CS/AR-3/2000-2001

RAINFALL-RUNOFF ANALYSIS USING FLOOD ANALYSIS AND PROTECTION SYSTEMS (FLAPS) MODEL

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2000-2001

PREFACE

Flood estimation has been a major concern of the hydrologists world over. Despite a substantial advancement in the methodology of design flood estimation, a large number of field practitioners still continue to use methods developed decades ago, and these are recommended by their departments with a set of procedures laid out for field use. The advancement includes the methods of design storm estimation, unit hydrograph derivation, flood frequency analysis and other distributed models for rainfall-runoff simulations have now been upgraded. Simple forecasting of the past have now been upgrade with the widespread use of large, fast electronic computers, more complex conceptual models yielding greater reliability and accuracy. Countries experiencing severe flood problems have developed effective and specific software which include empirical formulae, regional flood analysis for a wide range of settings to determine the flood. Conceptual distributed rainfall -runoff modeling is such a method that involves the transformation of spatially varying rainfall hydrograph and losses to flood hydrograph.

In this report, two models FLAPS and HEC-1 are used for rainfall-runoff simulation employing selected short-term events of three basins of North Eastern India: Myntdu-leska basin (Meghalaya), Krishnai and Dudhnai in Assam. The results are used to study the sensitivity of model parameters with respect to different hydrological parameters of the basin, and performance of these methods is evaluated by analyzing the isolated events, overall bias and efficiency. An attempt has also been made to evaluate the non-linearity in rainfall-runoff response using simple storage-runoff dynamic model. The report is prepared by P.K.Bhunya and Rajan Vats, Scientists and R.K.Nema, SRA of this Institute.

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CONTENTS

List Of Figures ..... (i)
List Of Tables .....(ii)
Abstract .....(iii)

1. INTRODUCTION 1

2. STUDY AREA 3
   2.1 General 3
   2.2 Existing observation network 4

3. METHODOLOGY 10
   3.1 Physical concept of FLAPS model 10
   3.2 Distributed flow model 12
   3.2.1 Model structure 13
   3.2.2. Parameter optimization of the model 14
   3.3 Non linear response measure 14

4. RESULTS AND DISCUSSION
   4.1 Rainfall analysis 16
   4.2 Runoff analysis 16
   4.3 Rainfall-runoff simulation with FLAPS 17
   4.3.1 Calibration and validation of FLAPS 17
   4.3.2 Sensitivity of parameters 20
   4.4 Calibration and validation of HEC-1 21
   4.5 Sensitivity of parameters 25
   4.6 Non linearity response of the basin 25

5. CONCLUSION AND REMARKS 37
   REFERENCES

LIST OF FIGURES

1A. Index map of Myntdu leska basin 5
1B. Index map of Krishnai basin 6
1C. Index map of Dudhnai basin 6
1D. FALPS Model Structure 11
2. Flood hydrograph using different approaches for Myntdu leska basin 30
3. Flood hydrograph using different approaches for Krishnai basin 32
4. Flood hydrograph using different approaches for Dudhnai basin 33
5. Peak flow variation with rainfall 34
6. Variation of peak with change in Tc & R 35
7. Variation of peak with change in loss rate 35
8. Observed peak Vs estimated peak using HEC 36
9. Observed peak Vs estimated peak using FLAPS...36

LIST OF TABLES

1A. Detailed inventory of data for Myntdu leska basin 8
1B. Detailed inventory of data for Dudhnai & Krishnai basin .9
2. Parameter of the model 12
3. Calibrated parameters for Myntdu leska basin 19
4. Calibrated parameters for Krishnai basin 19
5. Calibrated parameters for Dudhnai basin 19
6. Calibrated results for Myndu leska basin using HEC-1 22
7. Calibrated results for Krishnai basin using HEC-1 23
8. Calibrated results for Dudhnai basin using HEC-1 24
9. Overall results of calibrated parameters of FLAPS model 27
10. Sensitivity of FLAPS parameters 27
11. Sensitivity of parameters of HEC-1 model 28
12. Error in peak estimates with FLAPS and HEC for All events 28
13. Performance of FLAPS and HEC model 29
14. Measure of non linearity in rainfall-runoff Relationships for three basins 29

ABSTRACT

In this report a conceptual distributed hydrological catchment model, FLAPS is compared with HEC-1 in simulating the rainfall-runoff processes for selected events. The study areas are selected as three basins of North eastern region of India; Myntdu leska basin (Meghalaya), Krishnai basin (Assam) and Dudhnai basin (Assam). Through the established rainfall-runoff relationships and calibrated model parameters, the results are meant to be a design tool where historical design storm with a certain recurrence can be analyzed in terms of runoff. The primary objective of the study is to ; (i) Calibrate and validate the model for Krishnai, Dudhnai and Myntdu leska basins (ii) Study the sensitivity of the model parameters with respect to different land use conditions, incipient soil moisture and transmissivity on direct runoff and total recharge (iii) Comparison of the results with HEC-1.

Methods applied in FLAPS model is based on principles and experience of an earlier model (*Bengtsson, 1994*) . The model has the flexibility to treat the study area either as a linked system of a number of subbasins or a lumped system, which have parameters corresponding to their physiological conditions. In linked system subbasins are connected separately either by river reaches, channels or lakes represented by corresponding routines. The estimated runoff is used with the actual runoffs for calibrating model parameters. The calibrated model parameter is used on some test events to check the validity of the parameters for the basin. HEC-1 is also a distributed rainfall -runoff modeling based on Clark's method, also known as time-area histogram. The model involves the transformation of spatially varying rainfall excess hydrograph and losses into flood hydrograph. It assumes that the rainfall excess first undergoes pure translation that is estimated by a travel time-area histogram and the attenuation is routed through a linear reservoir at the catchment outlet. The time of concentration and storage constant of the basin are optimized using HEC-1 and the parameters are validated for storm. The parameters thus obtained are used in the model to arrive at unit hydrograph for the basin.

In this report, the main effort of the calibration work was concentrated on the flood peaks and their time of occurrence. However, a few numbers of computations were also done for checking the flood volume. The verification of the FLAPS and HEC model was done for the selected events. The broad conclusions arrived after the analysis for three test catchment is that HEC model tends to overestimate the peak for low rainfall events and overestimate for high rainfall events. However, the variations are within 15 % for maximum events analysed in the study. The performances of the two models for these selected events on basis of bias, RMSE, mean absolute error, efficiency and R^2. As observed both the models performs well on the analysed data, however, HEC model tend to be less biased than FLAPS. An attempt has also been made in this report to check the non-linearity in rainfall-runoff response using simple storage-runoff dynamic model for selected events. The results showed degree of regression coefficient (R^2) ranging from 62 to 91 % . Since only three basins are considered for the analysis the relationship of parameter 'B' (that represents the degree of non-linearity in catchment response) with the catchment area could not be established. However, It can be observed that Krishnai basin with an area of 950 Sq.km has a low B-parameter compared to Myntdu-Leska basin, a smaller catchment

1.0 Introduction:

The problem of flood and their computations is one of the primary and complex problems facing the hydrologists. The optimal development of water resources depends on flood flow control, the design and construction of culverts, bridges, spillways etc. and for taking proper measures for flood control mitigation. All these problems require accurate and reliable data of floods and proper procedure for analysis in order to arrive at desired design variables. With the widespread use of large, fast electronic computers, more complex conceptual models with greater reliability and accuracy have now been developed to model the rainfall-runoff process. Since rainfall data is generally in abundance in comparison to runoff data, the attempt has always been to convert rainfall to runoff. Over the period the water resources experts have tried to establish this relationship applying different concepts and methods. Presently a number of linear and non-linear models are available for use in the process of rainfall-runoff simulation and examples of types of mathematical catchment models and their concept can be found in a variety of hydrologic applications. But careful evaluations are needed to ensure that all the relevant processes are being properly quantified. The feasibility of application of any of these models to a basin is finalized after validating the model with real data. In many cases a relationship is established between rainfall and runoff with a given concept as per the existing hydro meterological conditions and data availability

So many authors have proposed mathematical model for estimation of runoff from reservoirs in a drainage basin. Nash has presented a mathematical expression for net runoff by considering n-linear reservoirs in a basin having the same storage-coefficients for all reservoirs. Basu (1989) has presented a mathematical expression of net discharge estimation from reservoirs where the storage coefficients are different. HYRROM developed by the Institute of Hydrology (1989) , is designed to produce hourly estimates of streamflows from hourly catchment rainfall and hourly potential evaporation derived from meteorological data using the Penman formula. Similarly, Kidd, (1978);Falk and Niemczynowicz (1979) have shown before a rainfall-runoff simulation model which operated well on small, impermeable urban catchments. Attempts have been made in the past to simulate runoff using finite element method (FEM) by Yadav (1997). Similarly, Gupta (1983) and Bhatacharya (1995) developed numerical GIUH model for simulation of rainfall-runoff processes in catchments. FLAPS (1995) is developed for rainfall-runoff simulation that considers system both as a lumped or distributed system. The above mentioned models have been practiced by many researchers over the years and they are improving gradually by introducing one or more effective parameters.

The method, which introduced the concept of time of concentration (Tc) for the first time, is still probably an appropriate and convenient method for certain simple problem. Distributed rainfall -runoff modeling is one such method that involves the transformation of spatially varying rainfall excess hydrograph and losses into flood hydrograph. It assumes that the rainfall excess first undergoes pure translation that is estimated by a travel time-area histogram and the attenuation is routed through a linear reservoir at the catchment outlet. In gauged areas the time interval between the end of the rainfall excess and the point of inflection of the resulting surface runoff provides a good way of estimating Tc from known rainfall-runoff data. The time of concentration and storage constant of the basin are optimized using HEC-1 and the parameters are validated for storm. The parameters thus obtained are used in the model to arrive at unit hydrograph for the basin. The probable maximum precipitation (PMP) is used to derive a critical sequence of the severe most storms and the same used to derive at design floods.

The FLAPS (Flood Analysis And protection Systems) is a conceptual model approach to rainfall-runoff simulation and is in between the hydraulic approach and the unit hydrograph approach based on black box analysis. Through the established rainfall-runoff relationships and calibrated model parameters, the results are meant to be comprised into a design tool where historical design storm with a certain recurrence can be analyzed in terms of runoff. (1) Calibrate and validate the model for Krishnai, Dudhnai and Myntdu leska basins (2) Study the sensitivity of the model parameters with respect to different land use conditions, incipient soil moisture and transmissivity on direct runoff and total recharge (3) Comparison of the results with HEC-1.

2.0 Study Area:

2.1 General:

The study area of *Myntdu river basin* is in the state of Meghalaya. The physiography of the entire region is divided into three divisions, namely, Meghalaya Plateau, the North Eastern Hills and Basin, and the Brahmaputra Valley accounting for 13%, 65% and 22% of the total area respectively. The Myntdu river basin lying between 25°10' to 25°17' north latitudes and 92°15' to 92°30' east longitudes is in Jayantia Hill district of Meghalaya, in the southern slope of the state adjoining Bangladesh. The geographical area of the catchment is about 350 sq.km. The area with elevation ranging from 595 to 1370 m above m.s.l. is narrow and steep, lying between the central upland region of Meghalaya and plains of Bangladesh. The area is in the highest rainfall zone of the country. The rains are of long duration and occur mostly between March and October. During March and April the rainfall is sporadic, but it is steady and heavy or very heavy during May and October. Annual rainfall in Khasi Jayantia and Garo Hills is over 10,000 mm. The basin is covered by Survey of India map Nos. 83 C/3 & 83 C/7 in 1:50000 scale.

The *Dudhnai basin* is on the south bank of the Brahmaputra. This basin mostly lies in the district of East Garo Hills in Meghalaya and partly (towards out-fall) in the district of Goalpara, Assam. On the east lies the Deosila sub-basin and on the west is Krishnai sub-basin. On the North is the Brahmaputra river where it outfalls and on the south west Khashi hill ranges limit the basin. The catchment area is about 476 Sq.Km. Basin elevation varies from 2100 metre to 2227 metre above mean sea level (m.s.l) and basin slope from south to north. 83% of sub-basin is within district of East Garo Hills in Meghalaya and 17% in Goalpara district of Assam. The study area is geographically located between 25° 35' N and 26° N latitude and 90° 40' E and 90° 55' E longitude. The outlet of the basin is at Dudhnai with gauge discharge site at bridge site of NH-37 crossing. The basin is covered in four Survey of India maps 78 K/9, 13, 14 in 1:50,000 scale.

The river *Krishnai* is a major south bank tributaries of the Brahmaputra. The entire command area is bounded between latitude 26° N to 26° 5'N & Longitude 90° 35' E and 90° 45'E. It originates in Meghalaya from Garo hills and meets with river Dudhnoi near Domuni at about 12 Km north from Dudhnoi town and finally flows towards Brahmaputra. A good number of streams originating from Garo hills falls to the Krishnai river in the

Meghalaya area which produces good discharges for Krishnai river. The catchment area of Krishnai is 953.88 Sq Km up to the G.D site at Belterghat. The main rainy season of this area is May to October with maximum monthly rainfall of 715mm The area is covered by Survey of India maps 78 K/9, 10,12,13 and 14 in 1:50,000 scale.

2.2 Existing Observation Network:

Rainfall in all the catchment occurs during June to October. There are also some pre-monsoon and post-monsoon showers. In the Myntdu-leska basin, daily rainfall records have been maintained at three different rain gauge stations namely *Pdengshkap, Bataw* and *Jarain* since 1976. Further, rainfall data of *Jowai* station are available with the Indian Meteorological department for substantial period. Apart from this, rainfall records of *Cherapunjee* (approximately 50 km. from Myntdu) is available for about 100 years. The rainfall data of the catchment is available from three rain gauge stations viz, Jowai, Jarain and Pdengshkap which fall within the catchment and a raingauge station at Bataw, which falls just outside the boundary of the catchment. The basin has an annual average rainfall 7500 mm. The location of these stations is shown in **Fig.1-A.** The detail data inventory for the basin is given in **Table-1A**

In Dudhnai basin, the existing observation network is not adequate as per the IMD norm, however, there are three ORG stations maintained by CWC at Damra, Dudhnoi , Rongmil and Wagesi. Hourly rainfall records for Damra, Dudhnai and Goalapare (external station). In this zone the bulk of the rainfall occurs during the month of May to September. Significant rainfall occurs in May and October too. The months from November to March are generally dry. Tropical storms and depressions affect the weather in this zone during the months from June and September. The basin has an average annual rainfall of 1817.20 mm. The location of these stations is shown in **Fig.1-B.** The detail data inventory for the basin is given in **Table-1-B**.

The average annual rainfall in the Krishnai basin is in the order of 4000mm. Daily rainfall records are available from Goalapara, Balbala & Bajengdoba and nearby sub-basin of Dudhnai. Hourly basin rainfall is calculated with isohyetal graphs using the records of Damra, Wagesi, Dudhnai and Goalapara. The main rainy season of this area is May to October with maximum monthly rainfall of 715mm Daily rainfall is available from two rain

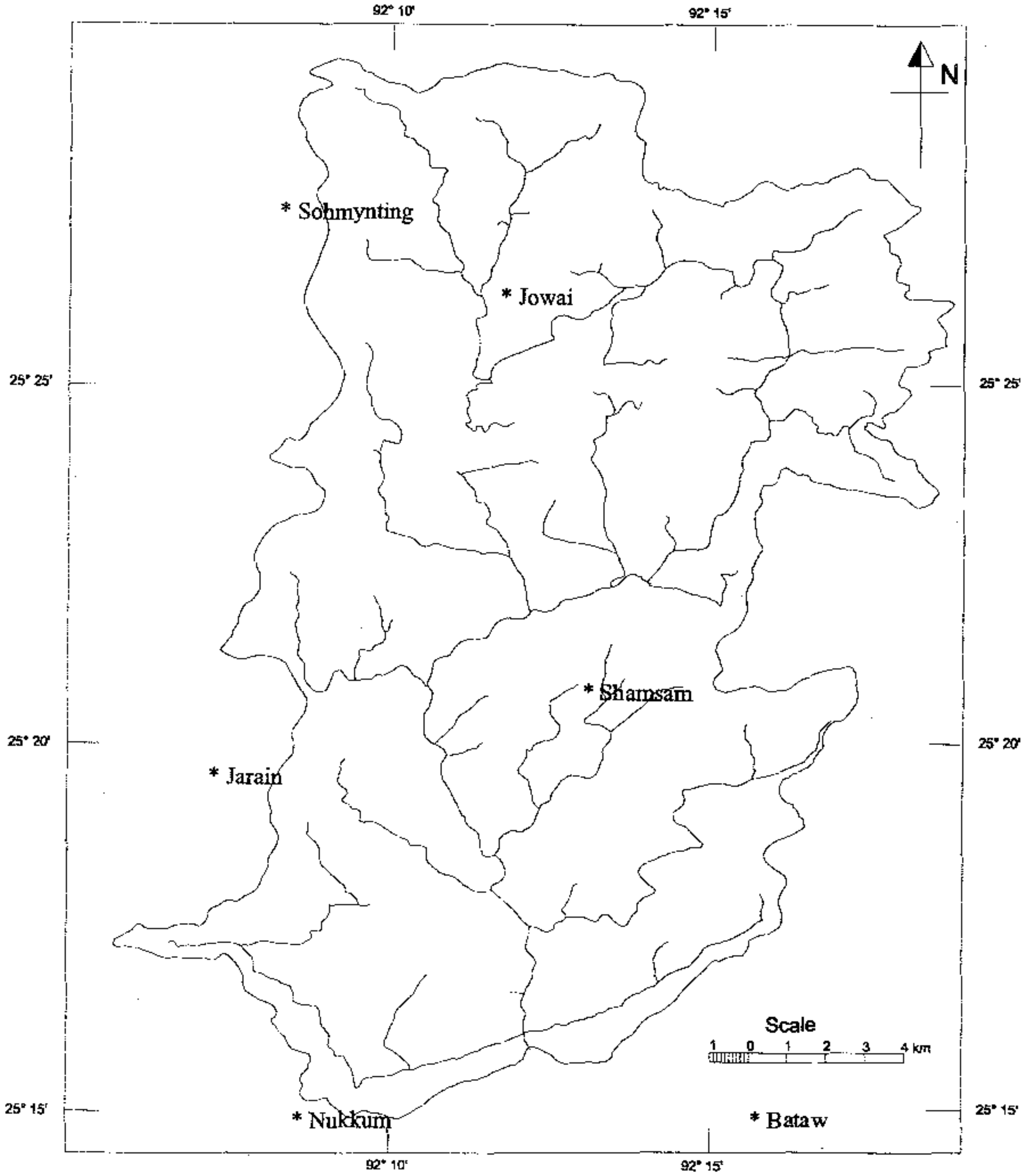


Fig.1A. Index Map Of Myntdu-leska Basin

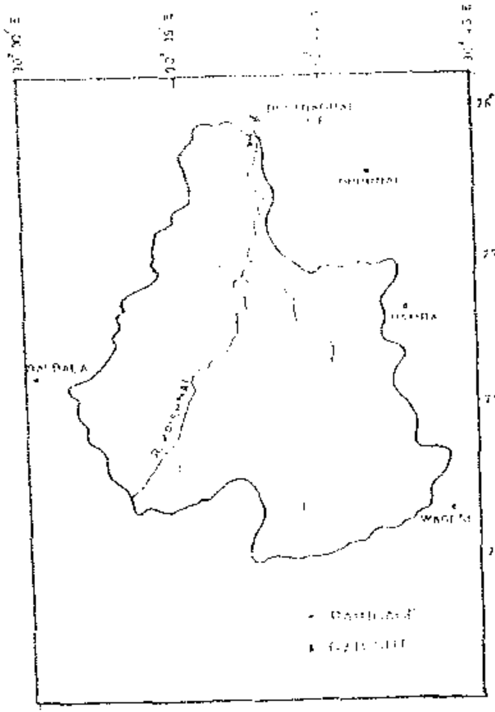


Fig.1B Index Map Of Krishnai Basin

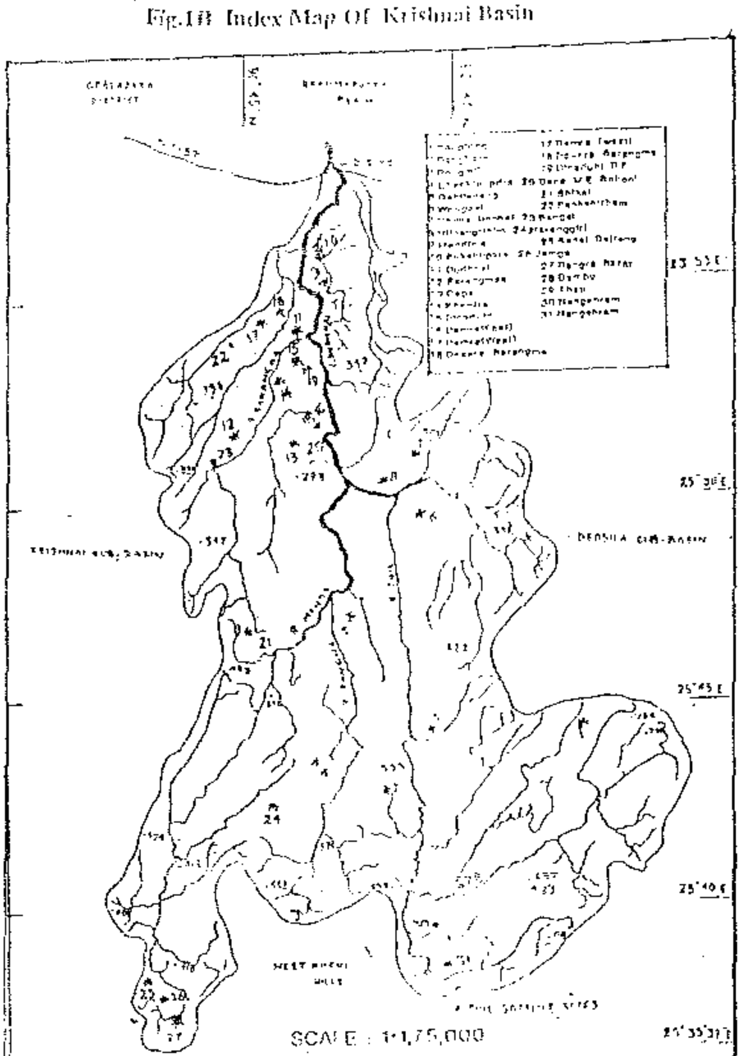


Fig. 1C Index Map of Dudhnai Basin

Fig. No. 6 : Chronological Growth of Treated Water Capacity, ELSR Storage along with Water Demand gauge stations at Balbala & Bajengdoba which fall within the catchment and four raingauge station Wagesi, Damra, Dudhnai & Goalapara which falls just outside the boundary of the catchment. The location of these stations is shown in **Fig.1-C.** The detail data inventory for the basin is given in **Table-1-B.**

Gauge And Discharge data for all the basins are maintained by CWC. For Myntdu-leska basin the discharge is measured at Leska dam site and is available from 1977. Another discharge station at Pesadwar about 20 km distance of Leska Weir was established in 1980. Central Water Commission is also maintaining a discharge site since 1970 at Kharkhana 18 down stream of dam site. Three hourly gauge data along with W.L is available only for 1985-1986 at Leska discharge site. The basin has a low runoff ratio of about 0.45 in the year 1992-93 and as high as 0.71 in the year 1983-84. The 90 % dependable year has been identified as 1985-86.

Gauge and discharge data for *Dudhnai basin* is measured at national highway bridge (NH crossing), Dudhnai town. The gauge data is available for the period 1955-90. It is reported that the average low water level at this site is 47 m and the maximum HFL observed so far is 52.15 m. The maximum discharge observed so far is 619.34 cumecs and the minimum is 0.2 cumecs. The monsoon yield accounts for 70% of the average annual yield. Gauge and discharge data for *Krishnai basin* is measured at Beltraghat and is available for the period 1972 –97. This site is maintained by Goalapara Investigation Div. Of Irrigation Deptt., Assam. Hourly dat along with the water level is available only for the year 1992.

The monthly evaporation data is maintained at *Umling* , however as per CWC's recommendations mean evaporations of Shillong are used for the report. The mean is calculated from the database of monthly evaporations for the period 1959-1975.

Table – 1.A

(Detailed Inventory of Data for Myntdu-leska basin)

Site / Type of Data	Period Of Record	Remarks
Daily Discharge Data :		
1.Leska Dam Site	1977-1991	Proposed dam site
2.Nukkum	March '92 to Jan '96	
Three Hourly (day time) Discharge Data(with W.L.):		
1.Leska Dam Site	1985-1986	
Daily Rainfall Data:		
1.Jowai	Jan'85-Mar'90	Then discontinued
2.Shamsham	1975-1989	Then discontinued
3.Jarain(MSEB)	1974-1991	Then discontinued
4.Bataw(MSEB)	1988-1991 ,1986-1987*	*Available monthly basis
5.Nukkum(Pdengshakap)	1974-1991	
6.Sohymting	1991-1996	June'91 to June'96
7.Dokhareng	1991-1995	Sept'91 to Feb'95
8.Jatah	1991-1996	Sept'91 to Dec'94
9.Pdengshkap	1974-1991	
Hourly Rainfall Data :		
1.Nukkum	1982-1987	June'82 to Oct'87
2.Jowai	June'96 to Oct'96	
Monthly Mean Evaporation :		
Shillong	Mean of 1959-1975	Supplied by Me.S.E.B

Table – 1.B

(Detailed Inventory of Data for Dudhnai and Krishnai basin)

Dudhnai / Type of Data	Period Of Record	Remarks
Daily Discharge Data :		
1.Dudhnai	1982-1995	
Hourly Discharge Data(with W.L.):		
1.Dudhnai	1985-1986	
Daily Rainfall Data:		
1.Damra	1983-91	Maintained by FC,Assam till '82
2.Dudhnai	1982-93	
3.Rongmil	1985-91	
4.Wagesi	1988-1991	
Hourly Rainfall Data :		
1.Damra	1983-1991	
2.Goalapara (external)	1992-93	
3.Dudhnai	1983-92	Supplied by IMD
Monthly Mean Evaporation :		
Shillong	Mean of 1959-	Supplied by Me.S.E.B
Krishnai / Type of	**Period Of Record**	**Remarks**
Daily Discharge Data :		
1.Beltraghat	1988-1995	
Hourly Discharge Data(with W.L.):		
1.Beltraghat	1992-1993	
Daily Rainfall Data:		
1.Balbala	1983-91	Maintained by FC,Assam till '82
2.Dudhnai	1982-93	
3.Bajendoba	1985-91	
4.Wagesi	1988-1991	
Hourly Rainfall Data :		
1.Damra	1983-1991	
2.Goalapara (external)	1992-93	
3.Dudhnai	1983-92	Supplied by IMD
Monthly Mean Evaporation :		
Shillong	Mean of 1959-	Supplied by Me.S.E.B

3.0 Methodology

The rainfall-runoff model is a conceptual distributed hydrological catchment model. Methods applied in this model is based on principles and experience of an earlier model (*Bengtsson, 1994*) . The model has the flexibility to treat the study area either as a linked system of a number of sub-basins or a lumped system, which have parameters corresponding to their physiological conditions. In linked system sub-basins are connected separately either by river reaches, channels or lakes represented by corresponding routines.. In the present case the model calculates the flow at the outlet of the basins for a given input i.e, rainfall, PET. The output runoff is used with the actual runoffs for calibrating model parameters. The calibrated model is then used for simulating runoff from actual rainfall values to fill up the missing series.

3.1.1 Physical Concept of the Model:

The physical concept of the model is shown in Figure.2 and is self-explanatory. The interrelationships between the different parameters of the model are given below:

1.Actual Evapotranspiration (AET) = PET . $(W/WM)^{\alpha}$

where,

W = Actual soil water content

WM = Max. soil water content.

α = Empirical coeff.

2.Runoff (Q) = Outflow = RS + OGR + LGR

where,

RS = Quick runoff from soil water storage.

OGR= Runoff component through upper outlet (controlled by depth threshold in the GW storage)

LGR= Runoff component through lower outlet

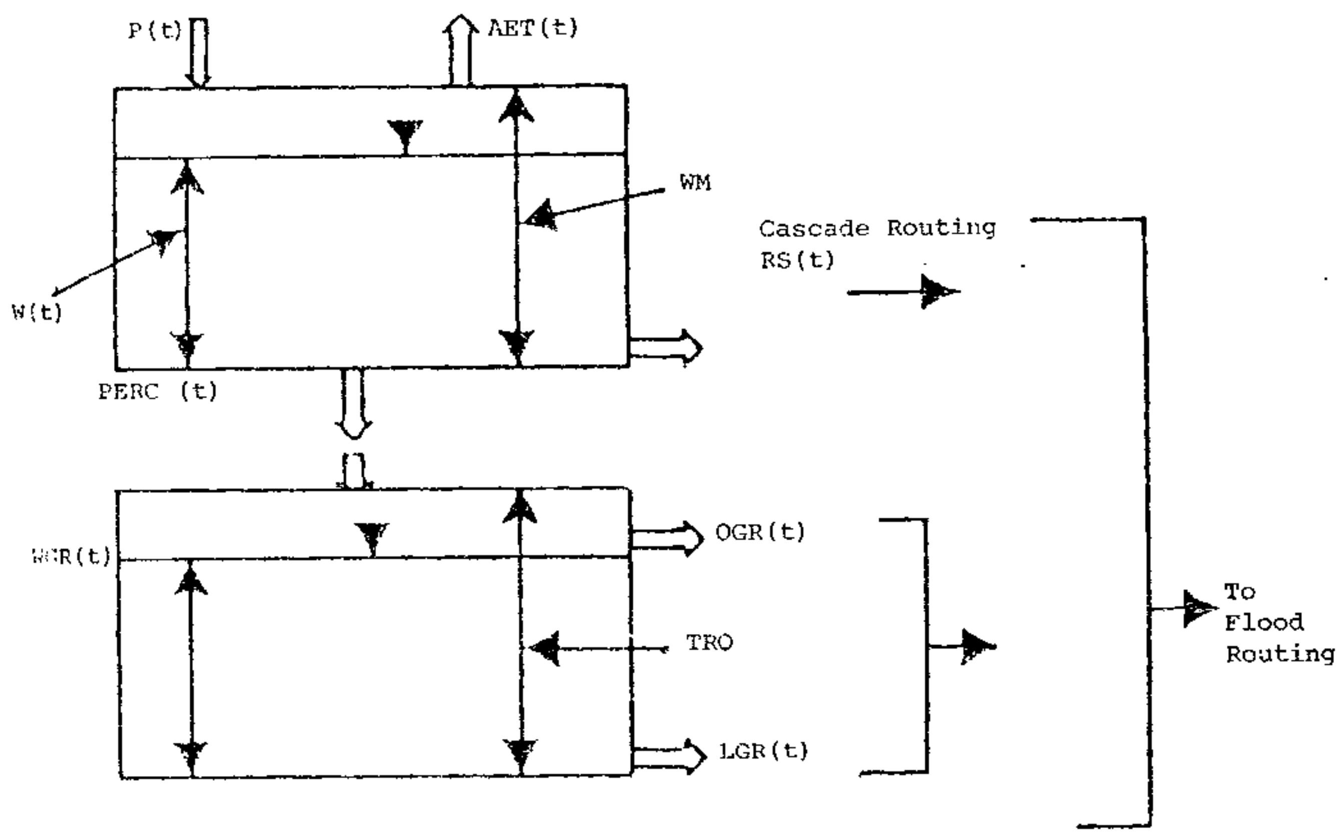
3.The quick runoff component (RS) =FR . (P-AET).(W/WM)

where FR = P/P_{max}

P_{max} = Empirical value of rain intensity which controls the maximum amount of rain converting into quick runoff.

W= Soil water storage and τ is a coeff.

Fig. 1d FLAPS model structure



4. PERCOLATION= P - AET - RS (W/WM)' and supply water to the ground water storage. PERC is restricted with upper limit PERCMAX.

ß = Empirical coeff.

Table-2

(Parameters Of The Model)

Sl	Parameter	Component	Effect
[illegible]	WM : Maximum soil water content	Water storage	Peak flow
[illegible]	TRO: Threshold of upper outlet	Quick runoff	Initial condition of flood
[illegible]	TO : Time coeff. of upper outlet	Quick runoff	Intensity of quick runoff
[illegible]	[illegible] coeff. of lower outlet	Low flow	Intensity of low flow
5	FC :Limit of percolation	Percolation	Residence time
6	Alpha Coeff : calculates AET	Evapotranspiration	Water balance,initial flow
7	Beta: Coeff: calculates percolation	Percolation	Late flow
8	Overland :Fraction of direct runoff	Initial overland flow	Initial flow

5.Runoff from the groundwater storage = (WGR-TRO)/TO AND LGR = WGR/TL

where,

TL and TO = Time coefficients of the lower and upper outlets.

WGR = Stored groundwater and

TRO = Threshold of the upper outlet.

The nature of the parameters and their effect on the physical characteristics of the flow are shown in the table above.

3.2 Distributed Flow Model

Distributed rainfall -runoff modeling involves the transformation of spatially varying rainfall excess hydrograph and losses into flood hydrograph. Due to temporary storage of water on the basin the rainfall is subjected to attenuation. The combined effect of translation and attenuation is reflected during transformation of excess rainfall hyetograph to surface runoff hydrograph. Clark's method, also known as Time-area histogram method use development of an IUH due to an instantaneous rainfall excess over a catchment. It is assumed that the rainfall excess first undergoes pure translation and this is achieved by a travel time-area histogram and the attenuation by routing the results of the above through a linear reservoir at the catchment outlet. Time here refers to the time of concentration, Tc, is the time required for a unit volume of water from the farthest point of catchment to reach the outlet. It represents the maximum time of translation of the surface runoff of the catchment. In gauged areas the time interval between the end of the rainfall excess and the point of inflection of the resulting surface runoff provides a good way of estimating Tc from known rainfall-runoff data.

The total catchment area drains into the outlet in T_C hours. If a rainfall excess of 1 cm occurs instaneously and uniformly over the catchment area, this time-area histogram represents the sequence in which the volume of rainfall will be moved out of the catchment and arrive at the outlet. The hydrograph of outflow obtained by this figure while properly accounting for the sequence of arrival of flows, do not provide for the storage properties of the catchment. To overcome this deficiency, Clark assumed a linear reservoir to be hypothetically available at the outlet to provide the requisite attenuation. The linear reservoir at the outlet is assumed to be describe by $S = KQ$, where K is the storage time constant.

3.2.1 Model Structure

The model considers the catchment to be distributed into various isochronal zones. The isochronal map is prepared based on T_C computed from California formula. The contour of equal time of travel is prepare on the plot at the same time interval as that of sampling interval of available rainfall records. Model is calibrated using past records. During running of the model average rainfall over each isochrone zones and discharge at the outlet is required. The value of K can be estimated by considering the point of inflection of a surface runoff hydrograph. At this point the inflow into the channel has ceased and beyond this point the flow is entirely due to withdrawal from the channel storage. The third parameter i.e., time-area histogram represents the area of the watershed that contributes runoff to the outlet at any given time after an instantaneous excess rainfall event. This is accomplished by either estimating overland flow and channel travel times or simply by assuming a constant velocity and basing the histogram on travel distance alone. In HEC-1, a generalized watershed shape with a time-area histogram symmetric about Tc/2 is used. If no specific time-area histogram is given, a default parabolic shape basin is assumed.

3.2.2 Parameter Optimization Of The Model

Calibration and validation of the model parameters using the historical storm events are prerequisites for applying the model for estimating design flood. Time of concentration (T_C) and the storage coefficient (K) are two parameters of the model which are calibrated from the observed rainfall-runoff events using HEC-I. Average hourly rainfall over the basin with the weightage factor as estimated along with the hourly runoff for the basin is used. The parameters are optimized employing univariate search technique as described below ;

Objective function , STDER = $\sqrt{\sum_{1}^{N}(Qobs_i - Qcom_i)^2 * WT_i / N}$

Weight, WT_I = ($Qobs_I$ + Qav_I) / (2*Qav_I)

The weighted function , WT_I , emphasize accurate reproduction of peak flows rather than low flows by biasing the objective function.

Initial input are required in the model which include the initial loss parameters and constraints in the upper and lower limits of the parameter value to be fixed on the physical characteristic of the basin. For different trial values of the Tc optimum values of storage constant coefficients are is evaluated using optimization technique. Model parameters for the catchment are finally chosen based on the above trial runs. In order to verify the validity of the model parameters, different sets of parameter values are used to reproduce those storms and evaluate various error functions. The objective function for the optimization runs is a least square function representing sum of squares of difference between observed and estimated values.

3.3 Non linear Response Measure

Any basin response though non-linear behaves linearly within certain domain and with some limitations and constraints. As the application of linear methods to highly nonlinear watersheds is limited, there have been various efforts to take into account the nonlinearly. One such approach has been the use of concept of nonlinear reservoir, whereby the nonlinearly is assumed to be accounted for by a power function of the outflow. The non-linear reservoir model that relates outflow with storage is the following power function,

Dynamic equation: $S = K Q^n$

Where, K is the storage coefficient and 'n' is the exponent (for n>1 the equation becomes non-linear)

The continuity equation is: $dS/dt = I - Q$

Where, 'S' is the storage, 'Q' is the runoff, 'I' is the rainfall intensity. The introduction of a third parameter, the time lag (τ), in the dynamic equation of the model turns the finite difference scheme from implicit to explicit. The solution can be then be obtained step by step with calculations performed in a computer. The dynamic equation becomes:

$S_{t-} = K (Q_t)^n$

By rewriting the dynamic equation (3) to the following form:

$Q_t = A \ \Sigma (S_{t-})^B$

Where , 'τ' is the time lag in hours , i.e, Q_t is runoff at the outlet at any time 't' is proportional to the accumulated storage (ΣS) in the reservoir at a time equal to 't -τ' .

$B = 1/n$ and $A = 1 / k^{1/n}$;

Taking logarithm of both sides, a straight-line equation is obtained. Parameter 'B' is a slope of that line and Ln (A) is an intercept point on the Y-axis. Parameters 'A' and 'B' can be obtained by plotting Ln(Q) against Ln (S_{t-}) with different time lags 'τ'. The plot which shows the least scatter defines the value of 'τ'. This plot is then used to calculate the values of 'A' and 'B'. Alternatively, 'Q' is plotted directly against $S_{t-\tau}$ for different values of τ. A and B parameters are then calculated by linear regression of ln (Q_t) and ln (S_{t-}). The model is calibrated using observed rainfall-runoff data from one or more events. This gives an idea of the degree of non-linearity of the basin.

4.0 RESULTS AND DISCUSSION

4.1 Rainfall Analysis:

Isohyetal maps were prepared using monthly rainfall and these are used to interpolate areal rainfall values. The monthly mean rainfall for the basin is calculated for the available period. In the next step the weightages of each individual raingauge (W_{m1}) stations are estimated using the following relation

$W_{m1} = P_{mean} / P_1$

Where, P_{mean} is the monthly isohyetal mean and P_1 represents the monthly rainfall for a individual station.

W_{mi} is the weightage factor for a individual station and 'n' is the total number of raingauge stations in the basin

Hourly mean rainfall for the basin is,

Hourly $P_{mean} = \; (W_{mi} P_i / n)$

For checking the validity of the method few random daily observations were analysed.

Double mass curve analysis was used to check the consistency of raingauge stations. Four of the major base station viz., *Shamsam, Bataw, Jarain* and *Nukkum* in the neighborhood of the problem station were selected for Myntdu leska basin. Similarily monthly rainfall data of *Rongmil, Wagesi, Dudhnai*, *Damra* and *Goalapara* are selected for analysis of Dudhnai and Krishnai basins. The data of the annual rainfall of each station and also the average rainfall of the group of base stations is used as per the procedure, and individual values are plotted against cumulative ones for various consecutive time periods. From the results it is observed that there is significant change in slope for Shamsam during last three years. As change in slope is normally taken as significant only where it persists for more than five years the stations are presumed to be more or less consistent.

4.2 Runoff Analysis:

As the scope of this study is limited to the modeling of flood events, rainfall excess intensity is computed using a uniform infiltration rate, namely a constant ϕ– index. After separating the baseflow from the observed runoff, the volume of direct runoff is used to evaluate ϕ -index. From the runoff data it is observed that the rivers carry negligible flow except during monsoon. Nineteen flood events were selected for the study. The availability of data is given in **Table-1**.

4.3 Rainfall-Runoff Simulation with FLAPS Model:

The model is applied to the study area as a lumped system In the present case the model calculates the flow at the outlet of the basins for a given input i.e., rainfall, PET. The normal PET values supplied by IMD are used along with rainfall for the study. The computed runoff is used with the actual runoffs for calibrating model parameters. The calibrated model is then used for simulating runoff from actual rainfall values to fill up the missing series. The details of the procedure and analysis are covered in a technical report by Bhunya, 1999.

4.3.1 Calibration and Validation of Flaps Model

To test the credibility of the model, a split-sample test is carried out in which the model parameters are calibrated using a given series of events and then the model is validated by applying the calibrated set of parameters to a different set of events. The calibration of the model for Myntdu-leska basin on five sets of event gave the following values of the parameters; TRO=10 Hr, TO=3Hr,TL=6 Hr, WM=240 mm, FC=22.0, Alpha=0.5, Beta=2.0, $Q_{Overland}$=10 %. The calibrated hydrographs are shown in **Fig.2-4.** The hydrologic response of the watershed is non-linear, as can be seen from the high value of 'FC' that effect the residence time in soil storage and low value of $Q_{overland}$ that effects the quick runoff. However, 'TO', the time coefficient for the upper storage is 3 hr indicating the release of water from the upper part of sub surface storage is quick which in turn results a quick rising limb. And a reasonably low value of 'TL' effects the delayed flow after the rain has ceased. The above calibrated parameters are used to validate the results for another set of events. The flood was simulated using these parameters and was compared with the observed flood. **Table-3** and **Table-12.** present the observed and the computed runoff and present the validation of flood hydrographs.

The short analysis of the simulations can point out some characteristics for the catchment. There were three flood events during the period Aug 1996 .The first one had its peak on 3rd Aug, 96 (118 cumecs) while the second one on 5th Aug (154 cumecs). These flood waves were caused by 13.96 and 36.60-mm excess rainfall, respectively. The antecedent moisture amount was close to 240 mm and the rainfall fell in both cases about a week ago. However the peak flows and the flood volumes are quite different. The FLAPS model underestimated flood wave of 3rd Aug,96 i.e 102 as against 118 cumecs and HEC model at 124 cumecs. Further, if one closely observes the simulated peaks, the model underestimates the low peaks. The reason being the parameter that effects the residence time (lag is in an average high for the catchment and coupled with a low value of the parameter controlling the quick runoff component results in a low peak for small basin area. However, in the second case the standard error of estimate of peak is low (approximately 8 %) . The reason might be due to the fact that for the storm of 3rd Aug, the initial losses are high as it occurred after a long dry spell but the overall calibrated parameter for initial moisture is high at 240 for the catchment. This results in slow rise of the rising limb, slow quick runoff and high loss eventually giving a low peak. But for cases where in , the storms have occurred within a short dry spell (having interval between two storms less than 2-3 days) the results shows better fit of the peak. However, the validity of any hydrologic model is best treated by the model's ability to reproduce observed events. The maximum standard error of estimate is 27% and in an average the error are within 15%.

In this section some selected events from Krishnai and Dudhnai basin are analysed. The simulated hydrographs are shown in **Fig.3 & 4** and the performance of the model are tabulated in **Tab-4 and 12.** The model was calibrated for Krishnai basin on five sets of event. The calibrated parameters are as follows; TRO=6Hr, TO= 2 Hr,TL=6 Hr, WM=220 mm, FC=22.0, Alpha=0.3, Beta=2.0, $Q_{Overland}$=10 %. Than the parameters were used to validate two events of 15th Aug, 92 and 28th Sept. The first event predicted the peak at 249 cumecs against an observed value of 263 cumecs. The second event predicted a peak of 564 as against an observed value of 642 cumecs. The first peak was due to an excess rainfall of 26.6 mm and the second was due to an excess rainfall of 69.3 mm. The initial moisture in the first case ought to be lower than the second event as the storm on 15th Aug had a dry spell before it and the second event had a wet spell on 22nd Sept, preceding it. This is evident from the loss rate estimates as 0.97mm/hr and 0.8-mm/hr resp. The hydrologic response of the watershed is non-linear, as can be seen from the high value of 'FC' that effect the residence time in soil storage and low value of $Q_{overland}$ that effects the quick runoff. However, 'TO', the time coefficient for the upper storage is 2 hr lower than for Myntdu-leska basin , indicating that the release of water from the upper part of sub surface storage is quicker

Table-3
(Calibrated parameters for Myntdu-Leska basin)

Event	TRO	TO	TL	WM	FC	ALFA	BETA	$Q_{overland}$	R^2
1	10.0	3.0	6.0	240.0	22.0	0.5	2.0	10.0	0.87
2	10.0	3.0	6.0	240.0	22.0	0.5	2.0	10.0	0.88
3	10.0	3.0	5.0	200.0	22.0	0.5	2.0	10.0	0.72
4	10.0	4.5	6.0	240.0	22.0	0.5	2.0	10.0	0.93
5	10.0	3.0	6.0	100.0	22.0	0.5	2.0	10.0	0.89

(Validation of the model)

Event	TRO	TO	TL	WM	FC	ALFA	BETA	$Q_{overland}$	R^2
6	10.0	3.0	6.0	240.0	22.0	0.5	2.0	10.0	0.66
7	10.0	3.0	6.0	240.0	22.0	0.5	2.0	10.0	0.69
8	10.0	3.0	6.0	240.0	22.0	0.5	2.0	10.0	0.72

Table-4
(Calibrated parameters for Krishnai basin)

Event	TRO	TO	TL	WM	FC	ALFA	BETA	$Q_{overland}$	R^2
1	6.0	2.0	6.0	220.0	22.0	0.3	2.0	10.0	0.61
2	6.0	2.0	6.0	220.0	22.0	0.3	2.0	10.0	0.88
3	10.0	2.0	5.0	220.0	22.0	0.3	2.0	10.0	0.82
4	6.0	2.5	6.0	220.0	22.0	0.3	2.0	10.0	0.76

(Validation of the model)

Event	TRO	TO	TL	WM	FC	ALFA	BETA	$Q_{overland}$	R^2
5	6.0	2.0	6.0	220.0	22.0	0.3	2.0	10.0	0.68
6	6.0	2.0	6.0	220.0	22.0	0.3	2.0	10.0	0.77

Table-5
(Calibrated parameters for Dudhnai basin)

Event	TRO	TO	TL	WM	FC	ALFA	BETA	$Q_{overland}$	R^2
1	10.0	3.0	6.0	240.0	22.0	0.5	2.0	12.0	0.67
2	10.0	3.0	6.0	240.0	22.0	0.5	2.0	12.0	0.73
3	10.0	1.0	5.0	200.0	10.0	0.5	2.0	12.0	0.92
4	6.0	4.5	3.0	240.0	22.0	0.5	2.0	12.0	0.83

(Validation of the model)

Event	TRO	TO	TL	WM	FC	ALFA	BET	$Q_{overland}$	R^2
1	6.0	0.5	2.0	240.0	22.0	0.5	2	12.0	0.88
2	6.0	0.5	2.0	240.0	22.0	0.5	2	12.0	0.81

resulting a quick rising limb and a reasonably low value of 'TL' effects the late flow after the rain has ceased. The time of concentration of the basin estimated using HEC-1 is 7 hrs and the basin area is large with a conical shape with the dome towards the outlet (gauging site at Beltaraghat). As the rain gages used for estimating the basin rainfall mostly lies outside the catchment towards upper part of the catchment, the basin rainfall might be overvalued. This seems one of the reasons for peak to be underestimated by the model other than the reasons sited earlier.

One aspect of the input parameters that is often overlooked is the spatial distribution of the rainfall. The derived model is spatially lumped and time invariant. For small sub watersheds flood routing can reduce the effect of spatial lumping. A storage model that incorporates the effect of the magnitude of the rainfall intensity is likely to predict the runoff hydrograph more accurately.

4.3.2 Sensitivity of Parameters

The model sensitivity can be illustrated by some alterations in the effective parameters. To ascertain the sensitivity of parameters for FLAPS model, the effective parameters of the distributed and lumped model wase altered and the results are presented in **Table-10**. As can be seen an increment/decrement of 10 % value of soil moisture parameter increased the peak by 8 %. The soil moisture parameter in fact modulates the storage and eventually the peak, so it can be said that this is partially sensitive compared to time parameters. When the lower layer has a low conductivity (generally due to consolidation of soil) water bulb rises in the upper storage, the time of release of water in the upper outlet threshold (TRO) is. effected. The quicker the dissipation, higher is the peak and time to peak. As seen from the results, an increase of TRO by 0.1 (10%) effects the initial flood volume by 15%. Time coefficient of upper layer (TO) and time coefficient of bottom layer (TL) represents the time required to dissipate the stored water from upper and lower storage respectively. It is to be noted that TO differs from TRO as the former refers to the flow below threshold i.e. the lateflow in the initial rising limb. It was observed that the parameter TO is more sensitive than TL. Limit of percolation, FC effects the residence time and eventually the lag time and Tp. This is not that sensitive in changing the time to peak. Time to peak is the resultant effect of all the above parameters. Alpha coefficient effects the total loss and is sensitive w.r.t water balance. To calculate the sensitivity of alpha an alteration of alpha is compared with the total loss after calculating the volume of flow. The method for calculating the sensitivity is given in the note below **Table-10**. This is sensitive in the range of 7-15% for a change in parameter value of 10-15 %. Beta coeff. and $Q_{overland}$ effects the late flow and the quick runoff are partially sensitive.

4.4 Calibration and Validation of HEC-1 Model

Calibration and validation of the model parameters for a catchment using the historical events are prerequisites for applying the model for estimating design flood. Average hourly discharge values at gauge site with the corresponding hourly rainfall are the input to the model. For different travel times (T_c) , optimum values of storage coefficients (R) is evaluated minimizing the sum of squares of the differences of between observed and computed direct surface runoff hydrograph ordinates using Rosenbrock optimization technique. The calibration results thus obtained for different trial runs are given in **Table-6-8.** Model parameters for the catchment are finally chosen based on the above trial runs. In selecting the model parameters for the catchment, more weights are given to those parameter values, which are derived from available severe most historical events, rather than those derived from minor ones. But in absence of any data pertaining to historical storms, the available storms of 1992 and 1993 for Dudhnai and Krishnai basins and 1996 for Myntdu-leska basin have been considered to calibrate the model.

Based on the above considerations, the final value parameters for Mytdu basin are; the catchment time of concentration (T_c) is equal to 3.3 Hrs and storage coefficient (R) is equal to 8.4 Hrs. for Krishnai; Tc=7.3 hr, R=27.4 Hrs., for Dudhnai; Tc=5.1hr, R=13.5 hr. Standard error of estimate of peak varies between 3 to 20 %. More or less in an average the SEE is 10%. The same events as considered for FLAPS model are considered in this section to compare the performance of both these models. For Myntdu leska basin; the first one had its peak on 3rd Aug, 96 (118 cumecs) while the second one on 5th Aug (154 cumecs). 13.96 and 36.60-mm excess rainfall caused these flood waves, respectively. The antecedent precipitation amount ought to be low as gap between preceding rainfall that fell in both cases was about a week ago. The model estimated both as 124 and 149 cumecs, which is close to the observed value. The model estimates the peak closely for most of the events in Myntdu–leska basin and fairly close for other two basins. There are two events on for 21st Aug, 96 and 28th Sept,

Table-6

(Calibrated Results For Myntdu basin using HEC-1)

Parameters	22nd Sept'96	5th Sept'96	3rd Aug'96	21st Aug'96	15th Aug '96
T_c (Hours)	3.0	3.9	3.0	3.5	2.81
R (Hours)	8.0	8.4	7.40	10	10.22
Uniform loss rate, mm/h	0.8	0.5	0.86	0.51	0.94
Obs. Peak (m^3/s)	134	57	118	98	163
Comp. Peak (m^3/s)	132	69	124	118	182
Standard Error	34	8	22	14	42
Av. Absolute Error	28	7	20	35	37

(Validation Results)

Parameters	23rd July'96	5th Aug '96
T_c (Hours)	3.3	3.3
R (Hours)	8.40	8.42
Total Loss (mm)	6.04	9.7
Uniform loss rate(mm/h)	0.86	0.97
Obs. Hydrograph Peak (m^3/s)	128	154
Comp. Hydrograph Peak (m^3/s)	124	149
Standard Error	14	18
Av. Absolute Error	24	29

Table-7

(Calibrated Results For Krishnai basin using HEC-1)

Parameters	22^{nd} Sept'93	28^{th} Sept'92	30^{th} Aug'92	12^{th} Sept'92
T_c (Hours)	7.6	7	7.4	7.3
R (Hours)	25	24.4	27.1	29
Uniform loss rate, mm/h	1.2	0.8	0.86	0.87
Obs. Peak (m^3/s)	183	642	100	348
Comp. Peak (m^3/s)	168	578	114	361
Standard Error	27	18	22	32
Av. Absolute Error	21	27	20	29

(Validation Results)

Parameters	3^{rd} July'92	15^{th} Aug'92
T_c (Hours)	7.3	7.3
R (Hours)	27.4	27.4
Total Rainfall(mm)	25.5	36.3
Excess Rainfall (mm)	19.9	26.6
Total Loss (mm)	5.6	9.7
Uniform loss rate(mm/h)	0.8	0.97
Obs. Hydrograph Peak (m^3/s)	118	263
Comp. Hydrograph Peak (m^3/s)	124	249
Standard Error	14	18
Av. Absolute Error	24	29

Table-8
(Calibrated Results For Dudhnai basin using HEC-1)

Parameters	22nd Sept'93	28th Sept'92	30th Aug'92	12th Sept'92
T_c (Hours)	5.2	5.1	5.4	4.9
R (Hours)	12.4	14.4	12.1	14.9
Total Loss (mm)	14.4	8.8	1.74	11.5
Uniform loss rate, mm/h	1.8	0.88	0.87	2.3
Obs. Peak (m^3/s)	254	113	312	136
Comp. Peak (m^3/s)	269	131	343	147
Standard Error	32	28	12	23
Av. Absolute Error	24	17	26	13

(Validation Results)

Parameters	3rd July'92	15th Aug'92
T_c (Hours)	5.1	5.1
R (Hours)	13.5	13.5
Total Loss (mm)	10.8	10.1
Uniform loss rate(mm/h)	1.8	1.3
Obs. Hydrograph Peak (m^3/s)	271.2	243.7
Comp. Hydrograph Peak (m^3/s)	268.4	255.5
Standard Error	36	21
Av. Absolute Error	34	19

92, where the peaks are slightly overestimated. It may be mentioned here that for Krishnai basin and Dudhnai basin the basin rainfall is estimated from raingages that lie more towards upper part of the basin; this might be one of the reason as the total basin rainfall, one of the input to HEC is biased.

As has been mentioned earlier estimation of overland flow and channel travel times is accomplished in the model simply by assuming a constant velocity and basing the histogram on travel distance alone. Secondly, a generalized watershed shape with a time-area histogram symmetric about Tc/2 is used. If no specific time-area histogram is given, a default parabolic shape basin is assumed. These are some of the drawbacks that are taken into account in the Mod Clark model in an attempt to improve (Daniel, 1998).

4.5 Sensitivity of Parameters

For evaluating the sensitivity of HEC-1 model, the time of concentration, Tc in the HEC-1 model was varied from 3 hours to 8 hours and the sorage coefficient, R was changed from 3 to 7 hrs. The peak (Qp) and the time to peak (Tp) evaluated corresponding to with change in Tc for different values of storage coefficient, R. it is observed that the peak decreases with Tc and for a fixed value of Tc , the peak decreases with increase in R. Time to peak (Tp) is found to increase with increase in Tc, however there is no change in Tp for different values of storage coefficients, R corresponding to a time of concentration.

4.6 Non-linearity Response of the Basin

Based on a method discussed in Ch.2 of the report, an attemp has been made in this study to analyze the non-linear behavior of the basins. The introduction of a time lag parameter in the dynamic non linear equation S=f (k, Q, n) makes its solution implicit to explicit. The method uses forced runoff as a variable with accumulated storage lag to establish a non-linear relationship that can be used for approximate runoff prediction in the basin. The method was tested on short-term rainfall and discharge data of Myntdu Leska basin, Krishnai basin and Dudhnai basins for some of the selected events. The analysis was carried on ten selected events distributed over two years and the results showed degree of regression coefficient (R^2) ranging from 62 to 91 % . The goodness of fit is checked using error in peak estimates (PEAK) and chi square test. The PEAK gave low values indicating a good fit and chi square showed a better fit except for two events of Krishnai basin. In the dynamic equation parameter 'A' is largely a scale parameter dependent on the units used and the other parameter 'B' that represents the degree of non-linearity in catchment response. Since only three basins are considered for the analysis the relationship of parameter 'B' with the catchment area could not be established. However, It can be observed that Krishnai basin with an area of 950 Sq.km has a low B-parameter compared to Myntdu-Leska basin, a smaller catchment. Since the B-parameter represents the degree of non-linearity in the catchment response, the indirect conclusion can be drawn that the non-linearity in the catchment response depends upon the area and characteristics of the catchment. More refined result could be obtained if database is expanded covering other basins in the region and comparing with other tested models. The results are given in **Table-14.**

Fig.5 depicts the pattern of peak runoff variation for the two models with the observed peak for different values of total rainfall. The variations are high for FLAPS than HEC model. HEC model tends to overestimate the peak for low rainfall events and overestimate for high rainfall events. However, the variations are within 15 % for maximum events analysed in the study. **Table-13** compares the performance of the two models for these selected events on basis of bias, RMSE, mean absolute error, efficiency and R^2. As observed both the models performs well on the analysed data, however, HEC model tend to be less biased than FLAPS.

Table-9

(Overall Results of Calibrated Parameters of FLAPS Model)

Sl	Parameter	Component	Effect
1	WM : Maximum soil water content	220-240	Partially sensitive
2	TRO :Threshold of upper outlet	6-10	Highly sensitive to peak
3	TO :Time coeff. of upper outlet	Low	Highly sensitive to shape
4	TL :Time coeff. of lower outlet	Low	Highly sensitive to rising limb
5	FC :Limit of percolation	22.0	-
6	Alpha : Coeff. used to calculate AET	0.3-0.5	-
7	Beta : Coeff. used to calculate percolation	2.0	-
8	Qoverland :Fraction of direct runoff	10-12	-

Table-10

(Parameter Sensitivity of FLAPS Model)

Sl	Parameter	Change in parameter	Sensitive component	Sensitivity in %
1	WM	10-50 %	Peak flow	8-12
2	TRO	10-50 %	Initial flood volume(up to Tp)	15-23
3	TO	10-50 %	Quick runoff(slope of rising limb)	5-10
4	TL	10-50 %	low flow(slope of falling limb)	1-7
5	FC	10-50 %	Residence time(time lag)	1-5
6	Alpha Coeff	10-50 %	Water balance (total loss)	7-15
7	Beta: Coeff	10-50 %	Late flow(Volume after inflection)	1-5
8	$Q_{Overland}$	10-50 %	Initial flow(flow after 1 hr of	1-3

*Note : * The values are average of analysed events of three basins (total number of events considered are eight)*

*** Slope of rising limb= (Qp-Qo)/(Tp-T0), In case of falling limb , T0 is replaced with final T i.e. Tb.*

****Time lag is calculated as per recommendations of Flood Studies report,1975 i.e., time between centre of hyetograph to hydrograph peak.*

*****Flood volume is calculated with trapezoidal rule with 5hrs ordinates as base.*

Table-11
(Sensitivity of Parameters for HEC Model)

Sl	Tc (Hr)	Variation of Peak in %				
		R=3	R=4	R=5	R=6	R=7
1	3	0	-20.25	-33.74	-42.94	-50.31
2	4	-4.29	-22.70	-35.58	-44.17	-51.53
3	5	-3.85	-25.15	-36.81	-45.40	-52.15
4	6	-3.33	-26.99	-38.04	-46.63	-52.76
5	7	-3.45	-28.83	-39.26	-47.85	-53.99
6	8	-4.29	-31.29	-41.10	-48.47	-54.60

Table-12
(Error in Peak Estimates with FLAPS and HEC for All Events)

Sl	Date of event	Excessl rainfall	Peak in cumecs			Standard Error of Estimate	
		Mm	Observed	FLAPS	HEC	FLAPS	HEC
1	22nd Sept,96	14.6	134	121	132	-9.7	-1.5
2	5th Sept,96	10	169	154	164	-8.9	-3.0
3	3rd Aug,96	13.96	118	102	124	-13.6	5.1
4	21st Aug,96	29.5	98	93	118	-5.1	20.4
5	15th Aug,96	33.62	163	182	182	11.7	11.7
6	23rd July,96	23.9	128	113	124	-11.7	-3.1
7	5th Aug,96	36.6	154	142	149	-7.8	-3.2
8	22nd Sept'93	12	183	189	168	3.3	-8.2
9	28th Sept'92	69.3	642	564	578	-12.1	-10.0
10	30th Aug'92	8.97	100	114	114	14.0	14.0
11	12th Sept'92	32.4	348	371	361	6.6	3.7
12	3rd July'92	19.9	118	124	124	5.1	5.1
13	15thAug'92	26.8	263	214	249	-18.6	-5.3
14	22nd Sept'93	21.2	254	269	269	5.9	5.9
15	28th Sept'92	19.3	113	128	131	13.3	15.9
16	30th Aug'92	39	312	298	343	-4.5	9.9
17	12th Sept'92	9.4	136	147	147	8.1	8.1
18	3rd July'92	21.4	271.2	268.4	268.4	-1.0	-1.0
19	15th Aug'92	16	243.7	239	255.5	-1.9	4.8

Table-13

(Performance of FLAPS and HEC Model

Statistical criteria	Flaps	HEC
Bias	3.578947	1.105263
Mean Abs. Error	14.2	9.6
Efficiency	0.982378	0.991604
RMSE	2.49	3.61
R^2	0.988	0.992

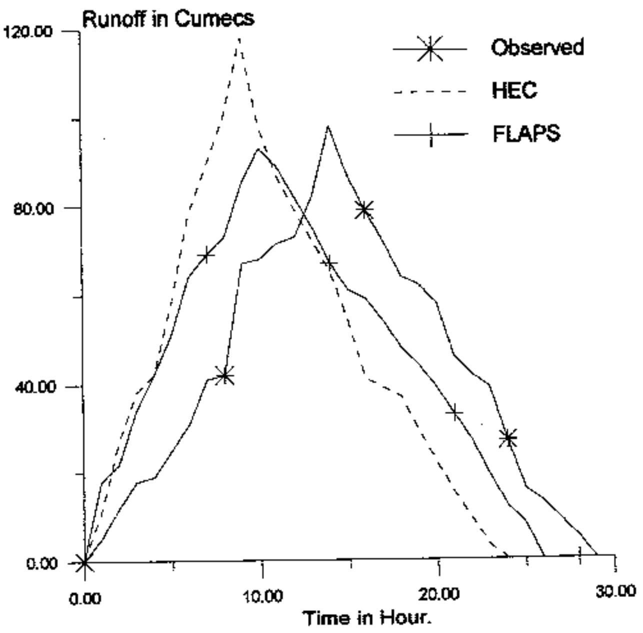
Table-14

(Measure of non-linearity in rainfall-runoff relationship for three basins)

Sl.	Event no.	Excess rainfall	$(Qp)_{obs}$	Non-linear Parameters			Linear Parameters			PEAK	Chi^2
		mm	m3/s	A	B	R^2	A	B	R^2	%	
1	Myntdu-Leska(1)	36.6	154	0.22	0.54	0.8	0.81	0.17	0.86	5.44	Ok
2	Myntdu-Leska(2)	33.6	163	0.22	0.95	0.8	0.033	0.09	0.77	13.15	Ok
3	Myntdu-Leska(3)	14	118	0.23	0.66	0.7	0.083	0.09	0.86	19.87	Ok
6	Krishnai (1)	12	183	0.10	-0.05	0.3	0.103	-0.05	0.53	5.71	Ok
7	Krishnai (2)	69.3	642	0.10	0.01	0.3	0.621	0.01	0.70	3.341	Rej
8	Krishnai (3)	20	118	0.56	0.03	0.8	0.112	0.03	0.90	25.53	Ok
9	Dudhnai (1)	21.4	271	0.53	0.05	0.9	0.016	0.05	0.90	4.911	Ok
10	Dudhnai (2)	16	243	0.35	0.05	0.4	0.169	0.05	0.61	11.97	Rej

Note:, Linear parameters A and B = Parameters of multiple linear regression., Non linear parameters A and B= parameters estimated using equation given in Ch.2, $(Qp)_o$ = Observed peak in an event, R^2 = Coefficient of regression, PEAK= Error in peak estimate = $((P_O-P_C)/P_O)$ x 100 %,., Chi square test is performed at 0.05 significant level.

Hydrograph for Myntdu basin on 21.8.96



Hydrograph for Myntdu basin on 22.9.96

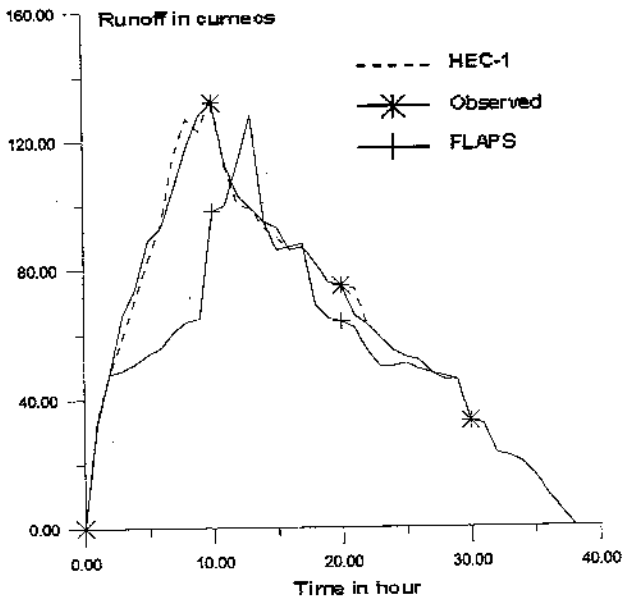
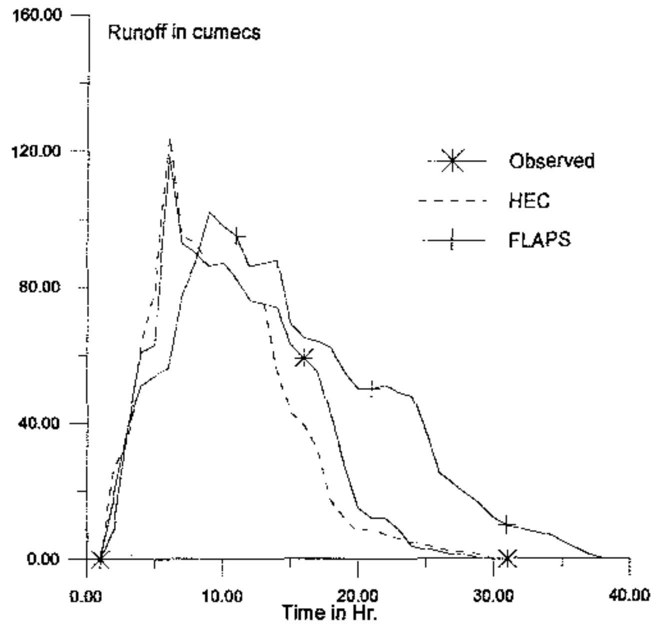
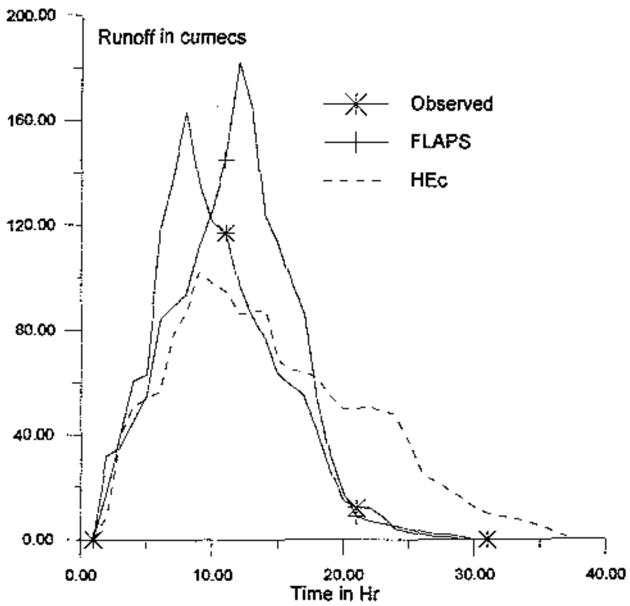


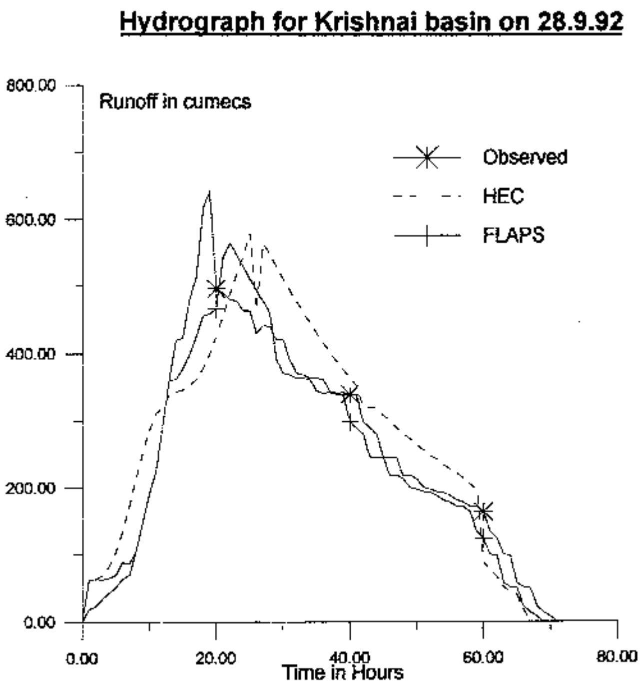
Fig.2. Flood hydrographs using different approaches for Myntdu basin.

Hydrograph for Myndu-leska basin on 3.8.96



Hydrograph for Myntdu-leska basin on 15.8.96





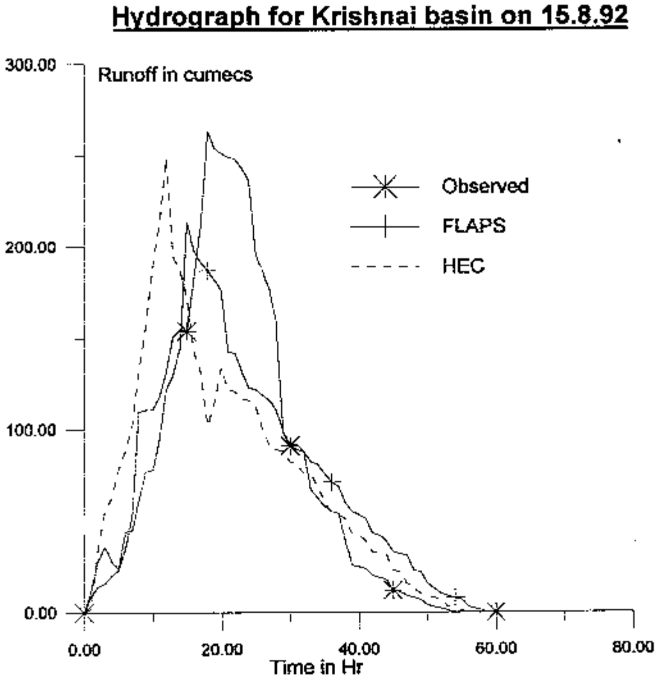
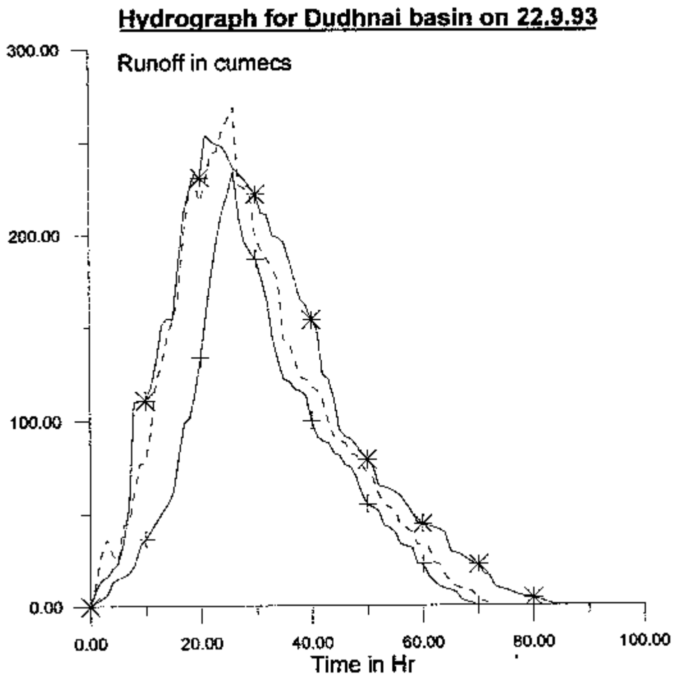


Fig.3 Flood hydrographs using different approaches for Krishnai basin



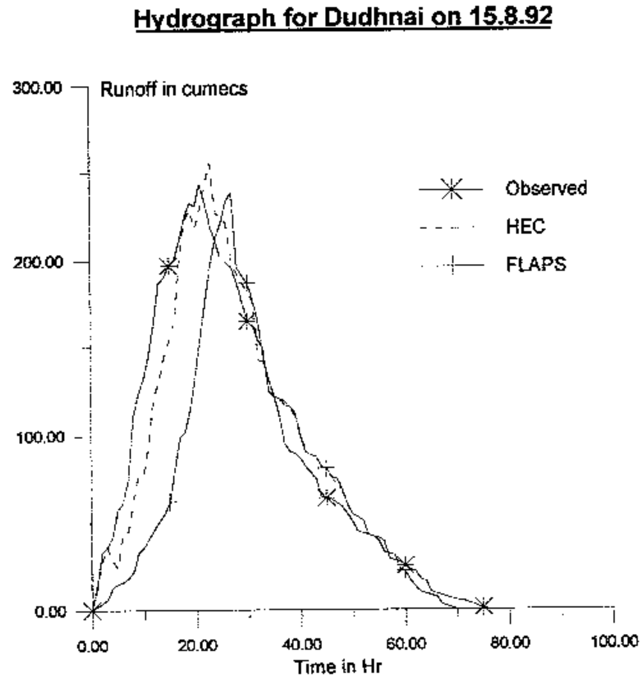


Fig.4 Flood hydrographs using different approaches for Dudhnai basin

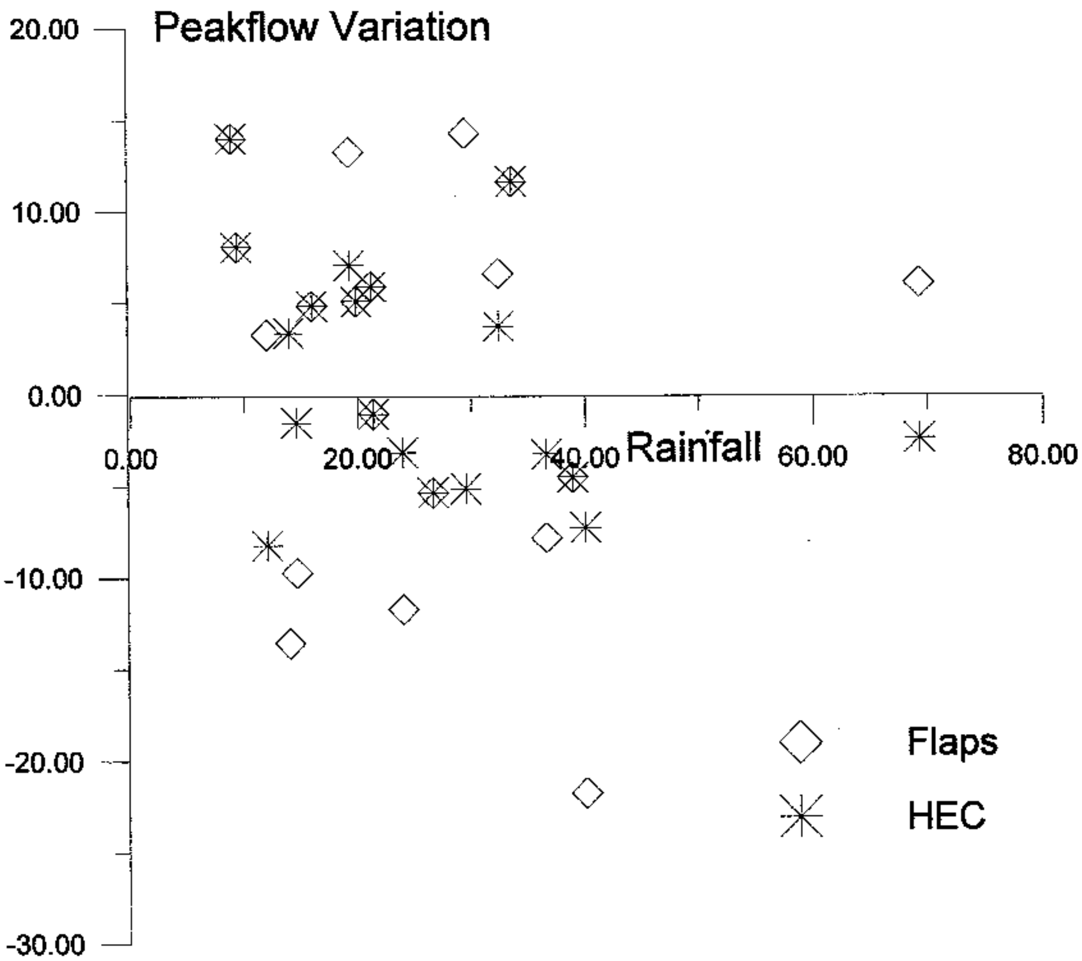


Fig.5 Peakflow variation with rainfall

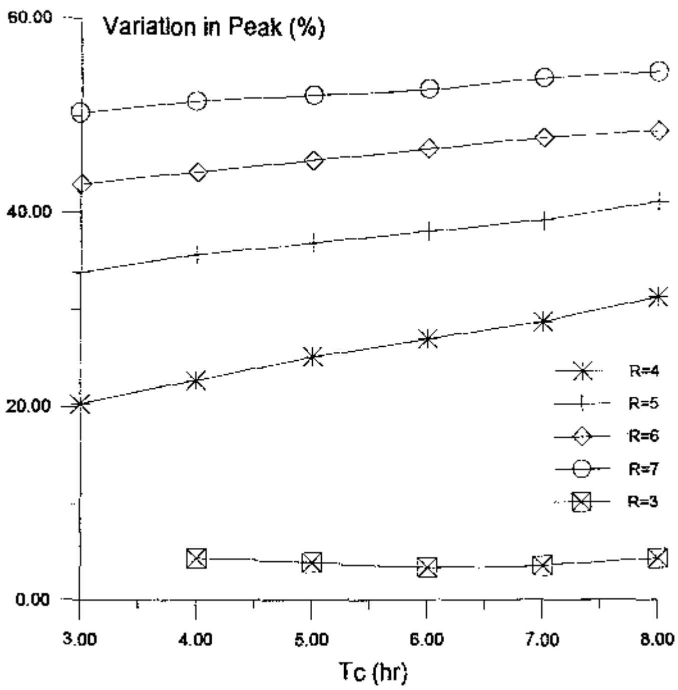


Fig.6 Variation of peak (%) with change in Tc and R

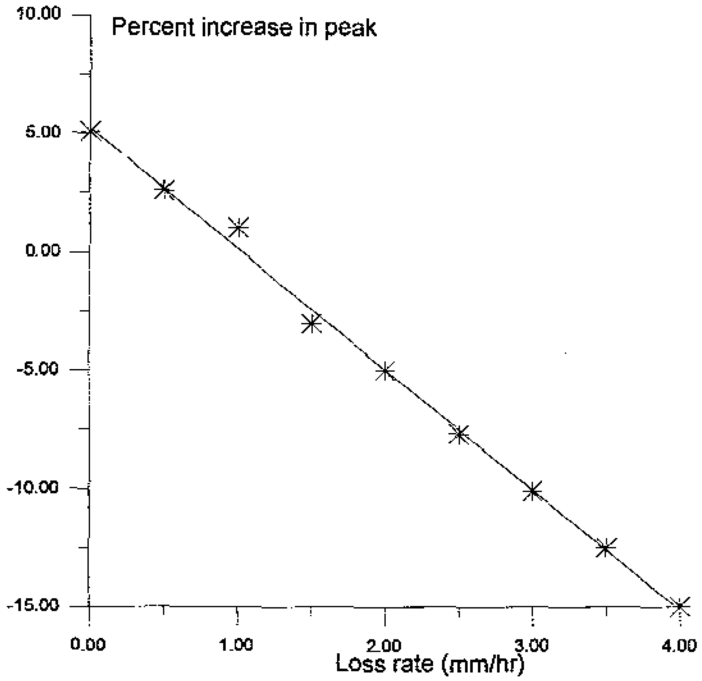


Fig.7 Variation of peak (%) with change in loss rate

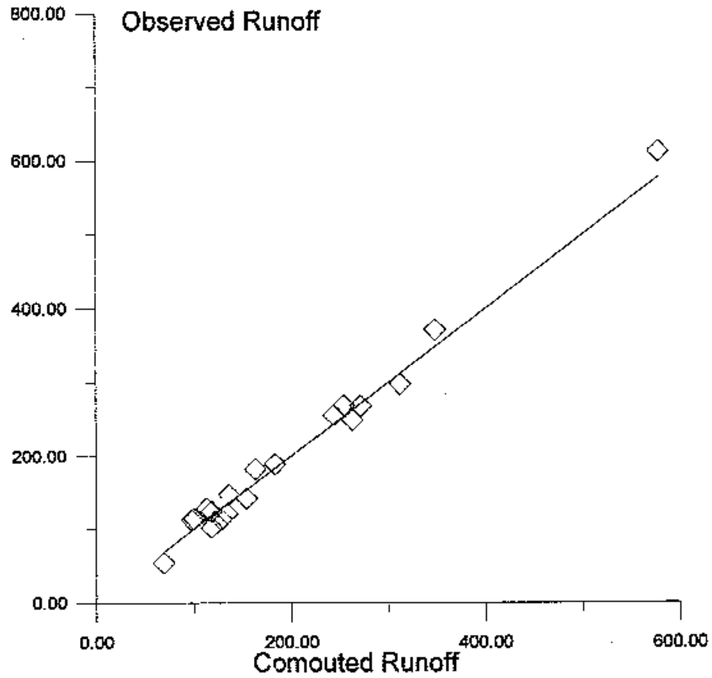


Fig.8 Observed peak Vs estimated peak using HEC

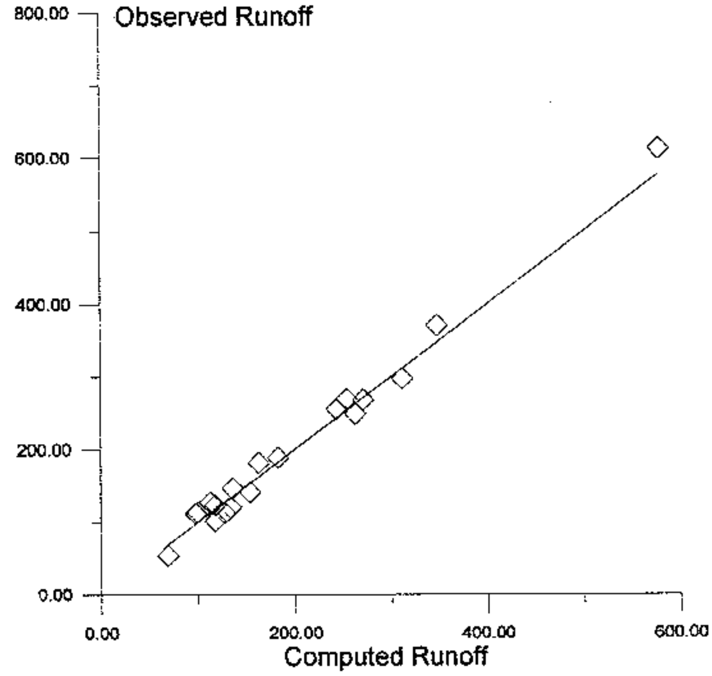


Fig.9 Observed peak Vs estimated peak using FLAPS

6.0 CONCLUSION AND REMARKS

In this report, the main effort of the calibration work was concentrated on the flood peaks and their time of occurrence. However, a few numbers of computations were also done for checking the flood volume. The performance of the FLAPS model and HEC-1 model were analysed and compared for the selected events. The following are broad conclusions from the analysis carried out for three basins:

1. For calibrating the parameters of FLAPS model, following ground realities were considered: (1) Due to high transmissivity, time coefficients of the upper and lower outlets from the groundwater storage have relative low values (2) the lower time coefficient always is greater than the upper time coefficient as the lower layer is always compact with a low transmissivity w.r.t the upper layer. For Myntdu-leska basin, the concentration time of the flow is very short, less then four hours and the runoff coefficient is relatively high (at times exceeding 20%). The effective model parameter values reflect these conditions because the time coefficients of the upper and lower outlets from the groundwater storage have relative low values.

2. The calibration of the model for Myntdu-leska basin on five sets of event gave the following values of the parameters; TRO=10 Hr, TO=3Hr,TL=6 Hr, WM=240 mm, FC=22.0, Alpha=0.5, Beta=2.0, $Q_{Overland}$=10 %.; for Krishnai and Dudhnai basin the calibrated parameters are :TRO=6Hr, TO= 2 Hr,TL=6 Hr, WM=220 mm, FC=22.0, Alpha=0.3, Beta=2.0, $Q_{Overland}$=10 %. The hydrologic response of the watersheds are non-linear, as can be seen from the high value of 'FC' which effect the residence and low value of $Q_{overland}$ which effects the quick runoff. However, 'TO', the time coefficient for the upper storage is 3 hr indicating that the release of water from the upper part of sub surface storage is quick resulting in a quick rising limb. A reasonably low value of 'TL' effects the late flow after the rain has ceased.

3. The hydrograph was simulated with high accuracy for Dudhnai basin and Myntdu-leska basin. For Krishnai basin peak was comparatively overestimated for some events.

4. The soil moisture parameter that modulates the storage and the peak, is partially sensitive compared to time parameters. Time coefficient for release of water above the upper outlet threshold (TRO), time coefficient of upper layer (TO) and time coefficient of

bottom layer (TL are more sensitive. Sensitivity of alpha is in the range of 7-15% parameter range of 10-15 %. Beta coeff. and $Q_{overland}$ effects the late flow and the quick runoff respectively, are partially sensitive

5. The HEC-1 Model was applied to selected events for three basins. The simulated parameters for Mytdu basin are; the catchment time of concentration (T_c) is equal to 3.3 Hrs and storage coefficient (R) is equal to 8.4 Hrs. for Krishnai; Tc=7.3 hr, R=27.4 Hrs., for Dudhnai; Tc=5.1hr, R=13.5 hr. Standard error of estimate of peak varies between 3 to 20 %. The model estimates the peak accurately for most of the events in Myntdu – leska basin and fairly accurate for other two basins. There are two events on for 21st Aug, 96 and 28th Sept, 92, where the peaks are slightly overestimated.

6. Estimation of overland flow and channel travel times is accomplished in the HEC-1 model simply by assuming a constant velocity and basing the histogram on travel distance alone. Secondly, a generalized watershed shape with a time-area histogram symmetric about Tc/2 is used. If no specific time-area histogram is given, a default parabolic shape basin is assumed. For small basins, flow routing can reduce the effect of spatial lumping and incorporate the translation lag. A time area diagram, if used as an input to the model is likely to predict the runoff hydrograph more accurately

7. In case of HEC-1 model, it is observed that the peak decreses with decrease in time of concentration, Tc for a fixed value of R. For a given Tc, the peak decreases with increase in R. Time to peak (Tp) is found to increase with increase in Tc, however there is no change in Tp with change in R.

8. To check the non-linearity in rainfall-runoff response a simple storage-runoff dynamic mode was tested on short-term rainfall and discharge data of Myntdu Leska basin, Krishnai basin and Dudhnai basins for some of the selected events. The analysis was carried on ten selected events distributed over two years and the results showed degree of regression coefficient (R^2) ranging from 62 to 91 % . Since only three basins are considered for the analysis the relationship of parameter 'B' (that represents the degree of non-linearity in catchment response with the catchment area could not be established. However, It can be observed that Krishnai basin with an area of 950 Sq.km has a low B-parameter compared to Myntdu-Leska basin, a smaller catchment.

9. HEC –1 model tends to slightly overestimate the in case of high rainfall events. However, the variations are within 15 % for maximum number of events analysed in the study. The performances of the two models were compared on basis of bias, RMSE, mean absolute error, efficiency and R^2. As observed both the models perform well on the given data, however, HEC-1 model tend to be less biased than FLAPS model.

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