.75	-0.15	-0.84	14.38	11.01	8.43
10.73	8.99	7.69	0.21	0.64	0.79	-0.10	-0.85	10.87	9.11	7.64
6.97	5.22	3.91	0.36	1.12	0.73	-0.16	-0.83	6.99	5.22	3.90
6.90	5.93	5.20	0.18	0.55	0.79	-0.10	-0.85	6.98	6.00	5.18
5.19	4.22	3.49	0.25	0.77	0.77	-0.13	-0.84	5.25	4.26	3.48

Frequency Analysis of Maximum Rainfall Intensity by Log Pearson Type -III Distribution

15 minutes duration

Rinfall Intensity in mm/hr

Year	Intensity of I in discenc		I = ln I	Rank (m)	(I-I)	(I-I)2	(I-I)3
1996	100	40	3 69	1	-0 46	0 21	-0 098
1197	40	40	3 69	2	-0 46	0 21	-0 098
1998	40	40	3 69	3	-0 46	0 21	-0 098
1999	98	56	4 03	4	-0 12	0 02	-0 002
2000	40	98	4 58	5	0 43	0 19	0 082
2001	120	100	4 61	6	0 46	0 21	0 094
2002	56	120	4 79	7	0 64	0 41	0 259
Sigma			29 07			1 46	0 140
Mean			4 15				
Std dev			0 49				
Co-eff Skew			0 25				

KT (Frequency factor) corresponding to probability of exceedence (1/T=1/1 25) and skewness of 0 25
from Statistical Table = - 0 853

IT (Rainfall intensity corresponding to 1 25 years return period) = I - 0 49 * 0 853 = 3 73

IT in natural domain = exponential to the power 3 73 = 41 68

KT (Frequency factor) corresponding to probability of exceedence (1/T=1/2) and skewness of 0 25
from Statistical Table = - 0 050

IT (Rainfall intensity corresponding to 2 years return period) = I - 0 49 * 0 050 = 4 13

IT in natural domain = exponential to the power 4 13 = 62 18

KT (Frequency factor) corresponding to probability of exceedence (1/T=1/5) and skewness of 0 25
from Statistical Table = 0 824

IT (Rainfall intensity corresponding to 5 years return period) = I + 0 49 * 0 824 = 4 56

IT in natural domain = exponential to the power 4 56 = 95 58

KT (Frequency factor) corresponding to probability of exceedence(1/T=1/10) and skewness of 0 25
from Statistical Table = 1 309

IT (Rainfall intensity corresponding to 10 years return period) = I + 0 49 * 1 309 = 4 79

IT in natural domain = exponential to the power 4 79 = 120 30

KT (Frequency factor) corresponding to probability of exceedence (1/T=1/25) and skewness of 0 25
from Statistical Table = 1 849

IT (Rainfall intensity corresponding to 25 years return period) = I + 0 49 * 1 849 = 5 06

IT in natural domain = exponential to the power 5 06 = 157 59

KT (Frequency factor) corresponding to probability exceedence (1/T=1/50) and skewness of 0 25
from Statistical Table = 2 211

IT (Rainfall intensity corresponding to 50 yrears return period) = I + 0 49 * 2 211 = 5 24

IT in natural domain = exponential to the power 5 24 = 188 67

Appendix- 5.3

Observed and Predicted Weekly Rainfall by Normal Distribution

Rainfall in mm

Week	Observed weekly rainfall (O)			**Mean of Weekly Rainfall**	**Standard Deviation**	Predicted weekly rainfall by **Normal distribution (E)**			alpha = 0.78*Std. Dev.	u=I-0.5772* alpha
	I 0.2	I 0.5	I 0.8			I 0.2	I 0.5	I 0.8		
1	297.30	41.10	18.82	120.49	190.46	280.48	120.49	-39.50	148.56	34.74
2	89.92	43.30	9.42	49.63	34.34	78.48	49.63	20.78	26.79	34.17
3	53.58	28.30	17.60	33.78	20.63	51.11	33.78	16.45	16.09	24.49
4	175.78	57.10	36.34	88.20	67.60	144.98	88.20	31.42	52.73	57.77
5	124.68	39.00	21.28	64.36	49.66	106.07	64.36	22.65	38.73	42.00
6	140.54	44.40	29.42	73.00	73.14	134.44	73.00	11.56	57.05	40.07
7	156.44	50.00	29.18	79.41	89.65	154.72	79.41	4.10	69.93	39.05
8	277.92	105.70	37.18	133.56	104.05	220.96	133.56	46.16	81.16	86.72
9	153.30	33.00	12.46	68.61	80.03	135.84	68.61	1.38	62.42	32.58
10	104.86	63.50	21.92	64.19	44.08	101.22	64.19	27.16	34.38	44.34
11	162.86	65.30	20.88	88.57	69.59	147.03	88.57	30.11	54.28	57.24
12	261.70	40.20	14.82	107.20	118.02	206.34	107.20	8.06	92.06	54.07
13	300.22	74.40	17.38	126.07	157.03	257.98	126.07	-5.84	122.48	55.37
14	169.30	58.70	30.60	82.08	73.78	144.06	82.08	20.10	57.55	48.86
15	127.70	63.41	20.10	70.23	52.48	114.31	70.23	26.15	40.93	46.60
16	95.30	65.10	36.90	65.17	27.53	88.30	65.17	42.04	21.47	52.78
17	114.20	60.30	31.20	68.35	39.70	101.70	68.35	35.00	30.97	50.48
18	225.90	92.80	47.40	117.37	86.76	190.25	117.37	44.49	67.67	78.31
19	69.50	36.50	14.80	38.83	26.45	61.05	38.83	16.61	20.63	26.92
20	59.50	39.90	15.50	38.47	20.89	56.02	38.47	20.92	16.29	29.06
21	112.60	36.55	22.70	55.83	44.16	92.92	55.83	18.74	34.44	35.95
22	64.00	34.30	13.00	36.88	24.42	57.39	36.88	16.37	19.05	25.89
23	118.90	50.90	9.10	58.42	51.74	101.88	58.42	14.96	40.36	35.13
24	42.00	22.30	5.50	23.32	16.45	37.14	23.32	9.50	12.83	15.91
25	130.60	28.30	22.30	56.15	62.07	108.29	56.15	4.01	48.41	28.21
26	99.00	8.70	0.80	32.87	53.84	78.10	32.87	-12.36	42.00	8.63

Appendix-5.4

Predicted Weekly Rainfall Value by Gumbel's EV and Log-Normal Distributions

Rainfall in mm

Predicted weekly rainfall by **Gumbel EV distribution (E)**			Co-eff. of variation= SD/Mean weekly rainfall	Co-efficient of skew	K= Log-Probability frequency factor			**Predicted weekly rainfall by Log-Normal**		
I 0.2	I 0.5	I 0.8			K 0.2	K 0.5	K 0.8	I 0.2	I 0.5	I 0.8
257.58	89.71	-36.57	1.58	8.69						
74.35	44.08	21.31	0.69	2.41	0.569	-0.260	-0.740	69.17	40.70	24.22
48.63	30.45	16.77	0.61	2.06	0.604	-0.240	-0.764	46.24	28.83	18.02
136.86	77.27	32.46	0.77	2.75	0.535	-0.270	-0.720	124.37	69.95	39.53
100.10	56.33	23.41	0.77	2.77	0.533	-0.270	-0.720	90.83	50.95	28.60
125.65	61.18	12.69	1.00	4.01	0.419	-0.299	-0.649	103.65	51.13	25.53
143.94	64.92	5.48	1.13	4.83	0.377	-0.300	-0.623	113.21	52.52	23.56
208.45	116.74	47.76	0.78	2.81	0.529	-0.270	-0.719	188.60	105.47	58.75
126.21	55.68	2.62	1.17	5.09	0.370	-0.300	-0.620	98.22	44.60	18.99
95.92	57.07	27.84	0.69	2.38	0.572	-0.258	-0.742	89.40	52.82	31.48
138.66	77.32	31.18	0.79	2.84	0.526	0.270	-0.716	125.17	107.36	38.74
192.15	88.13	9.88	1.10	4.64	0.384	-0.300	-0.624	152.52	71.79	33.56
239.10	100.69	-3.42	1.25	5.67						
135.19	70.16	21.24	0.90	3.42	0.469	-0.290	-0.679	116.68	60.68	31.98
108.00	61.75	26.95	0.75	2.66	0.544	-0.254	-0.724	98.78	56.90	32.23
84.99	60.72	42.47	0.42	1.34	0.702	-0.188	-0.812	84.50	59.99	42.82
96.93	61.93	35.61	0.58	1.94	0.622	-0.238	-0.772	93.04	58.90	37.70
179.82	103.35	45.83	0.74	2.62	0.548	-0.262	-0.728	164.91	94.64	54.21
57.87	34.56	17.02	0.68	2.36	0.574	-0.256	-0.744	54.01	32.06	19.15
53.51	35.09	21.24	0.54	1.79	0.641	-0.220	-0.781	51.86	33.87	22.15
87.62	48.69	19.41	0.79	2.87	0.523	-0.270	-0.713	78.93	43.91	24.34
54.46	32.93	16.74	0.66	2.28	0.582	-0.250	-0.752	51.09	30.78	18.52
95.66	50.06	15.75	0.89	3.35	0.475	-0.295	-0.675	83.00	43.16	23.50
35.16	20.66	9.76	0.71	2.47	0.563	-0.260	-0.740	32.58	19.04	11.15
100.83	46.12	4.97	1.11	4.67	0.383	-0.300	-0.623	79.92	37.53	17.48
71.62	24.17	-11.527	1.64	9.31						

Appendix-5.5

Probability Analysis of Weekly Rainfall by Log Pearson Type-III Distribution

1st Week

Year	weekly rainfall,i (mm)	i in discending order	I = ln I	Rank (m)	(I-I)	(I-I)2	(I-I)3
1996.00	39.20	543.30	6.30	1	2.25	5.05	11.36
1997.00	41.10	133.30	4.89	2	0.84	0.71	0.60
1998.00	19.50	49.20	3.90	3	-0.15	0.02	0.00
1999.00	543.30	41.10	3.72	4	-0.33	0.11	-0.04
2000.00	49.20	39.20	3.67	5	-0.38	0.15	-0.06
2001.00	17.80	19.50	2.97	6	-1.08	1.17	-1.26
2002.00	133.30	17.80	2.88	7	-1.17	1.37	-1.60
			28.32			**8.58**	**8.99**
		I	4.05				

n (no of data) =7

Standard deviation = 1.196

Co-efficient of Skewness = 1.227

KT (Frequency factor) corresponding to 80 % probability (recurrence interval) and skewness of 1.227 from Statistical Table = - 0.844

IT (Rainfall corresponding to 80 % probability) = I + 1.196 * (-0.844) = 3.04

IT in natural domain = exponential to the power 3.04 = **20.9 mm**

KT (Frequency factor) corresponding to 50 % probability (recurrence interval) and skewness of 1.227 from Statistical Table = 0.732

IT (Rainfall corresponding to 50 % probability) = I + 1.196 * (-0.195) = 3.81

IT in natural domain = exponential to the power 3.81 = **45.2 mm**

KT (Frequency factor) corresponding to 20 % probability (recurrence interval) and skewness of 1.227 from Statistical Table = 0.732

IT (Rainfall corresponding to 20 % probability) = I + 1.196 * (0.732) = 4.92

IT in natural domain = exponential to the power 4.92 = **137 mm**

KT (Frequency factor) corresponding to 10 % probability (recurrence interval) and skewness of 1.227 from Statistical Table = 1.34

IT (Rainfall corresponding to 10 % probability) = I + 1.196 * (1.34) = 6.58

IT in natural domain = exponential to the power 6.58 = **720.5 mm**

Computation of Rainfall Erosion-Index (EI30) Appendix-6.1

Month & Year	Date	Rainfall (cm)	Rainfall intensity-I (cm/hr)	KE(=210.3+89log 10I) in metre-ton/ha-cm	KE of rainfall in metre-tonne /hr6(=5*3)	I30(Max 30 minute-Rainfall intensity of the storm in cm/hr)	EI30(=KE of rainfall*I30/100) in metric tonne-cm/ha-hr
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
May,1996	**3**	0.35	0.35	169.72	59.4	1.32	0.78408
		1.65	1.32	221.03	364.7	1.32	4.81404
							5.59812
	11	1.75	2.33	243.00	425.25	2.33	**9.908325**
	12	1.00	2.00	237.09	237.09	2.00	4.7418
		0.23	0.46	180.29	41.47	2.00	0.8294
							5.5712
	16	0.80	3.20	255.26	204.21	1.70	3.47157
		0.10	0.20	148.09	14.81	1.70	0.25177
		0.50	1.00	210.30	105.15	1.70	1.78755
		0.20	0.80	201.68	40.34	1.70	0.68578
							6.19667
	25	2.00	8.00	290.68	581.36	4.00	**23.2544**
	30	2.50	5.00	272.51	681.28	5.00	**34.064**
June,1996	**4**	0.40	1.78	232.59	93.04	9.80	9.11792
		1.90	3.80	261.90	497.61	9.80	48.76578
		0.60	2.40	244.14	146.48	9.80	14.35504
		0.60	1.20	217.35	130.41	9.80	12.78018
							85.01892
	6	0.30	0.20	148.09	44.43	9.40	4.17642
		2.20	8.80	294.36	647.59	9.40	60.87346
		2.50	10.00	299.30	748.25	9.40	70.3355
		0.60	2.40	244.14	146.48	9.40	13.76912
		0.30	1.20	217.35	65.21	9.40	6.12974
							155.28424
	8	1.00	1.33	221.32	221.32	1.33	2.943556
		0.05	0.20	148.09	7.40	1.33	0.09842
		0.10	0.40	174.88	17.49	1.33	0.232617
		0.25	0.50	183.51	45.88	1.33	0.610204
							3.884797
	12	0.20	0.80	201.68	42.14	1.53	0.644742
		1.53	1.53	226.74	346.91	1.53	5.307723
							5.952465
	18	0.13	0.50	183.51	23.86	1.45	0.34597
		1.10	4.40	267.57	294.33	1.45	4.267785
		0.70	2.80	250.09	175.06	1.45	2.53837
							7.152125
	19	0.05	0.20	148.09	7.40	2.0	0.148
		0.07	0.14	134.31	9.40	2.0	0.188
		0.44	1.76	232.15	102.15	2.0	2.043

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.40	1.60	228.47	91.39	2.0	1.8278
		0.90	3.60	259.81	233.83	2.0	4.6766
		0.10	0.04	85.88	8.59	2.0	0.1718
		0.05	0.20	148.09	7.40	2.0	0.148
							9.2032
	20	0.22	0.22	151.78	33.39	0.60	0.20034
		0.07	0.14	134.31	9.4	0.60	0.0564
		0.43	0.29	162.45	69.85	0.60	0.4191
		0.25	0.13	131.44	32.86	0.60	0.19716
		0.30	0.60	190.56	57.17	0.60	0.34302
		0.11	0.04	85.88	9.45	0.60	0.0567
							1.27272
	25	3.55	0.55	187.19	664.53	0.53	**3.522009**
	26	0.05	0.02	59.09	2.95	4.00	0.118
		0.10	0.40	174.88	17.49	4.00	0.6996
		0.20	0.16	139.47	27.89	4.00	1.1156
		0.62	2.48	245.41	152.15	4.00	6.086
		1.00	4.00	263.88	263.88	4.00	10.5552
		1.00	2.00	237.09	237.09	4.00	9.4836
		1.00	1.33	221.32	221.32	4.00	8.8528
		1.00	0.8	210.68	210.68	4.00	8.4272
		1.00	1.00	210.30	210.30	4.00	8.412
		1.00	1.33	221.32	221.32	4.00	8.8528
		1.00	2.00	237.09	237.09	4.00	9.4836
		1.00	4.00	263.88	263.88	4.00	10.5552
		1.00	2.00	237.09	237.09	4.00	9.4836
		0.85	3.40	257.6	218.96	4.00	8.7584
							100.8836
	27	1.00	1.00	210.3	210.3	1.04	2.18712
		2.20	1.33	221.32	44.26	1.04	0.460304
		0.45	1.80	233.02	104.86	1.04	1.090544
		0.35	0.28	161.1	56.39	1.04	0.586456
		0.20	0.40	174.88	34.97	1.04	0.363688
		0.02	0.02	59.09	1.18	1.04	0.012272
							4.700384
	30	0.30	0.60	190.56	57.17	0.60	0.34302
		0.05	0.10	121.30	6.07	0.60	0.03642
		0.10	0.20	148.09	14.81	0.60	0.08886
		0.05	0.07	107.51	5.38	0.60	0.03228
		2.78	0.43	177.68	493.95	0.60	2.9637
							3.46428
July,1996	1	2.77	4.27	266.41	273.96	0.64	1.753344
		2.00	4.70	270.12	540.24	0.64	3.457536
		0.55	4.44	244.78	134.63	0.64	0.861632
		1.45	6.44	282.05	408.97	0.64	2.617408
		1.00	3.07	253.66	453.66	0.64	2.903424
		0.15	1.20	217.35	32.6	0.64	0.20864
							11.801984

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	5	1 55	3 26	255 98	396 77	3 26	12 934702
		1 15	3 29	256 33	294 78	3 29	9 698262
							22 632964
	10	2 38	0 21	149 98	356 95	0 21	**0.749595**
	11	2 38	0 21	149 98	356 95	1 33	4 747435
		1 00	0 67	194 82	194 82	1 33	2 591106
		1 00	0 21	149 98	149 98	1 33	1 994734
		1 00	0 50	183 51	183 53	1 33	2 440949
		1 00	0 30	165 03	165 03	1 33	2 194899
		1 00	2 22	241 13	241 13	1 33	3 207029
		1 00	2 20	240 78	240 78	1 33	3 202374
		1 00	0 67	194 82	194 82	1 33	2 591106
							22.969632
	12	1 00	0 67	194 82	194 82	0 67	1 305294
		1 00	0 33	167 45	167 45	0 67	1 121915
		0 45	0 09	117 23	52 75	0 67.	0 353425
		0 50	0 09	117 23	58 62	0 67	0 392754
							3.173388
	15	0 05	0 20	148 09	7 4	0 75	0 0555
		0 15	0 15	136 97	20 55	0 75	0 154125
		0 75	0 75	199 18	149 39	0 75	1 120425
		0 35	0 23	153 49	53 72	0 75	0 4029
		0 27	0 54	186 48	50 35	0 75	0 377625
		0 02	0 08	112 67	2 25	0 75	0 016875
							2.12745
	29	1 00	0 33	167 45	167 45	4 00	6 698
		1 00	4 00	263 88	263 88	4 00	10 5552
		1 00	4 00	263 88	263 88	4 00	10 5552
		1 00	4 00	263 88	263 88	4 00	10 5552
		1 00	4 00	263 88	263 88	4 00	10 5552
		1 00	2 00	237 09	237 09	4 00	9 4836
		0 73	0 36	170 81	124 69	4 00	4 9876
							63.3900
Aug.,1996	**1**	1 3	5 2	274 02	356 23	2 6	**9.26198**
	3	1 5	0 86	204 47	306 71	0 94	2 883074
		0 82	0 82	202 63	166 16	0 94	1 561904
		0 47	0 94	207 91	97 72	0 94	0 918568
							5.363546
	13	0 15	0 05	94051	14 18	0 8	0 11344
		0 45	0 12	128 35	57 76	0 8	0 46208
		0 4	0 8	201 68	80 67	0 8	0 64536
		0 6	0 15	136 97	82 18	0 8	0 65744
		0 05	0 1	121 3	6 07	0 8	0 04856
							1.92688
	14	1	0 14	134 31	134 31	0 31	0 416361
		1	0 31	165 03	165 03	0 31	0 511593
		0 4	0 23	153 49	61 4	0 31	0 19034
							1.118294

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	15	0.5	0.67	194.82	97.41	0.75	0.730575
		0.15	0.05	94.51	14.18	0.75	0.10635
		0.35	1.4	223.31	78.16	0.75	0.5862
		0.05	0.1	121.3	6.07	0.75	0.045525
		0.35	0.23	153.49	53.72	0.75	0.4029
							1.87155
	20	0.05	0.20	148.09	7.40	1.90	0.1406
		0.95	1.90	235.11	223.35	1.90	4.24365
		0.20	0.80	201.68	40.35	1.90	0.76665
		0.10	0.057	99.57	9.96	1.90	0.18924
							5.34014
	21	1.00	4.00	263.88	263.88	2.00	5.2776
		1.00	1.00	210.3	210.3	2.00	4.206
		0.05	0.05	94.51	4.73	2.00	0.0946
		0.05	0.2	148.09	7.4	2.00	0.148
		0.10	0.10	121.30	12.13	2.00	0.2426
							9.9688
	23	0.3	1.2	217.35	65.2	0.82	0.53464
		0.05	0.2	148.09	7.4	0.82	0.06068
		0.05	0.1	121.3	6.07	0.82	0.049774
		0.1	0.07	107.51	10.75	0.82	0.08815
		1.02	0.82	202.63	206.68	0.82	1.694776
							2.42802
	29	0.8	1.07	212.92	170.33	1.07	1.822531
		0.35	0.7	196.51	68.78	1.07	0.735946
		0.65	0.43	177.67	115.49	1.07	1.235743
		0.4	0.4	174.88	69.95	1.07	0.748465
							4.542685
	30	0.80	1.07	212.92	170.34	1.07	1.822638
		0.35	0.70	196.51	68.78	1.07	0.735946
		0.65	0.43	177.68	115.49	1.07	1.235743
		0.40	0.40	174.88	69.95	1.07	0.748465
		0.60	0.17	141.81	85.09	1.07	0.910463
							5.453255
Sept,1996	8	1.00	4.00	263.88	263.88	2.80	7.38864
		0.40	1.60	228.47	91.39	2.80	2.55892
		0.60	2.40	244.14	146.48	2.80	4.10144
		0.75	3.00	252.76	189.57	2.80	5.30796
		0.05	0.05	94.51	4.73	2.80	0.13244
							19.4894
	14	1.00	4.00	263.88	263.88	2.70	7.12476
		0.35	1.40	223.39	78.36	2.70	2.11572
		0.65	2.60	247.23	160.70	2.70	4.3389
		0.40	0.09	117.23	46.89	2.70	1.26603
							14.84541
	25	1.00	1.33	221.32	221.32	1.33	2.943556
		0.20	0.40	174.88	34.98	1.33	0.465234
		0.05	0.02	59.09	2.95	1.33	0.039235

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.20	0.40	174.88	34.98	1.33	0.465234
							3.913259
	30	0.02	0.04	85.88	1.72	2.40	0.04128
		0.18	0.72	197.6	35.57	2.40	0.85368
		0.8	1.6	228.47	182.77	2.40	4.38648
		0.05	0.1	121.3	6.07	2.40	0.14568
		1.2	2.4	244.14	292.97	2.40	7.03128
		1.05	1.39	223.03	234.18	2.40	5.62032
							18.07872
Oct.,1996	1	1.3	5.2	274.02	356.23	2.6	9.26198
	3	1.25	1.25	218.92	273.65	1.25	3.420625
		1.07	0.61	191.19	204.57	1.25	2.557125
		0.47	0.47	181.12	85.12	1.25	1.064
							16.30373
	4	0.10	0.40	174.88	17.49	3.80	0.66462
		0.90	3.60	259.81	223.83	3.80	8.50554
		1.00	4.00	263.88	263.88	3.80	10.02744
		0.15	0.15	136.17	20.59	3.80	0.78242
							19.98002
	5	1.00	0.36	170.81	170.81	0.36	0.614916
		0.4	0.32	166.26	66.5	0.36	0.2394
		0.1	0.2	148.09	14.81	0.36	0.053316
		0.03	0.12	128.35	3.85	0.36	0.01386
		0.03	0.12	128.35	3.85	0.36	0.01386
		0.15	0.15	136.97	20.55	0.36	0.07398
							1.009332
	13	0.1	0.4	174.88	17.49	0.40	0.06996
		0.05	0.03	74076	3.74	0.40	0.01496
		0.2	0.4	174.88	34.98	0.40	0.13992
		0.2	0.06	101.56	20.31	0.40	0.08124
		0.95	0.38	172.9	164.26	0.40	0.65704
		0.1	0.04	85.88	8.59	0.40	0.03436
							0.99748
	14	0.15	0.3	163.7637917	24.56456875	0.49	0.120366387
		0.15	0.05	94.50833039	14.17624956	0.49	0.069463623
		0.1	0.1	121.3	12.13	0.49	0.059437000
		0.05	0.03	74.76379167	3.738189584	0.49	0.018317129
		0.1	0.2	148.0916696	14.80916696	0.49	0.072564918
		0.45	0.36	170.8109226	76.86491516	0.49	0.376638084
		0.27	0.15	136.9721221	36.98247296	0.49	0.181214117
		0.73	0.49	182.7274511	133.3910393	0.49	0.653616093
		0.4	0.27	159.691375	63.87655	0.49	0.312995095
							1.864612446
	15	0.05	0.2	148.0916696	7.404583481	0.90	0.066641251
		0.4	1.6	228.4666785	91.38667138	0.90	0.822480042
		0.15	0.05	94.50833039	14.17624956	0.90	0.127586246
		0.05	0.1	121.3	6.065	0.90	0.054585
		0.4	0.53	185.7605524	74.30422096	0.90	0.668737989

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0 3	0 24	155 1388005	46 54164015	0 90	0 418874761
							2 15890529
	20	0 05	0 1	121 3	6 065	1 80	0 10917
		1 35	1 8	233 019253	314 5759915	1 80	5 662367847
		0 1	0 06	101 5554613	10 15554613	1 80	0 18279983
							5 954337677
	21	2 00	2 00	237 0916696	474 1833392	2 00	9 483666785
		0 05	0 05	94 50833039	4 725416519	2 00	0 09450833
		0 05	0 20	148 0916696	7 404583481	2 00	0 14809167
		0 10	0 13	131 4409584	13 14409584	2 00	0 262881917
							9 989148701
	23	0 30	1 20	217 3471309	65 20413927	1 00	0 652041393
		0 05	0 20	148 0916696	7 404583481	1 00	0 074045835
		0 05	0 07	107 5137256	5 375686278	1 00	0 053756863
		0 10	0 07	107 5137256	10 75137256	1 00	0 107513726
		1 00	1 00	210 3	210 3	1 00	2 103
							2 990357816
	29	0 10	0 20	148 0916696	14 80916696	1 40	0 207328337
		0 07	0 14	134 3053952	9 401377662	1 40	0 131619287
		0 10	0 20	148 0916696	14 80916696	1 40	0 207328337
		1 05	1 40	223 3053952	234 4706649	1 40	3 282589309
		1 10	0 44	178 5672882	196 424017	1 40	2 749936238
							6.57880151
May,1997	1	2 92	1 95	236 1130804	689 4501948	1 95	**13.4442788**
	19	0 03	0 03	74 76379167	2 24291375	0 35	0 007850198
		0 18	0 12	128 3471309	23 10248356	0 35	0 080858692
		0 05	0 03	74 76379167	3 738189584	0 35	0 013083664
		0 15	0 15	136 9721221	20 54581831	0 35	0 071910364
		0 55	0 09	117 2275833	64 47517084	0 35	0 225663098
		1 30	0 35	169 7220559	220 6386727	0 35	0 772235355
		0 05	0 20	148 0916696	7 404583481	0 35	0 025916042
							1.197517413
	22	0 55	1 10	213 983949	117 6911719	1 10	1 294602891
		0 80	0 36	170 8109226	136 6487381	1 10	1 503136119
		0 80	0 64	193 0500177	154 4400141	1 10	1 698840156
							4 496579166
	28	1 00	4 00	263 88	263 88	4 00	10 55520000
		1 00	4 00	263 88	263 88	4 00	10 55520000
		1 00	4 00	263 88	263 88	4 00	10 55520000
		0 40	1 60	228 47	91 39	4 00	3 65560000
		0 30	0 15	136 97	41 09	4 00	1 64360000
							36.96480000
June,1997	10	1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 52	0 30	163 76379	85 15717	1 33	1 132590383
		0 48	0 64	193 05002	92 66401	1 33	1 232431313
		0 25	0 11	124 98395	31 24599	1 33	0 41557163
							5.724186514
	17	0 05	0 20	148 09167	7 40458	1 00	0 074045835

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		1 00	1 00	210 30000	210 30000	1 00	2 103
		0 25	0 12	128 34713	32 08678	1 00	0 320867827
							2.497913662
	19	0 85	0 57	188 57286	160 28693	0 57	0 913635517
		1 00	0 57	188 57286	188 57286	0 57	1 074865314
							1.988500831
	24	0 85	0 24	155 13880	131 86798	0 32	0 421977537
		0 95	0 32	166 25835	157 94543	0 32	0 505425378
							0.927402916
	27	0 75	0 17	141 80995	106 35747	1 33	1 414554291
		0 15	0 02	59 09167	8 86375	1 33	0 117887881
		0 70	0 70	196 51373	137 55961	1 33	1 829542785
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 40	0 27	159 69138	63 87655	1 33	0 849558115
							7.155136259
July,1997	7	1 10	1 10	213 98395	235 38234	1 10	2 589205783
		0 35	0 08	112 67501	39 43625	1 10	0 433798784
		0 20	0 40	174 88334	34 97667	1 10	0 384743346
		0 20	0 07	107 51373	21 50275	1 10	0 236530196
							3.644278109
	15	0 20	0 80	201 67501	40 33500	2 95	1 189882552
		0 50	1 00	210 30000	105 15000	2 95	3 101925
		0 05	0 07	107 51373	5 37569	2 95	0 158582745
		0 25	0 50	183 50833	45 87708	2 95	1 353373937
		1 00	4 00	263 88334	263 88334	2 95	7 784558507
		0 95	1 90	235 10907	223 35362	2 95	6 5889317
		0 05	0 07	107 51373	5 37569	2 95	0 158582745
		0 10	0 40	174 88334	17 48833	2 95	0 515905851
		0 15	0 15	136 97212	20 54582	2 95	0 60610164
		0 35	0 08	112 67501	39 43625	2 95	1 163369466
							22.62121414
	26	0 10	0 40	174 88334	17 48833	2 47	0 431961848
		1 85	2 47	245 25003	453 71255	2 47	11 20670007
		0 05	0 03	74 76379	3 73819	2 47	0 092333283
							11.7309952
Aug.,1997	2	1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 30	0 20	148 09167	44 42750	1 33	0 590885762
		0 05	0 03	74 76379	3 73819	1 33	0 049717921
							3.584196871
	3	0 95	0 95	208 31740	197 90153	0 95	1 880064543
		1 30	1 04	211 81597	275 36076	0 95	2 615927195
		0 05	0 20	148 09167	7 40458	0 95	0 070343543
		0 35	0 35	169 72206	59 40272	0 95	0 564325836
		0 15	0 10	121 30000	18 19500	0 95	0 1728525
							5.303513617
	5	0 95	0 95	208 31740	197 90153	1 04	2 058175921
		1 30	1 04	211 81597	275 36076	1 04	2 863751877
		0 05	0 20	148 09167	7 40458	1 04	0 077007668

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.35	0.35	169.72206	59.40272	1.04	0.617788284
		0.15	0.10	121.30000	18.19500	1.04	0.189228
		0.15	0.05	94.50833	14.17625	1.04	0.147432995
							5.953384744
	10	1.00	0.50	183.50833	183.50833	0.96	1.761679972
		0.60	0.16	139.46668	83.68001	0.96	0.803328068
		0.30	0.20	148.09167	44.42750	0.96	0.426504008
		0.10	0.03	74.76379	7.47638	0.96	0.07177324
		0.25	0.33	167.44774	41.86194	0.96	0.401874578
		2.15	0.96	208.72214	448.75260	0.96	4.308024964
		0.05	0.04	85.88334	4.29417	0.96	0.041224003
							7.814408833
	11	1.00	1.00	210.30000	210.30000	1.00	2.103
		0.20	0.20	148.09167	29.61833	1.00	0.296183339
		0.05	0.01	32.30000	1.61500	1.00	0.01615
		0.10	0.08	112.67501	11.26750	1.00	0.112675009
		0.20	0.40	174.88334	34.97667	1.00	0.349766678
		0.05	0.04	85.88334	4.29417	1.00	0.04294167
		0.40	0.32	166.25835	66.50334	1.00	0.665033392
							3.585750088
	13	1.00	0.31	165.03119	165.03119	0.80	1.320249526
		0.45	0.60	190.55546	85.74996	0.80	0.685999661
		0.25	0.33	167.44774	41.86194	0.80	0.334895481
							2.341144668
	14	0.33	0.65	193.64929	63.90427	1.60	1.022468245
		1.00	0.50	183.50833	183.50833	1.60	2.936133286
		1.00	0.80	201.67501	201.67501	1.60	3.226800141
		0.05	0.20	148.09167	7.40458	1.60	0.118473336
		0.05	0.07	107.51373	5.37569	1.60	0.08601098
		0.08	0.15	136.97212	10.95777	1.60	0.175324316
		0.15	0.12	128.34713	19.25207	1.60	0.308033114
		0.55	0.55	187.19228	102.95575	1.60	1.647292058
							9.520535477
	20	0.70	2.80	250.09706	175.06795	3.20	5.602174251
		4.80	3.20	255.25835	1225.24007	3.20	39.20768226
		0.45	0.26	158.23263	71.20468	3.20	2.278549843
							47.08840636
	22	0.80	1.60	228.46668	182.77334	1.60	2.924373484
		0.20	0.40	174.88334	34.97667	1.60	0.559626686
		0.75	1.00	210.30000	157.72500	1.60	2.5236
							6.00760017
	28	0.55	0.55	187.19228	102.95575	0.57	0.586847796
		0.10	0.01	32.30000	3.23000	0.57	0.018411
		1.00	0.57	188.57286	188.57286	0.57	1.074865314
							1.68012411
	29	0.40	0.53	185.76055	74.30422	1.80	1.337475977
		0.30	0.30	163.76379	49.12914	1.80	0.884324475
		0.90	1.80	233.01925	209.71733	1.80	3.774911898

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.14	0.11	124.98395	17.49775	1.80	0.314959551
							6.311671902
	31	0.90	0.72	197.60259	177.84233	0.72	1.280464797
		0.50	0.33	167.44774	83.72387	0.72	0.602811866
							1.883276664
Sept.,1997	**3**	1.00	1.00	210.30000	210.30000	2.00	4.206
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	1.00	210.30000	210.30000	2.00	4.206
		1.00	0.80	201.67501	201.67501	2.00	4.033500177
		1.00	0.57	188.57286	188.57286	2.00	3.771457243
		0.10	0.40	174.88334	17.48833	2.00	0.349766678
		0.35	0.12	128.34713	44.92150	2.00	0.898429916
							22.20698741
	13	0.05	0.20	148.09167	7.40458	1.44	0.106626002
		0.9	0.72	197.60259	177.84233	1.44	2.560929595
		1.00	0.67	194.82066	194.82066	1.44	2.805417467
		1.00	0.33	167.44774	167.44774	1.44	2.411247465
		0.10	0.04	85.88334	8.58833	1.44	0.123672008
		0.03	0.03	74.76379	2.24291	1.44	0.032297958
							8.040190496
	19	0.80	0.40	174.88334	139.90667	0.50	0.699533357
		0.25	0.50	183.50833	45.87708	0.50	0.229385413
		0.43	0.12	128.34713	55.18927	0.50	0.275946331
							1.204865101
	22	1.00	0.50	183.50833	183.50833	1.40	2.569116625
		0.70	1.40	223.30540	156.31378	1.40	2.188392873
		0.30	1.20	217.34713	65.20414	1.40	0.91285795
		0.65	1.30	220.44096	143.28662	1.40	2.006012721
		0.05	0.05	94.50833	4.72542	1.40	0.066155831
							7.742536
	23	0.30	0.67	194.82066	58.44620	0.40	0.233784789
		1.00	0.50	183.50833	183.50833	0.40	0.734033322
		0.65	0.52	185.02430	120.26579	0.40	0.481063174
		0.10	0.08	112.67501	11.26750	0.40	0.045070004
							1.493951288
Oct.,1997	**9**	0.10	0.20	148.09167	14.80917	2.00	0.296183339
		0.90	1.20	217.34713	195.61242	2.00	3.912248356
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		0.30	0.40	174.88334	52.46500	2.00	1.049300035
							9.999565123
	19	2.65	3.53	259.05195	686.48766	3.53	**24.23301455**
May,1998	**18**	1.00	0.50	183.50833	183.50833	1.20	2.202099965
		0.90	1.20	217.34713	195.61242	1.20	2.347349014
							4.549448978
	28	0.38	1.5	225.97212	85.86941	2.00	1.717388128
		0.63	1.25	218.92499	137.92274	2.00	2.758454889
		5.00	2.00	237.09167	1185.45835	2.00	23.70916696
		0.40	0.80	201.67501	80.67000	2.00	1.613400071

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
							29.79841005
June,1998	**2**	1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 35	0 70	196 51373	68 77980	1 33	0 914771392
							3 85836458
	14	1 00	1 00	210 30000	210 30000	1 00	2 103
		0 38	0 65	193 64929	73 58673	1 00	0 735867297
							2.838867297
	17	0 15	0 60	190 55546	28 58332	0 60	0 171499915
		0 05	0 10	121 30000	6 06500	0 60	0 03639
		0 05	0 20	148 09167	7 40458	0 60	0 044427501
		0 20	0 27	159 69138	31 93828	0 60	0 19162965
		0 53	0 42	176 76919	93 68767	0 60	0 562126014
		0 45	*0 45*	*179 43591*	*80 74616*	*0 60*	*0 484476967*
							1.490550047
	18	0 25	0 25	156 71666	39 17917	0 50	0 195895826
		0 23	0 30	163 76379	37 66567	0 50	0 18832836
		0 05	0 07	107 51373	5 37569	0 50	0 026878431
		0 50	0 50	183 50833	91 75417	0 50	0 458770826
		0 45	0 40	174 88334	78 69750	0 50	0 393487513
							1.263360957
July,1998	**11**	0 93	1 85	234 07828	217 69280	2 00	4 353856079
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	0 50	183 50833	183 50833	2 00	3 670166608
		0 55	0 31	165 03119	90 76715	2 00	1 815343098
		0 13	0 25	156 71666	20 37317	2 00	0 407463318
		0 08	0 15	136 97212	10 95777	2 00	0 219155395
							15.20781789
	13	0 35	0 23	153 49378	53 72282	0 37	0 198774442
		0 65	0 37	171 86995	111 71547	0 37	0 413347238
		0 10	0 13	131 44096	13 14410	0 37	0 048633155
		0 15	0 10	121 30000	18 19500	0 37	0 0673215
		0 25	0 20	148 09167	37 02292	0 37	0 136984794
		0 05	0 02	59 09167	2 95458	0 37	0 010931959
		0 25	0 11	124 98395	31 24599	0 37	0 115610153
							0.99160324
	14	0 25	0 20	148 09167	37 02292	1 00	0 370229174
		0 05	0 02	59 09167	2 95458	1 00	0 029545835
		0 25	0 15	136 97212	34 24303	1 00	0 342430305
		1 00	1 00	210 30000	210 30000	1 00	2 103
		0 35	0 16	139 46668	48 81334	1 00	0 488133375
		0 10	0 20	148 09167	14 80917	1 00	0 14809167
							3.481430358
	15	0 03	0 10	121 30000	3 63900	0 80	0 029112
		0 13	0 50	183 50833	23 85608	0 80	0 190848664
		0 05	0 20	148 09167	7 40458	0 80	0 059236668
		0 03	0 10	121 30000	3 63900	0 80	0 029112
		0 13	0 50	183 50833	23 85608	0 80	0 190848664
		0 13	0 25	156 71666	20 37317	0 80	0 162985327

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.58	0.38	172.90074	100.28243	0.80	0.802259434
		1.00	0.33	167.44774	167.44774	0.80	1.339581925
		1.00	0.80	201.67501	201.67501	0.80	1.613400071
		0.15	0.30	163.76379	24.56457	0.80	0.19651655
							4.613901302
	16	0.58	0.38	172.90074	100.28243	0.80	0.802259434
		1.00	0.33	167.44774	167.44774	0.80	1.339581925
		1.00	0.80	201.67501	201.67501	0.80	1.613400071
		0.15	0.30	163.76379	24.56457	0.80	0.19651655
							3.95175798
	17	0.70	0.56	187.88873	131.52211	0.56	0.736523839
		1.00	0.50	183.50833	183.50833	0.56	1.02764665
		0.15	0.20	148.09167	22.21375	0.56	0.124397002
							1.888567491
	19	0.60	0.30	163.76379	98.25828	4.00	3.930331
		0.40	1.60	228.46668	91.38667	4.00	3.655466855
		0.30	1.20	217.34713	65.20414	4.00	2.608165571
		0.70	2.20	240.77562	168.54293	4.00	6.741717321
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	1.00	210.30000	210.30000	4.00	8.412
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		4.00	5.33	274.97872	1099.91489	4.00	43.99659546
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	0.50	183.50833	183.50833	4.00	7.340333215
		0.65	0.87	204.91721	133.19619	4.00	5.327847551
							160.4660367
	20	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		1.00	0.44	178.56729	178.56729	1.33	2.374944933
		0.20	0.33	167.44774	33.48955	1.33	0.44541099
							8.707542298
Aug.,1998	**1**	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.55	1.10	213.98395	117.69117	1.33	1.565292587
		0.05	0.05	94.50833	4.72542	1.33	0.06284804
		0.40	0.53	185.76055	74.30422	1.33	0.988246139
		1.00	0.67	194.82066	194.82066	1.33	2.591114744
		0.30	0.60	190.55546	57.16664	1.33	0.760316291
							8.911410987
	2	1.00	0.57	188.57286	188.57286	0.57	1.074865314
		0.25	0.33	167.44774	41.86194	0.57	0.23861303
							1.313478345
	14	0.05	0.03	74.76379	3.73819	2.80	0.104669308
		0.15	0.30	163.76379	24.56457	2.80	0.687807925

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.02	0.03	74.76379	1.49528	1.33	0.019887169
		0.05	0.10	121.30000	6.06500	1.33	0.0806645
							10.15295737
	28	1.00	1.33	221.32280	221.32280	1.30	2.877196349
		0.25	0.50	183.50833	45.87708	1.30	0.596402074
		0.05	0.01	32.30000	1.61500	1.30	0.020995
		0.05	0.20	148.09167	7.40458	1.30	0.096259585
							3.590853008
	29	1.00	0.50	183.50833	183.50833	4.00	7.340333215
		1.00	0.50	183.50833	183.50833	4.00	7.340333215
		0.15	0.20	148.09167	22.21375	4.00	0.888550018
		0.85	0.85	204.01828	173.41554	4.00	6.936621669
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		0.15	0.15	136.97212	20.54582	4.00	0.821832732
		0.05	0.14	134.30540	6.71527	4.00	0.26861079
							83.7132827
	30	0.55	0.37	171.86995	94.52847	2.00	1.890569488
		1.00	0.57	188.57286	188.57286	2.00	3.771457243
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		0.50	0.67	194.82066	97.41033	2.00	1.948206574
		0.10	0.13	131.44096	13.14410	2.00	0.262881917
		0.07	*0.28*	*161.09706*	*11.27679*	*2.00*	*0.225535891*
		0.02	0.08	112.67501	2.25350	2.00	0.045070004
		0.05	0.20	148.09167	7.40458	2.00	0.14809167
							21.88655802
	31	0.15	0.03	74.76379	11.21457	1.33	0.149153764
		0.85	0.43	177.67869	151.02689	1.33	2.008657619
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.50	0.67	194.82066	97.41033	1.33	1.295557372
							6.396961943
Sept.,1998	**1**	1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		0.22	0.18	144.01925	31.68424	4.00	1.267369426
							70.23728233
	3	0.88	0.44	178.56729	157.13921	0.45	0.707126461
		1.00	0.31	165.03119	165.03119	0.45	0.742640358

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		1 00	0 31	165 03119	165 03119	0 45	0 742640358
		0 08	0 32	166 25835	13 30067	0 45	0 059853005
							2.252260183
	16	0 05	0 05	94 50833	4 72542	8 00	0 378033322
		0 75	2 00	237 09167	177 81875	8 00	14 22550018
		0 20	0 40	174 88334	34 97667	8 00	2 798133428
		4 00	8 00	290 67501	1162 70004	8 00	93 01600283
							110.4176698
	20	0 15	0 20	148 09167	22 21375	3 70	0 821908766
		0 85	3 40	257 60162	218 96138	3 70	8 101571063
		1 00	4 00	263 88334	263 88334	3 70	9 763683551
		0 47	0 94	207 90838	97 71694	3 70	3 61552671
							22.30269009
Oct.,1998	**3**	1 00	2 00	237 09167	237 09167	2 80	6 638566749
		1 00	4 00	263 88334	263 88334	2 80	7 388733498
		0 40	1 60	228 46668	91 38667	2 80	2 558826799
		0 10	0 20	148 09167	14 80917	2 80	0 414656675
							17.00078372
May,1999	**2**	1 00	0 36	170 81092	170 81092	0 60	1 024865535
		0 20	0 60	190 55546	38 11109	0 60	0 228666554
		0 05	0 02	59 09167	2 95458	0 60	0 017727501
		0 05	0 10	121 30000	6 06500	0 60	0 03639
							1.30764959
	4	0 15	0 60	190 55546	28 58332	1 60	0 457333107
		0 65	2 60	247 23263	160 70121	1 60	2 571219331
		0 10	0 10	121 30000	12 13000	1 60	0 19408
		0 25	0 50	183 50833	45 87708	1 60	0 734033322
		0 20	0 27	159 69138	31 93828	1 60	0 5110124
		0 35	0 28	161 09706	56 38397	1 60	0 902143563
		0 10	0 40	174 88334	17 48833	1 60	0 279813343
		0 35	0 14	134 30540	47 00689	1 60	0 752110213
		0 26	0 26	158 23263	41 14048	1 60	0 658247732
							7.05999301
	5	0 90	0 33	167 44774	150 70297	3 70	5 576009764
		0 15	0 07	107 51373	16 12706	3 70	0 596701177
		0 85	3 40	257 60162	218 96138	3 70	8 101571063
		1 00	4 00	263 88334	263 88334	3 70	9 763683551
		1 00	2 00	237 09167	237 09167	3 70	8 772391776
		0 40	1 60	228 46668	91 38667	3 70	3 381306841
		0 25	0 25	156 71666	39 17917	3 70	1 449629112
							37.64129328
	6	0 05	0 20	148 09167	7 40458	1 60	0 118473336
		0 85	1 13	215 02398	182 77038	1 60	2 924326148
		0 05	0 20	148 09167	7 40458	1 60	0 118473336
		0 40	1 60	228 46668	91 38667	1 60	1 462186742
		0 25	1 00	210 30000	52 57500	1 60	0 8412
		0 27	0 54	186 48304	50 35042	1 60	0 805606753
		0 40	0 32	166 25835	66 50334	1 60	1 064053428

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.10	0.20	148.09167	14.80917	2.80	0.414656675
		0.70	2.80	250.09706	175.06795	2.80	4.90190247
		0.30	0.60	190.55546	57.16664	2.80	1.600665875
		0.05	0.04	85.88334	4.29417	2.80	0.120236675
		0.15	0.15	136.97212	20.54582	2.80	0.575282913
		0.03	0.06	101.55546	3.04666	2.80	0.085306587
		0.15	0.30	163.76379	24.56457	2.80	0.687807925
		0.35	0.09	117.22758	41.02965	2.80	1.148830317
		0.07	0.07	107.51373	7.52596	2.80	0.210726902
							10.53789357
	16	0.22	0.13	131.44096	28.91701	1.04	0.300736913
		0.78	1.04	211.81597	165.21645	1.04	1.718251126
		1.00	0.44	178.56729	178.56729	1.04	1.857099797
		0.20	0.09	117.22758	23.44552	1.04	0.243833373
		0.80	0.64	193.05002	154.44001	1.04	1.606176147
		1.00	0.50	183.50833	183.50833	1.04	1.908486636
		1.00	0.80	201.67501	201.67501	1.04	2.097420092
		0.20	0.40	174.88334	34.97667	1.04	0.363757346
		0.40	0.80	201.67501	80.67000	1.04	0.838968037
							10.93472947
	17	1.00	0.44	178.56729	178.56729	0.80	1.428538306
		1.00	0.80	201.67501	201.67501	0.80	1.613400071
		0.55	0.44	178.56729	98.21201	0.80	0.785696068
		0.10	0.02	59.09167	5.90917	0.80	0.047273336
		0.10	0.03	74.76379	7.47638	0.80	0.059811033
							3.934718814
	22	0.08	0.03	74.76379	5.98110	2.00	0.119622067
		0.19	1.84	233.86879	44.43507	2.00	0.888701388
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	0.57	188.57286	188.57286	2.00	3.771457243
		0.40	0.16	139.46668	55.78667	2.00	1.115733428
							10.63734752
	23	1.00	1.00	210.30000	210.30000	1.00	2.103
		0.55	0.27	159.69138	87.83026	1.00	0.878302563
		0.45	0.20	148.09167	66.64125	1.00	0.666412513
		0.05	0.03	74.76379	3.73819	1.00	0.037381896
		0.01	0.007	18.51373	0.18514	1.00	0.001851373
		0.04	0.16	139.46668	5.57867	1.00	0.055786671
							3.742735016
	25	1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	1.00	210.30000	210.30000	4.00	8.412
		0.10	0.13	131.44096	13.14410	4.00	0.525763833
							19.4930974
	26	0.95	0.95	208.31740	197.90153	1.33	2.63209036
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		1.00	1.23	218.30155	218.30155	1.33	2.90341068
		0.50	1.00	210.30000	105.15000	1.33	1.398495
		0.10	0.13	131.44096	13.14410	1.33	0.174816475

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
							7.334319742
	8	0.05	0.20	148.09167	7.40458	3.86	0.285816922
		0.93	3.72	261.07832	242.80284	3.86	9.372189591
		1.00	4.00	263.88334	263.88334	3.86	10.18589689
		0.68	0.91	206.65468	140.52519	3.86	5.424272143
							25.26817555
	10	1.00	2.00	237.09167	237.09167	1.67	3.959430883
		1.00	4.00	263.88334	263.88334	1.67	4.406851765
		1.00	1.32	221.03108	221.03108	1.67	3.691219034
							12.05750168
	13	0.20	0.40	174.88334	34.97667	2.46	0.860426029
		0.80	1.60	228.46668	182.77334	2.46	4.496224232
		1.00	4.00	263.88334	263.88334	2.46	6.491530145
		0.23	0.92	207.07712	47.62774	2.46	1.171642326
							13.01982273
	22	0.97	0.97	209.12268	202.84900	2.00	4.056980076
		1.00	1.00	210.30000	210.30000	2.00	4.206
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		0.48	0.64	193.05002	92.66401	2.00	1.85328017
		0.22	0.22	151.77562	33.39064	2.00	0.667812722
		0.02	0.02	59.09167	1.18183	2.00	0.023636668
		0.07	0.14	134.30540	9.40138	2.00	0.188027553
							24.27510495
	23	0.20	0.16	139.46668	27.89334	1.60	0.446293371
		0.80	1.60	228.46668	182.77334	1.60	2.924373484
		1.00	0.31	165.03119	165.03119	1.60	2.640499052
		0.90	1.20	217.34713	195.61242	1.60	3.129798685
		1.00	0.80	201.67501	201.67501	1.60	3.226800141
		1.00	1.33	221.32280	221.32280	1.60	3.541164737
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.25	1.00	210.30000	52.57500	1.33	0.6992475
		0.15	0.12	128.34713	19.25207	1.33	0.256052526
		0.15	0.15	136.97212	20.54582	1.33	0.273259384
							20.08108207
	29	0.17	0.05	94.50833	16.06642	1.20	0.192796994
		0.15	0.15	136.97212	20.54582	1.20	0.24654982
		0.05	0.01	32.30000	1.61500	1.20	0.01938
		0.20	0.40	174.88334	34.97667	1.20	0.419720014
		0.40	0.09	117.22758	46.89103	1.20	0.5626924
		1.00	0.22	151.77562	151.77562	1.20	1.821307423
		1.00	0.50	183.50833	183.50833	1.20	2.202099965
		1.00	0.67	194.82066	194.82066	1.20	2.337847889
		1.00	0.80	201.67501	201.67501	1.20	2.420100106
		1.00	1.00	210.30000	210.30000	1.20	2.5236
		0.90	1.20	217.34713	195.61242	1.20	2.347349014
							15.09344362

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	30	1 00	1 33	221 32280	221 32280	1 33	2 943593187
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 50	0 50	183 50833	91 75417	1 33	1 220330397
		0 30	0 17	141 80995	42 54299	1 33	0 565821716
		0 20	0 80	201 67501	40 33500	1 33	0 536455524
		0 10	0 40	174 88334	17 48833	1 33	0 232594841
							8 442388853
June,1999	**7**	1 00	1 33	221 32280	221 32280	2 40	5 311747105
		1 00	4 00	263 88334	263 88334	2 40	6 333200141
		1 00	0 80	201 67501	201 67501	2 40	4 840200212
		0 10	0 20	148 09167	14 80917	2 40	0 355420007
							16.84056747
	23	0 25	0 25	156 71666	39 17917	1 00	0 391791652
		0 08	0 32	166 25835	13 30067	1 00	0 133006678
		0 20	0 20	148 09167	29 61833	1 00	0 296183339
		0 20	0 20	148 09167	29 61833	1 00	0 296183339
		0 20	0 10	121 30000	24 26000	1 00	0 2426
		1 00	0 44	178 56729	178 56729	1 00	1 785672882
		1 00	0 57	188 57286	188 57286	1 00	1 885728622
		0 75	1 00	210 30000	157 72500	1 00	1 57725
		0 25	0 14	134 30540	33 57635	1 00	0 335763488
		0 35	0 70	196 51373	68 77980	1 00	0 687798039
		0 35	0 09	117 22758	41 02965	1 00	0 410296542
		0 84	0 04	85 88334	72 14200	1 00	0 72142005
							8.763694631
	24	0 70	0 15	136 97212	95 88049	1 33	1 275210456
		0 05	0 10	121 30000	6 06500	1 33	0 0806645
		0 20	0 07	107 51373	21 50275	1 33	0 28598651
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 60	1 20	217 34713	130 40828	1 33	1 734430105
		0 15	0 60	190 55546	28 58332	1 33	0 380158145
		0 10	0 04	85 88334	8 58833	1 33	0 114224841
							6.814267745
	29	0 05	0 07	107 51373	5 37569	2 00	0 107513726
		0 25	0 33	167 44774	41 86194	2 00	0 837238703
		0 15	0 12	128 34713	19 25207	2 00	0 385041393
		0 10	0 10	121 30000	12 13000	2 00	0 2426
		0 05	0 20	148 09167	7 40458	2 00	0 14809167
		0 32	0 64	193 05002	61 77601	2 00	1 235520113
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	0 44	178 56729	178 56729	2 00	3 571345764
		0 35	1 40	223 30540	78 15689	2 00	1 563137766
		0 65	0 37	171 86995	111 71547	2 00	2 234309395
		0 55	0 31	165 03119	90 76715	2 00	1 815343098
							16.88197502
July,1999	**1**	0 40	0 32	166 25835	66 50334	0 50	0 332516696
		0 20	0 07	107 51373	21 50275	0 50	0 107513726
		4 00	0 50	183 50833	734 03332	0 50	3 670166608

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.15	0.30	163.76379	24.56457	0.50	0.122822844
		0.40	0.40	174.88334	69.95334	0.50	0.349766678
							4.582786552
	3	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.50	*2.00*	*237.09167*	*118.54583*	*1.33*	*1.576659603*
							4.52025279
	8	0.10	0.13	131.44096	13.14410	2.00	0.262881917
		0.10	0.40	174.88334	17.48833	2.00	0.349766678
		0.05	0.07	107.51373	5.37569	2.00	0.107513726
		0.05	0.20	148.09167	7.40458	2.00	0.14809167
		0.08	0.30	163.76379	13.10110	2.00	0.262022067
		0.55	1.10	213.98395	117.69117	2.00	2.353823439
		1.00	2.10	238.97752	238.97752	2.00	4.779550345
		0.83	1.11	214.33375	177.89701	2.00	3.557940169
							11.82159001
	9	1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	*1.00*	*210.30000*	*210.30000*	*4.00*	*8.412*
		1.00	1.00	210.30000	210.30000	4.00	8.412
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	0.80	201.67501	201.67501	4.00	8.067000354
		1.00	0.50	183.50833	183.50833	4.00	7.340333215
		1.00	0.25	156.71666	156.71666	4.00	6.268666431
		0.15	*0.30*	163.76379	24.56457	4.00	0.98258275
		0.05	0.03	74.76379	3.73819	4.00	0.149527583
		0.10	0.02	59.09167	5.90917	4.00	0.236366678
		0.05	0.03	74.76379	3.73819	4.00	0.149527583
							91.09225071
	10	1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	0.50	183.50833	183.50833	2.00	3.670166608
		1.00	*2.00*	237.09167	237.09167	2.00	4.741833392
		1.00	0.80	201.67501	201.67501	2.00	4.033500177
		0.30	0.60	190.55546	57.16664	2.00	1.143332768
		0.10	*0.20*	148.09167	14.80917	2.00	0.296183339
		0.20	0.40	174.88334	34.97667	2.00	0.699533357
		0.23	0.23	153.49378	35.30357	2.00	0.706071376
		0.10	0.03	74.76379	7.47638	2.00	0.149527583
							19.86660452
	11	0.35	0.12	128.34713	44.92150	1.00	0.449214958
		1.00	1.00	210.30000	210.30000	1.00	2.103
		1.00	0.80	201.67501	201.67501	1.00	2.016750088
		0.93	0.31	165.03119	153.47901	1.00	1.534790074
							6.103755121
	12	0.75	0.60	190.55546	142.91660	1.67	2.386707153
		0.25	0.33	167.44774	41.86194	1.67	0.699094317
		0.50	0.67	194.82066	97.41033	1.67	1.62675249

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.50	2.00	237.09167	118.54583	1.67	1.979715441
		1.00	0.67	194.82066	194.82066	1.67	3.253504979
		0.50	*0.50*	*183.50833*	*91.75417*	*1.67*	*1.532294559*
		0.10	0.08	112.67501	11.26750	1.67	0.188167265
		0.20	0.27	159.69138	31.93828	1.67	0.533369193
		0.20	0.09	117.22758	23.44552	1.67	0.391540128
		0.25	0.25	156.71666	39.17917	1.67	0.654292059
		0.15	0.10	121.30000	18.19500	1.67	0.3038565
		0.60	0.40	174.88334	104.93000	1.67	1.752331059
		0.55	0.44	178.56729	98.21201	1.67	1.640140542
							16.94176568
	17	0.50	0.33	167.44774	83.72387	0.50	0.418619352
		0.50	0.50	183.50833	91.75417	0.50	0.458770826
		0.40	0.11	124.98395	49.99358	0.50	0.249967898
							1.127358076
	18	0.35	0.16	139.46668	48.81334	4.00	1.952533498
		0.65	0.87	204.91721	133.19619	4.00	5.327847551
		0.30	0.40	174.88334	52.46500	4.00	2.098600071
		0.15	0.06	101.55546	15.23332	4.00	0.609332768
		0.13	0.52	185.02430	24.05316	4.00	0.962126347
		0.07	0.06	101.55546	7.10888	4.00	0.284355292
		0.35	0.28	161.09706	56.38397	4.00	2.255358907
		0.10	0.08	112.67501	11.26750	4.00	0.450700035
		1.00	0.50	183.50833	183.50833	4.00	7.340333215
		1.00	1.00	210.30000	210.30000	4.00	8.412
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	0.67	194.82066	194.82066	4.00	7.792826298
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	0.50	183.50833	183.50833	4.00	7.340333215
		0.70	0.70	196.51373	137.55961	4.00	5.502384316
							140.8502234
	19	1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	0.80	201.67501	201.67501	4.00	8.067000354
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		0.20	0.20	148.09167	29.61833	4.00	1.184733357
		0.80	0.40	174.88334	139.90667	4.00	5.596266855
		0.35	0.23	153.49378	53.72282	4.00	2.148912884
		0.05	0.25	156.71666	7.83583	4.00	0.313433322

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.60	2.40	244.13880	146.48328	4.00	5.859331212
		0.40	0.80	201.67501	80.67000	4.00	3.226800141
		0.05	0.03	74.76379	3.73819	4.00	0.149527583
		0.55	1.10	213.98395	117.69117	4.00	4.707646878
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		0.30	0.60	190.55546	57.16664	4.00	2.286665535
		0.12	0.08	112.67501	13.52100	4.00	0.540840042
		0.05	0.03	74.76379	3.73819	4.00	0.149527583
							101.4981769
	27	0.15	0.12	128.34713	19.25207	2.00	0.385041393
		0.10	0.08	112.67501	11.26750	2.00	0.225350018
		0.25	0.20	148.09167	37.02292	2.00	0.740458348
		0.05	0.05	94.50833	4.72542	2.00	0.09450833
		0.60	0.80	201.67501	121.00501	2.00	2.420100106
		0.20	0.20	148.09167	29.61833	2.00	0.592366678
		0.40	0.53	185.76055	74.30422	2.00	1.486084419
		0.40	0.40	174.88334	69.95334	2.00	1.399066714
		1.00	1.00	210.30000	210.30000	2.00	4.206
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
							20.71726532
Aug.,1999	**8**	0.10	0.13	131.44096	13.14410	1.07	0.140641825
		0.80	1.07	212.91516	170.33212	1.07	1.822553737
		0.75	1.00	210.30000	157.72500	1.07	1.6876575
							3.650853063
	9	0.30	0.40	174.88334	52.46500	0.55	0.28855751
		0.60	0.22	151.77562	91.06537	0.55	0.500859541
		0.45	0.36	170.81092	76.86492	0.55	0.422757033
		0.55	0.55	187.19228	102.95575	0.55	0.566256645
		0.70	0.35	169.72206	118.80544	0.55	0.653429915
		0.10	0.20	148.09167	14.80917	0.55	0.081450418
		0.10	0.10	121.30000	12.13000	0.55	0.066715
							2.580026063
	12	0.80	0.80	201.67501	161.34001	0.48	0.774432034
		0.20	0.16	139.46668	27.89334	0.48	0.133888011
		0.05	0.07	107.51373	5.37569	0.48	0.025803294
		0.60	0.48	181.93047	109.15828	0.48	0.523959754
		0.10	0.40	174.88334	17.48833	0.48	0.083944003
		0.30	0.40	174.88334	52.46500	0.48	0.251832008
		0.12	0.12	128.34713	15.40166	0.48	0.073927947
							1.867787052
	13	1.00	1.00	210.30000	210.30000	1.10	2.3133
		0.45	0.60	190.55546	85.74996	1.10	0.943249533
		0.55	1.10	213.98395	117.69117	1.10	1.294602891
		0.10	0.40	174.88334	17.48833	1.10	0.192371673
		0.10	0.06	101.55546	10.15555	1.10	0.111711007
							4.855235105

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	17	0.45	0.26	158.23263	71.20468	2.23	1.587864422
		0.30	0.20	148.09167	44.42750	2.23	0.99073327
		1.00	4.00	263.88334	263.88334	2.23	5.884598465
		0.35	0.47	181.11671	63.39085	2.23	1.413615917
							9.876812073
	20	0.85	1.13	215.02398	182.77038	0.50	0.913851921
		0.25	1.00	210.30000	52.57500	0.50	0.262875
		0.08	0.06	101.55546	8.12444	0.50	0.040622185
		0.26	0.25	156.71666	40.74633	0.50	0.203731659
							1.421080765
	21	0.45	0.30	163.76379	73.69371	0.67	0.493747832
		0.60	0.40	174.88334	104.93000	0.67	0.703031024
		0.05	0.03	74.76379	3.73819	0.67	0.02504587
		0.35	0.23	153.49378	53.72282	0.67	0.359942908
		0.50	0.40	174.88334	87.44167	0.67	0.585859186
		0.50	0.67	194.82066	97.41033	0.67	0.652649202
		0.28	0.16	139.46668	39.05067	0.67	0.261639489
							3.081915511
	24	1.00	0.44	178.56729	178.56729	0.46	0.821409526
		0.70	0.46	180.28545	126.19981	0.46	0.580519139
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
							4.345521853
	25	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.50	0.67	194.82066	97.41033	1.33	1.295557372
		0.50	0.18	144.01925	72.00963	1.33	0.957728032
		0.30	0.24	155.13880	46.54164	1.33	0.619003814
							5.815882406
	27	0.15	0.60	190.55546	28.58332	0.50	0.142916596
		0.35	0.13	131.44096	46.00434	0.50	0.230021677
		0.10	0.02	59.09167	5.90917	0.50	0.029545835
		0.90	0.45	179.43591	161.49232	0.50	0.807461612
		0.40	0.27	159.69138	63.87655	0.50	0.31938275
		0.25	0.50	183.50833	45.87708	0.50	0.229385413
		0.50	0.33	167.44774	83.72387	0.50	0.418619352
							2.177333234
	28	1.00	0.80	201.67501	201.67501	0.80	1.613400071
		0.30	1.20	217.34713	65.20414	0.80	0.521633114
		0.55	0.24	155.13880	85.32634	0.80	0.682610722
		0.15	0.12	128.34713	19.25207	0.80	0.154016557
		0.10	0.08	112.67501	11.26750	0.80	0.090140007
							3.061800471
	30	0.90	0.51	184.27375	165.84637	0.51	0.845816493
		0.50	0.40	174.88334	87.44167	0.51	0.445952515
							1.291769008
Sept.,1999	**3**	1.33	2.66	248.11447	329.99224	2.66	8.777793566
		0.10	0.40	174.88334	17.48833	2.66	0.465189682
							9.242983248
	7	0.20	0.80	201.67501	40.33500	1.50	0.605025027

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.05	0.04	85.88334	4.29417	1.50	0.064412504
		0.75	1.50	225.97212	169.47909	1.50	2.542186373
		0.30	1.20	217.34713	65.20414	1.50	0.978062089
							4.189685993
	8	0.35	0.13	131.44096	46.00434	2.40	1.10410405
		1.20	2.40	244.13880	292.96656	2.40	7.031197455
		0.13	0.04	85.88334	11.16483	2.40	0.267956018
		0.12	0.48	181.93047	21.83166	2.40	0.523959754
		0.05	0.05	94.50833	4.72542	2.40	0.113409996
							9.040627274
	9	1.00	2.00	237.09167	237.09167	2.00	4.741833392
		0.15	0.30	163.76379	24.56457	2.00	0.491291375
		0.05	0.20	148.09167	7.40458	2.00	0.14809167
		0.05	0.20	148.09167	7.40458	2.00	0.14809167
							5.529308107
	10	1.00	0.24	155.13880	155.13880	0.87	1.349707564
		0.01	0.04	85.88334	0.85883	0.87	0.007471851
		0.65	0.87	204.91721	133.19619	0.87	1.158806842
							2.515986257
Oct.,1999	**5**	2.45	9.80	298.51912	731.37185	5.00	36.56859229
		0.05	0.20	148.09167	7.40458	5.00	0.370229174
		0.25	0.50	183.50833	45.87708	5.00	2.29385413
							39.23267559
	6	0.50	0.33	167.44774	83.72387	2.00	1.674477406
		0.45	0.80	201.67501	90.75375	2.00	1.81507508
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	0.57	188.57286	188.57286	2.00	3.771457243
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	0.80	201.67501	201.67501	2.00	4.033500177
		0.20	0.80	201.67501	40.33500	2.00	0.806700035
		0.10	0.20	148.09167	14.80917	2.00	0.296183339
		0.10	0.20	148.09167	14.80917	2.00	0.296183339
							21.86186593
	16	2.48	3.31	256.56469	636.28043	3.31	21.06088239
		0.15	0.60	190.55546	28.58332	3.31	0.946107865
		0.35	1.40	223.30540	78.15689	3.31	2.586993003
		0.15	0.30	163.76379	24.56457	3.31	0.813087226
							25.40707049
	17	0.65	0.29	162.45342	105.59472	0.93	0.982030935
		1.00	0.57	188.57286	188.57286	0.93	1.753727618
		0.40	0.80	201.67501	80.67000	0.93	0.750231033
		0.30	0.20	148.09167	44.42750	0.93	0.413175758
		0.70	0.93	207.49498	145.24649	0.93	1.350792336
		0.60	0.27	159.69138	95.81483	0.93	0.891077873
		0.40	0.23	153.49378	61.39751	0.93	0.570996852
		0.60	0.80	201.67501	121.00501	0.93	1.125346549
							7.837378953

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	18	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		1.00	1.00	210.30000	210.30000	1.33	2.79699
		1.00	0.67	194.82066	194.82066	1.33	2.591114744
		0.55	0.10	121.30000	66.71500	1.33	0.8873095
		0.10	0.03	74.76379	7.47638	1.33	0.099435843
		0.15	0.12	128.34713	19.25207	1.33	0.256052526
		0.20	0.05	94.50833	18.90167	1.33	0.251392159
		1.00	0.50	183.50833	183.50833	1.33	2.440660794
		0.40	0.20	148.09167	59.23667	1.33	0.787847682
							13.05439644
	19	1.00	1.00	210.30000	210.30000	2.14	4.50042
		1.00	4.00	263.88334	263.88334	2.14	5.647103459
		0.58	*0.29*	*162.45342*	*94.22298*	2.14	*2.016371872*
							12.16389533
May,2000	1	0.40	1.60	228.46668	91.38667	*0.80*	0.731093371
		0.40	1.60	228.46668	91.38667	0.80	0.731093371
		0.20	*0.80*	*201.67501*	40.33500	0.80	0.322680014
		0.45	1.80	233.01925	104.85866	0.80	0.838869311
		0.05	0.10	121.30000	6.06500	0.80	0.04852
		0.50	0.40	174.88334	87.44167	0.80	0.699533357
		0.30	0.60	190.55546	57.16664	0.80	0.457333107
							3.829122531
	2	1.00	0.50	183.50833	183.50833	0.50	0.917541652
		0.30	0.40	174.88334	52.46500	0.50	0.262325009
		0.70	0.31	165.03119	115.52183	0.50	0.577609168
		0.15	0.30	163.76379	24.56457	0.50	0.122822844
							1.880298672
	10	1.40	1.87	234.49390	328.29146	1.87	6.13905038
		0.10	0.07	107.51373	10.75137	1.87	0.201050667
							6.340101047
	17	0.82	0.47	181.11671	148.51570	2.00	2.970314033
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		0.50	2.00	237.09167	118.54583	2.00	2.370916696
		0.50	0.40	174.88334	87.44167	2.00	1.748833392
		0.50	0.25	156.71666	78.35833	2.00	1.567166608
		0.41	0.55	187.19228	76.74883	2.00	1.534976691
							14.93404081
	22	0.20	0.40	174.88334	34.97667	0.60	0.209860007
		0.80	0.32	166.25835	133.00668	0.60	0.798040071
		0.60	0.40	174.88334	104.93000	0.60	0.629580021
		0.40	0.13	131.44096	52.57638	0.60	0.3154583
		0.30	0.60	190.55546	57.16664	0.60	0.34299983
		0.10	0.20	148.09167	14.80917	0.60	0.088855002
		0.10	0.10	121.30000	12.13000	0.60	0.07278
		0.03	0.03	74.76379	2.24291	0.60	0.013457483
		0.52	0.26	158.23263	82.28097	0.60	0.493685799
		1.00	0.50	183.50833	183.50833	0.60	1.101049982
		0.10	0.08	112.67501	11.26750	0.60	0.067605005
							4.133371501
	23	0.15	0.30	163.76379	24.56457	0.70	0.171951981
		0.85	0.68	195.39329	166.08430	0.70	1.162590095

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.35	0.70	196.51373	68.77980	0.70	0.481458628
		0.05	0.10	121.30000	6.06500	0.70	0.042455
		0.20	0.40	174.88334	34.97667	0.70	0.244836675
		0.10	0.20	148.09167	14.80917	0.70	0.103664169
							2.206956547
	24	0.10	0.40	174.88334	17.48833	1.33	0.232594841
		0.05	0.03	74.76379	3.73819	1.33	0.049717921
		0.50	0.50	183.50833	91.75417	1.33	1.220330397
		0.35	0.70	196.51373	68.77980	1.33	0.914771392
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.25	0.50	183.50833	45.87708	1.33	0.610165199
		0.75	1.00	210.30000	157.72500	1.33	2.0977425
		0.30	1.20	217.34713	65.20414	1.33	0.867215052
							8.93613049
June,2000	**5**	1.00	1.33	221.32280	221.32280	1.50	3.319841941
		0.50	2.00	237.09167	118.54583	1.50	1.778187522
		0.50	0.25	156.71666	78.35833	1.50	1.175374956
		0.05	0.10	121.30000	6.06500	1.50	0.090975
		0.05	0.20	148.09167	7.40458	1.50	0.111068752
		0.30	0.30	163.76379	49.12914	1.50	0.736937063
		0.39	0.26	158.23263	61.71072	1.50	0.925660874
							8.138046107
	6	0.85	0.85	204.01828	173.41554	1.33	2.306426705
		1.20	0.96	208.72214	250.46657	1.33	3.33120535
		0.10	0.10	121.30000	12.13000	1.33	0.161329
		0.70	0.70	196.51373	137.55961	1.33	1.829542785
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.96	0.96	208.72214	200.37325	1.33	2.66496428
							13.23706131
	7	0.25	0.33	167.44774	41.86194	0.50	0.209309676
		0.15	0.20	148.09167	22.21375	0.50	0.111068752
		0.35	0.28	161.09706	56.38397	0.50	0.281919863
		0.50	0.50	183.50833	91.75417	0.50	0.458770826
							1.061069117
	8	0.35	0.23	153.49378	53.72282	2.00	1.074456442
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		0.40	0.80	201.67501	80.67000	2.00	1.613400071
		0.60	0.34	168.60162	101.16097	2.00	2.023219483
		0.69	0.69	195.95757	135.21072	2.00	2.704214453
		0.60	0.22	151.77562	91.06537	2.00	1.821307423
							13.97843126
	9	1.00	1.33	221.32280	221.32280	3.00	6.639683881
		1.00	4.00	263.88334	263.88334	3.00	7.916500177
		1.00	2.00	237.09167	237.09167	3.00	7.112750088
		1.00	0.44	178.56729	178.56729	3.00	5.357018646
		1.00	0.57	188.57286	188.57286	3.00	5.657185865
		0.63	0.36	170.81092	107.61088	3.00	3.228326437
							35.91146509
	12	0.15	0.12	128.34713	19.25207	1.00	0.192520696
		1.00	0.57	188.57286	188.57286	1.00	1.885728622

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0.50	1.00	210.30000	105.15000	1.00	1.0515
		0.50	0.29	162.45342	81.22671	1.00	0.812267109
		0.05	0.20	148.09167	7.40458	1.00	0.074045835
							4.016062262
	13	1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.55	0.55	187.19228	102.95575	1.33	1.369311524
		0.10	0.10	121.30000	12.13000	1.33	0.161329
		0.35	0.70	196.51373	68.77980	1.33	0.914771392
		0.43	0.43	177.67869	76.40184	1.33	1.016144443
							6.405149546
	20	0.90	0.45	179.43591	161.49232	1.00	1.614923224
		1.00	0.80	201.67501	201.67501	1.00	2.016750088
		1.00	1.00	210.30000	210.30000	1.00	2.103
		1.00	0.50	183.50833	183.50833	1.00	1.835083304
		0.40	1.60	228.46668	91.38667	1.00	0.913866714
		1.16	0.11	124.98395	144.98138	1.00	1.449813808
		0.16	0.11	124.98395	19.99743	1.00	0.199974318
							10.13341146
	21	0.40	0.80	201.67501	80.67000	1.33	1.072911047
		0.45	0.36	170.81092	76.86492	1.33	1.022303372
		1.00	0.36	170.81092	170.81092	1.33	2.27178527
		1.00	0.36	170.81092	170.81092	1.33	2.27178527
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		0.39	0.39	173.90475	67.82285	1.33	0.902043938
							10.48442208
	22	0.80	1.60	228.46668	182.77334	2.18	3.984458872
		1.00	1.33	221.32280	221.32280	2.18	4.824836954
		0.50	2.00	237.09167	118.54583	2.18	2.584299199
		0.50	0.25	156.71666	78.35833	2.18	1.708211602
		0.60	1.20	217.34713	130.40828	2.18	2.842900472
		0.40	0.80	201.67501	80.67000	2.18	1.758606077
		1.00	4.00	263.88334	263.88334	2.18	5.752656795
		1.00	0.36	170.81092	170.81092	2.18	3.723678112
		0.40	0.40	174.88334	69.95334	2.18	1.524982718
		0.10	0.40	174.88334	17.48833	2.18	0.38124568
		0.05	0.10	121.30000	6.06500	2.18	0.132217
		0.10	0.40	174.88334	17.48833	2.18	0.38124568
							29.59933916
	23	1.00	0.29	162.45342	162.45342	2.00	3.249068436
		0.20	0.80	201.67501	40.33500	2.00	0.806700035
		0.05	0.05	94.50833	4.72542	2.00	0.09450833
		1.30	1.73	231.48610	300.93193	2.00	6.018638683
		0.45	0.18	144.01925	64.80866	2.00	1.296173277
		0.05	0.20	148.09167	7.40458	2.00	0.14809167
		0.05	0.04	85.88334	4.29417	2.00	0.085883339
		1.00	0.80	201.67501	201.67501	2.00	4.033500177
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	4.00	263.88334	263.88334	2.00	5.277666785
		0.05	0.10	121.30000	6.06500	2.00	0.1213
		0.15	0.60	190.55546	28.58332	2.00	0.571666384

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0 05	0 07	107 51373	5 37569	2 00	0 107513726
		0 75	1 00	210 30000	157 72500	2 00	3 1545
		1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	1 00	210 30000	210 30000	2 00	4 206
		0 05	1 00	210 30000	10 51500	2 00	0 2103
		1 00	1 33	221 32280	221 32280	2 00	4 426455921
		0 10	0 40	174 88334	17 48833	2 00	0 349766678
		0 19	0 05	94 50833	17 95658	2 00	0 359131655
							43 46469849
July,2000	**6**	0 55	1 10	213 98395	117 69117	2 00	2 353823439
		0 15	0 20	148 09167	22 21375	2 00	0 444275009
		0 30	0 60	190 55546	57 16664	2 00	1 143332768
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 25	1 00	210 30000	52 57500	2 00	1 0515
							25 03193157
	31	0 05	0 20	148 09167	7 40458	2 00	0 14809167
		0 05	0 03	74 76379	3 73819	2 00	0 074763792
		0 05	0 20	148 09167	7 40458	2 00	0 14809167
		0 55	0 24	155 13880	85 32634	2 00	1 706526806
		0 30	0 09	117 22758	35 16828	2 00	0 7033655
		1 00	0 80	201 67501	201 67501	2 00	4 033500177
		1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	0 80	201 67501	201 67501	2 00	4 033500177
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 35	1 40	223 30540	78 15689	2 00	1 563137766
		0 05	0 20	148 09167	7 40458	2 00	0 14809167
		0 05	0 10	121 30000	6 06500	2 00	0 1213
		0 55	1 10	213 98395	117 69117	2 00	2 353823439
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	0 50	183 50833	183 50833	2 00	3 670166608
		1 00	1 00	210 30000	210 30000	2 00	4 206
							45.54785945
Aug , 2000	**1**	1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	0 80	201 67501	201 67501	2 00	4 033500177
		1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	1 00	210 30000	210 30000	2 00	4 206
		0 10	0 40	174 88334	17 48833	2 00	0 349766678
		0 25	1 00	210 30000	52 57500	2 00	1 0515
		0 15	0 30	163 76379	24 56457	2 00	0 491291375
		0 20	0 80	201 67501	40 33500	2 00	0 806700035
		0 25	0 10	121 30000	30 32500	2 00	0 6065
		0 30	0 15	136 97212	41 09164	2 00	0 821832732
		0 70	1 40	223 30540	156 31378	2 00	3 126275532
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 40	0 80	201 67501	80 67000	2 00	1 613400071
		0 05	0 10	121 30000	6 06500	2 00	0 1213

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
							30.38189999
	2	1 00	1 33	221 32280	221 32280	1 34	2 965725467
		1 00	1 33	221 32280	221 32280	1 34	2 965725467
		0 40	0 32	166 25835	66 50334	1 34	0 891144746
		0 30	0 06	101 55546	30 46664	1 34	0 408252954
		0 30	0 30	163 76379	49 12914	1 34	0 658330443
		0 10	0 20	148 09167	14 80917	1 34	0 198442837
							8.087621914
	9	0 05	0 06	101 55546	5 07777	1 80	0 091399915
		0 65	2 60	247 23263	160 70121	1 80	2 892621747
		0 25	1 00	210 30000	52 57500	1 80	0 94635
		0 43	0 57	188 57286	81 08633	1 80	1 459553953
		0 10	0 08	112 67501	11 26750	1 80	0 202815016
							5.592740631
	20	1 00	4 00	263 88334	263 88334	2 66	7 019296823
		1 00	1 33	221 32280	221 32280	2 66	5 887186375
		0 85	1 70	230 80995	196 18846	2 66	5 21861306
							18.12509626
	22	0 40	0 53	185 76055	74 30422	1 33	0 988246139
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 40	0 53	185 76055	74 30422	1 33	0 988246139
							4.920085465
	30	0 40	0 13	131 44096	52 57638	0 45	0 236593725
		0 05	0 05	94 50833	4 72542	0 45	0 021264374
		0 05	0 02	59 09167	2 95458	0 45	0 013295626
		0 10	0 13	131 44096	13 14410	0 45	0 059148431
		0 05	0 20	148 09167	7 40458	0 45	0 033320626
		0 35	0 05	94 50833	33 07792	0 45	0 14885062
		0 45	0 45	179 43591	80 74616	0 45	0 363357725
							0.875831128
	31	0 05	0 20	148 09167	7 40458	0 65	0 048129793
		0 10	0 10	121 30000	12 13000	0 65	0 078845
		0 25	1 00	210 30000	52 57500	0 65	0 3417375
		0 15	0 30	163 76379	24 56457	0 65	0 159669697
		0 10	0 40	174 88334	17 48833	0 65	0 11367417
		0 15	0 30	163 76379	24 56457	0 65	0 159669697
		0 05	0 03	74 76379	3 73819	0 65	0 024298232
		0 20	0 10	121 30000	24 26000	0 65	0 15769
		0 02	0 04	85 88334	1 71767	0 65	0 011164834
							1.094878923
Sept , 2000	**1**	0 35	1 40	223 30540	78 15689	0 96	0 750306128
		0 65	0 52	185 02430	120 26579	0 96	1 154551617
		1 00	0 57	188 57286	188 57286	0 96	1 810299477
		0 05	0 20	148 09167	7 40458	0 96	0 071084001
		0 03	0 06	101 55546	3 04666	0 96	0 029247973
		0 15	0 30	163 76379	24 56457	0 96	0 23581986
							4.051309056
	3	0 13	0 07	107 51373	13 97678	1 84	0 257172832
		0 80	0 80	201 67501	161 34001	1 84	2 96865613
		1 00	0 27	159 69138	159 69138	1 84	2 9383213

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0 92	1 84	233 86879	215 15928	1 84	3 958930814
							10.12308108
	9	0 75	0 43	177 67869	133 25902	0 50	0 666295097
		0 25	0 50	183 50833	45 87708	0 50	0 229385413
		0 25	0 33	167 44774	41 86194	0 50	0 209309676
		0 20	0 08	112 67501	22 53500	0 50	0 112675009
		0 10	0 20	148 09167	14 80917	0 50	0 074045835
		0 37	0 25	156 71666	57 98516	0 50	0 289925822
							1 581636852
	17	1 00	0 80	201 67501	201 67501	0 80	1 613400071
		1 00	0 29	162 45342	162 45342	0 80	1 299627375
		0 05	0 07	107 51373	5 37569	0 80	0 04300549
							2.956032935
	18	1 00	1 00	210 30000	210 30000	1 00	2 103
		0 20	0 40	174 88334	34 97667	1 00	0 349766678
		0 15	0 30	163 76379	24 56457	1 00	0 245645688
		0 15	0 30	163 76379	24 56457	1 00	0 245645688
		0 05	0 10	121 30000	6 06500	1 00	0 06065
							3.004708053
	21	1 00	1 00	210 30000	210 30000	1 00	2 103
		0 15	0 60	190 55546	28 58332	1 00	0 285833192
		0 05	0 05	94 50833	4 72542	1 00	0 047254165
							2.436087357
Oct , 2000	**17**	1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
							10.01950018
	27	1 00	0 36	170 81092	170 81092	0 50	0 854054613
		1 00	0 27	159 69138	159 69138	0 50	0 798456875
		1 00	0 50	183 50833	183 50833	0 50	0 917541652
		0 36	0 29	162 45342	58 48323	0 50	0 292416159
							2.862469299
May, 2001	**9**	1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		1 00	1 33	221 32280	221 32280	2 00	4 426455921
							14.4459561
	10	1 00	1 33	221 32280	221 32280	1 33	2 943593187
		1 00	0 44	178 56729	178 56729	1 33	2 374944933
		0 35	1 40	223 30540	78 15689	1 33	1 039486615
							6 358024735
June,2001	**4**	1 00	0 27	159 69138	159 69138	2 50	3 992284375
		1 00	4 00	263 88334	263 88334	2 50	6 597083481
		1 00	1 00	210 30000	210 30000	2 50	5 2575
		1 00	0 57	188 57286	188 57286	2 50	4 714321554
		1 00	4 00	263 88334	263 88334	2 50	6 597083481
		1 00	1 33	221 32280	221 32280	2 50	5 533069901
		1 00	1 33	221 32280	221 32280	2 50	5 533069901
		1 00	1 33	221 32280	221 32280	2 50	5 533069901
		1 00	4 00	263 88334	263 88334	2 50	6 597083481
		1 00	4 00	263 88334	263 88334	2 50	6 597083481
		1 00	2 00	237 09167	237 09167	2 50	5 92729174
		0 60	2 40	244 13880	146 48328	2 50	3 662082008

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	5	1.00	1.21	217.66790	217.66790	1.96	4.2662908
		1.98	1.96	236.31079	467.89536	1.96	9.170749152
							13.43703995
	9	0.90	3.60	259.81092	233.82983	1.80	4.208936946
		0.10	0.40	174.88334	17.48833	1.80	0.314790011
		0.45	0.90	206.22758	92.80241	1.80	1.670443425
							6.194170381
	19	0.60	0.30	163.76379	98.25828	0.80	0.7860662
		1.00	0.80	201.67501	201.67501	0.80	1.613400071
		0.73	0.73	198.13573	144.63909	0.80	1.15711269
							3.556578961
	20	0.80	0.64	193.05002	154.44001	1.00	1.544400141
		0.20	*0.13*	*131.44096*	*26.28819*	*1.00*	*0.262881917*
		1.00	1.00	210.30000	210.30000	1.00	2.103
		0.60	0.48	181.93047	109.15828	1.00	1.091582821
		0.40	0.40	174.88334	69.95334	1.00	0.699533357
		0.20	0.27	159.69138	31.93828	1.00	0.31938275
		0.75	0.23	153.49378	115.12033	1.00	1.151203331
		0.25	0.17	141.80995	35.45249	1.00	0.354524885
		0.40	0.27	159.69138	63.87655	1.00	0.6387655
							8.165274701
	24	0.20	0.80	201.67501	40.33500	1.33	0.536455524
		0.80	1.07	212.91516	170.33212	1.33	2.265417262
		1.00	1.33	221.32280	221.32280	1.33	2.943593187
		1.00	0.57	188.57286	188.57286	1.33	2.508019067
		0.15	*0.20*	*148.09167*	*22.21375*	1.33	*0.295442881*
							8.548927921
July, 2001	**23**	0.10	0.40	174.88334	17.48833	2.30	0.40223168
		1.15	4.60	269.28545	309.67826	2.30	7.122600074
							7.524831754
	28	0.10	0.2	148.09167	14.80917	2.00	0.296183339
		0.80	1.07	212.91516	170.33212	2.00	3.406642499
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	1.00	210.30000	210.30000	2.00	4.206
		1.00	0.80	201.67501	201.67501	2.00	4.033500177
		1.00	1.00	210.30000	210.30000	2.00	4.206
		1.23	0.82	202.62943	249.23420	2.00	4.984684048
							48.95325547
	29	1.00	1.33	221.32280	221.32280	4.00	8.852911842
		0.75	1.00	210.30000	157.72500	4.00	6.309
		0.25	0.17	141.80995	35.45249	4.00	1.41809954
		0.15	0.60	190.55546	28.58332	4.00	1.143332768
		0.10	0.40	174.88334	17.48833	4.00	0.699533357
		0.05	0.20	148.09167	7.40458	4.00	0.296183339
		0.38	0.76	199.69241	75.88312	4.00	3.035324628
		0.30	0.11	124.98395	37.49518	4.00	1.499807388

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		1.00	1.00	210.30000	210.30000	4.00	8.412
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		0.75	1.50	225.97212	169.47909	4.00	6.779163662
		0.25	0.50	183.50833	45.87708	4.00	1.835083304
		1.00	0.80	201.67501	201.67501	4.00	8.067000354
		0.25	0.05	94.50833	23.62708	4.00	0.945083304
		0.75	1.50	225.97212	169.47909	4.00	6.779163662
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
							207.340935
	30	1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	1.33	221.32280	221.32280	4.00	8.852911842
		1.00	4.00	263.88334	263.88334	4.00	10.55533357
		1.00	2.00	237.09167	237.09167	4.00	9.483666785
		1.00	0.40	174.88334	174.88334	4.00	6.995333569
		0.15	0.30	163.76379	24.56457	4.00	0.98258275
		0.02	0.04	85.88334	1.71767	4.00	0.068706671
		0.73	0.58	189.24509	138.14892	4.00	5.52595667
		0.10	0.08	112.67501	11.26750	4.00	0.450700035
		0.20	0.40	174.88334	34.97667	4.00	1.399066714
		0.80	0.32	166.25835	133.00668	4.00	5.320267138
		1.00	0.57	188.57286	188.57286	4.00	7.542914486
		0.55	0.73	198.13573	108.97465	4.00	4.35898616
							92.13076031
	31	1.00	0.36	170.81092	170.81092	0.40	0.68324369
		0.40	0.40	174.88334	69.95334	0.40	0.279813343
		0.10	0.08	112.67501	11.26750	0.40	0.045070004
		0.05	0.04	85.88334	4.29417	0.40	0.017176668
		0.45	0.60	190.55546	85.74996	0.60	0.514499745
		0.60	0.60	190.55546	114.33328	0.60	0.685999661
		0.40	0.40	174.88334	69.95334	0.60	0.419720014
		1.00	0.22	151.77562	151.77562	0.60	0.910653712
		0.35	0.14	134.30540	47.00689	0.60	0.28204133
							3.838218166
Aug., 2001	**8**	1.10	1.47	225.19124	247.71037	1.47	3.641342396
		0.15	0.08	112.67501	16.90125	1.47	0.248448394
							3.88979079

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	10	3 00	12 00	306 34713	919 04139	7 00	64 33289749
		0 50	2 00	237 09167	118 54583	7 00	8 298208436
		0 12	2 40	244 13880	29 29666	7 00	2 050765924
							74.68187185
	11	1 00	1 33	221 32280	221 32280	3 80	8 41026625
		1 00	4 00	263 88334	263 88334	3 80	10 02756689
		0 90	3 60	259 81092	233 82983	3 80	8 885533552
							27.32336669
	13	1 00	0 50	183 50833	183 50833	0 50	0 917541652
		1 00	0 27	159 69138	159 69138	0 50	0 798456875
		0 35	0 15	136 97212	47 94024	0 50	0 239701214
							1.955699741
	25	0 20	0 09	117 22758	23 44552	1 70	0 398573783
		0 80	0 46	180 28545	144 22836	1 70	2 451882079
		0 80	0 46	180 28545	144 22836	1 70	2 451882079
		0 15	0 60	190 55546	28 58332	1 70	0 485916426
		0 70	2 80	250 09706	175 06795	1 70	2 976155071
							8.76440944
	26	0 70	0 35	169 72206	118 80544	0 35	0 415819037
		1 00	0 33	167 44774	167 44774	0 35	0 586067092
		0 40	0 32	166 25835	66 50334	0 35	0 232761687
							1 234647817
	27	1 00	0 44	178 56729	178 56729	1 00	1 785672882
		0 50	1 00	210 30000	105 15000	1 00	1 0515
							2.837172882
Sept., 2001	**6**	1 00	0 80	201 67501	201 67501	1 31	2 641942616
		0 95	1 27	219 53853	208 56160	1 31	2 73215702
		0 05	0 20	148 09167	7 40458	1 31	0 097000044
		0 98	1 31	220 73715	216 32240	1 31	2 833823472
							8.304923151
	17	1 00	4 00	263 88334	263 88334	2 93	7 731781839
		0 70	0 93	207 49498	145 24649	2 93	4 255722089
		0 10	0 13	131 44096	13 14410	2 93	0 385122008
							12.37262594
	18	0 32	1 28	219 84169	70 34934	2 36	1 660244422
		0 68	2 72	248 97663	169 30411	2 36	3 995576998
		1 00	2 00	237 09167	237 09167	2 36	5 595363403
		1 00	2 00	237 09167	237 09167	2 36	5 595363403
		0 40	1 60	228 46668	91 38667	2 36	2 156725445
		0 28	0 22	151 77562	42 49717	2 36	1 002933288
							20.00620696
	19	0 50	0 50	183 50833	91 75417	0 80	0 734033322
		0 40	0 11	124 98395	49 99358	0 80	0 399948637
		0 40	0 09	117 22758	46 89103	0 80	0 375128267
		0 60	0 80	201 67501	121 00501	0 80	0 968040042
		0 65	0 65	193 64929	125 87204	0 80	1 006976301
		0 35	0 14	134 30540	47 00689	0 80	0 376055106
		1 00	0 36	170 81092	170 81092	0 80	1 366487381
							5 226669056
	20	1 00	0 40	174 88334	174 88334	0 40	0 699533357

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		0 60	0 24	155 13880	93 08328	0 40	0 372333121
		0 32	0 11	124 98395	39 99486	0 40	0 159979455
		0 08	0 32	166 25835	13 30067	0 40	0 053202671
		1 00	0 31	165 03119	165 03119	0 40	0 660124763
		1 00	0 25	156 71666	156 71666	0 40	0 626866643
		0 10	0 20	148 09167	14 80917	0 40	0 059236668
							2 631276678
	30	1 00	1 00	210 30000	210 30000	2 00	4 206
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 45	0 90	206 22758	92 80241	2 00	1 85604825
		0 15	0 15	136 97212	20 54582	2 00	0 410916366
							11.21479801
Oct, 2001	**4**	1 00	4 00	263 88334	263 88334	3 33	8 787315196
		1 00	1 33	221 32280	221 32280	3 33	7 370049108
		1 00	4 00	263 88334	263 88334	3 33	8 787315196
		1 00	2 00	237 09167	237 09167	3 33	7 895152598
		0 40	1 60	228 46668	91 38667	3 33	3 043176157
		0 35	0 23	153 49378	53 72282	3 33	1 788969976
		0 10	0 13	131 44096	13 14410	3 33	0 437698391
		0 15	0 06	101 55546	15 23332	3 33	0 507269529
							38.61694615
	5	0 80	1 60	228 46668	182 77334	1 60	2 924373484
		0 15	0 30	163 76379	24 56457	1 60	0 3930331
		0 10	0 20	148 09167	14 80917	1 60	0 236946671
		0 65	0 33	167 44774	108 84103	1 60	1 741456503
		0 05	0 10	121 30000	6 06500	1 60	0 09704
		0 05	0 20	148 09167	7 40458	1 60	0 118473336
							5.511323094
	6	0 80	0 46	180 28545	144 22836	1 33	1 918237156
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		0 50	2 00	237 09167	118 54583	1 33	1 576659603
		0 20	0 20	148 09167	29 61833	1 33	0 393923841
		0 10	0 20	148 09167	14 80917	1 33	0 196961921
							7.029375708
	8	1 00	0 57	188 57286	188 57286	0 57	1 074865314
		0 05	0 20	148 09167	7 40458	0 57	0 042206126
		0 05	0 03	74 76379	3 73819	0 57	0 021307681
		0 25	0 50	183 50833	45 87708	0 57	0 261499371
							1 399878492
	30	1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 95	1 90	235 10907	223 35362	2 00	4 467072339
		0 05	0 10	121 30000	6 06500	2 00	0 1213
		0 20	0 27	159 69138	31 93828	2 00	0 6387655
							9 968971232
	31	0 08	0 08	112 67501	9 01400	0 93	0 083830207
		0 72	0 72	197 60259	142 27387	0 93	1 323146957
		0 40	1 60	228 46668	91 38667	0 93	0 849896044
		0 25	0 25	156 71666	39 17917	0 93	0 364366236
		0 12	0 24	155 13880	18 61666	0 93	0 173134901
							2.794374345

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May, 2002	**2**	1 00	2 00	237 09167	237 09167	2 80	6 638566749
		1 40	5 60	276 88873	387 64423	2 80	10 85403839
		0 25	1 00	210 30000	52 57500	2 80	1 4721
		0 60	1 20	217 34713	130 40828	2 80	3 651431799
		0 07	0 07	107 51373	7 52596	2 80	0 210726902
		0 10	0 20	148 09167	14 80917	2 80	0 414656675
							23.24152051
	3	0 65	2 60	247 23263	160 70121	1 34	2 15339619
		0 15	0 15	136 97212	20 54582	1 34	0 275313965
		0 20	0 27	159 69138	31 93828	1 34	0 427972885
		0 40	0 80	201 67501	80 67000	1 34	1 080978047
							3.937661087
	4	0 40	0 80	201 67501	80 67000	1 50	1 210050053
		0 75	1 50	225 97212	169 47909	1 50	2 542186373
		0 10	0 13	131 44096	13 14410	1 50	0 197161438
		0 08	0 32	166 25835	13 30067	1 50	0 199510018
							4.148907881
	11	0 65	1 30	220 44096	143 28662	1 60	2 292585967
		0 05	0 05	94 50833	4 72542	1 60	0 075606664
		0 30	0 30	163 76379	49 12914	1 60	0 7860662
		1 00	0 80	201 67501	201 67501	1 60	3 226800141
		0 80	3 20	255 25835	204 20668	1 60	3 267306855
		0 20	0 27	159 69138	31 93828	1 60	0 5110124
		1 00	1 00	210 30000	210 30000	1 60	3 3648
		1 00	1 00	210 30000	210 30000	1 60	3 3648
		1 00	0 80	201 67501	201 67501	1 60	3 226800141
		0 28	0 19	146 10907	40 91054	1 60	0 654568636
							20.77034701
	19	0 15	0 60	190 55546	28 58332	2 00	0 571666384
		0 85	1 70	230 80995	196 18846	2 00	3 923769218
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		1 00	4 00	263 88334	263 88334	2 00	5 277666785
		0 15	0 60	190 55546	28 58332	2 00	0 571666384
							15.62243555
	21	1 00	4 00	263 88334	263 88334	2 70	7 124850159
		0 35	1 40	223 30540	78 15689	2 70	2 110235984
		0 13	0 26	158 23263	20 57024	2 70	0 555396524
							9.790482668
	22	0 40	0 80	201 67501	80 67000	2 50	2 016750088
		0 10	0 10	121 30000	12 13000	2 50	0 30325
		0 55	2 20	240 77562	132 42659	2 50	3 310664756
		1 25	*2 50*	*245 71666*	*307 14583*	*2 50*	*7 678645649*
		0 15	0 60	190 55546	28 58332	2 50	0 71458298
		0 25	0 33	167 44774	41 86194	2 50	1 046548379
							15 07044185
	24	1 00	4 00	263 88334	263 88334	2 67	7 045685157
		1 00	1 33	221 32280	221 32280	2 67	5 909318654
		0 12	0 24	155 13880	18 61666	2 67	0 497064717
							13.45206853
June, 2002	**1**	0 45	0 90	206 22758	92 80241	1 60	1 4848386

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		0 55	0 55	187 19228	102 95575	1 60	1 647292058
		0 80	1 60	228 46668	182 77334	1 60	2 924373484
		0 05	0 05	94 50833	4 72542	1 60	0 075606664
							6.132110807
	4	1 00	2 00	237 09167	237 09167	2 00	4 741833392
		1 00	2 00	237 09167	237 09167	2 00	4 741833392
		0 80	1 06	212 55222	170 04178	2 00	3 400835552
		0 05	0 05	94 50833	4 72542	2 00	0 09450833
							12.97901067
	5	0 05	0 04	85 88334	4 29417	1 20	0 051530004
		0 90	1 20	217 34713	195 61242	1 20	2 347349014
		0 05	0 20	148 09167	7 40458	1 20	0 088855002
		0 30	1 20	217 34713	65 20414	1 20	0 782449671
		0 10	0 40	174 88334	17 48833	1 20	0 209860007
							3.480043697
	13	0 15	0 05	94 50833	14 17625	1 33	0 188544119
		0 75	1 00	210 30000	157 72500	1 33	2 0977425
		0 40	0 80	201 67501	80 67000	1 33	1 072911047
		0 60	0 40	174 88334	104 93000	1 33	1 395569047
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		1 00	1 00	210 30000	210 30000	1 33	2 79699
		0 15	0 60	190 55546	28 58332	1 33	0 380158145
							10.87550805
	14	1 00	0 22	151 77562	151 77562	6 68	10 13861132
		1 15	0 07	107 51373	123 64078	6 68	8 259204398
		1 25	0 15	136 97212	171 21515	6 68	11 43717219
		1 45	1 00	210 30000	304 93500	6 68	20 369658
		1 00	0 16	139 46668	139 46668	6 68	9 316374121
		0 60	1 00	210 30000	126 18000	6 68	8 428824
		0 10	1 20	217 34713	21 73471	6 68	1 451878834
		0 30	0 06	101 55546	30 46664	6 68	2 035171444
		1 00	1 20	217 34713	217 34713	6 68	14 51878834
		1 00	4 00	263 88334	263 88334	6 68	17 62740706
		1 00	2 00	237 09167	237 09167	6 68	15 83772353
		0 45	2 00	237 09167	106 69125	6 68	7 126975589
		0 65	0 45	179 43591	116 63334	6 68	7 791107374
		1 00	2 60	247 23263	247 23263	6 68	16 51513955
		1 00	4 00	263 88334	263 88334	6 68	17 62740706
		1 00	1 33	221 32280	221 32280	6 68	14 78436278
		0 20	2 00	237 09167	47 41833	6 68	3 167544706
		0 05	0 20	148 09167	7 40458	6 68	0 494626177
		0 10	0 06	101 55546	10 15555	6 68	0 678390481
		0 65	0 87	204 91721	133 19619	6 68	8 897505409
		3 34	6 68	283 70511	947 57505	6 68	63 29801342
							259 8018858
	15	1 00	4 00	263 88334	263 88334	2 21	5 831821797
		0 72	0 41	175 83776	126 60319	2 21	2 797930489
		0 23	0 13	131 44096	30 23142	2 21	0 668114391
		1 00	0 57	188 57286	188 57286	2 21	4 167460254
		0 50	0 50	183 50833	91 75417	0 70	0 642279156

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							15 31813064
	16	1 00	1 33	221 32280	221 32280	3 00	6 639683881
		1 00	4 00	263 88334	263 88334	3 00	7 916500177
		1 00	2 00	237 09167	237 09167	3 00	7 112750088
		1 00	4 00	263 88334	263 88334	3 00	7 916500177
		1 00	1 00	210 30000	210 30000	3 00	6 309
		1 00	1 00	210 30000	52 57500	1 34	0 704505
		0 25	0 60	190 55546	28 58332	1 34	0 383016477
		0 15	0 40	174 88334	34 97667	1 34	0 468687349
		0 20	0 40	174 88334	17 48833	1 34	0 234343675
		0 10	1 80	233 01925	104 85866	1 34	1 405106095
		0 45	0 20	148 09167	14 80917	1 34	0 198442837
		0 10	2 68	248 40400	166 43068	1 34	2 230171082
		0 67	0 04	85 88334	4 29417	1 34	0 057541837
		0 05	0 80	201 67501	40 33500	1 34	0 540489024
		0 20					**42.1167377**
	17	0 25	1 00	210 30000	52 57500	1 33	0 6992475
		0 25	0 50	183 50833	45 87708	1 33	0 610165199
		0 75	1 00	210 30000	157 72500	1 33	2 0977425
		0 30	0 60	190 55546	57 16664	1 33	0 760316291
		0 05	0 07	107 51373	5 37569	1 33	0 071496627
		0 65	1 30	220 44096	143 28662	1 33	1 905712085
		1 00	1 33	221 32280	221 32280	1 33	2 943593187
		1 00	0 80	201 67501	201 67501	1 33	2 682277618
							11.77055101
	18	0 80	1 07	212 91516	170 33212	1 07	1 822553737
		0 55	0 55	187 19228	102 95575	1 07	1 101626564
		0 05	0 10	121 30000	6 06500	1 07	0 0648955
		0 12	0 24	155 13880	18 61666	1 07	0 19919822
							3.188274021
	19	0 30	0 40	174 88334	52 46500	1 70	0 89190503
		0 55	0 73	198 13573	108 97465	1 70	1 852569118
		0 05	0 20	148 09167	7 40458	1 70	0 125877919
		0 12	0 24	155 13880	18 61666	1 70	0 316483153
		0 05	0 10	121 30000	6 06500	1 70	0 103105
		0 75	0 75	199 18045	149 38534	1 70	2 539550769
		0 65	2 60	247 23263	160 70121	1 70	2 731920539
							8.561411528
	20	1 00	0 80	201 67501	201 67501	2 40	4 840200212
		1 00	0 67	194 82066	194 82066	2 40	4 675695779
		1 00	4 00	263 88334	263 88334	2 40	6 333200141
		0 60	0 80	201 67501	121 00501	2 40	2 904120127
		0 40	0 27	159 69138	63 87655	2 40	1 5330372
		0 65	0 43	177 67869	115 49115	2 40	2 771787604
		0 35	0 35	169 72206	59 40272	0 67	0 397998221
		1 00	0 67	194 82066	194 82066	0 67	1 305298405
		0 20	0 16	139 46668	27 89334	0 67	0 186885349
		0 60	0 34	168 60162	101 16097	0 67	0 677778527
		0 20	0 20	148 09167	29 61833	0 67	0 198442837
							25.8244444

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	21	0.85	3.40	257.60162	218.96138	2.70	5.911957262
		1.00	2.00	237.09167	237.09167	2.70	6.40147508
		0.20	0.27	159.69138	31.93828	2.70	0.862333425
		0.10	0.10	121.30000	12.13000	2.70	0.32751
		0.05	0.10	121.30000	6.55020	2.70	0.1768554
							13.68013117
	23	0.15	0.30	163.76379	24.56457	1.73	0.424967039
		0.30	1.20	217.34713	65.20414	1.73	1.128031609
		0.05	0.20	148.09167	7.40458	1.73	0.128099294
		0.45	1.80	233.01925	104.85866	1.73	1.814054884
		0.40	0.22	151.77562	60.71025	1.73	1.050287281
		0.60	0.24	155.13880	93.08328	1.73	1.610340749
		1.00	1.33	221.32280	221.32280	1.73	3.828884372
		0.80	3.20	255.25835	204.20668	1.73	3.532775537
		0.20	1.60	228.46668	45.69334	1.73	0.790494707
		0.08	0.16	139.46668	11.15733	1.73	0.193021883
		0.50	1.00	210.30000	105.15000	1.73	1.819095
		0.25	1.00	210.30000	52.57500	1.73	0.9095475
		0.15	0.20	148.09167	22.21375	1.73	0.384297883
		0.20	0.80	201.67501	40.33500	1.73	0.697795531
		0.75	1.00	210.30000	157.72500	1.73	2.7286425
		0.35	0.70	196.51373	68.77980	1.73	1.189890608
							22.23022638
	30	0.95	1.27	219.53853	208.56160	1.27	2.648732379
		0.05	0.20	148.09167	7.40458	1.27	0.09403821
		0.35	0.35	169.72206	59.40272	1.27	0.754414539
		0.10	0.07	107.51373	10.75137	1.27	0.136542431
		0.48	0.32	166.25835	79.80401	1.27	1.01351089
							4.647238449
July,2002	5	0.25	0.20	148.09167	37.02292	1.07	0.396145216
		0.75	0.75	199.18045	149.38534	1.07	1.598423131
		0.40	1.60	228.46668	91.38667	1.07	0.977837384
		0.40	0.53	185.76055	74.30422	1.07	0.795055164
							3.767460895
	20	0.25	0.50	183.50833	45.87708	0.53	0.243148538
		0.15	0.12	128.34713	19.25207	0.53	0.102035969
		0.25	1.00	210.30000	52.57500	0.53	0.2786475
		0.35	0.13	131.44096	46.00434	0.53	0.243822978
		0.60	0.60	190.55546	114.33328	0.53	0.605966367
		0.40	0.53	185.76055	74.30422	0.53	0.393812371
		0.15	0.10	121.30000	18.19500	0.53	0.0964335
		0.15	0.60	190.55546	28.58332	0.53	0.151491592
		0.65	0.37	171.86995	111.71547	0.53	0.59209199
		1.00	0.57	188.57286	188.57286	0.53	0.999436169
		0.15	0.20	148.09167	22.21375	0.53	0.117732877
							3.824619851
	21	0.15	0.60	190.55546	28.58332	2.00	0.571666384
		0.70	1.40	223.30540	156.31378	2.00	3.126275532
		1.00	2.00	237.09167	237.09167	2.00	4.741833392
		0.48	0.64	193.05002	92.66401	2.00	1.85328017
		0.50	0.50	183.50833	91.75417	2.00	1.835083304

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
		1.00	1.33	221.32280	221.32280	2.00	4.426455921
		1.00	0.67	194.82066	194.82066	2.00	3.896413149
		1.00	0.67	194.82066	194.82066	2.00	3.896413149
		0.07	0.14	134.30540	9.40138	2.00	0.188027553
		0.10	0.05	94.50833	9.45083	2.00	0.189016661
		0.25	1.00	210.30000	52.57500	2.00	1.0515
							25.77596521
	22	1.00	1.33	221.32280	221.32280	1.40	3.098519145
		0.70	1.40	223.30540	156.31378	1.40	2.188392873
		0.30	0.30	163.76379	49.12914	1.40	0.687807925
		0.65	0.87	204.91721	133.19619	1.40	1.864746643
		0.35	0.70	196.51373	68.77980	1.40	0.962917255
		0.15	0.60	190.55546	28.58332	1.40	0.400166469
		0.85	0.57	188.57286	160.28693	1.40	2.24401706
		0.20	0.80	201.67501	40.33500	1.40	0.564690025
		0.10	0.13	131.44096	13.14410	1.40	0.184017342
		0.10	0.03	74.76379	7.47638	1.40	0.104669308
		0.60	0.34	168.60162	101.16097	1.40	1.416253638
		0.35	0.70	196.51373	68.77980	1.40	0.962917255
		0.05	0.20	148.09167	7.40458	1.40	0.103664169
		0.15	0.30	163.76379	24.56457	1.40	0.343903963
		0.20	0.27	159.69138	31.93828	1.40	0.44713585
		0.80	0.16	139.46668	111.57334	1.40	1.562026799
							17.13584572
	23	1.00	1.33	221.32280	221.32280	2.50	5.533069901
		0.40	0.40	174.88334	69.95334	2.50	1.748833392
		0.10	0.10	121.30000	12.13000	2.50	0.30325
		0.50	0.40	174.88334	87.44167	2.50	2.18604174
		0.28	0.28	161.09706	45.10718	2.50	1.127679454
		0.18	0.36	170.81092	30.74597	2.50	0.768649152
		0.15	0.10	121.30000	18.19500	2.50	0.454875
		0.28	0.56	187.88873	52.60885	2.50	1.315221141
		1.00	1.33	221.32280	221.32280	2.50	5.533069901
		1.00	1.33	221.32280	221.32280	2.50	5.533069901
		1.00	1.33	221.32280	221.32280	2.50	5.533069901
		1.00	1.33	221.32280	221.32280	2.50	5.533069901
		1.00	2.00	237.09167	237.09167	2.50	5.92729174
		1.00	4.00	263.88334	263.88334	2.50	6.597083481
		1.00	1.00	210.30000	210.30000	2.50	5.2575
		1.00	0.80	201.67501	201.67501	2.50	5.041875221
		0.55	1.10	213.98395	117.69117	2.50	2.942279298
							61.33592912
	24	0.95	1.90	235.10907	223.35362	1.90	4.243718722
		0.45	0.90	206.22758	92.80241	1.90	1.763245838
							6.00696456
	31	0.85	3.40	257.60162	218.96138	3.70	8.101571063
		1.00	4.00	263.88334	263.88334	3.70	9.763683551
		1.00	4.00	263.88334	263.88334	3.70	9.763683551
		0.15	0.30	163.76379	24.56457	3.70	0.908889044
							28.53782721

Appendix-6.2

Frequency Analysis for Monsoon Erosion Index and Maximum Single Storm Erosion Index

Monsoon Erosion Index

(1) Gumbel's Extreme Value Type-I Distribution

$E_T = u + \alpha Z_T$

Where, E_T = T year return period Erosion Index
u & α are the parameters of the distribution

$Z_T = -\log_e \{ -\log_e (1 - 1/T)\}$

Probability of non- exceedance =1-1/T

$\bar{E} = u + 0.5772\,\alpha$ ---------(1)

Where, $\bar{E}$ =Mean of the Erosion Indices Series

σ_{n-1} = Standard deviation of the series
Monsoon Erosion Indices series is given at Table- 6.4
n = number of data in the series

$\bar{E} = 732.62$
$\sigma_{n-1} = 265.54$

$\sigma_{n-1}^{\ 2} = \alpha^2\, \pi^2/6$

$\alpha = \sqrt{\sigma_{n-1}^{\ 2} * 6/\pi^2}$

$\alpha = 206.96$
$732.62 = u + 0.5772 * 206.96$
or, $u = 613.16$
Z_T for 1.25 years, 2 years, 5 years, 10 years and 20 years return period.
$Z_T = -\log_e \{-\log_e (1-1/T)\}$
$= -\log_e \{-\log_e (1-1/1.25)\}$
$Z_{1.25} = -0.48$
$Z_2 = -\log_e \{-\log_e (1-1/2)\}$
$Z_2 = 0.37$
$Z_5 = -\log_e \{-\log_e (1-1/5)\}$
$Z_5 = 1.50$ $Z10 = -\log_e \{-\log_e (1-1/10)\}$
$Z_{10} = 2.25$
$Z_{20} = -\log_e \{-\log_e (1-1/20)\}$

$Z_{20} = 2.97$

Erosion Index corresponding to 1.25 years, 2 years, 5 years, 10 years and 20 years return period can be given by

$E_{1.25} = u + \alpha Z_2$
$E_{1.25} = 613.69 - 206.96 * 0.48$
$E_{1.25} = 513.82$
$E_2 = 613.16 + 206.96 * 0.37$
$E_2 = 689.74$
$E_5 = 613.16 + 206.96 * 1.5$
$E_5 = 923.6$
$E_{10} = 613.16 + 206.96 * 2.25$
$E_{10} = 1078.82$
$E_{20} = 613.16 + 206.96 * 2.97$
$E_{20} = 1227\ 83$

(2) Log Person Type –III Distribution

$y_T = \bar{y} + \sigma y\, K_T$
Where, y_T = T year return period Erosion Index in ln domain

$\bar{y}$ = Mean of the transformed series in ln domain (Table-6.)
σ_y = standard deviation of the transformed series in ln domain
K_T = frequency facter computed from standard Statistical table corresponding to probability of exceedence , $f(x) = 1/T$ and co-efficient of skewness, g_y of the series.

$$E_T = e^{(\bar{y} + \sigma_y K_T)}$$

Where, E_T = T year return period Erosion Index in natural domain
g_y = Co-officient of skewness = $n/(n-1)(n-2) * \sum \frac{(y-\bar{y})^3}{\sigma y^3}$

No of data	y= ln E	y in discending order	Rank (m)	(y-y)	(y-y) 2	(y-y) 3
1	6 78	6 94	1	0 43	0 1849	0 079507
2	5 63	6 87	2	0 36	0 1296	0 046656
3	6 46	6 8	3	0 29	0 0841	0 024389
4	6 94	6 78	4	0 27	0 0729	0 019683
5	6 08	6 46	5	-0 05	0 0025	-0 00012
6	6 87	6 08	6	-0 43	0 1849	-0 07951
7	6 8	5 63	7	-0 88	0 7744	-0 68147
	y=6 51				1 4333	-0 59087

$\sigma y = \sqrt{\sum (y - \bar{y})^2 / n-1} = \sqrt{(1\ 43)/6} = 0.49$

$g_y = n/(n-1)(n-2) * \sum \frac{(y-\tilde{y})^3}{\sigma y^3} = (7/6*5) * - 0.59/(0.49)^3$

$= - 1.17$

Erosivity Index corresponding to 1.25 years, 2 years, 5 years, 10 years and 20 years return period

$y_T = \bar{y} + \sigma y K_T$

$y_{1.25} = 6.51 + 0.49 * (-0.732) = 6.15$

$y_{1.25}$ (natural ddomain) $= e^{y_{T1.25}} = 468.72$

$y_{T2} = \bar{y} + \sigma y K_T = 6.51 + 0.49 * (0.195)$

$= 6.61$

$y_{T2\ (\text{natural domain})} = e^{yT2} = 742.48$

$y_{T5} = 6.51 + 0.49 * 0.841 = 6.92$

$y_{T5\ (\text{natural domain})} = 1012.32$

$y_{T10} = 6.51 + 0.49 * 1.086 = 7.04$

$y_{T10\ (\text{natural domain})} = 1141.39$

$y_{T20} = 6.51 + 0.49 * 1.217 = 7.11$

and $y_{T20\ (\text{natural domain})} = 1224.15$

Goodness of Fit test

(1) Computation for Goodness of Fit for Gumble's Extreme Value Type-I Distribution.

Rank (m)	E obs	E comp	Probability of non excedance {1-f(x)=G(x)}	Eobs - E comp
1	1028.15	1004.31	0.86	23.84
2	966.64	834.61	0.71	132.03
3	878.99	733.2	0.57	145.79
4	641.5	648.34	0.43	-6.84
5	436.29	656.62	0.29	-220.33
6	278.27	753.89	0.14	-475.62
				-401.13

E_{Comp} = Computed value as per adopted probability distribution
$= u + \alpha * Zx$

When $Zx = -\log e\ [-\log e\ \{1-f(x)\}]$
$Zn = -\log e\ \{-\log e\ G(x)\}$
$Z_1 = 1.89$; , $Z_2 = 1.07$; $Z_3 = 0.58$; $Z_4 = 0.17$
$Z_5 = -0.21$; and $Z_6 = -0.68$

$E_{Comp1} = 613.16 + 206.96 * Zx$
$= 613.16 + 206.96 * Z1 = 1004.31$
$E_{Comp2} = 834.61$
$E_{Comp3} = 733.20$
$E_{Comp4} = 648.34$
$E_{Comp5} = 656.62$
$E_{Comp6} = 753.89$

$D_{Index} = 1/\bar{E} * \sum |E_{obs} - E_{Comp}| = 1/732.62 * (401.13) = 0.55$

(2) Computation for Goodness of Fit for Log Pearson Type-III Distribution.

			n+1	
1	1028.15	1085.72	0.14	-57.57
2	966.64	925.19	0.29	41.45
3	878.99	796.32	0.43	82.67
4	641.5	665.14	0.57	-23.64
5	436.29	533.79	0.71	-97.5
6	278.27	391.5	0.86	-113.23
				-167.82

$y_T = \bar{y} + \sigma y K_T$

$E_T = e^{(\bar{y} + \sigma_y K_T)}$

Where, E_T = T year return period Erosion Index in natural domain

$\bar{y}$ = Mean of the transformed series in ln domain (Refer Table)
σ_y = standard deviation of the transformed series in ln domain

K_T = frequency facter computed from standard Statistical table corresponding to probability of exceedence , $f(x)$ and co-efficient of skewness, g_y = -1.17 of the series.

$y_{T1} = \bar{y} + \sigma y K_T$

$= 6.51 + 0.49 * 0.988 = 6.99$

$y_{T1 \text{ (natural domain)}} = e^{yT1} = 1085.72$

$y_{T2} = 6.51 + 0.49 * 0.65 = 6.83$
$y_{T2 \text{ (natural domain)}} = e^{yT2} = 925.19$
$y_{T3} = 6.51 + 0.49 * 0.346 = 6.68$
$y_{T3 \text{ (natural domain)}} = e^{yT3} = 796.32$
$y_{T4} = 6.51 + 0.49 * (-0.02) = 6.50$
$y_{T4 \text{ (natural domain)}} = e^{yT4} = 665.14$
$y_{T5} = 6.51 + 0.49 * (-0.45) = 6.28$
$y_{T5 \text{ (natural domain)}} = e^{yT5} = 533.79$
$y_{T6} = 6.51 + 0.49 * (-1.097) = 5.97$
$y_{T6 \text{ (natural domain)}} = e^{yT6} = 391.50$

$D_{Index} = 1/\bar{E} * \sum |E_{obs} - E_{Comp}| = 1/732.62 * 167.82 = 0.23$

Since value of D_{Index} in case of Log Pearson Type-III comes less w.r.t. Gumbel's Extreme Value distibution , the Monsson Erosion Index computed by Log Pearson Type-III for the return period of 2 years, 5 years, 10 years and 20 years may be used in predicting the soil loss.

Maximum Single Storm Erosion Index

(1) Gumbel's Extreme Value Type-I Distribution

$E_T = u + \alpha Z_T$

Where, E_T = T year return period Erosion Index
u & α are the parameters of the distribution

$Z_T = -\log_e \{ -\log_e (1 - 1/T)\}$

Probability of non- exceedance =1-1/T

$\bar{E} = u + 0.5772\, \alpha$ --------- (1)

Where, $\bar{E}$ =Mean of the Erosion Indices Series
σ_{n-1} = Standard deviation of the series
Monsoon Erosion Indices series is given at table
n = number of data in the series

$\bar{E} = 153.31$
$\sigma_{n-1} = 76.45$

$\sigma_{n-1}{}^2 = \alpha^2 \ \Pi^2 /6$

$\alpha = \sqrt{\sigma_{n-1}{}^2 * 6 / \Pi^2} \quad = \quad \sqrt{76.45^2 * 6 / \Pi^2} \quad = \quad 76.45 * \sqrt{6} / \Pi$

$\alpha = 59.61$

$\bar{E} = u + 0.5772\ \alpha$
$153.31 = u + 0.5772 * 59.61$
or, $u = 118.90$
Z_T for 1.25 years, 2 years, 5 years, 10 years and 20 years return period.

$Z_T = -\log_e \{ -\log_e (1-1/T)\}$
$Z_{1.25} = -0.48$
$Z_2 = 0.37$; $Z_5 = 1.50$; $Z_{10} = 2.25$ and $Z_{20} = 2.97$
Erosion Index after 2 years, 5 years, 10 years and 20 years can be given by
$E_2 = u + \alpha\ Z_T$
$E_{1.25} = 118.90 + 59.61 * (-0.48) = 90.28$
$E_2 = 118.90 + 59.61 * 0.37$
$E_2 = 140.96$
$E_5 = 208.32$
$E_{10} = 253.02$
$E_{20} = 295.94$

(2) Log Pearson Type –III distribution

$y_T = \bar{y} + \sigma y\ K_T$
Where, y_T = T year return period Erosion Index in ln domain

$\bar{y}$ = Mean of the transformed series in ln domain (Refer Table)
σ_y = standard deviation of the transformed series in ln domain
K_T = frequency facter computed from standard Statistical table corresponding to probability of exceedence , $f(x) = 1/T$ and co-efficient of skewness, g_y of the series.

$E_T = e^{(\bar{y} + \sigma y\ K_T)}$
Where, E_T = T year return period Erosion Index in natural domain
g_y = Co-officient of skewness = $n /(n-1)\ (n-2) * \dfrac{\sum (y-\bar{y})^3}{\sigma y^3}$
where, n = number of data = 7

y= ln E	y in discending order	Rank (m)	(y-y)	(y-y) 2	(y-y) 3
5 05	5 61	1	0 74	0 55	0 41
3 85	5 45	2	0 58	0 34	0 20
5 08	5 08	3	0 21	0 04	0 01
4 95	5 05	4	0 18	0 03	0 01
4 12	4 95	5	0 08	0 01	0 00
5 61	4 12	6	-0 75	0 56	-0 42
5 45	3 85	7	-1 02	1 04	-1 06
Sigma	34 11			2 57	-0 87

$\bar{y} = 4.87$

$\sigma y = \sqrt{\sum (y- \bar{y})^2 /n-1} = \sqrt{2.57 /6} = 0.65$

$g_s = n /(n-1) (n-2) * \dfrac{\sum (y-\bar{y})^3}{\sigma y^3}$

$g_s = (7 /30) * - 0.87/0.65^3 = 76.45 = - 0.74$

Erosivity Index for 1.25 years, 2 years, 5 years, 10 years and 20 years

$y_T = \bar{y} + \sigma y K_T$

$y_{T1\ 25} = 4.87 + 0.65 * (-0.857) = 4.31$

$y_{T1\ 25\ (natural\ domain)} = e\ y^{T1\ 25} = 74.74$

$y_{T2} = \bar{y} + \sigma y K_T = 4.87 + 0.65 * (0.116)$
$= 4.95$

$y_{T2\ (natural\ domain)} = e^{yT2} = 141.17$

$y_{T5} = 4.87 + 0.65 * 0.857 = 5.43$

$y_{T5\ (natural\ domain)} = 228.15$; $y_{T10\ (natural\ domain)} = 281.17$ and $y_{T20\ (natural\ domain)} = 320.90$

Goodness of Fit test

(1) Computation of Goodness of Fit for Gumble's Extreme Value Type-I Distribution

Rank (m)	E obs values in discen-ding order	E comp.	Probability of exc-eedance {6f(x)= m / n+1	Probability of non excedance {1-f(x)=G(x)}	Ebs-Ecomp
1	274.44	231.56	0.14	0.86	42.88
2	160.73	182.68	0.29	0.71	-21.95
3	155.28	153.47	0.43	0.57	1.81
4	140.85	129.03	0.57	0.43	11.82
5	61.73	106.38	0.71	0.29	-44.65
6	47.09	78.36	0.86	0.14	-31.27
					-41.36

E_{Comp} = Computed value as per adopted probability distribution
$= u + \alpha * Zx$

When $Zx = -\log e\,[-\log e\,\{1-f(x)\}]$
$Zn = -\log e\,\{-\log e\, G(x)\}$
$Z_1 = 1.89;$, $Z_2=1.07$; $Z_3 =0.58$; $Z_4 =0.17$
$Z_5 = -0.21$; and $Z_6 = -0.68$
$u = 118.90$
$\alpha = 59.61$
$E_{Comp1} = 118.90 + 59.61 * Z_1$
$= 118.90 + 59.61 * 1.89 = 231.56$
$E_{Comp2} = 118.90 + 59.61 * 1.07 = 182.68$
$E_{Comp3} = 153.47$
$E_{Comp4} = 129.03$
$E_{Comp5} = 106.38$
$E_{Comp6} = 78.36$

$D_{Index} = 1/\bar{E} \sum E_{obs} - E_{Comp}$

$= (1/153.31) * 41.36 = 0.27$

(2) Computation for Goodness of Fit for Log Pearson Type-III Distribution.

Rank (m)	E obs values	E comp	Probability of exceedance $\{f(x)=\frac{m}{n+1}$	Eobs - E comp
1	274.44	258.32	0.14	16.12
2	160.73	196.87	0.29	-36.14
3	155.28	157.24	0.43	-1.96
4	140.85	122.49	0.57	18.36
5	61.73	92.72	0.71	-30.99
6	47.09	63.1	0.86	-16.01
				-50.62

$$y_T = \bar{y} + \sigma y\, K_T$$

$$E_T = e^{(\bar{y} + \sigma_y K_T)}$$

Where, E_T = T year return period Erosion Index in natural domain

$\bar{y}$ = Mean of the transformed series in ln domain (Refer Table-6.)
σ_y = standard deviation of the transformed series in ln domain
K_T = frequency facter computed from standard Statistical table corresponding to probability of exceedence , $f(x)$ and co-efficient of skewness, g_y of the series.

$$y_{T1} = y + \sigma y\, K_T$$

$$= 4.87 + 0.65 * 1.053 = 5.55$$

$y_{T1\,(\text{natural domain})} = e^{y_{T1}} = 258.32$

Similarly. $y_{T2\,(\text{natural domain})} = 196.87$; $y_{T3\,(\text{natural domain})} = 157.24$;

$y_{T4\,(\text{natural domain})} = 122.49$; $y_{T5\,(\text{natural domain})} = 92.72$ and

$y_{T6\,(\text{natural domain})} = 63.10$

$D_{\text{Index}} = 1/\bar{E} * \sum |E_{obs} - E_{Comp}| = (1/153.31) * 50.62 = 0.33$

Since value of D_{Index} in case of Gumbel's Extreme Value distibution comes less w.r.t. Log Pearson Type-III, the maximum single Erosion Index computed by Gumbel's Extreme Value distibution for the return period of 2 years, 5 years, 10 years and 20 years may be used in predicting the soil loss.

Appendix-6.3

Estimation of Sediment Load by Empirical Relationship

(1) Garde et al. (1983) analysed the data from 31 large and small reservoirs in India. The absolute volume of eroded material was expressed in terms of hydrometerologic landuse and catchment variables.

$$Vs = 1.182 * 10^{-6} * P^{1\ 29} * A^{1\ 03} * D_d^{0\ 40} * S^{0\ 08} * F_c * 2.42$$
(1)

Where A = catchment area in Km ^{2} = 136.45 Km^2
L = stream length in Km = 22.15 km
S = catchment slope = 16 %
D_d = drainage density = 2.90
F_c = vegetation cover factor = 0.002 (value of cover factor for the pristine forest has been taken: Ref.-Schulz, E.F. (1981) "Sediment Yield Estimates in Planning Land Use Changes"
P = annual mean precipitation in mm = 1541.7 mm (during monsoon period)
Vs = sediment yield rate in Mm^3/100 km/year

Though the relationship indicated at (1) above has been developed to estimate the sediment yield rate, the same has been used to estimate the sediment yield rate from Umiew watershed during monsoon by substituting the value precipitation (= 1541.7 mm) taken place during monsoon in 1996 in place of annual mean precipitation.

$$Vs = 1.182 * 10^{-6} * P^{1\ 29} * A^{1\ 03} * D_d^{0\ 40} * S^{0\ 08} * F_c * 2.42$$
$$= 1.182 * 10^{-6} * (1541.7)^{1\ 29} * (136.45)^{1\ 03} * (2.9)^{0\ 40} * (0.16)^{0\ 08} * 0.002 * 2.42$$
$$= 0.0157 \text{ Mm3/100 Km}$$

Vs = 0.09 ton/ha.

(2) Garde and Kothyari (1987) analysed erosion data along with other data characterising 50 Indian catchments to obtain a relationship for annual sediment yield. Use of data from 104 other catchments spread evenly over India has been made for the estimation of erosion rates from the catchments. Based on these values, an iso-erosion map of India has been prepared on the basis of this study. They concluded that the land use variable has been found to be the most influential factor affecting the sediment yield followed by catchment slope, rainfall variables and drainage density.

$$Vs = 1.067 * 10^{-6} * P^{1\ 38} * A^{1\ 29} * D_d^{0\ 40} * S^{0\ 13} * F_c * 2.51$$

Where A = catchment area in Km ^{2} = 136.45 Km^2 = 13645 ha.
L = stream length in Km = 22.15 km
S = catchment slope = 16 %
D_d = drainage density = 2.90
F_c = vegetation cover factor = 0.002
P = annual mean precipitation in mm = 1541.7 mm (during monsoon period)

Vs = sediment yield rate in Mm^3

$Vs = 1.067 * 10^{-6} * (1541.7)^{1..38} * (136.45)^{1..29} * 2.(90)^{0.40} * (0.16)^{0.13} * 0.002 * 2.51$

$= 0.092\ Mm^3$

$= 0.092 * 1.8 * 10^6 = 1{,}65{,}600$ ton (Unit weight of sediment load has been taken to 1.8 ton/m^3)

Vs = 1,65,600/13645 = 12.14 ton/ha.

Appendix-6.4

Discharge Ordinates of SUH

Time (hrs)	Estimated discharge ordinates of SUH	Modified discharge ordinates of SUH
0.0	0.0	0.0
1.0	3.0	3.0
2.0	6.0	6.0
3.0	9.0	9.0
4.0	12.0	12.0
5.0	15.0	15.0
6.0	**19.0**	**19.0**
7.0	25.0	25.0
7.3	**28.5**	**28.5**
8.0	34.0	34.0
9.0	**38.0**	**38.0**
10.0	36.0	36.0
11.0	32.0	32.0
12.0	**28.5**	**28.5**
12.0	28.2	28.2
13.0	23.0	24.0
14.0	20.0	21.0
14.6	**19.0**	**19.0**
15.0	18.3	17.5
16.0	17.0	14.5
17.0	15.3	11.5
18.0	14.0	8.8
19.0	13.0	6.5
20.0	11.4	4.5
21.0	10.0	3.5
22.0	9.0	2.5
23.0	7.7	1.5
24.0	6.3	1.0
25.0	5.0	0.8
26.0	4.0	0.6
27.0	2.7	0.5
28.0	1.2	0.2
29.0	0.0	0.0
Sum	511.1	452.1
Deduct	-76	-76
Net Sum	435.1	376.1

Estimation of Flood Peak for 25 years and 50 years return period

It has been studied that the critical storm duration which causes severe floods in small and medium catchments, has the value of 1.1 tp (Flood Estimation Report for South Brahmaputra Sub-Zone-2 (b) (Revised), CWC, 2000, pp. 25)

Therefore, computation of flood peaks of 25-year and 50 -year return periods have been computed for 24-hr point rainfall at Maphlang site of Umiew watershed. This 24-hr point rainfall value has been taken from the Isopluvial maps prepared by India Meteorological Department (IMD).

The design strom duration, $T_D = 1.1\ t_p$

$= 1.1 \times 8.5 = 9.35$ hrs

$= 9.00$ hrs (Rounded off to nearest full hours)

Estimation of Point Rainfall and Areal Rainfall for Storm Duration

The point rainfall for the Mawphlang site of river Umiew from the Isopluvial Map prepared by IMD for the 25-years and 24-hour point rainfall has been found to be 560 mm. This point rainfall has firstly been converted into point rainfall of 9.00 hrs storm duration by the conversion curve prepared by IMD (Flood Estimation Report for South Brahmaputra Sub-Zone-2 (b) (Revised), CWC, 2000, Fig.-13).

So, 560 mm point rainfall of 25-year and 24-hour has been worked out to 459.2 mm (= 0.82 x 560) point rainfall of 9.00 hrs duration. The areal reduction factor of 0.9121 correspnding to the catchment area of 136.45 mm^2 and for storm duration of 9 hrs has been interpolated from the Areal Reduction Factor Table (Flood Estimation Report for South Brahmaputra Sub-Zone-2 (b) (Revised), CWC, 2000, pp. A-16). 25- year point rainfall of 9 hrs has been converted into 9 hrs areal rainfall by applying the convesion factor of 0.9121. Thus, 25-yr 9hrs areal rainfall has been found to 418.8 mm (= 0.9121*459.2). Now, 25-yr and 9hrs areal rainfall has been split into 1-hour rainfall increments by using time distribution co-effecients. The effective hourly rainfall during storm duration of 9 hours are computed in Table-6.6 (a).

Table - 6.6 (a) : Hourly Effective Rainfall Increments for 25-Year Return Period					
Duration (hr)	Distribution Co-efficient	Strom Rainfall (cm)	Rainfall Increments (cm)	Loss Rate/hr (cm)	Effective hourly rainfall (cm)
1	0.38	15.91	15.91	0.36	15.55
2	0.59	24.71	8.8	0.36	8.44
3	0.71	29.73	5.02	0.36	4.66
4	0.80	33.5	3.77	0.36	3.41
5	0.86	36.02	2.52	0.36	2.16
6	0.91	38.11	2.09	0.36	1.73
7	0.95	39.79	1.68	0.36	1.32
8	0.98	41.04	1.25	0.36	0.89
9	1.00	41.88	0.84	0.36	0.48

Computation of flood peak

In order to compute flood peak discharge, the effective rainfall increments have been rearranged against the ordinate of SUH such that maximum value of 1-hour effective rainfall is placed against the maximum ordinate of modified SUH, next lower value of effective rainfall against next lower value of ordinate of modified SUH and so on. The modified ordinates of SUH are shown at Appendix-6.4. The flood peak computation is shown in Table-6.6 (b). The sum of the product of SUH ordinates and effective hourly rainfall gives total direct surface runoff to which the base flow has been added to get total peak discharge.

The average base flow rate of 0.05 cumecs/Km2 has been recommended by the Central Water Commission (CWC) for estimating base flow for the river catchment falling in South Brahmaputra sub-zone – 2(b) (Flood Estimation Report for South Brahmaputra Sub-zone-2(b),Revived, CWC, 2000, pp.18). Therefore, the base flow for the entire watershed of river Umiew has been estimated to be 6.82 cumecs (=0.05 * 136.45)

Table - 6.6 (b) : 25-Year Flood Peak			
Time (hr)	SUH modified ordinates (cumecs)	1-hour effective rainfall (cm)	Direct runoff (cumecs)
6	19.0	0.48	9.12
7	25.0	1.73	43.25
8	34.0	4.66	158.44
9	38.0	15.55	590.09
10	36.0	8.44	303.84

11	32.0	3.41	109.12
12	28.5	2.16	61.55
13	24.0	1.32	31.68
14	21.0	0.89	18.69
		Total	1325.78
		Base Flow	6.82
	Flood Peak (Q25)		1332.6

Therefore, the total flood peak discharge of 25-year return period has been computed to 1332.60 cumecs. Similarly, the total flood peak discharge corresponding to 50-year return period and 24-hr rainfall has been computed to 1637.7 cumecs. The computational details are shown in Table- 6.6 © and 6.6 (d). The Isophivial Map of IMD has been used to obtain 50-yr and 24-hr rainfall for the Mawphlang site of Umiew watershed. This rainfall value has come to 680 mm which has been used in the computation of total peak discharge for 50-yr return period. The point rainfall of 680 mm corresponding to 50-year and 24-hour has been converted into 557.6 mm (= 0.82*680) point rainfall of 50-year 9 hours duration. Again, this 50-yr 9 hrs duration rainfall of 508.59 mm (= 0.9121 x 557.6) has been converted into areal rainfall of 50-year and 9 hours duration. The rest procedure has been followed the same as has been done for the computation of 25-yr flood peak to determine hourly effective rainfall increments and 50-yr flood peak. The computation of hourly effective rainfall increments and 50-yr flood peak are shown in Table-6.6 © and 6.6 (d).

Table - 6.6 (c) : Hourly Effective Rainfall Increments for 50-Year Return Period					
Duration (hr)	Distribution Co-efficient	Strom Rainfall (cm)	Rainfall Increments (cm)	Loss Rate/hr (cm)	Effective hourly rainfall (cm)
1	0.38	19.33	19.33	0.36	18.97
2	0.59	30	10.67	0.36	10.31
3	0.71	36.11	6.11	0.36	5.75
4	0.80	40.69	4.58	0.36	4.22
5	0.86	43.74	3.05	0.36	2.69
6	0.91	46.28	2.54	0.36	2.18
7	0.95	48.32	2.04	0.36	1.68
8	0.98	49.84	1.52	0.36	1.16
9	1.00	50.86	1.02	0.36	0.66

Table - 6.6 (d) : 50-Year Flood Peak			
Time (hr)	SUH modified ordinates (cumecs)	1-hour effective rainfall (cm)	Direct runoff (cumecs)
6	19.0	0.66	12.54

7	25.0	2.18	54.5
8	34.0	5.75	195.5
9	38.0	18.97	720.86
10	36.0	10.31	371.16
11	32.0	4.22	135.04
12	28.5	2.69	76.67
13	24.0	1.68	40.32
14	21.0	1.16	24.36
		Total	1630.95
		Base Flow	6.82
	Flood Peak (Q50)		1637.77