APPLICATION OF UNIT RESPONSE FLOOD ROUTING THEORY TO A LINEAR DISTRIBUTED PARAMETER MODEL

(CHAMBAL BASIN - MADHYA PRADESH)

A DISSERTATION
Submitted in Partial fulfilment of the requirements for the award of the degree
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in
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by
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A C K N O W L E D G E M E N T

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Roorkee

DATED April, 1978 (Prakash Chand Garg)

C E R T I F I C A T E

Certified that the dissertation entitled "APPLICATION OF UNIT RESPONSE FLOOD ROUTING THEORY TO LINEAR DISTRIBUTED PARAMETER MODELS FOR THE CHAMBAL BASIN AT GANDHI SAGAR SITE IN MADHYA PRADESH", which is being submitted by Shri Prakash Chand Garg, partial fulfilment of the requirements for the award of the Degree of Master of Engineering in Hydrology of the University of Roorkee, Roorkee is a record of the candidate's own bonafide work carried out by him under my supervision and guidence. To the best of my knowledge the matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is further to certify that Shri P.C.Garg has worked for a period of six months from October 1977 to March 1978 in the preparation of this dissertation under my guidence, at this University.

Dated April 1, 1978

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S Y N O P S I S

The proposed study is aimed at developing a suitable hydrologic model for the 8,800 square miles natural catchment of Chambal River in Madhya Pradesh, contributing to the Gandhi Sagar Reservoir.

A linear distributed parameter model has been detailed for simulating the catchment action, i.e. starting from the observed rainfall upto prediction of the reservoir levels at the Gandhi Sagar Reservoir. This has been achieved by dividing the catchment into five sub-basins in the upper reaches of the tributaries, keeping in view, the drainage characteristics and in between the outlets of the sub-basins and upto the Gandhi Sagar Reservoir, the catchment is termed as intermediate sub-basins-divided in six parts.

Suitable input functions are separately defined for the sub-basins and Intermediate sub-basins. Attempts are made to develop relationships between rainfall excess/ϕ - index and rainfall intensity and its duration. These relationships can be of great use for prediction purposes.

The transformation process of the hydrologic system of these sub-basins and Intermediate sub-basins have been taken care off by suitable hydrologic models. Attempts are made to develop relationships between catchment constants - thus model parameters and catchment physiographical characteristics to develop the transfer function for Intermediate sub-basins (ungauged catchments). The properties of linear reservoirs and linear channels have been used for the same. The computed and observed responses are compared at the outlets of sub-basins and intermediate sub-basins, for the verification of the propose model.

The flow concentration so computed at the outlets of these sub-basins and intermediate sub-basins have been routed upto Gandhi Sagar Reservoir, by using the Unit Response Theory. In all Ten Unit Responses have been formulated and tested for routing the flows upto the Reservoir.

Two storms have been tested and a comparision between the observed and computed reservoir levels at the Gandhisagar is given. The overall efficiency of the model for the entire catchment have been worked out and found as 89 percent and 81 percent for the two storms.

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CHAPTER - I

INTRODUCTION

1.1 GENERAL FEATURES OF THE CHAMBAL BASIN:

River Chambal is one of the main tributaries of River Yamuna. The length of river is about 600 miles. Largest flow is through Madhya Pradesh and Rajasthan State. This river rises in the northern slope of Vindhya Mountains, about 20 miles South-West of Mhow in M.P., at an elevation of about 2800 feet above the mean sea level. It flows, first in northerly direction for a length of about 225 miles, and after passing by the historic part of Chaurasigarh, it flows in North-Easterly direction for a length of about 375 miles through Rajasthan, M.P. and Uttar Pradesh State, before joining the River Yamuna, South-West of Etawah at an elevation of 400 feet above mean sea level.

The present study pertains to the basin upto Gandhi Sagar dam, which is constructed on River Chambal at a distance of about 218 miles from the source. The index map showing the catchment area of Chambal and its tributaries upto Gandhisagar dam may be seen in Fig. No.1-1.

1.1.1. Size of The Basin:-

The total drainage area at Gandhisagar has been reported to be 8,890 sq.miles. In present study, from the toposheet 1" = 4 miles map the area has been computed as 8,800 sq.miles and this figure has been adopted.

1.1.2 Drainage Pattern:-

The four important tributary of the River Chambal are, Shipra, Chhoti-Kalisindh, Shivana and Retum. The first two

GANDHISAGAR RESERVOIR CATCHMENT

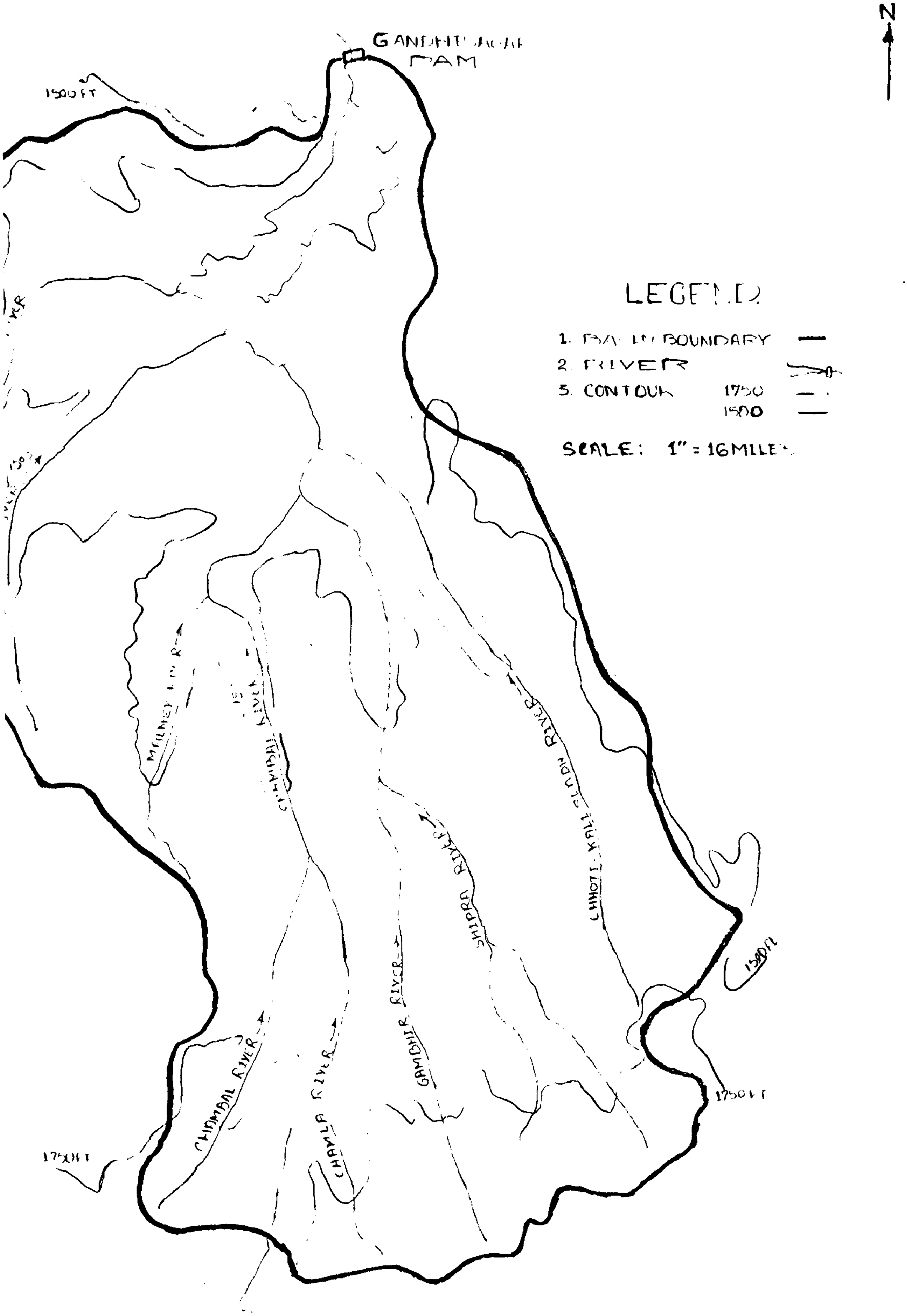

FIG.NO. 1.1 INDEX MAP

tributaries are running almost parallel to the main Chambal, River. These tributaries together with Chambal, control about two-thirds of the total catchment. The Shipra and Chhoti-Kalisindh rivers are closely spaced. The other two tributaries Shivana and Retum drain about one-half of the remaining area and join the reservoir in its middle reaches from West.

As the basin is traversed by monsoon depression and cyclonic storms in the same general direction as the main river i.e. in the West-North-Westerly direction, the flow concentrations from different areas synchronise at the out let.

1.1.3 Slope:-

Originating at an elevation of about 2,800 feet above mean sea level, the Chambal river drops to a level of 1,750 feet above mean sea level after traversing a length of about 10 miles. Thereafter it has a fairly uniform gradient of about 3.30 feet per mile, except near the confluence of River Chambal with Shipra, and Chhoti-Kali-Sindh where it has relatively steeper gradient which varies from 6 to 10 feet per mile. At the dam site its bed is at 1120 feet (above mean sea level) and the length of the river is about 218 miles.

1.2 SIGNIFICANCE AND NEED FOR A HYDROLOGIC MODEL OF THE BASIN:

Large drainage basins require greater attention regarding hydrologic investigations in view of growing development of water resources. The transformation of rainfall excess into direct runoff is a complex process, which is the basic problem of hydrologic investigations, occupies a central place in applied hydrology. The transformation needs for proper design of hydrostructures and also for reservoir regulation. Hence correct estimation of this require not only the knowledge of the peak flood but also the time distribution of discharges through out the period of flows. The flood peak and time distribution of runoff from a drainage basin during a storm depend upon the meteorological conditions and also on the physiographical characteristics of the basin.

The available concept, regarding the transformation of rainfall excess in the direct runoff, the synthetic approach empirical formulae give only the knowledge of flood peak, but the time distribution of runoff throughout the period of flows can conventionally be predicted only by Unit Hydrograph approach proposed by Sherman (1932). This approach is based on the availability of gauging data and unable to predict the direct runoff-considering the distributed input. Hence in the proposed study, the procedure of developing a distributed parameter model is explained, which will be helpful in the prediction of runoff from different parts of a sub-catchment and also given an idea regarding the variation of rainfall and infiltration index, with respect to time in different parts of the catchment.

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1.3 STATEMENT OF THE PROBLEM:

The present study is aimed at simulating the direct runoff hydrograph, for a natural catchment at Gandhi Sagar Dam, using a linear distributed parameter model.

Basically the approach consists of the following:-

(i) To develop suitable input function.

(ii) To formulate the linear distributed parameter model for gauged sub-basins.

(iii) Formulation of distributed parameter model for gauged and ungauged intermediate sub-basins.

(iv) Routing of the flow concentrations from all the sub-basins and intermediate sub-basin to the Gandhi Sagar Reservoir.

CHAPTER - II

LITERATURE SURVEY

2.1 SYSTEM CONCEPT IN HYDROLOGY:

For mathematical representation of a drainage basin, the entire hydrological cycle may be treated as an engineering system. It is preferred to consider the hydrological system as a black box in which:

1. Input function
2. System function (Transformation process)
3. Output function or Response.

In surface water hydrology where a natural catchment is studied as a hydrologic system the input function is generally the hyetograph, system function is a function, is the catchment action on hyetograph. The output function or response is the runoff hydrograph observed at the outlet(Fig. No.2-1.

2.1.1. Linear And Non-Linear Hydrologic System:-

Any system is said to perform a linear operation of a step input to the system, produces the output response, which is directly proportional to the input at any time. Linear systems are easy to work with as the principle of homogenity and super-position hold good.

(a) The homoginity of system ensures

$$f(\alpha Q) = \alpha f(Q) \quad \ldots \quad \ldots \quad \ldots 2.1\ a$$

(b) The principle of super position states:

$$f(Q_1) + f(Q_2) + - - f(Q)_n = f(Q_1+Q_2+ - - Q_n) \quad \ldots \quad \ldots \quad \ldots 2.1\text{ b}$$

However depending upon the nature of the Input function a linear or non-linear hydrologic system may be further be classified into lumped or distributed system.

2.1.2. Lumped And Distributed Parameter: Systems:

The hydrological system is defined as a lumped system when the system components are the function of time only and spatial co-ordinates are not accounted for input. A lumped system may be located at any point in the working space of entire system. It can be represented by an ordinary differential equation

$$f(Q) = a_n \frac{d^nQ}{dt^n} + a_{n-1} \frac{d^{n-1}Q}{dt^{n-1}} + \ldots - - a_oQ \quad \ldots \quad \ldots \quad \ldots 2.2$$

where a_n, a_{n-1} . . . . a_o etc. are all constants and are said to be linear and time invariant only.

However if a_n, a_{n-1} . . . a_o (or any of these) is a function of Q the system would be a nonlinear system Fig.No.2-2(a).

Mathematical equations representing a distributed system involved spatial co-ordinates as shown in Fig.No. 2.2 (b), input to such a system is distributed and therefore, it cannot be located at a single point. The distributed system can only be described by partial differential equations and, therefore, theoretical solution to such system requires complete knowledge of the boundary conditions.

2.1.3 Catchment Action:-

As shown in Fig.No.2-3, as a result of the catchment action, output response gets distributed over a larger time period which,not only attenuates the input hydrograph peak but also shifts it in time. The translation and attenuation of input hydrograph is due to storage actions of the basin system. In most of the conceptual models, the catchment action is represented through conceptual identities such as linear channels and linear or non-linear reservoirs.

2.1.4 The Linear Channel:

A linear channel conceptually represents the pure translatory effects of a system and, therefore can be defined as:

"A conceptual channel on which the time(T) required to translate a discharge (Q) of any magnitude through a channel reach of given length (x), is always constant. Thus when an inflow hydrograph is routed through the channel, its shape is not affected.

If $F = f(t)$ be the inflow function to a linear channel, after routing the outflow function $Q(t)$ would be identical to the inflow function except for a time lag which is introduced by the system and whose magnitude is given by the translation time (Δt) of the linear channel". Hence

$$Q(t) = f(t - \Delta t) \qquad \text{.. .. .. 2.3}$$

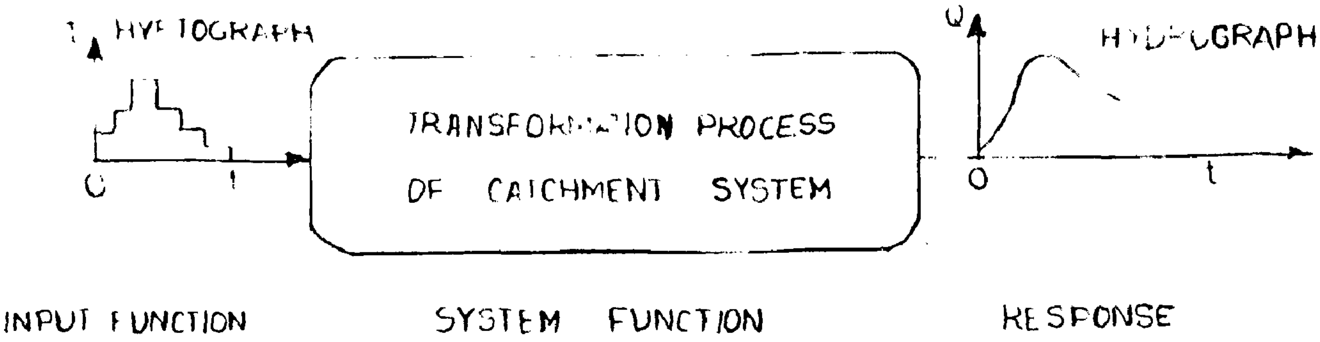
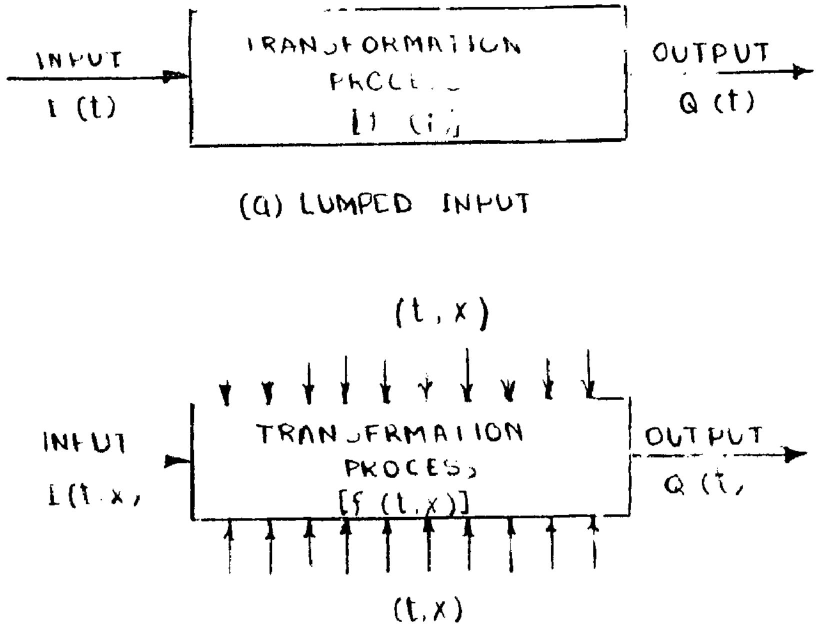


FIG.2.1_CATCHMENT AS AN ENGINEERING SYSTEM



(a) LUMPED INPUT

(b) DISTRIBUTED INPUT

FIG. 2.2. INPUT TO A SYSTEM

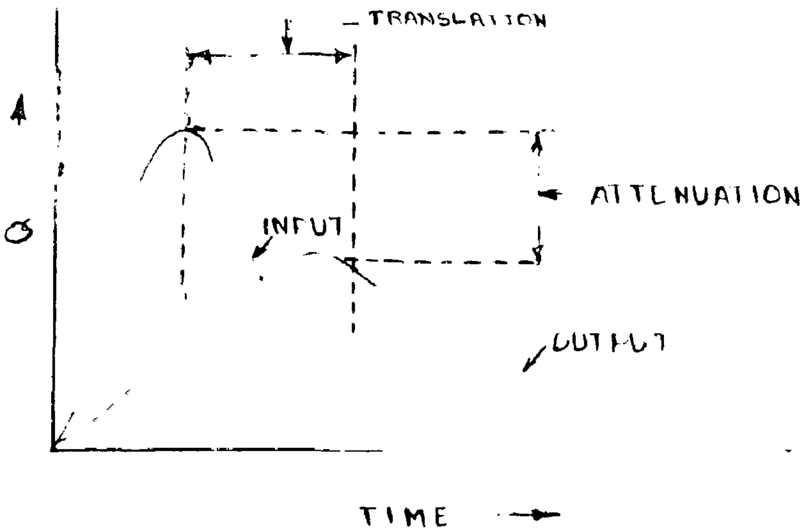


FIG 2.3 THE CATCHMENT ACTION

2.1.5 Concept Of Reservoir-Linear And Non-Linear Reservoirs:

The catchment action on its input precipitation is analogous to the reservoir action on its inflow hydrograph. A reservoir too, translates and attenuates the inflow hydrograph by regulating its outflow over a desired period of time. This analogy suggests that a drainage basin system could perhaps be analytically represented by the reservoir concept.

A reservoir may be classified as a linear or non-linear depending upon its mode of operation. A linear reservoir is a conceptual identity in which the storage S is directly proportional to the outflow Q

$$S \propto Q$$

$$S = KQ \quad \ldots \quad \ldots \quad \ldots \quad 2.4$$

where the constant K has the dimension of time and equal to the average delaytime, imposed on its flow by the reservoir model.

The functional relationship between the storage and discharge of a non-linear reservoir may be written as

$$S = KQ^B \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad 2.5$$

where K and B are dimentional constants which represents the two characteristics parameters of a non-linear conceptual model.

2.1.6 Derived Identities - Unit Hydrograph (U.H.), Instantaneous Unit Hydrograph (I.U.H.):

These identities are derived with the help of conceptual identities or from available record of input and response functions to represent the transfarmation process of a system.

In linear hydrologic modelling the derived identities are: (1) the Unit Hydrograph and (2) the Instantaneous Unit Hydrograph.

As per the definitions given by Sherman "The discharge time relationship resulting from a study of effective rainfall of unit duration uniformly distributed over a catchment" is called Unit Hydrograph.

If the duration of the effective precipitation become infinitesimally small, the resulting unit hydrograph is defined as IUH and represented by U(o,t).

2.2 REVIEW OF SOME CONCEPTUAL MODELS:

Utilising the properties and concepts discussed in the above section different hydrologists have proposed various hydrologic models which have got a direct relevance in the development of the proposed model. A brief summary of these hydrologic approaches is presented in this article.

In the year 1930, the committee of floods, suggested that the hydrograph due to an Instantaneous storm could provide a good indication of watershed response. It was considered that the hydrograph would reflect the width of the watershed and the velocity of flow, all other factors being constant. This idea was not adopted by other investigator at that time probably because of crudeness of the available data and the difficulties inherent in the derivation of IUH by numerical or graphical differentiation of the S-curve based on Unit Hydrograph of finite duration.

The most notable of the early attempts to derive a relationship between rainfall and runoff was in a series of articles by Zoch (Zoch, R.T.1934-37) in which it was assumed that the runoff from each elementary area of the watershed was related to the storage S over the elementry area by a linear relationship $S = KQ$

2.2.1 Lumped Model:

In these model the input function is function of time only. It does not have spatial co-ordinates. It is considered to be located at a single point in the working space some of such models are discussed in the following paragraphs.

Clark (Clark,C.O. 1945) derived the Instantaneous Unit Hydrograph by routing the time area concentration diagram through a linear reservoir. Time of concentration T and the storage coefficient K were the two parameters of the model, T was defined as time interval from the end of excess rainfall to apoint on the falling limb of the hydrograph where the ratio of rate of decrease in discharge to total discharge was greater, and K was a coefficient of linear storage discharge ~~discharge~~ relationship.

$$St = K \quad Q(t) \qquad .. \quad .. \quad .. 2.6$$

where St = Storage in the reservoir at the instant t

Qt = the outflow rate at the same instant

$K = Q \,/\, \frac{dQ}{dt}$

Q = rate of direct surface runoff at the point of inflection on the falling limb.

Kelly (Kelly, J.J.O., 1955) showed that a logical extension of the procedure of which Unit Hydrographs of unit period could be derived by means of time-shift of the S-curve is the reduction to values approaching zero of the unit period and time shift. This leads to the concept of the Instantaneous Unit Hydrograph. This unit hydrograph corresponding to a rainfall of unit volume at an instant has special property. Its ordinates are the slope of the S-curve and conversely, the S-curve is its integral. A two parameter model for the Unit Hydrograph based on the routing of time area diagram through a reservoir was proposed.

Nash (Nash, J.E. 1957) proposed a conceptual model by considering a drainage basin as 'n' identical linear reservoirs in series. He has shown that a cascade of equal linear storages results in the gamma density function. The governing relation would be the continuity or conservation of mass equation.

$$I - Q = \frac{ds}{dt} \qquad .. \quad .. \quad .. \; 2.7$$

where s is the volume of surface storage on the watershed at time 't', that would eventually become runoff. Storage S in a linear reservoir is directly proportional to the outflow Q, or

$$S = KQ \qquad .. \quad .. \quad .. \; 2.8$$

Substituting equation 2.7 in equation 2.8 and considering the condition that Q = 0 when t = 0, the following equation for outflow can be derived:

$$Q = I(1 - e^{-t/K}) \qquad .. \quad .. \quad .. \; 2.9(a)$$

When t = ∞, the above equation gives Q = I, which means that the outflow approaches an equilibrium condition becoming equal to inflow. If the inflow terminates at time to since outflow began, a similar derivation gives the outflow at 't' in terms of discharge Q_o at to as:

$$Q = Q_o \, e^{-r/K} \qquad .. \quad .. \quad .. \; 2.9(b)$$

Where r = t-to being equal to the time since inflow terminated.

For an Instantaneous inflow which fills the reservoir of storage So in t_o = 0 equation 2.8 shows Q_o = So/K and equation 2.9(b) gives the outflow as $Q = Ie^{-t/K} = \frac{So}{K} \, e^{-t/K}$

.. .. 2.9(c

For a unit input or So = 1 the IUH of the linear reservoir is therefore

$$U(o,t) = \frac{1}{K} e^{-t/K} \quad \ldots \quad \ldots \quad \ldots 2.9(d)$$

This is the hydrograph for the outflow from the 1st reservour, outflow Hyd. from 2nd Res. = $U(o,t) = \frac{t}{K} e^{-t/K}$

.. .. 2.9(e)

continuing this routing procedure we get outflow from the n^{th} reservoir as,

$$U(o,t) = \frac{1}{K\Gamma(n)} \left(\frac{t}{K}\right)^{n-1} e^{-t/K} \quad \ldots \quad \ldots \quad \ldots 2.10$$

which is the IUH of the simulated basin for an input of one inch per hour per square mile.

The parameters of the model n and K were evaluated by method of moments from the observed rainfall excess hyetograph and direct runoff hydrograph. The definition of taking out the moments adopted here is

$$Mn = \frac{\int_{-\infty}^{+\infty} Y\, X^n\, dx}{\int_{-\infty}^{+\infty} Y\, dx} \quad \ldots \quad \ldots \quad \ldots 2.11$$

where Mn = n^{th} movemt of ERH or DRH

Y = ERH or DRH Ordinate at Y-axis

X = Time period ar abscissa of ERH or DRH

Now the first and second moment (M_1 & M_2) of IUH are related with the model parameter and the first and second Moment of ERH and DRH by the following relationships.

$$M_1 = nK = MDRHI - MERHI \quad \ldots \quad \ldots \quad \ldots \quad 2.12$$

$$M_2 = n(n+1)K^2 = MDRH2 - MERH2 - 2nK\, MERHI \quad \ldots \quad 2.13$$

where MERHI = First Moment of ERH about the origin
MERH2 = Second Moment of ERH about the origin
MDRHI = First Moment of DRH about the origin
MDRH2 = Second Moment of DRH about the origin

Nash (Nash, J.E. 1960) further proposed two relationships relating the model parameters with catchment characteristics by studying about 30 British catchments.

$$K = C_1(A)^{0.25} * (OLS)^{-0.3} * (L)^{-0.085} \quad \ldots \quad \ldots \quad 2.14$$

$$n = C_2(L)^{0.085}$$

where C_1 and C_2 are the constants derived for the catchments

A = Catchment area in square KM's.

L = Length of main channel in KM's.

OLS = Weighted overland slope in parts per 10,000

2.2.2 <u>Distributed Parameter Models:</u>

In the Previous section the model where input functions is lumped have been discussed. In nature the rainfall excess is rarely lumped rather it is always distributed. In this section some of the models which are capable of accounting for spatial distribution of rainfall excess are discussed.

Dooge (Dooge, J.C.I. 1957) introduced the concept of linear channel and modified the Nash-model by adding linear channels in addition to linear reservoir in the series. In this model the catchment area was divided the by means of isochrones and represented each inter-isochronal area by a combinations of linear channel and linear reservoir in the series. The outflow from the linear channel was represented by time area concentration diagram and considered as input to the linear reservoir of the set. The output was obtained by adding the partial curves obtained by routing the time-area concentration diagram for the upper most reach of the basin through n-linear reservoirs, next through (n-1) linear reservoirs and so on. A general equation for the IUH of the model for equality spaced identical linear reservoirs was given for unit input as:

$$U(t) = \frac{1}{T} \int_{0}^{t/K} P(m,n-1) \quad W(\tau') \; dm \qquad \ldots \quad \ldots \quad \ldots \; 2.16$$

where T = Maximum Translation Time

t = current time measured from time of occurence of the Instantaneous Rainfall Excess

$P(m,n-1)$ = Poisson's distribution function

$m = (t-\tau)/K$

τ = Storage coefficient for linear reservoir

$n(\tau)$ = No. of linear reservoir D/s of τ.

and $W(\tau')$ = Ordinate of dimensionless time area concentration diagram at time τ'.

As the catchment was divided into several parts by isochrones and input on each part was fed to the model seperately, it was possible to account for the spatial distribution of rainfall excess.

Laurenson proposed the concept of distributed input in non linear reservoirs. He divided the catchment by isochrones in several sub-areas. These sub-areas were represented by non-linear reservoirs in series. The inputs were tried to account for the following features:

(i) Rainfall excess is variable in time and space.
(ii) Storage in the catchment is distributed not lumped
(iii) Storage discharge relation is non-linear,
(iv) Different input elements pass through different amount of storages.

Procedure:

(1) Hyetograph of rainfall for furthest of up-stream of area is determined with shape given by nearest recording raingauge, and scale the maximum ordinate equal to average rainfall for the sub areas.

(2) Losses are subtracted to know rainfall excess.

(3) Find out the inflow hydrograph for rainfall by converting hydrograph by relation.

$$Q = iA$$

where i = intensity of rainfall,
A = Sub area

(4) The inflow hydrograph is routed through storage for sub areas by non linear routing method.

(5) Similarly next sub area rainfall hydrograph is developed and added with time shift to outflow hydrograph

from upstream. The combined hydrograph is routed through appropriate storage.

$$S = K(q) \quad q$$

where K is a function of q

$$(I-Q) = \frac{ds}{dt}$$

$$(i_1+i_2)\frac{\Delta t}{2} - (q_1+q_2)\frac{\Delta t}{2} = S_2-S_1 \quad \dots\dots 2.17$$

Writting $S_2 = K_2(q_2)\ q_2$ and $S_1 = K(q_1)\ q_1$ and substituting in 2.17. We get

$$q_2 = C_o i_2 + C_1 i_1 + C_2\, q_1 \quad \dots\dots 2.18$$

$$\text{where } C_o = C_1 = \frac{0.5\Delta t}{K_2+0.5\Delta t} \quad \dots\dots 2.19$$

$$C_2 = \frac{K_1 - 0.5\Delta t}{2K_2 + 0.5\Delta t} \quad \dots\dots 2.20$$

where 1&2 represents start and end of Δt respectively

Since the value of the coefficients C_o, C_1 & C_2 depend on K_2 and K_2 depends on q_2, this equation is solved by iteration method by assuming $K_2 = K_1$ and find q_2. Redetermine K_2 knowing q_2 and find second value of q_2 by iteration. This q_2 becomes q_1 for next routing period. From this q_1 corresponding value of K_1 is determined.

A cascade of linear channels fed with distributed inputs, has successfully been used to represent the catchment action (Mathur, 1972). Each linear channel of the series network receives its distributed input from

from a sub-watershed area which is assigned in it. This study concluded that different sub areas of drainage basins system are directly correlated to the basin's response function through the linear channel concept. Further it was shown that rainfall input on different sub area need notbe the same and thus spatial non-uniformity of rainfall is taken into account. The model is capable of identifying the parts of the sub area contributing to flood peaks, thus enabling the flood forecasting programmes.

2.3 REVIEW OF SOME FLOOD ROUTING METHODS:

Flood routing may be considered under two broad types, namely, reservoir routing and open channel routing.

The former types provides methods for evaluating the modifying effects on a flood wave passing through a reservoir. In design and planning it applies to the determination of the location and capacity of reservoirs, of the size of outlet structures and spillways.

Open channel routing are used to determine the time and magnitude of flood waves in rivers, to develop design elevations for flood walls and levees, to estimates benefits from completed or proposed reservoirs etc.

2.3.1 Reservoir Routing Methods:

On initial, prior to the selection of a routing method is theselection of a proper routing period. This is the time interval at which the ordinates of a hydrograph used in the routing, are represented. The period must be sufficiently short to define the hydrograph adequately. Theoretically, it should be equal to, or some what shorter than the travel time of the flow through the reach. Also, the period must be short enough so that the hydrograph during the period approximates a straight line.

1. The Puls Method
2. Step by Step Method
3. Garret's Method
4. Cheng's Graphical Method
5. Goodrichs Semigraphical Method (1937)
6. Steinberg's Method(1938)
7. S.M.Woodward's Method (Calculus Method)

The Puls Method:

This method assumes invariable discharge storage relationships and neglects the variable slope occurring during the passage of a flood wave.

In a given time interval the difference bettwen inflow and outflow is equal to the change in storage. Rewriting the equation 2.7 as $I - Q = \frac{ds}{dt} = \Delta S$

or if expressed infinite time intervals,

$$1/2\,(I_1 + I_2)\,\Delta t - 1/2\,(Q_1 + Q_2)\,\Delta t = S_2 - S_1 \quad \ldots \quad 2.21$$

where the subscript 1 refer to values at the beginning of any time period of length Δt and subscript 2 refer to values at the end of the period, and I, Q & S are instantaneous value of inflow, outflow and storage, respectively. Arranging the equation 2.21 so that all known values are on the left; the expression becomes

$$1/2\ (I_1 + I_2)\ \Delta t + S_1 - 1/2\ Q_1\ \Delta t = S_2 + 1/2\ Q_2\ \Delta t \qquad \text{.. .. .. 2.22}$$

Routing is accomplished by substituting the known values in the above equation to obtain $S_2 + \frac{1}{2} Q_2 \Delta t$. Then Q_2 is obtained from the relationship between Q_2 and $S_2 + 1/2\ Q_2\ \Delta t$. Plot outflow vs. storage curve. Knowing storage curve it is easy to plot either $S - \frac{1}{2}$ Qt or $S + \frac{1}{2}$ Q.t. curves.

Step: 1	Compute $1/2\ (I_1+I_2)$
Step: 2	From the $S-1/2\ Q.t$ curve read the value of $S_1-1/2\ Q_1.t$, corresponding to a given value of Q_1.
Step: 3	Compute $S_2 + 1/2\ Q_2 t$ by use of equation 2.22 i.e. value in Step 1 + Step 2.
Step: 4	From $S + \frac{1}{2}\ Q_2.t$ curve read the value of Q_2 corresponding to that of $S_2+\frac{1}{2}\ Q_2 t$.
Step: 5	Determine $S_1 - 1/2\ Q_1.t$ or actually $S_2-\frac{1}{2}\ Q_2.t$. The next routing period by substracting Q_2t from $S_2+\frac{1}{2}Q_2.t$ or by reading it from the $S-1/2$ Qt curve for an Q_2 To obtain Q_3 for period 3, repeat Steps 1 to 5 and so on.

2.3.2 Channel Routing:

In almost all the flood control problems, it becomes necessary to know the flood hydrograph of the river at various points on its path. The behaviour of the river will change when the tributaries are discharging different quantities at different periods. Even if there is no tributary contribution, the hydrographs at different points of a stream will not be the same, due to local inflow, or even due to its own valley storage or the channel characteristics may be completely changed by the introduction of a reservoir or an embankment.

1. The Muskingham Method
2. The Working Value Method
3. Meyer's Method
4. Successive Average lag Method(TatumMethod)
5. The Progressive Average Lag Method (U.S. Army)

The Muskingham Method:

This method was developed by G.T. MC Carthy and others in connection with studies of the Muskingham conservancy District Flood Control Project of the U.S.Army Crops of Engineers in 1934-35. This method involves the concept of Wedge and Prism storages in a channel flow.

Storage volume can be correctly related to outflow with a simple linear function only, when inflow and outflow are equal i.e. when a steady flow exists. During the advance of a flood wave, however, inflow always exceeds outflow, thus producing a wedge of storage. Conversely, during the recession outflow exceeds the inflow, resulting in a negative wedge storage. The Wedge can be related to the difference between the instantaneous values of inflow and outflow. ~~In Figure~~ The Wedge storage is represented by KX(I-O). In addition, there is a storage of prism, or prism storage, as represented by KO. In these expressions, K is a coefficient and X a parameter. The total storage is therefore

$$S = KO + KX \ (I-O) \qquad \ldots \quad \ldots \quad \ldots \ 2.23$$

This equation is known as the Muskinghum equation.

The constant X expresses the relative importance of inflow and outflow in determining storage. If storage is entirely a function of outflow, as in reservoir, then X = 0, but if the Wedge storage is significant, then X will be the function of Inflow and outflow both; and the value will be greater than zero. With a limiting value of 0.5 when inflow and outflow have equal weights as in uniform channels. For most streams X is between 0 and 0.3 with a mean value of 0.2.

Putting the equation 2.23 in the subscript from indicate the routing period, starts and ends.

$$S_2 - S_1 = K\left\{ x(I_2 - I_1) + (1-x)\ (Q_2 - Q_1)\right\}$$

When the storage is the function of outflow only for linearity condition $x = 0$

$$S_2 = S_1 = K\left\{ Q_2 - Q_1 \right\} \qquad \ldots \quad \ldots \quad \ldots \ 2.24$$

Comparing the equation 2.21 & 2.23.

$$\frac{I_1 + I_2}{2}\Delta t - \frac{Q_1 - Q_2}{2}\Delta t = K(Q_2 - Q_1)$$

$$\frac{I_1 + I_2}{2}\Delta t - \frac{Q_1}{2}\Delta t + KQ_1 = \frac{Q_2}{2}\Delta t + KQ_2$$

$$\frac{I_1 + I_2}{2}\Delta t - (0.5\Delta t - K)\ Q_1 = Q_2(0.5\Delta t + K)$$

$$Q_2 = \frac{0.5(I_1 + I_2)\Delta t}{0.5\Delta t + K} - \frac{0.5\Delta t - K}{0.5\ t + K}\ Q_1$$

$$Q_2 = C_o I_1 + C_1 I_2 + C_2 Q_1 \quad \text{.. .. .. 2.25}$$

where $C_o = C_1 = \frac{0.5\Delta t}{0.5\Delta t + K}$ 2.26

$$C_2 = \frac{K - 0.5\Delta t}{K + 0.5\Delta t} \quad \text{.. .. .. 2.28}$$

2.4 UNIT RESPONSE THEORY OF FLOW ROUTING IN OPEN CHANNEL:

Open channel flow routing has been widely used in the past by engineers and hydrologists. The routing method selected for a particular problem depend largely on available data, accuracy desired, and availability of special equipment such as digital and analog computers.

2.4.1 Basic Theory:

This theory has been detailed by Sauer and described a hypothetical channel where flow losses and gains do not occurs. A flow input of unit rate and unit duration at one point in this channel will result in a specific flow response or unit

Response at a down stream location. The shape and timing of the unit response will be determined by the physical characteristics of the channel. Fig.No.2-6 shows the concept. The unit rate 1 cfs. and the unit duration is any period of time selected to best fit the problem. In a linear system, an input of any magnitude for unit duration will result in a response in direct proportion to the input magnitude i.e. an input of 100 cfs. for a period of unit duration will result in response ordinates 100 times greater than the unit response ordinate. Also inputs occurring at various times can be transformed to response hydrographs, lagged by the known flood wave travel time and summed to form the resultant outflow hydrograph. Fig. No.2-7 shows this process graphically.

2.4.2 Unit Response:

The unit response of an open channel is defined as the outflow hydrograph resulting from input of 1 cfs. occurring during a unit duration,'D'. It can be generally derived from observed stream flow record using techniques such as harmonic analysis. However this requires actual records of inflow and outflow. Synthetic derivation methods are desirable at sites where outflow records are not available. The synthetic derivation of unit response can be made by routing a translation hydrograph through reservoir type storage and transforming the resultant instantaneous hydrograph to the duration selected for use in a specific problems. Fig.No.2-4 shows a schematic diagram of the unit response derivation process.

2.4.3 Translation Hydrograph:

It is difficult to attach physical significance to the translation hydrograph for an open channel. It has one characteristics, however, the time base W that can sometime be computed from actual records. As commonly defined, the time base of the translation of hydrograph for a basin is the time from end of rainfall excess to the inflection point on the recession of the resultant outflow hydrograph. For an channel this same definition can be used, except that the flood wave travel time of the leading edge must be deducted to account for lag between the points of inflow and outflow. The shape of the translation hydrograph has little effect on the final results because storage routing tends to damp out irregularities. The time base (W) is difficult to estimate, even from actual stream flow records. But fortunately, it is rather insensitive, and successful routing results can be obtained with crude estimate of W. Where data are not available for estimating W, it can be taken equal to K (storage coefficient) for rough estimate. Adjustment can then be made to improve the fit of calibration data if necessary.

Proportionality Constant 'K':

For a linear response, [(exponential x = 1) in the equation $S = K\ Q^x$] K is the slope of the storage-discharge relation measured in hours and is equivalent to the time required for the centre of mass of the flood wave to travel through the reach minus the travel time, T required for the leading edge of the flood wave. The best estimate of K can be made by the recession hydrograph beyond the point of inflection. Rewriting the equation 2.9(b) i.e. the exponential relation for recession hydrograph is used

$$Q_t = Q_o\ e^{-t/K}$$

$$\frac{Q_t}{Q_o} = e^{-t/K} = r$$

$$-\frac{t}{K} = \log_e(r)$$

$$\frac{t}{K} = -\log_e(r) = \log_e(r)^{-1} = \log_e\left(\frac{1}{r}\right)$$

$$\frac{t}{K} = 2.3\log_{10}\left(\frac{1}{r}\right)$$

$$K = \frac{t}{2.3\log_{10}(1/r)} = \frac{0.434\,\Delta t}{\log_{10}(1/r)} \quad .. \quad .. \quad 2.29$$

where r = the receission coefficient computed for the time interval Δt. It is computed from the receission hydrograph beyond the point of inflection. Several discharges are determined along the recession at intervals of Δt, base flow is deducted from each and a recession coefficient r is computed for each pair of discharges by dividing the second by the first. An average of individual values of r is used as the best estimate.

$$r = \frac{r_1 + r_2 \ldots r_{n-1}}{n}, \quad r_1 = \frac{Q_2}{Q_1}, r_2 = \frac{Q_3}{Q_2} \ \ldots \ldots r_{n-1} = \frac{Q_n}{Q_{n-1}}$$

Duration 'D':

The duration 'D' is the routing computation interval. It should be a convenient multiple of 24 hrs., long enough to avoid excessive computations and short enough to define, the hydrograph adequately. A value of D between 0.1K and 0.1 usually be adequate, however some successful results have been made with D as large as K. For use in a real problem the instantaneous unit response may be transformed to a D-hour unit response for storage routing.

Transformation of a given unit response of duration D_1 to a unit response of another duration D_2, is accomplished by:

(1) forming the summation curve on the given unit response.
(2) Lagging a second, identical summation curve by the desired duration D_2.
(3) Taking differences of the two summation curves
(4) Dividing this difference by the ratio D_2/D_1.

Because the duration of the instantaneous unit response is theoritically zero, it is not possible to perform this calculation directly with an instantaneous unit response. Negligible error will result, however by averaging successive ordinates of the instantaneous unit response to form a unit response with duration equal to the routing computation interval. This is true only if the computation interval is relatively small, such as (0.1W). The unit response, thus formed then can be transformed to the desired duration D by performing the calculations previously described.

Now with the time base and shape established, the ordinate of the translation hydrograph can easily be determined, because by previous definition it was established that the unit response was the result of 1 cubic feet per sec. for duration D. Therefore, the volume of flow, V, or the area under the translation hydrograph is defined as

$$V = 1(\text{cusecs}) \times D(\text{Hr}) \quad \ldots \quad \ldots \quad \ldots \; 2.30$$

where V = volume, in cubic feet per second-hours

The translation hydrograph can then be defined as shown in Fig.No.2-5.

2.4.4 Storage Routing:-

The translation hydrograph is routed through storage to account for channel storage between inflow and outflow sites. The reservoir storage routing method has been found adequate for this purpose. The methods has already been described under para 2.3.

Rewriting the basic storage equation 2.8 as

$$S = K\ Q^{x}$$

where x = an exponent which provides for linear and non-linear routing.

For most of the open channel, a value of x = 1 has given satisfactory results, this provides linear storage routing. In some cases, however, it may be found that non linear conditions exists to such an extent that a value of x other than one may result in more accurate routings. If an outflow recession hydrograph is available, x can be estimated by a geophysical method described by Shen (Shen, J. 1962). This method also yields a corresponding estimate of K. The outflow recession hydrograph is first adjusted by substracting base and intervals, Δt, for several points on the recession. The average values of successive discharges are plotted (abscissa) versus the difference of successive discharges divided by Δt(ordinate on log.log paper. The value of x will be two minus the slope of the resultant plot and $K = \frac{x}{\text{intercept}}$

2.4.5 <u>Application to open channel Routing:</u>

The unit response thus formed is used to route flows in an open channel just as a unit hydrograph is used to compute a runoff hydrograph from a drainage basin. Inflow to a channel reach is used in the same manner as rainfall excess is used for a basin. The principle of lagging and super position apply except that a lag or leading edge travel time is used for open channel routing where as in basin hydrograph computations it is assumed that out flow begins as soon as rainfall excess occurs. The actual computation requires an inflow hydrograph, aunit response and a leading edge travel time.

2.4.5 (a) Inflow Hydrograph:

It can be considered a series of individual flow elements as shown in Fig. No.3-4. The flow magnitude of each element is multiplied by the unit response ordinate to form the flow response of the element. These flow responses are then lagged by a time equal to the leading edge travel time and summed to form the outflow hydrograph. This is shown in Fig.No.2-7.

2.4.5 (b) Travel Time Of Leading Edge:

T, can be obtained from actual records, if available and should be verified with several different period of flow and at different magnitudes of flow, if possible, it is found that T varies significantly with flow magnitude, a relation of T and anticendent flow can usually be developed. Antecedent flow is defined for this model as the average inflow for a selected time period immediately prior to the flow element to be routed. The time period used for computing antecedent flow is the travel time, T, corresponding to the lowest discharge to be routed. Each flow element of the inflow hydrograph is then routed using a travel time or lag, selected on the basis of the antecedent flow changes, when travel time is shortened as a result of this process, stacking of discharge response hydrograph will occur. This results in a steepening of the rising limb conversely when travel time is lengthened. There will be a gap, on separation, between response hydrographs. In most cases the summation of response hydrograph will give no indication

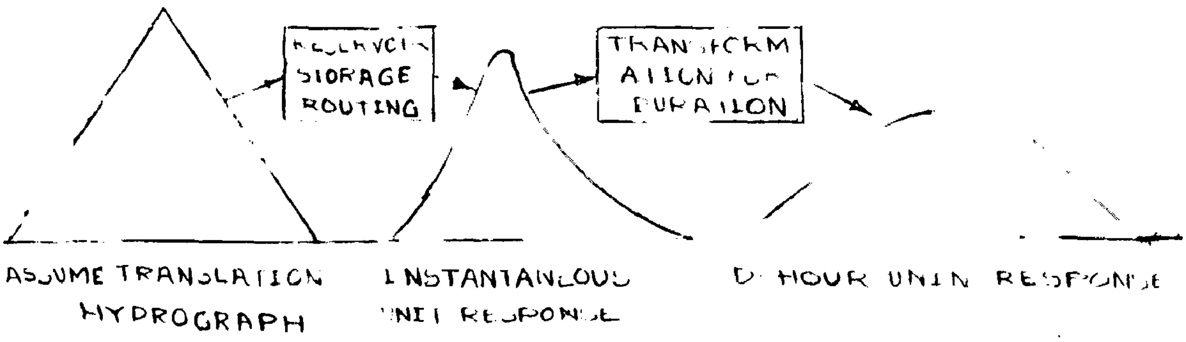


FIG 2.4. SCHEMATIC DIAGRAM OF UNIT RESPONSE DERIVATION

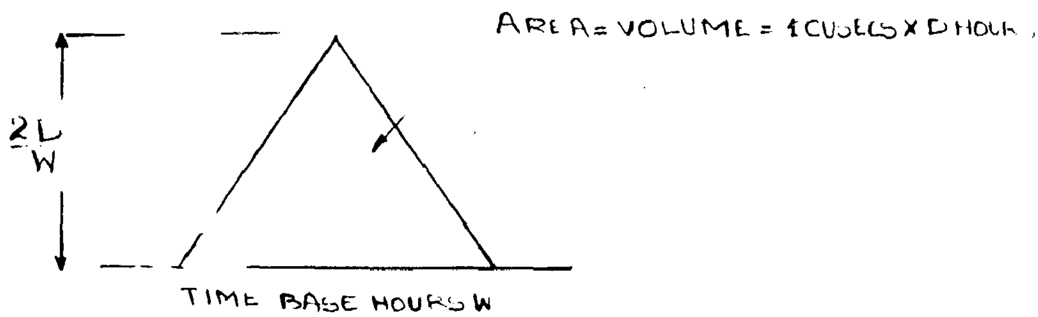


FIG.2.5. TRANSLATION HYDROGRAPH

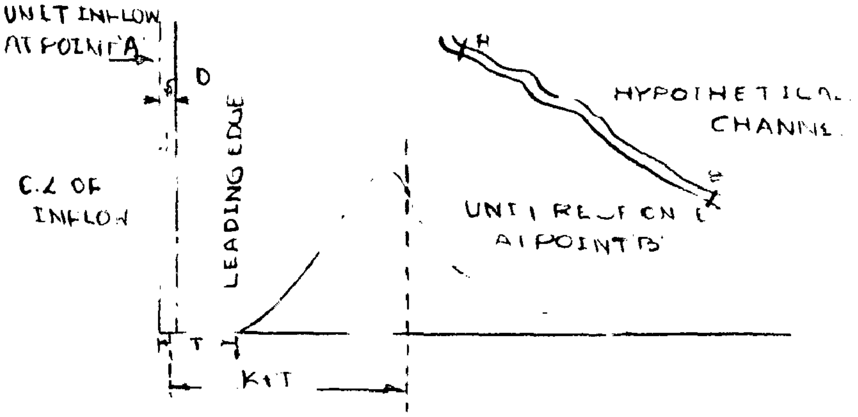


FIG 2.6. RELATION OF UNIT RESPONSE TO FLOW INPUT

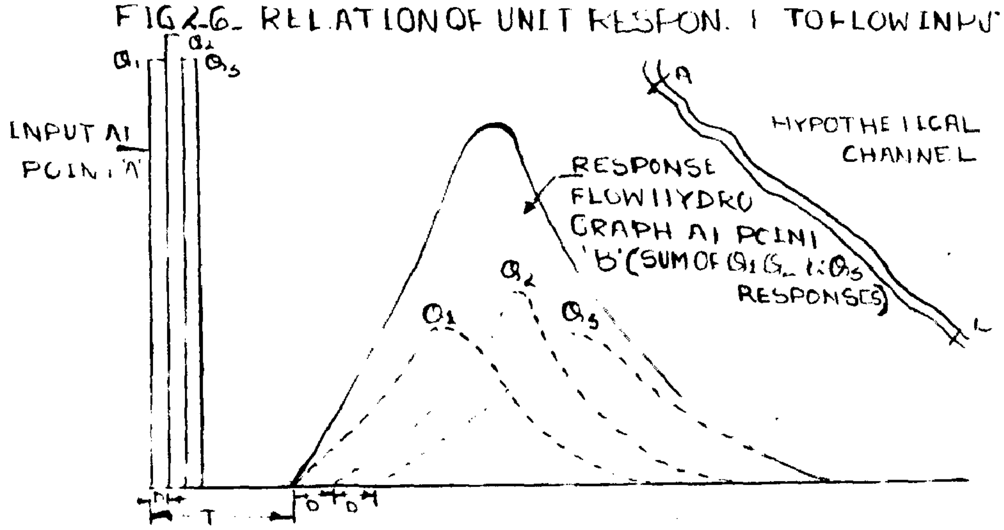


FIG 2.7. RELATION OF FLOW HYDROGRAPH TO MULTIPLE INPUT PATTERN

that stocking of separation has occured, however, where travel time varies greatly. The final results will sometimes indicate false peaks and troughs as a result of the stacking and separations where this occurs, more complete methods of routing are probably indicated.

In the absence of actual records, the leading edge travel time can be estimated from channel characteristics. The speed, or celerity, C of a Kinematic wave in an open channel is expressed by

$$C = \frac{1}{B}\frac{dQ}{dY} \qquad \text{.. .. .. 2.31}$$

in which B = The channel width
dQ = Change indischarge
dY = Corresponding change in depth

For practical application the above equation reduced to:

$$T = \frac{1.5\, L\, B}{Q_2 - Q_1} \qquad \text{.. .. .. 2.32}$$

T = Leading edged travel time hours.
L = Length in miles
B = Channel width in feet (average)
Q_2 = A discharge in cft/sec near mid range of flows to be routed
Q_1 = The discharge in cft/sec. at a stage 1 feet less than Q_2

Note: The factor 1.5 is the conversion factor of units.

CHAPTER - III

PROPOSED MODELS FOR CHAMBAL BASIN AT GANDHISAGAR SITE

3.1 INTRODUCTION:

The present study is aimed at simulating the direct runoff hydrograph for the Chambal Basin at Gandhi Sagar site, using a linear distributed parameter for gauged sub-basins, and developed some methodology to simulate the direct runoff hydrograph for intermediate gauged and ungauged sub-basins. Further it is proposed to develop a routing model for each flow concentration to compute the inflows to the Gandhi Sagar Reservoir. This has been attempted in the following phases:

1. To develope suitable input function for the proposed model.
2. Development of a conceptual model for computing responses from the gauged sub-basins of the catchment.
3. Development of suitable methodology for computation of responses from ungauge and gauged intermediate sub-basin of the catchment
4. Routing of the computed responses to Gandhi Sagar site to compute inflows to its reservoir.

3.1.1 The proposed conceptual model is to be developed keeping in view the availability of the following data:

(i) Short term storm data is available at different points in the catchment.

(ii) Corresponding runoff data available at the Gandhi Sagar reservoir site and also at a couple of sections on major tributing net work.

(iii) Area capacity characteristics of Gandhi Sagar reservoir

(iv) Topographic and physiographic details of the catchment.

3.1.2 The proposed model is a linear model. The assumption of linearity ensures application of the principle of homoginity and also the principle of superimposition. This makes the computations much simpler. Further the distributed nature of the proposed model has been attempted by spliting the catchment into different sub-basin. Also distributed input are taken care of by dividing these sub-basins into sub-areas. The sub-area's are arrived at keeping in view the meteorological homoginity. These sub-basins have been marked on the catchment topographic sheet given in Fig. No. 3.1 and are detailed as below:

1. Pat Sub-Basin
2. Mahidpur Sub-Basin includes Ujjain Sub-Basin
3. Nagda Sub-basin - includes Badnagar Sub-Basin
4. Mandsaur Sub-Basin
5. Chaldu Sub-Basin.

Above sub-basins have been demarketed keeping in view the drainage characteristics of the catchment. Thus these are representing the surface drainage of all the major tributaries in the catchment. The rest of the catchment i.e. in between the gauges of the sub-basins and the Gandhi Sagar reservoir has further been sub-divided, and these divisions are termed as Intermediate Sub-Basins (ISB). The following is the list of ISB adopted in the study and indicated in theFig.No.3.1

1. Choumahla ISB
2. Kalakhedi ISB
3. Barkheda ISB
4. Nahargarh ISB
5. Tumri ISB
6. Gandhi Sagar ISB

Thus in all, the catchment area has been divided into eleven sub-basins, to take into account the distributive nature of the response model.

3.1.3 **Sub Area :**

The above mentioned sub-basins and intermediate sub-basins are arrived at on the basis of drainage pattern. However, to take into account the uneven distribution of rainfall in time and space, the sub-basins are divided into sub-areas (Fig.No. 3.2). Thus a sub-area characteries:

i) The spatial uniformity of the precipitation over the area
ii) The drainage properties of the sub-basin.

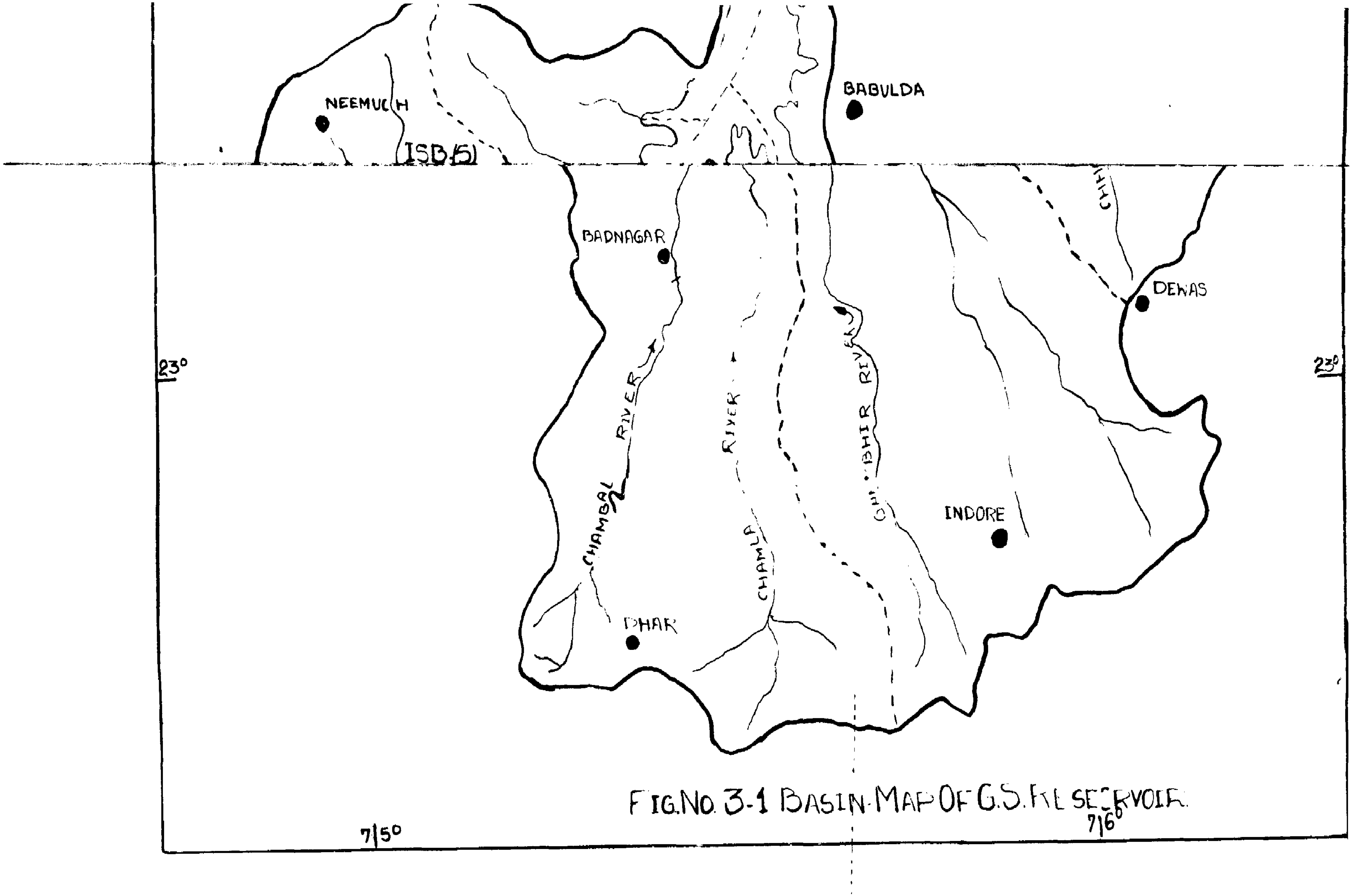


FIG.No. 3-1 BASIN-MAP OF G.S. RESERVOIR.

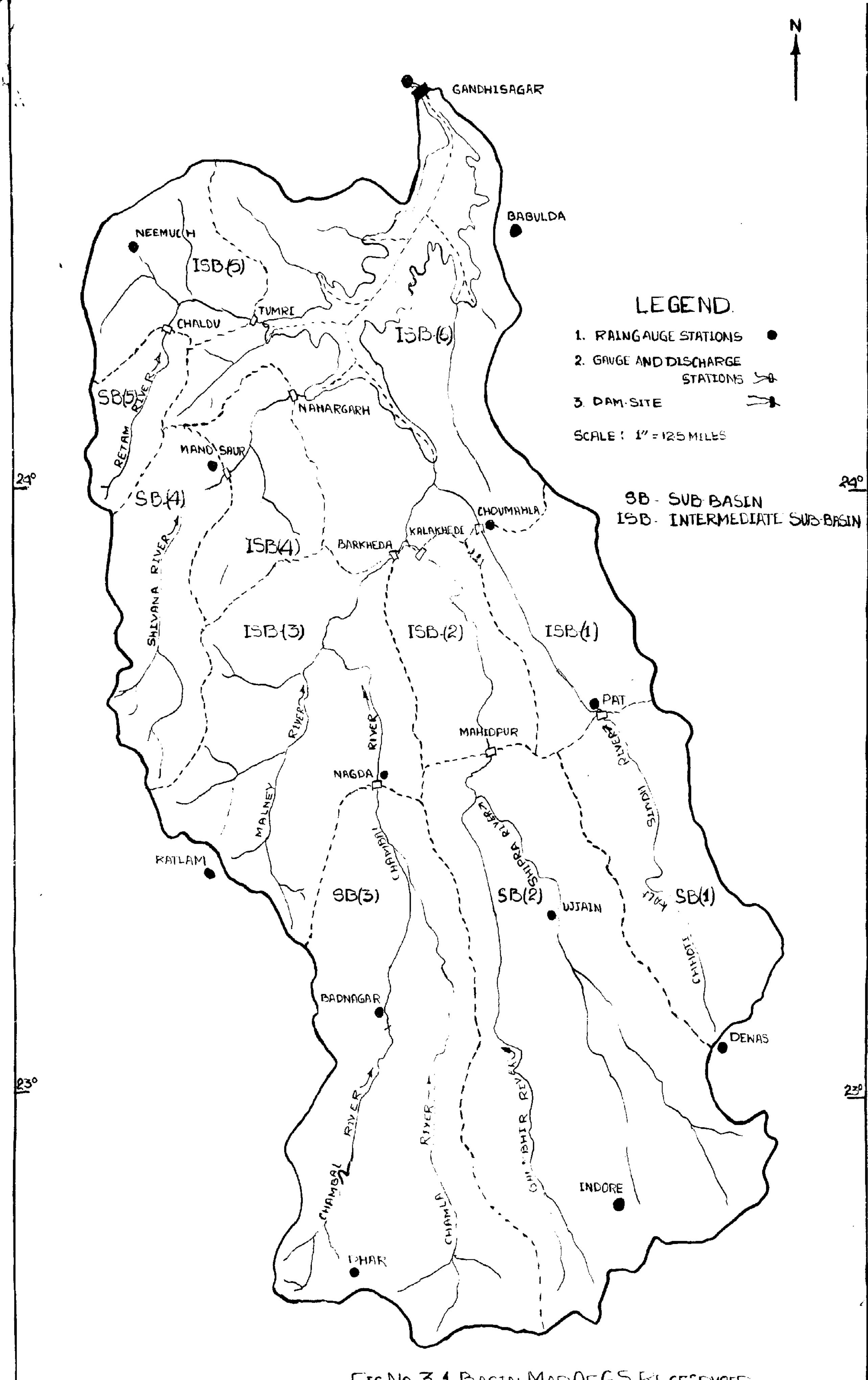


FIG.NO. 3-1 BASIN MAP OF G.S. RESERVOIR.

PLATE NO. 4

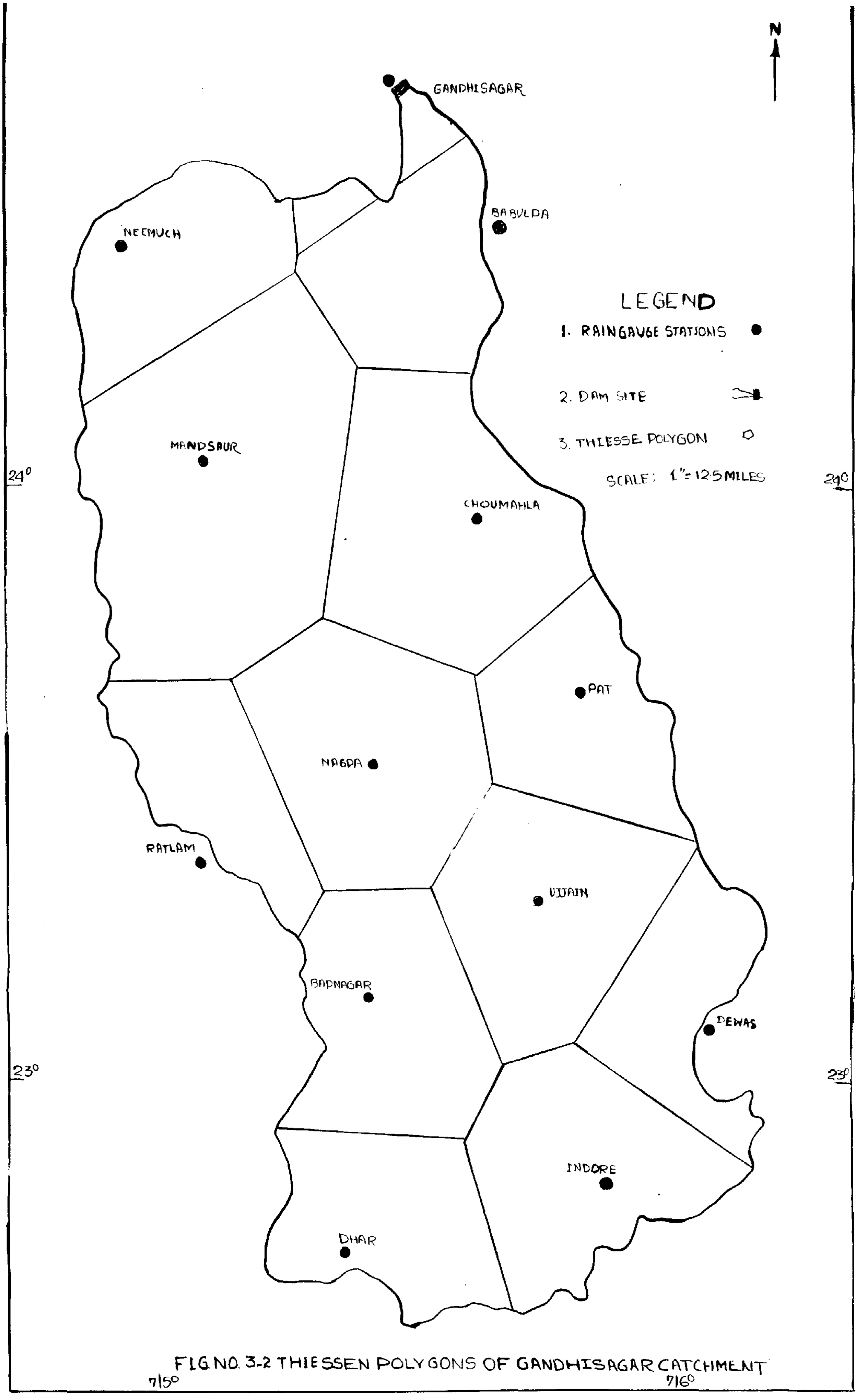


FIG NO. 3-2 THIESSEN POLYGONS OF GANDHISAGAR CATCHMENT

PLATE No. 5

3.2 INPUT FUNCTION:

For the entire sub-basin the following procedure is adopted to evaluate the distributed input to the sub-basin and sub areas.

Normally the input to a sub-basin i.e. the rainfall data is available over the different raingauges spread out over the entire basin. This procedure is adopted when no information is available about the variations in the infiltration rates for the different sub-areas and also sub-basins. Therefore a constant rate of abstraction in the form of ϕ - index is evaluated for the sub-basin and the ratio of rainfall excess to the weighted rainfall of the sub-basin is applied to get the rainfall excess of the sub-area.

3.2.1 Input Function For Sub-Basin:

The mean gross depth of precipitation over the entire sub-basin is evaluated by using the Thiessen weight equation:

$$Pa = \sum_{i=1}^{n} a_i P_i \qquad i = 1, n \quad \ldots \quad \ldots \quad 3.1$$

Where, Pa = Weighted mean depth of gross rainfall over the sub-basin.

ai = Thiessen weight of raingauge station $i = 1, n$

Pi = Observed point rainfall of the raingauge stations $i = 1, n$

The constant rate of abstraction i.e. the ϕ - index is evaluated using the observed hydrograph at the outlet of the sub-basin, (a suitable time variation in base flow is adopted) and corresponding hyetograph. The effective precipitation over the catchment for each time unit will thus be given by:

$$P_e = (P_a - \phi) \quad .. \quad .. \quad 3.2$$

where P_e = Weighted effective mean depth of rainfall excess over the sub-basin
P_a = Weighted mean depth of gross rainfall over the sub-basin.
ϕ = Phi - Index

3.2.2 Input Function For Sub-Area:

For this, a weight factor for each unit-hour duration of weighted precipitation is computed by the relation

$$F_j = \frac{Pei}{Pai} \quad i = I \text{ to } n \quad .. \quad .. \quad 3.3$$
$$j = I, n \text{ (each unit hr. duration)}$$

The weighted mean depth of gross rainfall over each sub-area is computed using the Thiessen weight equation

$$Pasi = \sum_{i=1}^{n} asi \; Psi \quad i = 1,n \quad .. \quad .. \quad 3.4$$

where, Pasi = Weighted mean depth of gross rainfall over the sub-area i = 1,n
a si = Thiessen weight of raingauge stations in the sub-area
Psi = Observed point rainfall of raingauge stations i = 1,n , influencing the sub-area.

The effective mean depth of precipitation for the each sub-area for each unit duration is obtained by the relationship:

$$Pesi = Fi \quad Pasi \quad .. \quad .. \quad 3.5$$
$$i = 1, n \text{ no. of R.G. Stations}$$
$$j = 1, n \text{ no. of unit durations.}$$

where, Pesi = Mean depth of effective rainfall over the sub-area for the duration considered.
Fj = Factor evaluated for the duration
Pasi = Mean depth of gross rainfall over the sub-area i = 1,n.

3.3 ANALYSIS OF GAUGED SUB-BASIN:

The gauged sub-basins adopted for the analysis are as follows:

1. Pat sub-basin
2. Mahidpur Sub-Basin - includes Ujjain sub-basin (analysed seperately)
3. Nagda Sub-Basin - includes Badnagar sub-basin (analysed seperately)
4. Mandsaur Sub-Basin
5. Chaldu Sub-Basin

3.3.1 Formulation Of Model For Gauged Sub-Basins:

Different models, which are based on the time area concept may serve the purpose of obtaining the differential responses, but for the present study, the model proposed by Nash (J.E.Nash, 1957), is used, which has been modified by Dooge (J.C. I Dooge, 1957) by introducing the concept of linear channel in addition to linear reservoir in the series. Thus broadly the following parameters have been used in the proposed model:

1. 'n' - No. of linear reservoirs
2. 'K' - The storage coefficient
3. - The linear channels

3.3.2 Methodology:

For hydrologic model the study involves the following aspects:

a. Analysis of the Input Function
b. Analysis of the Transfer Function.

3.3.2(a) Analysis of the Input Function:

In the proposed model, the input function for sub-basins has been detailed in section 3.2

3.3.2(b) Analysis of the Transfer Function:

In the proposed study, each sub-basin is to be modelled separately. Since a sub-basin has further been divided into sub-areas a suitable transfer function for each sub-area is to be arrived at. In the proposed model the transfer function for each sub-area of sub-basin is taken care of:

a. The unit hydrograph which is derived with the help of existing rainfall records and its corresponding runoff using the conceptual model proposed by Nash (J.E. Nash 1957)

b. A linear channel to account for the time lag of the different responses in reaching the outlet of the sub-basin.

The structure of the proposed model is shown in Fig.No.3.3

Unit Hydrographs For Different Sub-Areas Of A Sub-Basin:

(i) The parameters of the model 'n' and 'k' may be evaluated by method of moments about origin from the rainfall excess hyetograph and direct runoff hydrograph. The definition of takĩng out the moments adopted here is as proposed by Nash (J.E.Nash, 1957)

$$Mn = \frac{\int_{-\infty}^{+\infty} Y\, x^n\, dx}{\int_{-\infty}^{+\infty} Y\, dx} \qquad \cdot\cdot \quad \cdot\cdot \qquad 3.6$$

where, Mn = Nth moment of ERH or DRH
Y = ERH or DRH Ordinate at Y-axis
X = Time of ERH or DRH on Abscissa

The first and second moments (M1 and M2) of Instantaneous Unit Hydrograph are related with the model parameters n & k, and the first and second moments of ERH and DRH by the following relationships:

$$M1 = nK = MDRH\,1 - MERH1 \qquad \cdot\cdot \quad \cdot\cdot \qquad 3.7$$

$$M2 = n(n+1)\,K^2 = MDRH\ 2 - MERH2 - 2\ nK\ MERH\ 1 \cdot\cdot \quad 3.8$$

where, MERH1 = First moment of ERH about origin
MERH2 = Second moment of ERH about origin
MDRH1 = First moment of DRH about origin
MDRH2 = Second moment of DRH about origin

(ii) With the help of above mentioned relationships the model parameters may be evaluated. With these values, the value of catchment constants for the sub-basin may be worked out using the following two relationships between catchment characteristics and model parameter proposed by Nash (J.E.Nash, 1960).

$$K = C_1 (A)^{0.25} (OLS)^{-0.3} (L)^{-0.085} \quad .. \quad .. \quad 3.9$$

$$n = C_2 (L)^{0.085} \quad .. \quad .. \quad 3.10$$

where, C_1 & C_2 are the constants derived for the sub-basins.
A = Catchment area in square K.M.
L = Length of Main channel in K.M.
OLS = Weighted overland slope in parts per 10,000

(iii) These established values of C_1 and C_2 are representative for sub-basin and are adopted for computation of model parameters 'n' & 'k' for each sub areas of the sub-basin. These values are now used in the mathematical model proposed by Nash (J.E. Nash, 1957).

$$V (0,t) = \frac{1}{K(n-1)!} \left(\frac{t}{k} \right)^{n-1} e^{-\frac{t}{k}} \quad .. \quad .. \quad 3.11$$

to develop, an instantaneous unit hydrograph for each of the sub-areas. Since the rainfall excess duration of Instantaneous unit hydrograph is infinitesimally small, it is not possible to adopt it for use and therefore a workable solution based on pulse theory a unit hydrograph is adopted for practical application.

3.3.3 Identification of Model Parameters:

For a particular storm input differential outputs of each sub-area can be computed by cor-relating it on the unit hydrograph. The linear channel is used to give the appropriate time lag for routing these differential outputs, to the outlet

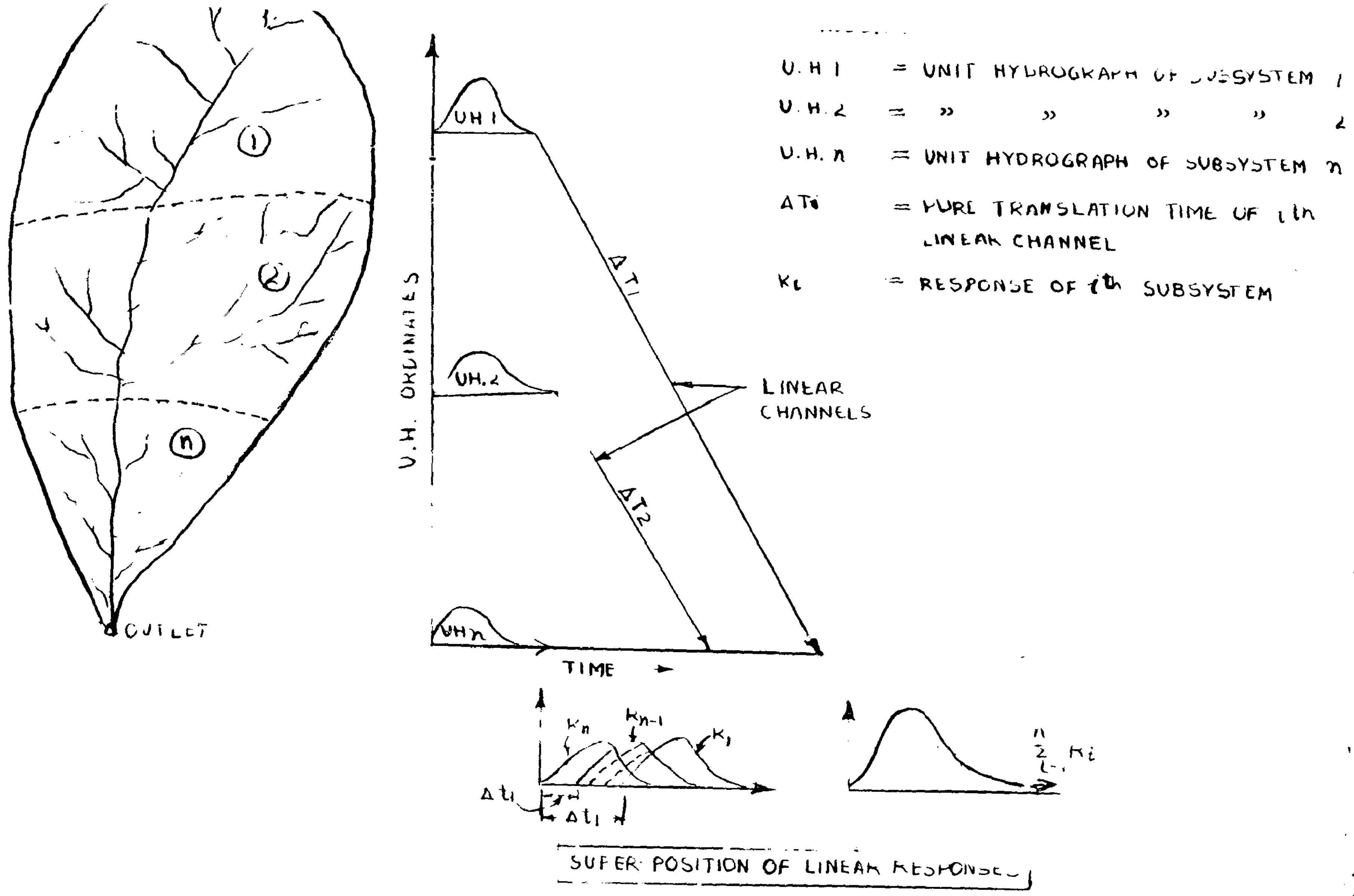


FIG. 3.3. STRUCTURE OF THE PROPOSED MODEL

of sub basin. As indicated in Fig. 3.3 the upper most sub area (marked as sub area-1) will have the largest value of the time lag and the value would reduce for the subsequent sub areas. The time lag for the sub area adjacent to outlet is practically zero as the sub area is contributing to the outlet directly. These values of the time lags can be arrived at by trial and error, considering the observed record of storm runoff at the outlet of sub basin.

3.3.4 Testing of The Model:

The Input function (excess rainfall) arrived at, as explained in section 3.2. For a observed rainfall runoff record the model parameters are established, as discussed in previous section, knowing the rainfall excess and the transfer function (unit hydrograph) of sub area, the differential responses of each of these sub area can be computed. These responses are subjected to pure translations as indicated by the linear channel which is assigned to it.

A close agreement between computed and observed direct runoff gives the best test of Model Parameters. If the two are not in close agreement, the model parameters need modifications, otherwise the same are adopted.

3.4 ANALYSIS OF INTERMEDIATE SUB-BASIN:

As explained in the previous section, all the five sub-basins in the catchment are modelled accordingly and the proposed models are tested at the outlets by comparing the computed and observed responses.

For computing the responses for the rest of the catchment area's it is necessary to adopt suitable input and transfer functions for the intermediate sub-basins. As explained in section 3.1, the intermediate sub-basins are the portions of the catchment between the outlets of sub-basin and some gauging site down stream. For some storms, discharge data at down stream gauges are not available, hence in the present study these Intermediate sub-basins are further classified into:

1. Gauged Intermediate Sub-Basin (Gauged ISB)
2. Ungauged Intermediate Sub-Basin (Ungauged ISB)

In the first case gauge data is available at downstream site while in the 2nd case the gauge data at downstream is not available.

As shown in Fig. 3.1 the above mentioned two catagories of the Intermediate sub-basins are detailed below:

TABLE NO.3.1 Intermediate Sub-Basins:

S.No.	Intermediate Sub-Basins(1974 Storm)			
	Gauged ISB		Ungauged ISB	
	ISB No.	Name of ISB	ISB No.	Name of ISB
1.	1	Choumahla	3	Barkheda
2.	2	Kalakhedi	5	Tumri
3.	4	Nahargarh	6	Gandhi Sagar
	Intermediate Sub-Basins (1977 Storm)			
1.	1	Choumahla	4	Nahargarh
2.	2	Kalakhedi	5	Tumri
3.	3	Barkheda	6	Gandhi Sagar

To work out the inflows at Gandhi Sagar, it is necessary to compute the contributions of these intermediate sub basins, and hence it is necessary to develop some methodology for the same. It has been attempted, on similar lines, to propose the modelling of sub-basins. The procedure is detailed in the following section.

3.4.1 Conceptual Modelling Of Intermediate Sub-Basins:

Formulation of conceptual model for an intermediate sub basin depends on the availability of data:

> In case of gauged intermediate sub basins the short term input rainfall data is available alongwith the corresponding runoff data at its outlet.
>
> But in case of ungauged intermediate sub-basin, only the storm rainfall data is available over the area and no runoff data is available at the outlet.

However the runoff at the outlet consist of two components. Firstly, is contribution of its area and secondly, the routed flow concentrations from the upstreams sub basins. For this reason the analysis proposed in section 3.3 for modelling the sub basins cannot be, directly, extended to the intermediate sub basins. Therefore, following procedure is proposed for the computation of input function and the transfer function.

3.4.1 (a) Input Function:

The Input Function described in section 3.2 for the modelling of gauged sub-basins, makes use of storm rainfall record and its corresponding runoff. However the same procedure cannot be used for intermediate sub-basins as the observed runoff for intermediate sub-basins are not available. To compute the input function, a graphical relationship has been attempted between intensity of weighted rainfall, duration of storm and ø-index from the available records of gauged basin parts of the catchment. Thus the ø-index and subsequently the rainfall excess for different sub areas of an intermediate sub basin have worked as discussed in section 3.2.

3.4.1 (b) Transfer Function:

The proposed transfer function for each of the sub areas of an intermediate sub basin will be the unit hydrograph as discussed in the conceptual representation of the sub basins, as discussed in section 3.3.

The methodology for the formulation of model as explained earlier depends on the availability of observed runoff data at the outlet of the sub basin. The contribution from intermediate sub basins are not available separately. Hence to compute the transfer function the basic requirement is to know the model parameters 'n' & 'K'. Therefore it is proposed to develop a procedure for working out the constants C_1 & C_2 used in equation No.3.9 & 3.10, to compute the parameters in terms of catchment characteristics such as area of intermediate sub basin, length of river and over land slope. This will facilitate in establishing the model parameters 'n' and 'K' for the sub areas of intermediate sub basins.

The above procedure has been attempted by developing graphical relationships involving catchment characteristics and C_1& C_2 from the gauged sub basins. These correlation curves have been used to develop the model parameters for the intermediate gauged and ungauged sub basins using equation 3.9 & 3.10.

3.4.2 Computation Of Responses From Intermediate Sub-Basins:

Knowing the rainfall excess and unit hydrographs the model of these intermediate sub basins are developed as discussed in section 3.3.

3.4.3 Identification Of Model Parameters:

The linear channel is used, to give the appropriate time lag for routing the responses from sub area. As indicated in Fig. No.3-3, the upper most sub area will have the longest time lag and the lower most will have the time lag, practically zero as the sub area contributing directly to the outlet of intermediate sub-basins. These values of time lags can be arrived at by trial & error, considering the observed record at the outlet.

3.4.4 Testing of Model:

The ungauged intermediate sub basin model responses cannot be verified as their runoff data are not available separately at the outlet, but the gauged intermediate sub basin response model can be verified. For the purpose the upstream computed runoff routed to the down stream section through linear channel. The response of sub areas of intermediate sub basins are superimposed to the translated response of the sub basin to compute the total response at its outlet. A comparison is made between computed and observed direct runoff.

3.5 CONCEPTUAL MODEL FOR ROUTING OF FLOW CONCENTRATION:

3.5.1 Introduction:

As discussed earlier in section 3.3, all the five sub basins in the catchment are modelled and the computed and observed responses at the outlet are compared.

Similarly in the section 3.4, all the six gauged and un-gauged intermediate sub basins in the catchment are modelled and the computed and observed responses are compared, where possible.

Having formulated the linear distributed parameter models for eleven sub basins in the catchment, next step is to route the flow concentrations from the respective outlets, to the Gandhi Sagar Reservoir. For the purpose the Unit Response Routing Theory proposed by Sauer (Sauer, V.B., 1973). In this process following steps are involved:

1. Unit Response for the flow concentrations at the outlets of all the five sub-basins(viz. Pat, Mahidpur, Nagda, Mandsaur and Chaldu) are formulated.
2. Unit Response for each flow concentration at the outlet of the five intermediate sub basins

(viz. Choumahla, Kalakhedi, Barkheda, Nahargarh and Tumri) are formulated.

3. The response of Gandhi Sagar Intermediate Sub-basin is directly contributing to the reservoir and needs no routing.

4. The computed responses at the outlets of sub-basins and intermediate sub basins are routed to the Gandhi Sagar Reservoir.

5. Some of the Unit responses at the outlet of sub-basins have been tested at the outlets of intermediate sub basins. This is achieved by superimposing the computed responses of the gauged intermediate sub basins, on to the routed flows from upstream outlet of sub basins, and comparing these responses with observed flows.

6. The unit response model at the out let of intermediate sub basins can only be tested by the observed and computed reservoir levels at Gandhi Sagar Reservoir.

3.5.2. Application Of Unit Response:

The Unit Response theory has been discussed in details in section 2.4. Different steps involved in the application of the theory refer to:

(i) the inflow hydrograph - which is to be routed.
(ii) the Unit Response
(iii) the travel time of leading edge
(iv) Routing of Inflow Hydrograph
(v) Testing of Unit Response Parameters.

3.5.2 (i) The Inflow Hydrograph:

The inflow hydrograph is the computed response at the outlet of, sub basin or intermediate sub basin, as worked out in section 3.3 and 3.4 respectively. It can be considered a series of individual flow elements as shown in Fig. No.3-4.

3.5.2 (ii) The Unit Response:

The schematic diagram for developing the model for unit response is shown in Fig. No.23. The procedure consist of

(a) Formulation of Translation Hydrograph
(b) routing the translation hydrograph to get the unit response, and
(c) converting the instantaneous unit response into desired routing period unit response.

3.5.2 (ii) (a) Formulation of Translation Hydrograph:

Formulation of Translation Hydrograph require the calculation of the parameters:

(i) proportionality constant 'K'
(ii) duration 'D'
(iii) time base 'W'
(iv) exponent (X)

The proportionality constant is the slope of the starage discharge relation measured in hours. The best estimate of K can be made by the recession curve beyond inflection point by treating the recession curve is an exponential relation. The equation used is:

$$K = \frac{0.434 \Delta t}{\log_{10}\left(\frac{1}{r}\right)} \quad \ldots \quad \ldots \quad \ldots \quad 3.12$$

where r = receission coefficient
Δt = time interval

The duration 'D' should be adopted such that it should be long enough to avoid excessive computations and short enough to define the hydrograph adequately. The value may be adopted between 0.1K & 0.4 K.

The value of W can usually be adopted equal to 'K' as the first trial and can be modified its value between 0.3 K to 0.7 K.

The exponent 'X' is the exponent to fix non linearity of the routing procedure. But in many open channels, the linear method yield acceptable result. Dooge and Harley (1967) studied the effect of a non linear on the attenuation and concluded that attenuation is almost independent of linearity.

Thus knowing all the parameters, translation hydrograph may be developed by the following equation.

$$V = 1 \text{ (cusec)} * D(\text{ Hour }) \quad .. \quad .. \quad 3.13$$

where V = Volume in cubic feet per sec. hours.

The translation hydrograph can be defined as shown in Fig. 2.5.

3.5.2 (ii) (b) Instantaneous Unit Response:

The ~~Muskingham~~ clark method of routing translation hydrograph is used to get the Instantaneous Unit Response. The ordinates of translation hydrograph at an appropriate duration of routing, are calculated. The shape of translation hydrograph has little effect on the final results because storage routing tends to damp out irregularities.

Knowing the value of 'K' & routing period Δt, the routing constants C_0 & C_1 & C_2 may be worked out by the equation 2.26, 2.27 & 2.28 respectively. Hence develop the routing equation as:

$$Q_2 = C_o I_1 + C_1 I_2 + C_2 Q_1 \quad .. \quad .. \quad .. \quad 3.14$$

In the above equation the subscript I and 2 refer to values at the beginning and end of routing period Δ t. The routing is followed by assuming $I_1 = I_2$ and initially the value of Q_2 is zero. Thus the value of Q_2 will give the instantaneous unit response.

3.5.2.(ii) (c) <u>The Unit Response:</u>

The duration of Instantaneous Unit Response is theoretically infinitesmally small it is not possible to perform this calculation directly. Therefore, it is to be transformed into Unit Response of required druation as explained in section 2.4.3.

3.5.2 (iii) <u>Travel Time Of Leading Edge:</u>

This has been explained in detail in section 2.4.5. For the present study the travel time of leading edge of inflow hydrograph has been found to be insignificant, as the basin is traversed by monsoon depression and cyclonic storms in the same general direction as the main river i.e. in the West-North Westerly direction, hence the flow concentration from different areas synchronise at the outlet.

3.5.2 (iv) <u>Routing Of Inflow Hydrograph:</u>

The inflow hydrograph, as shown in Fig.3.4, has been routed through the required channel length by using the unit response and travel time of leading edge of inflow hydrograph. Each flow element of inflow hydrograph is multiplied by unit response ordinates to form the flow response for that element. These flow responses are then lagged by a time equal to the travel time of leading edge and summed to form the outflow hydrograph. This conclusion of inflow hydrograph and unit response is shown in Fig. No.3-5 & 3-6.

3.5.3 Testing Of Unit Response Parameters:

Testing of Unit Response Parameters is possible only when the observed runoff data at the down stream (site upto which the flows from upstream are routed), are available. The routed hydrograph from upstream are added to the computed response of intermediate sub basin and are compared with observed flows.

3.5.4 Advantages Of Unit Response Method:

The advantages of the Unit Response Method over some of the more commonly used simplified methods are:

(i) Rapid changes inflow, such as reservoir releases can be routed as easily as gradual changes.

(ii) The full range of flow can be routed, thus providing complete routing error into the low range of flow conditions

(iii) Flow can be routed through long reaches of channel without sub dividing the reach into segments.

The method, however, will not work where variable back water significantly affects the flow.

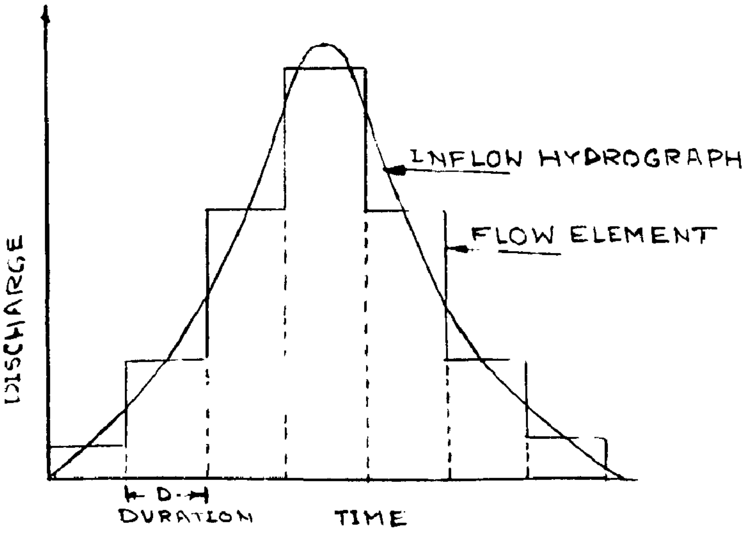


FIG. NO. 3-4 SUB-DIVISION OF INFLOW HYDROGRAPH IN TO FLOW ELEMENTS

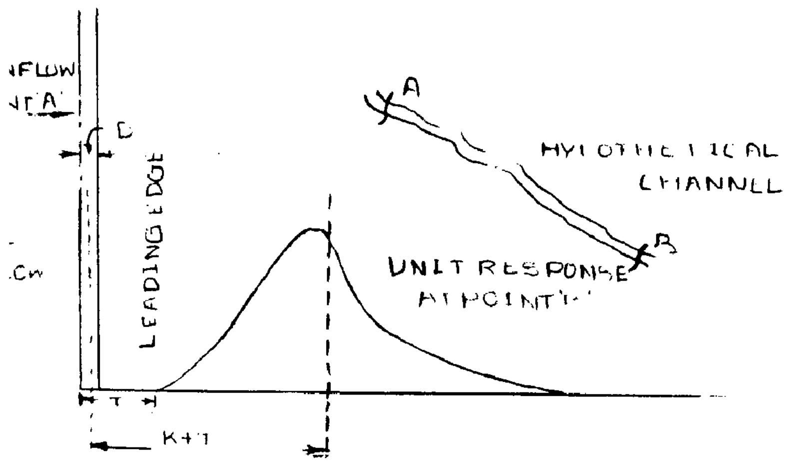
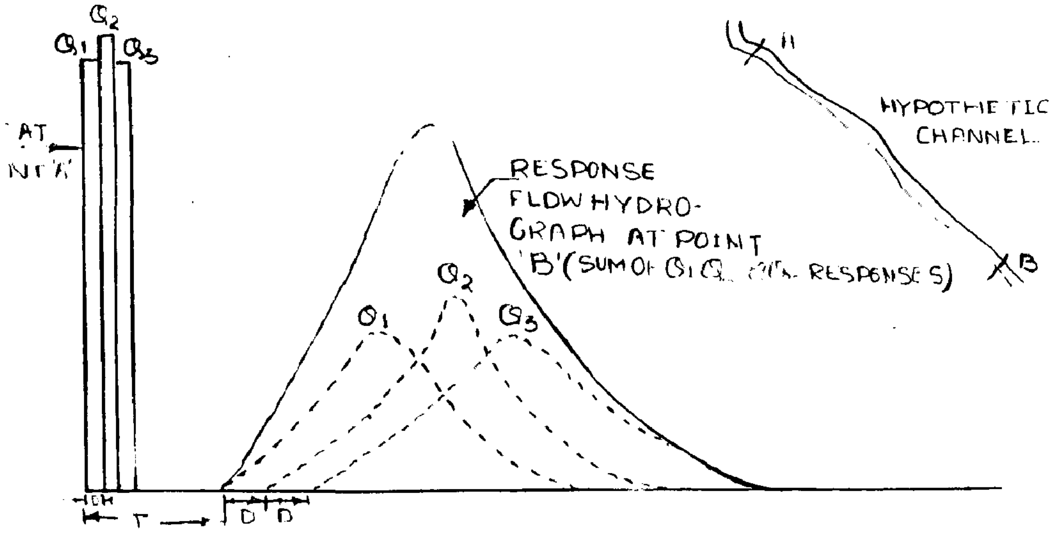


FIG NO 3-5 RELATION OF UNIT RESPONSE TO FLOW INPUT



NO. 3-6 RELATION OF FLOW HYDROGRAPH TO MULTIPLE INPUT PATTERN

3.6.1 Computation Of Flows At Gandhi Sagar Reservoir:

As explained in section 3.3 and 3.4, the flows at the outlets of the sub-basin and intermediate sub-basins are computed. From these outlets, upto the Gandhi Sagar Reservoir, separate unit responses for all the sub-basins and intermediate sub-basins have been computed. The inflow hydrograph is divided into flow elements, having the same duration as that of the corresponding unit response. Routed responses of each of the flow elements have been computed at the Gandhi Sagar Reservoir. The analysis is extended to all the ten inflow hydrographs, using their corresponding unit responses. As the travel timings of leading edges are not significant, the routed responses are super imposed to compute the inflows to the Gandhi Sagar Reservoir. To these flows, are added, the flows from the Gandhisagar intermediate sub-basin, and also the inputs directly falling on the reservoir to obtain the total inflows to the Gandhi Sagar. From these total inflows, the net volume of inflow at the Gandhi Sagar is estimated. Using the Area-Capacity relationships, the stages at the Gandhi Sagar Reservoir are computed at different times and compared with the observed stages.

3.6.2 Efficiency Of Model At Gandhi Sagar Reservoir:

Nash and Sutcliffe (Nash J.E., & Sutcliffe, J.V.1970) has proposed a relationship to work out the efficiency of model. This expression is used for comparision of observed and simulated direct runoff hydrographs. In the expression, the term $\sum (Q_o - \bar{Q}_o)^2$ represents the observed variance and the term $\sum (Q_c - Q_o)^2$ represent the residual to unexplained variance. The value will always be less than one.

Coefficient of efficiency =

$$\frac{\sum_{1}^{N} (Q_o - \bar{Q}_o)^2 - \sum_{1}^{N} (Q_c - Q_o)^2}{\sum_{1}^{N} (Q_o - \bar{Q}_o)^2} \quad \ldots \quad 3.15$$

Where, Q_o = Observed runoff

Q_c = Computed runoff

and N = Number of values.

CHAPTER - IV

APPLICATION OF THE PROPOSED MODEL ON CHAMBAL RIVER BASIN AT GANDHI SAGAR DAM SITE IN MANDHYA PRADESH

4.1 INTRODUCTION:

As discussed in Chapter-III, the proposed model has been applied to the Gandhi Sagar Reservoir catchment in Madhya Pradesh. The location of dam site, submergence area, raingauge stations, river gauge stations and other features of the catchment are shown in Fig.No.3-1 & 3-2. As mentioned earlier in section 1.3, the statement of the problem, the present study is carried out with following three stages, which are given below:

A - Application of proposed model for the gauged sub-basins.

B - Application of proposed model for the gauged and ungauged intermediate sub-basins.

C - Application of the unit response theory to compute the inflows to Gandhi Sagar Reservoir.

4.2 AVAILABILITY OF THE DATA:

The data used in the present study have been collected from the M.P. Irrigation Department. For the development of the proposed model short term storm data are required the rainfall run off data of the two storms were available as given below:

Storm I 18.8.74 to 22.8.74

Storm II 7.8.77 to 10.8.77

First storm data is used for the formulation of proposed model and for establishing the model parameters where with respect to catchment area, length of River, overland slope etc. for each gauge and discharge site.

4.3.1. Catchment Area And River Length:

Measured by a planimeter on 1" = 4 miles topographical map. The measurements for areas are carried out for all the sub basins of the catchment. The river length is measured by a thin thread.

4.3.2 Overland Slope:

9 Due to the non-availability of the contour of the catchment the river slope is considered as overland slope and measured in parts per 10,000.

The physiographical catchment characteristics are given in Appendix No.VII.

4.4. THIESSEN POLYGON:

Thiessen Polygons are plotted for the raingauge stations. Thiessen weight factor for sub basins and intermediate sub basins are shown in Appendix No. VII. The plotting is shown in the Fig. No. 3-2.

as the second storm data is used for testing the same.

4.2.1. Rainfall Data:

There are thirteen recording raingauge stations, evenly distributed over the entire catchment. The rainfall from these stations are available at 4-hours interval and are given in Appendix No. I & II.

4.2.2. Runoff Data:

There are twelve gauge and discharge sites in the catchment, where the runoff data has been collected. These sites are distributed in the catchment in such a manner, that, practically, flow of every main tributary of Chambal River could be measured at two or three places. The river gauge data is available at 6 Hr. interval during day time and at 12 Hours interval during night hours (Ref: Appendix No. III & IV).

4.2.3 Stages at Gandhi Sagar Reservoir:

Stages at hourly interval during storm period for both storms are available and are given in Appendix No. V.

4.2.4 Area-Capacity Relationship Of Gandhi Sagar Reservoir:

Area-capacity relationship of Gandhi Sagar is available, at one feet interval and is given in the Appendix No. VI.

4.3 PHYSIOGRAPHICAL CATCHMENT CHARACTERISTICS:

The physiographical catchment characteristics have been measured from a map of 1"-4 miles. This includes the data with respect to catchment area, length of River, overland slope etc. for each gauge and discharge site.

4.3.1. <u>Catchment Area And River Length:</u>

Measured by a planimeter on 1" = 4 miles topographical map. The measurements for areas are carried out for all the sub basins of the catchment. The river length is measured by a thin thread.

4.3.2 <u>Overland Slope:</u>

Due to the non-availability of the contour of the catchment the river slope is considered as overland slope and measured in parts per 10,000.

The physiographical catchment characteristics are given in Appendix No.VII.

4.4. <u>THIESSEN POLYGON:</u>

Thiessen Polygons are plotted for the raingauge stations. Thiessen weight factor for sub basins and intermediate sub basins are shown in Appendix No. VII. The plotting is shown in the Fig. No. 3-2.

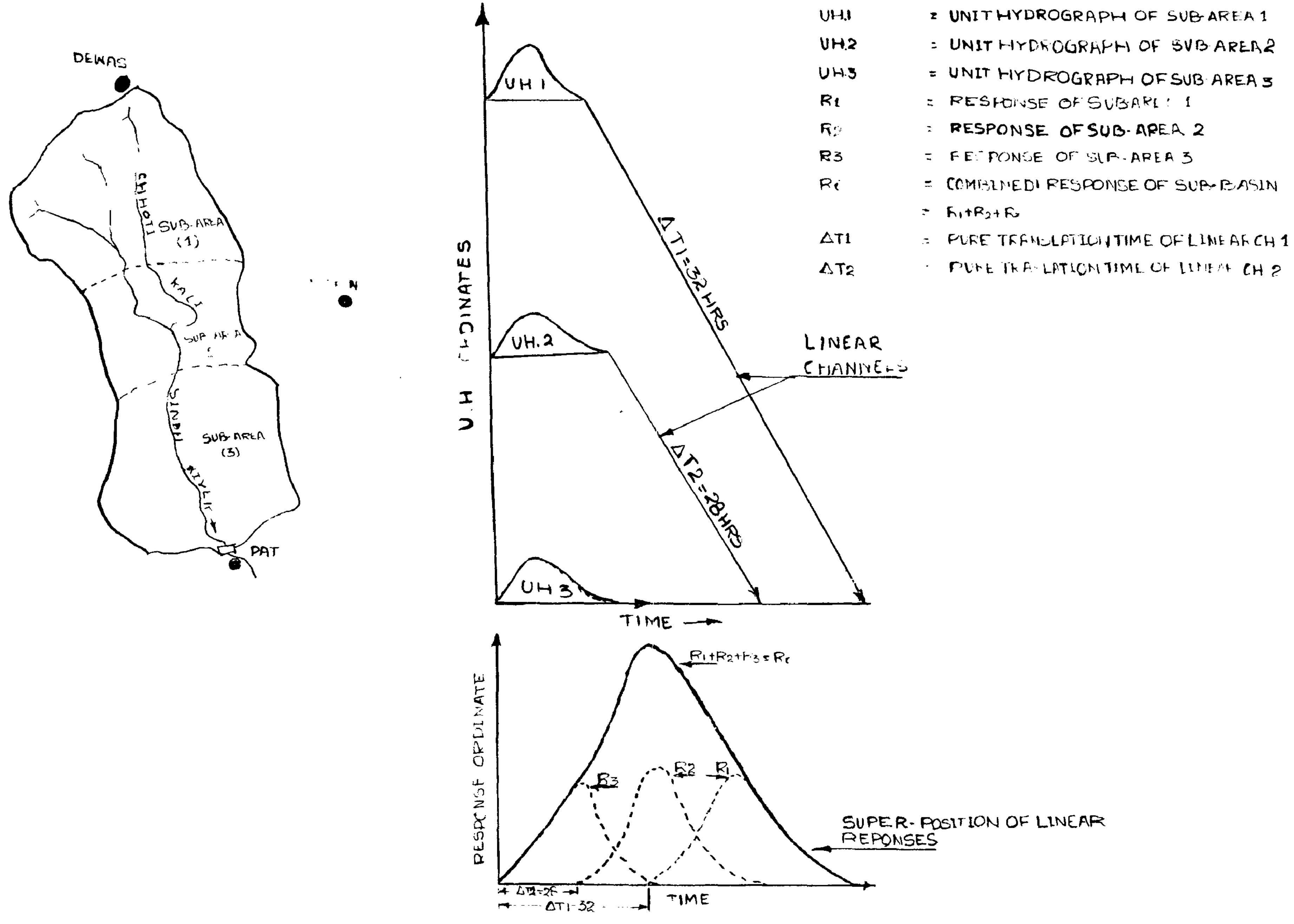


FIG NO 4(A)-0 STRUCTURE OF THE PROPOSED MODEL FOR PAT SUB-BASIN

C H A P T E R - IV (A)

APPLICATION OF PROPOSED MODEL TO THE GAUGED SUB-BASINS IN THE CATCHMENT

4 (A).1 INTRODUCTION:

The proposed model include the division of sub-basin into sub area. For each sub area an instantaneous unit hydrograph has been developed using the relationship proposed by Nash(Nash, J.E. 1957, 1960). Corresponding unit hydrographs for each sub area are computed. Linear channels are proposed for routing the flows from these sub areas to the outlet of sub basin.

The parameters of this conceptual model are (1) 'n'. The number of linear reservoirs in series (2) 'K' - the storage coefficient. In the present section the analysis is made to the following sub basins.

1. Pat sub-basin
2. Mahidpur-sub-basin includes Ujjain sub-basin
3. Nagda sub-basin includes Badnagar sub-basin
4. Mandsaur sub-basin
5. Chaldu sub-basin

4(A).2 DEVELOPMENT OF THE MODEL:

In these discussions, application of proposed model is discussed in details afor Pat sub-basin. Similar applications are extended to all other sub-basins and their findings are given in the Appendices, mentioned in subsequent sections.

4 (A).2.1 Division Of Sub-Basin:

Pat sub-basin is covered by three raingauge stations. Each raingauge influence area is shown in Fig. No. 3-2 by Thiessen Polygons. Hence the sub basin in question is divided into three sub areas. The physiographical characteristics of the sub basin has been worked out and tabulated as below in Table No. 4(A)-1.

TABLE NO. 4(A) - 1 Physiographical Characteristics of Pat Sub-Basin:

Name of Sub-Basin	Name of Sub-area	Thiessen weight Percentage	Physiographical Characteristics		
			Catchment area sq. miles	River length miles	Overland slope parts per 10,000
1	2	3	4	5	6
Pat		100	553	46	9.5
	1.Dewas	40	220	16	9.00
	2.Ujjain	25	140	12	8.50
	3.Pat	35	193	18	9.50

The physiographic details of other sub-basins are given in Appendix No. VIII.

4(A) 2.2 The Input Function

Input function for sub-basin and for its sub areas have been worked out as explained in the section 3.2, on the basis of direct run off hydrograph and effective rainfall hyetographs for the sub basin. The details of the working procedure are given in Table No. 4(A)-2. The details of the working procedure for input to other sub-basins are given in Appendix No.X(a)to Appendix No.IX(b).

) ITS SUB-AREAS

Date	ub-Area (2)		Sub Area (3)		Observed Runoff Th.Cu.		
	.F.of jain nch/Hr	R.F.E. inch/Hr Col.12 x 9	Rainfall of Pat inch/Hr	R.F.E.in inch Hr	Dischar-ge	Base flow	D.R.H. Ordinate
1	12	13	14	15	16	17	18
18.8.7					0.50	0.50	0
2	0.43	0.22	0.23	0.12	7.00	1.00	6.00
2	0.23	0.11	0.34	0.16	18.00	1.00	17.00
19.8.7							
	0.25	0.16	0.31	0.20	26.00	1.00	25.00
	0.41	0.33	0.12	0.10	31.50	1.00	30.50
1	0.34	0.25	0.47	0.35	35.75	1.25	34.50
1	0.35	0.26	0.40	0.30	42.50	1.50	41.00
2	0.29	0.19	0.32	0.20	52.50	1.50	51.00
2	0.21	0.12	0.46	0.27	61.25	1.75	59.50
20.8.7							
	0.25	0.18	0.38	0.27	70.00	2.00	68.00
	0.32	0.24	0.51	0.38	81.00	2.00	79.00
1					95.50	2.00	93.50
1					69.00	2.00	67.00
2					63.50	2.50	61.00
2					58.40	2.40	56.00
21.8.7							
					50.00	2.50	47.50
	x 4.I				38.50	2.50	36.00
1	.98"				26.00	2.50	23.50
1					6.00	3.00	3.00
2					5.00	3.00	2.00
2					3.00	3.00	0.00
							801

TABLE NO. 4(A) - 2

STATEMENT INDICATING THE RAINFALL EXCESS FOR PAT SUB BASIN AND ITS SUB-AREAS

Date & Time	Wtd. Rainfall in mm			Total wtd. R.F.in mm.Col. 2+3+4	Total WRF. inch/ Hr. Col.5/ 101.6	ø-index inch/Hr	Rainfall excess inch/Hr Col.6-7	Factor Col.8 / Col.6	Sub-Area (1)		Sub-Area (2)		Sub Area (3)		Observed Runoff Th.Cu.		
	Dewas 40%	Ujjain 25%	Pat 35%						R.F.of Dewas inch /Hr	R.F. excess inch/Hr Col.10x 9	R.F.of Ujjain inch/Hr	R.F.E. inch/Hr Col.12 x 9	Rainfall of Pat inch/Hr	R.F.E.in inch Hr	Discharge	Base flow	D.R.H. Ordinate
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18.8.74															0.50	0.50	0
20 Hr	3.44	11.00	8.10	22.50	0.21	0.10	0.11	0.52	0.08	0.04	0.43	0.22	0.23	0.12	7.00	1.00	6.00
24 Hr	2.32	5.75	12.30	20.30	0.19	0.10	0.09	0.47	0.06	0.03	0.23	0.11	0.34	0.16	18.00	1.00	17.00
19.8.74																	
4 Hr	10.80	6.50	11.20	28.50	0.27	0.10	0.17	0.63	0.26	0.16	0.25	0.16	0.31	0.20	26.00	1.00	25.00
8 Hr	40.00	10.50	4.40	54.90	0.52	0.10	0.42	0.81	0.98	0.79	0.41	0.33	0.12	0.10	31.50	1.00	30.50
12 Hr	15.60	8.75	16.70	41.00	0.39	0.10	0.29	0.74	0.38	0.28	0.34	0.25	0.47	0.35	35.75	1.25	34.50
16 Hr	18.00	9.00	14.40	41.40	0.39	0.10	0.29	0.74	0.44	0.33	0.35	0.26	0.40	0.30	42.50	1.50	41.00
20 Hr	11.20	7.50	11.20	29.40	0.28	0.10	0.18	0.64	0.28	0.18	0.29	0.19	0.32	0.20	52.50	1.50	51.00
24 Hr	4.00	5.25	16.50	25.80	0.24	0.10	0.14	0.58	0.10	0.06	0.21	0.12	0.46	0.27	61.25	1.75	59.50
20.8.74																	
4 Hr	16.00	6.30	13.70	36.00	0.34	0.10	0.24	0.71	0.39	0.28	0.25	0.18	0.38	0.27	70.00	2.00	68.00
8 Hr	18.16	8.10	18.30	44.50	0.40	0.10	0.30	0.75	0.45	0.34	0.32	0.24	0.51	0.38	81.00	2.00	79.00
12 Hr		1.75	4.40	6.20	0.06	0.06									95.50	2.00	93.50
16 Hr															69.00	2.00	67.00
20 Hr			Total		3.29	1.06	2.23			2.49					63.50	2.50	61.00
24 Hr							8.92"			9.96"					58.40	2.40	56.00
21.8.74																	
4 Hr															50.00	2.50	47.50
8 Hr															38.50	2.50	36.00
12 Hr															26.00	2.50	23.50
16 Hr															6.00	3.00	3.00
20 Hr															5.00	3.00	2.00
24 Hr															3.00	3.00	0.00
																	801

Note: (1) Weighted rainfall under Col. (2,3,10,12,14) are taken from appendix 4.I

(2) Depth of runoff in inches $= \frac{801000 \times 4 \times 60 \times 60 \times 12}{553 \times 5280 \times 5280} = 8.98"$

(3) Observed runoff are taken from appendix No.III

4 (A).2.3 The Transfer Function:

This has been worked out in following steps:

1. The model parameters 'n' & 'K' have been worked out by method of moments about origin from the rainfall excess hyetograph and direct runoff hydrograph, using the equation Nos. 3.6, 3.7 & 3.8.

2. With these values of 'n' & 'K' and physiographical characteristics of sub basin, the value of C_1 & C_2 have been calculated using equation No.3.9 & 3.10.

3. With the representative values of C_1 & C_2 for Pat sub basin, the model parameters for the sub areas are established and are shown in Table No. 4(A)-3 below.

TABLE NO.4(A)-3 Model Parameters Of Pat Sub-Basin & Its Sub-Areas:

Sub-basin Sub-area	Model Parameter n	Model Parameter K	Catchment Constant C_1	Catchment Constant C_2
Pat	3	6.68	3.08	2.08
(1) Dewas	3	5.94	3.08	2.08
(2) Ujjain	3	5.55	3.08	2.08
(3) Pat	3	5.55	3.08	2.08

Similarly the model parameters for other sub-basins are given in Appendix No.VIII.

4. With the established values of model parameters for each sub areas the Instantaneous Unit Hydrographs have been worked out using equation No.3.11. Subsequently, the unit hydrograph for each of the sub areas is computed and are given in Table No.4(A)-4. Similarly the unit hydrographs for each sub area of other sub basins are computed and given in Appendix No. X.

TABLE NO. 4 (A) -4 Unit Hydrographs For Sub-Area's of Pat Sub-Basin

Hours	Sub area-1 Th.Cusecs	Sub area-2 Th.Cusecs	Sub area-3 Th.Cusecs
1	2	3	4
0	0.	0	0
4	1.38	1.04	1.43
8	4.18	3.04	4.19
12	6.04	4.18	5.77
16	6.18	4.08	5.62
20	5.31	3.32	4.58
24	4.12	2.42	3.32
28	2.94	1.65	2.28
32	1.97	1.08	1.49
36	1.28	0.68	0.93
40	0.83	0.42	0.57
44	0.53	0.25	0.34
48	0.32	0.15	0.20
52	0.19	0.08	0.12
56	0.11	0.05	0.07
60	0.07	0.03	0.04
64	0.04	0.02	0.02
68	0	0	0

4 (A).2.4 Identification of Model Parameters:

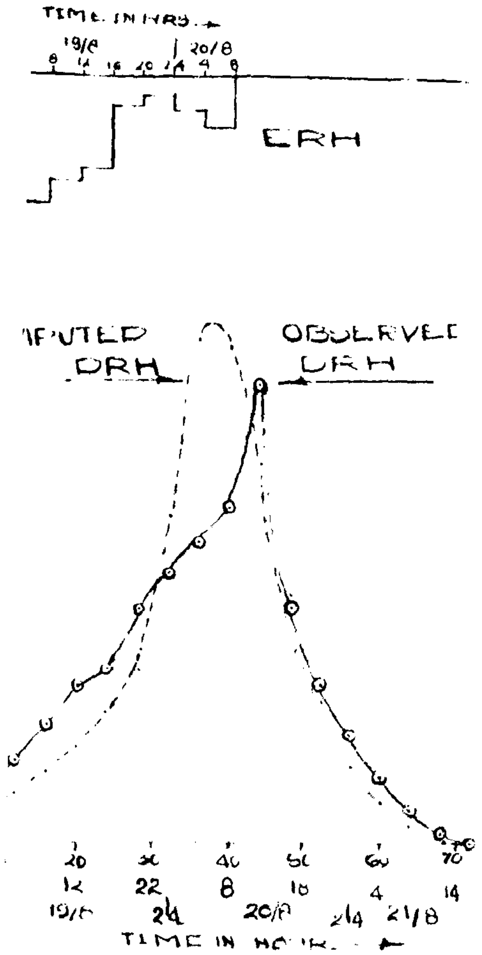
As discussed in section 3.3, knowing the transfer functions and effective rainfall for each sub area's of Pat sub-basin, the direct runoff hydrographs are computed. These are also termed as the differential responses of the basin. The linear channels are assigned to the sub areas.

The pure translation of the linear channels are worked out by trail and error. This is done in such a manner that the super-imposed differential response match agreeably with the observed response. The basic structure representing the Pat system is shown in Fig.No. 4(A)-0. A comparision of computed and observed direct runoff hydrograph is shown in Fig.No.4 (A)-3.

Similarly the analysis is extended to all other sub basins. The results of the comparisions of computed and observed hydrographs for storm 1974 are given in Fig. No.'s 4 (A)-1, 4 (A)-2 & 4(A)-4 to 4 (A)-7.

4 (A).3 TESTING OF MODEL:

For testing of model, the data of storm, Aug.1977, is used. The procedure adopted for working the input function for sub-basin and sub area, is same as explained for above in section 4 (A)-2. Using the same transfer functions for each sub-areas, as are formulated, the differential response for sub areas are computed. With the help of linear channels the flow is of each sub area is routed to the outlet in such a manner that the super-imposed differential response match agreeably with the observed response. The comparision is shown in Fig. No.'s 4 (A)-8 to 4 (A)-12.



•NO. 4(A)-1 (UJJAIN G&D SITE)

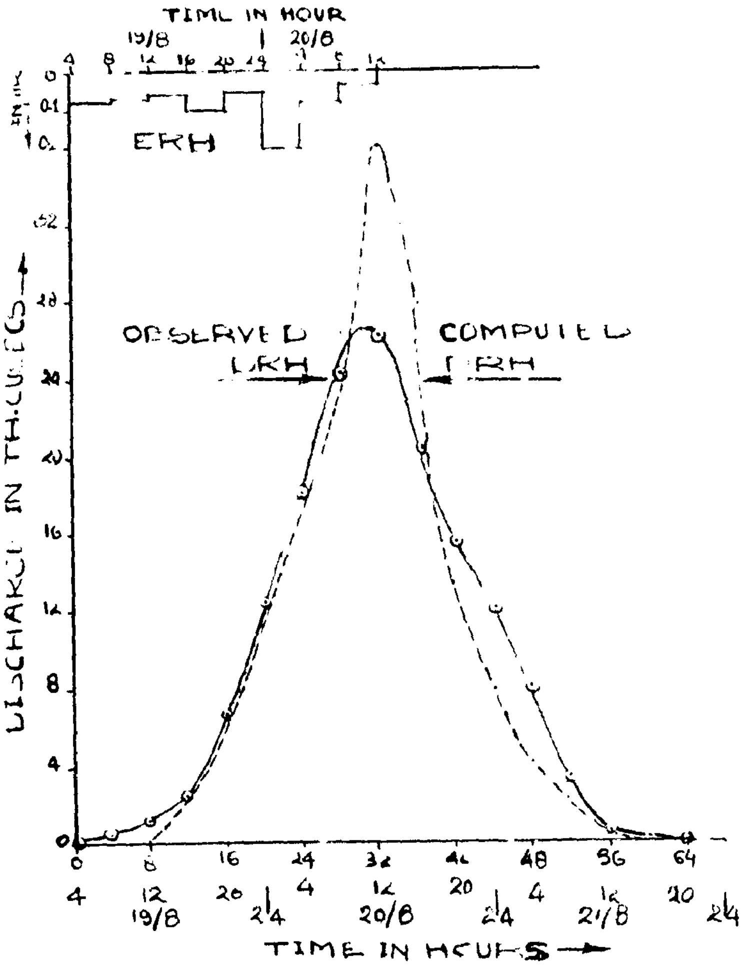
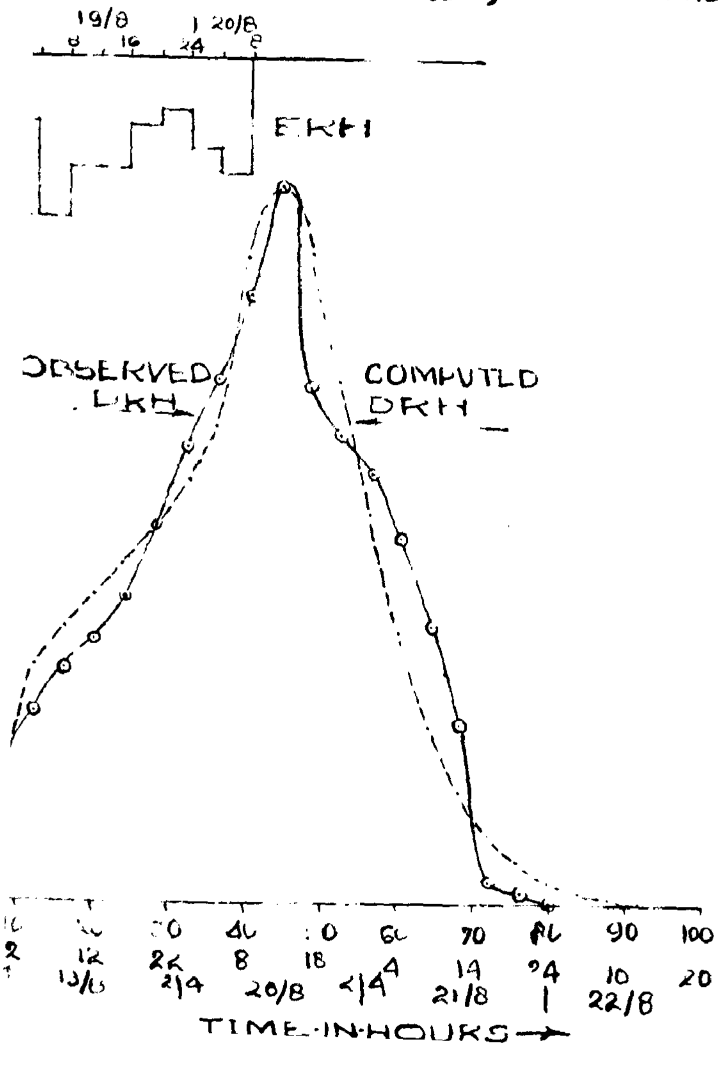


FIG.NO. 4(A)-2 (BADNAGAR G&D SITE)



IDENTIFICATION OF MODEL PARAMETERS.

COMPARISION OF OBSERVED AND COMPUTED DRH (1974 STORM)

PLATE NO-10

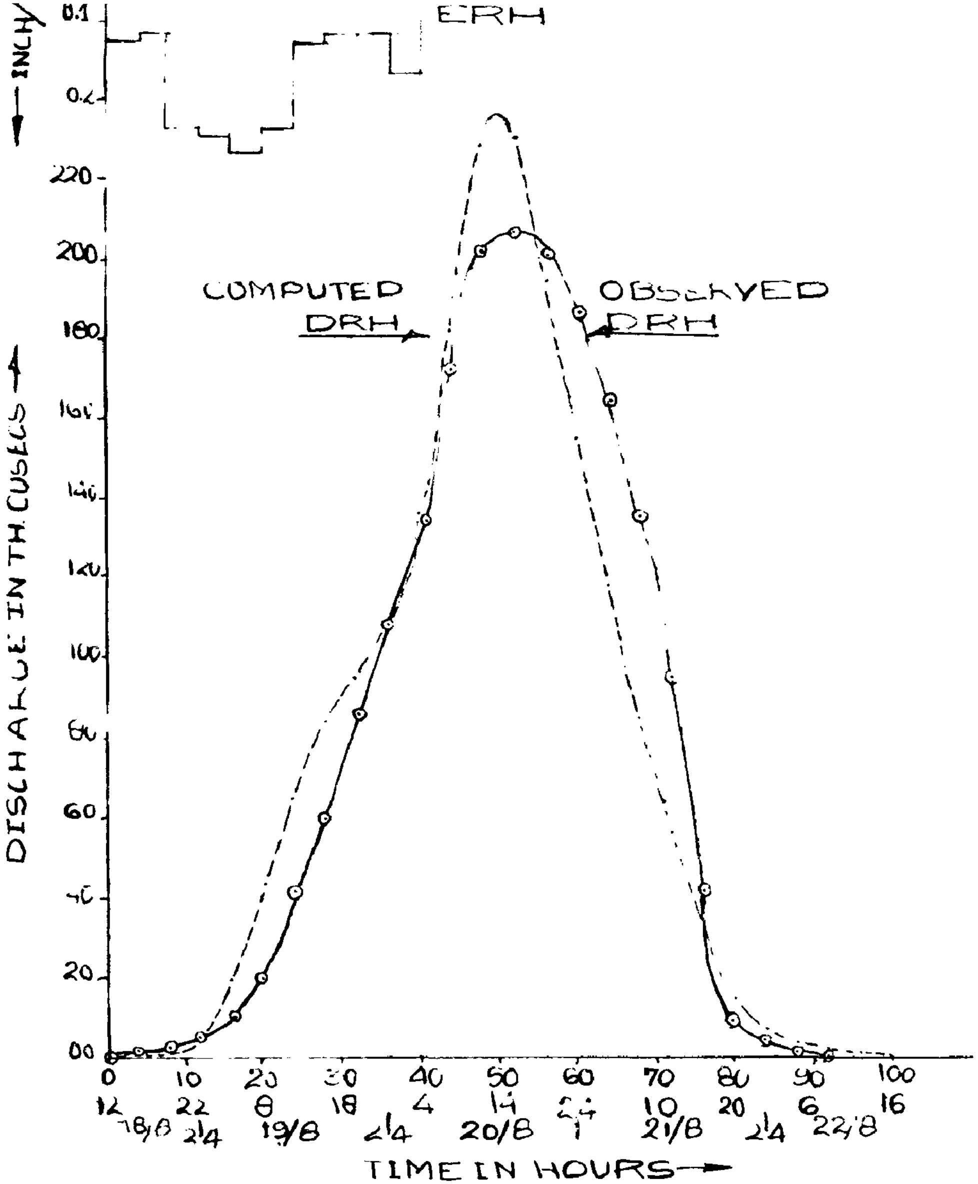


FIG. No. 4(A)-4 (MAHIDPUR G&D SITE)

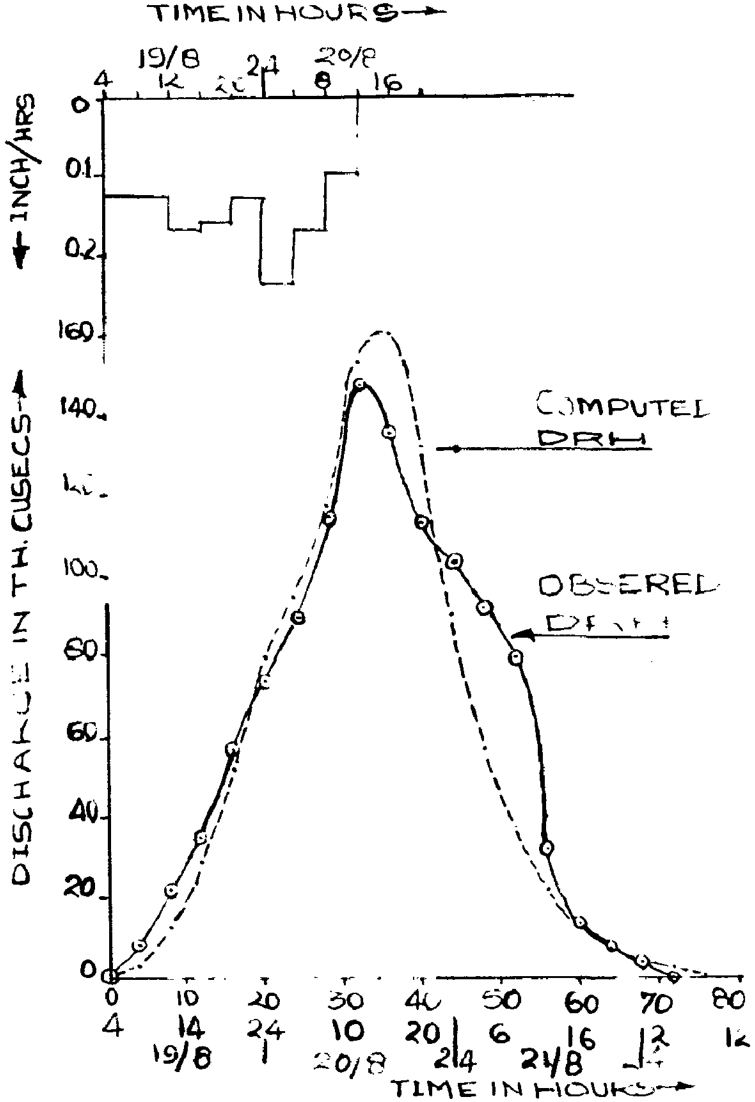


FIG No. 4A,-5.(NAGDA G&D SITE)

IDENTIFICATION OF MODEL PARAMETERS

(1974 STORM)

PLATE NO.11

1974 STORM

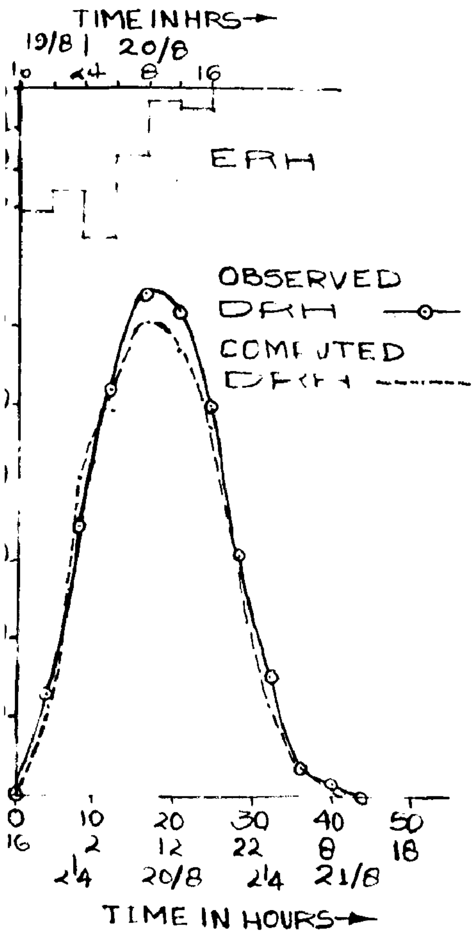


FIG.NO.4(A)-6 (MANDSAUR G&D SITE)

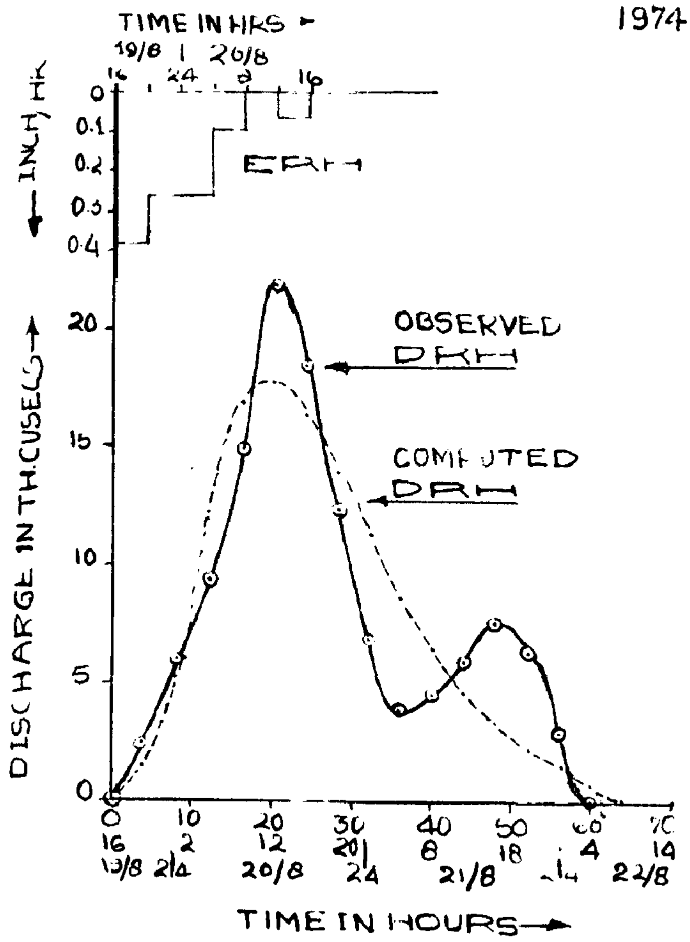


FIG.NO 4(A)-7 (CHALDU G&D SITE)

IDENTIFICATION OF MODEL PARAMETERS (1974 STORM)

PLATE NO.- 12

1977 STORM

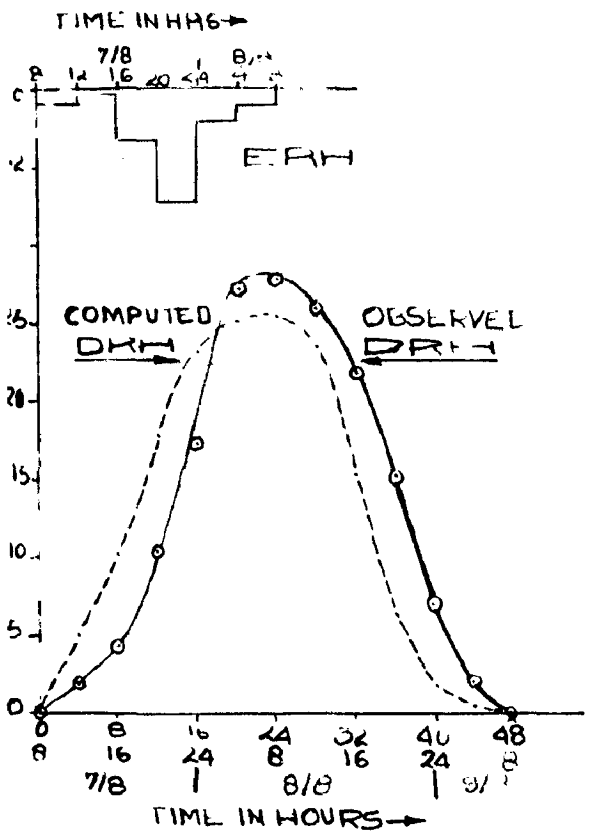


FIG. NO. 4(A)-8 (MANDSAUR G.&D. SITE)

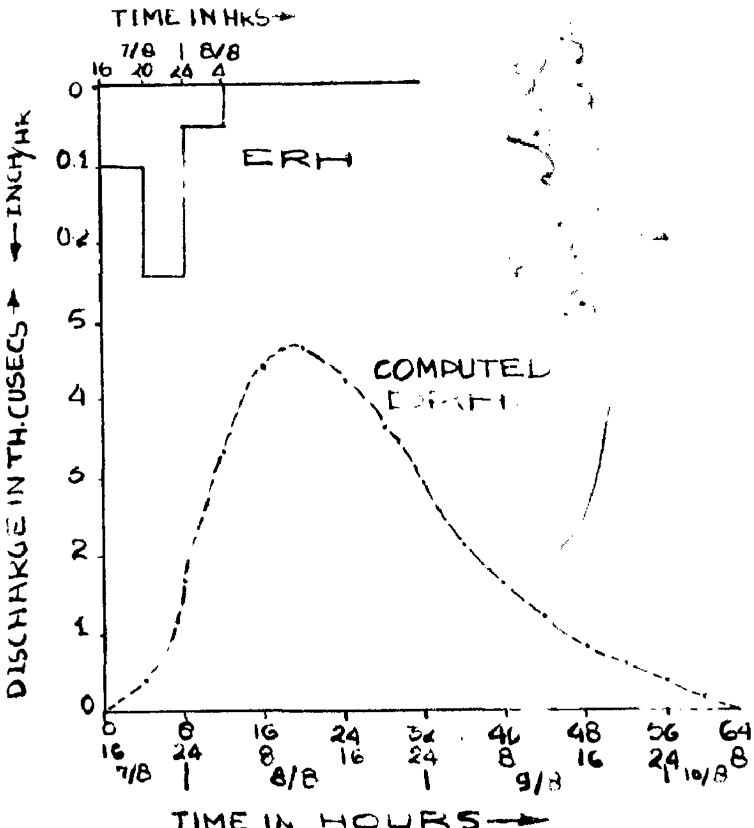
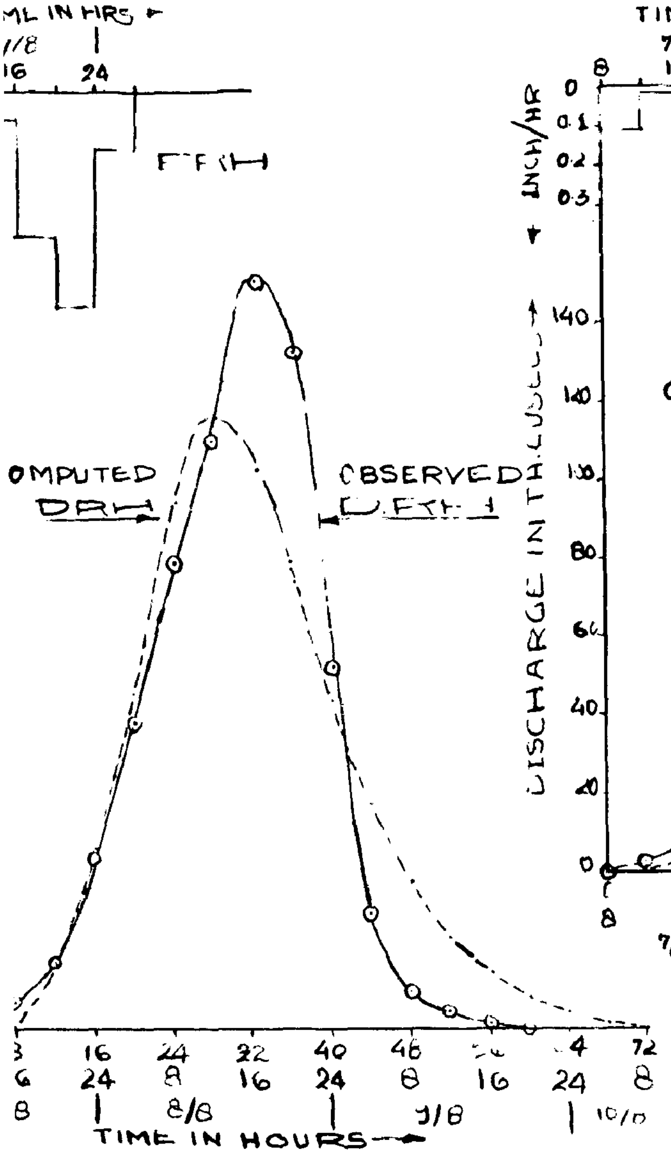


FIG. NO. 4(A)-9 (CHALLU G.&D. SITE)

TESTING OF MODEL (1977 STORM) PLATE NO-12



10.- 4(A)-10 (PAT G.&D. SITE)

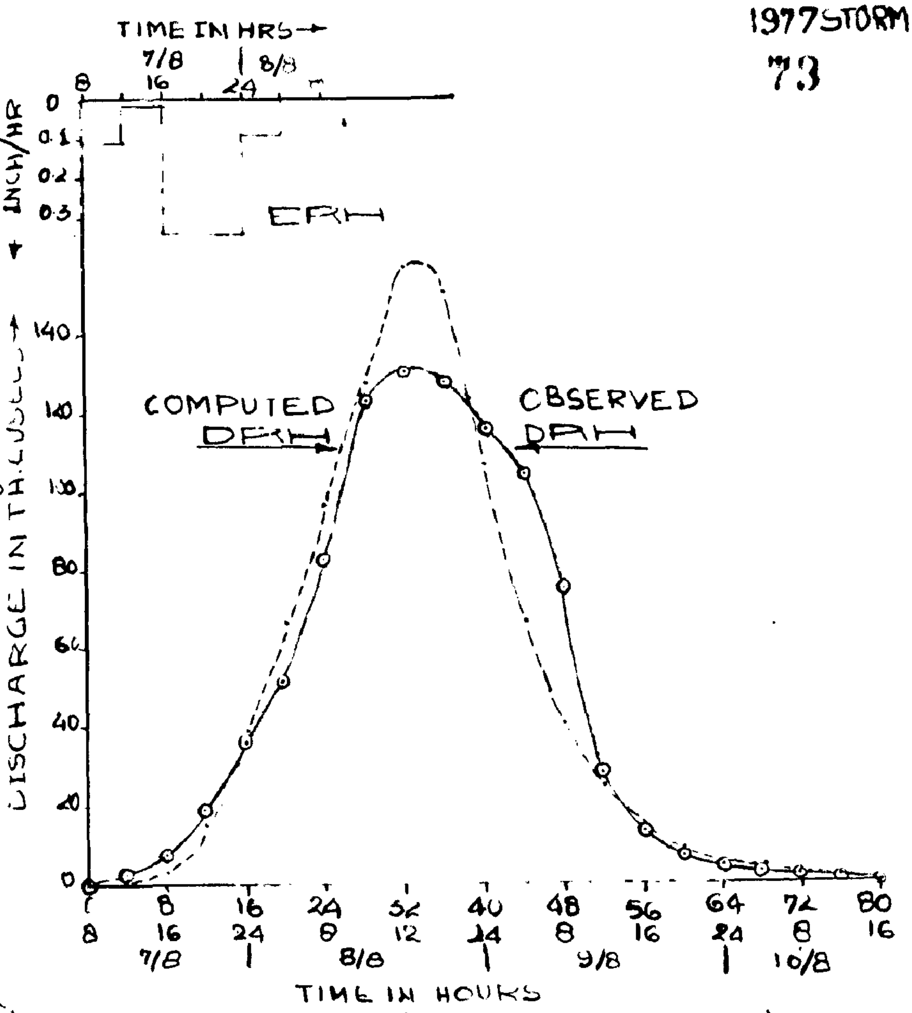


FIG. NO. 4(A)-11 (MAHIDPUR G.&D. SITE)

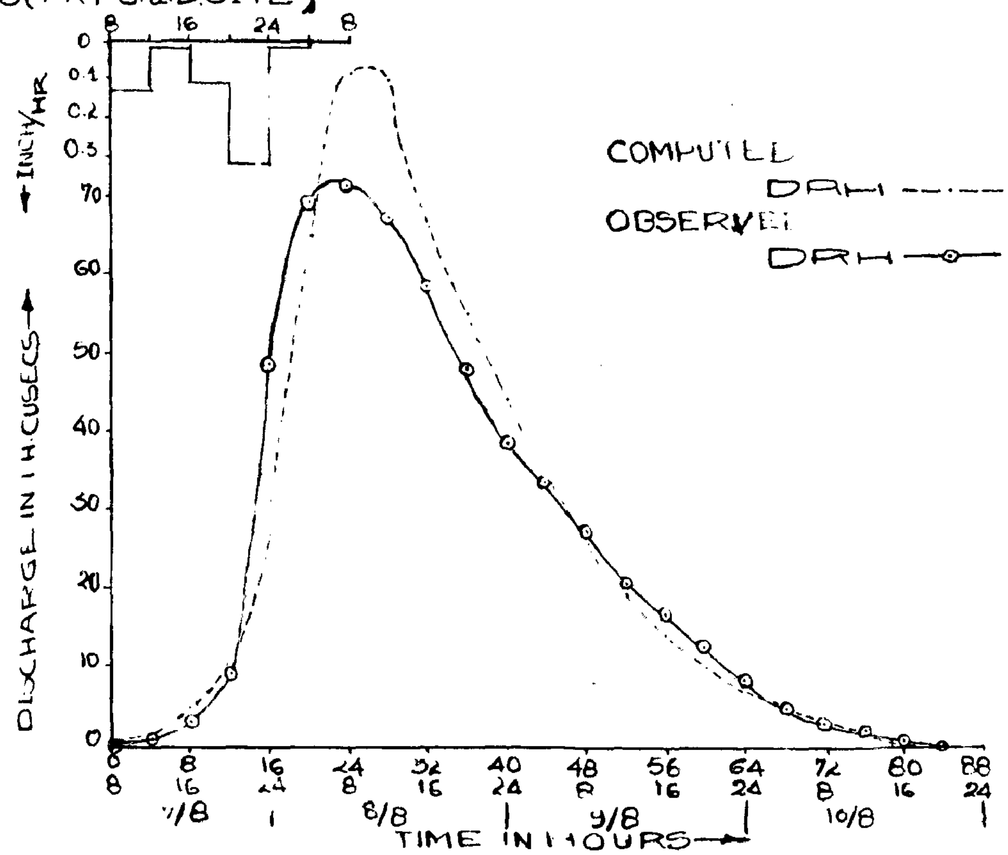


FIG. NO. 4(A)-12 (NAUDA G.&L. SITE)

TESTING OF MODELS (1977 STORM)

CHAPTER - IV (B)

APPLICATION OF PROPOSED MODEL FOR INTERMEDIATE SUB-BASINS IN THE CATCHMENT

4(B).1 INTRODUCTION:

As discussed in previous section, all the five sub-basins in the catchment are modelled accordingly and the proposed models are tested at the outlets by comparing the computed and observed responses.

Formulation of model for intermediate sub-basin depends on the availability of observed data at its outlet i.e. the self contribution at the outlet of intermediate sub-basin. But presently, the available observed data at the outlet of some intermediate sub-basin consists, two components. Firstly, its own contribution. and secondly the routed flow concentration from the upstream sub-basin. For this reason the proposed formulation of model, which includes the derivation of input function and transfer functions can not be directly extended to the intermediate sub-basin. Gauged Intermediate sub-basins may be verified at its outlet but ungauged intermediate sub-basins can not be verified. Working of model parameter for transfer function require the knowledge of catchment constants (C_1 & C_2 in the relation 3.9 & 3.10, proposed by Nash (J.E.Nash 1960). Hence an attempt is made to have the input function on the basis of rainfall and to have the model the parameters on the basis of catchment characteristics.

4 (B).2 INPUT FUNCTION OF THE INTERMEDIATE SUB BASINS:

For computing the rainfall excess of intermediate sub basins the relationships in the form of curves are developed between intensity of weighted rainfall, rainfall excess (percentage) or infiltration index (percentage) and duration of storm, from the analysis of the gauged sub basins. The details of storm characteristics of the gauged sub basins are given in the Table No. 4 (B)-1.

TABLE NO. 4 (B)-1 Details of Storm Characteristics of Gauged Sub-Basins:

Sl. No.	Name of sub-catchments	Storm duration Hrs.	Total Wtd. R.F. inches	Ø-index inches	Rainfall excess inches	Wtd. R.F. intensity Col.4/Col.3	Ø-index of T.W. R.F. % Col.5X 100/Col. 4	R.E.of T.W. R.F. % Col.6 X100 / Col. 4
	2	3	4	5	6	7	8	9
1.	Ujjain	44	12.16	6.24	5.92	0.276	51.32	48.68
2.	Badnagar	36	5.06	2.36	2.68	0.140	46.80	53.20
3.	Pat	44	13.16	4.24	8.92	0.299	32.20	67.80
4.	Mahidpur	44	11.84	4.92	6.92	0.269	41.56	58.44
5.	Nagda	36	5.64	0.88	4.76	0.157	15.60	84.40
6.	Mandsaur	24	9.12	4.32	4.80	0.380	47.37	52.63
7.	Chaldu	40	9.68	5.48	4.20	0.242	56.60	43.40

4 (B).2.1 Curves For Input Function:

Two curves given in Fig. No.4 (B)-1 and 4 (B)-2 have been plotted.

Between Rain excess (%) v/s intensity (inch/hr.) and duration (hrs.)

Between ø-index (%) v/s intensity (inch/hr.) & duration (hrs.) respectively. The details of these are given as follows:

4 (B).2.1 (a) Basis of Curves:

The above two curves have been drawn with the following basis:

(i) The storm duration in hours is written adjacent to the plotted points.

(ii) Two straight lines in each curve have been drawn by joining the points indicating 36 hrs. and 40 hrs. storm duration respectively. These two lines are found parallel to each other.

4 (B).2.1 (b) Conclusion Drawn:

From the above concept the following conclusion may be drawn:

(i) Since both the lines are parallel to each other, hence the lines drawn from other plotted points would also be parallel to these lines.

(ii) The value of rainfall excess or ø-index on each line increases or decreases respectively with the increase in weighted rainfall.

4 (B).2.1 (c) Procedure for Calculation Of Rainfall Excess or ø-index:

The procedure for the calculation of rainfall excess or ø-index require knowledge of weighted rainfall on the catchment and its duration and following procedure used for the same.

(i) For the known storm duration select the plot of same storm duration.

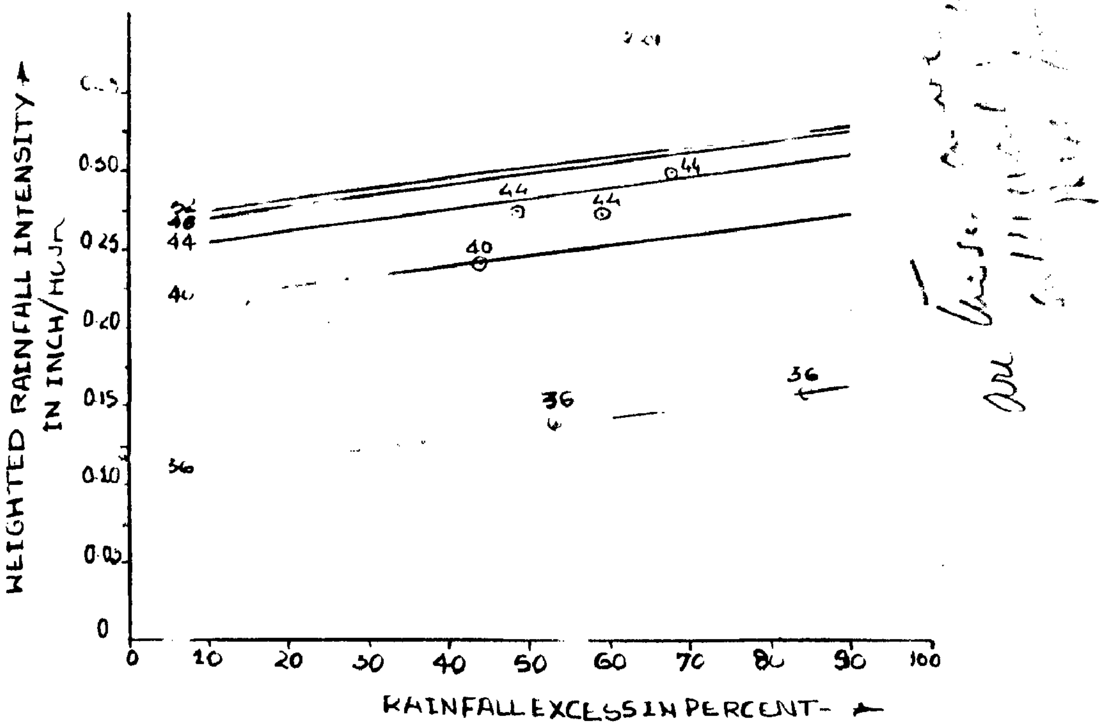


FIG No. 4(B)-1 CURVE FOR RAINFALL EXCESS

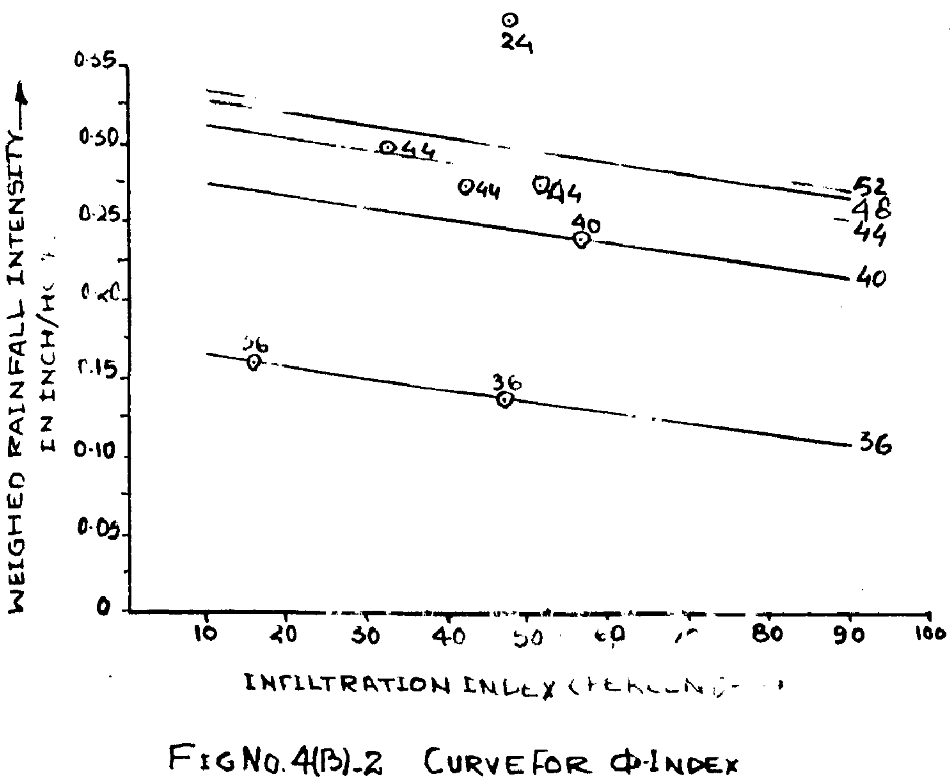


FIG No. 4(B)-2 CURVE FOR Φ-INDEX

DURATION OF STORM (HRS) IS INDICATED ADJACENT TO EACH PLOT

CURVES SHOWING RELATIONS BETWEEN RAINFALL INTENSITY AND RAINFALL EXCESS OR Φ-INDEX

(ii) Enter the weighted rainfall intensity from ordinate to the plot and read the rainfall excess or Ø-index on absicca.

4 (B).3 EVALUATION OF CONSTANTS C_1 & C_2 FOR INTERMEDIATE SUB-BASINS:

The tested values of model parameters and catchment constants for the gauged sub basins (worked out in Chapter-IV(A)), have been used. The values are tabulated below in Table No. 4 (B)-2.

TABLE NO. 4(B)-2 Model Parameters For Gauged Sub-Basins:

Name of Catchment	Catchment area in sq.miles	Length of river in miles	Length / Catchment area	Over-Land slope in parts per 10,000	Value of 'n'	'K'	C_1	C_2
1	2	3	4	5	6	7	8	9
Ujjain	77.5	40	0.05	16.60	5	4.10	2.03	3.51
Badnagar	358	38	0.11	65.36	8	1.93	1.74	5.63
Pat	553	46	0.08	9.50	3	6.68	3.08	2.08
Mahidpur	1707	76	0.04	39.65	9	3.14	1.75	5.98
Nagda	1477	72	0.05	37.00	4	4.89	2.75	2.67
Mandsaur	414	44	0.11	6.15	4	2.66	1.15	2.75
Chaldu	193	24	0.12	8.61	3	8.30	4.57	2.20

4 (B).3.1 Curves For Value Of C_1:

Two curves given in Fig.No.4 (B)-3 and 4 (B)-4 have been plotted.

Between C.A.(Sq.Miles) v/s C_1 & OLS

Between River length (Miles) v/s C_1 & OLS

respectively. The details of these are given as follows:

4 (B).3 1 (a) Concept of Drawing The Curves:

The above two curves have been drawn on the following lines.

(i) The value of storage coefficient 'K' is written adjacent to the plotted points.

(ii) Two straight lines in each curve have been drawn joining the points, having the value 6.68 to 4.89 hr. and 4.1 hr. to 3.14 hr.

(iii) On both the lines in both curves the value of 'K' decreases with the increase in catchment area or river length.

(iv) The average overland slope is marked on the lines.

4 (B).3.1 (b) Conclusion Drawn:

The following conclusion may be drawn:

(i) Both the lines are parallel to each other in both curves, hence the lines passing from other plotted points would also be parallel to these lines.

(ii) In both the figure the overland slope decreases with the increase in value of C_1.

(iii) The value of C_1 decreases with the increase in catchment area or river length.

4 (B).3.1 (c) Procedure For Calculation Of C_1:

The procedure for the calculation of C_1 require the knowledge of (i) overland slope in parts of 10,000 (ii) catchment area in sq. miles or the river length in miles, of a ungauged sub basin.

(i) With known overland slope the desired plot is fixed.
(ii) For known catchment area/river length, compute the value of C_1.
(iii) Take the average of two values of C_1 if both the plots corresponding to C.A. & river length are referred to.

4 (B).3.2 Curves for Value Of C_2:

Similar to C_1, two curves given in Fig. No. 4(B)-5 and Fig.No.4(B)-6 have been plotted.

Between OLS v/s C_2 & L/A ($Mile^{-1}$)

Between river length (Miles v/s C_2 & OLS

respectively. The details of these are given as follows.

4 (B).3.2 (a) Concept Of Drawing The Curves:

The above two curves have been drawn on the following concept.

(i) The value of no. of linear reservoir 'n' are indicated adjacent to the plotted points.
(ii) Two straight lines are drawn passing through the same 'n' ie through n = 3 & 4.
(iii) The values of L/A($Mile^{-1}$), varies from 0.05 to 0.11 (average 0.08) and 0.08 to 0.12 (average 0.10) on the two lines of Fig.No.4(B)-5. While in the Fig.No.4(B)-6 the value of slope increases with the increase in C_2

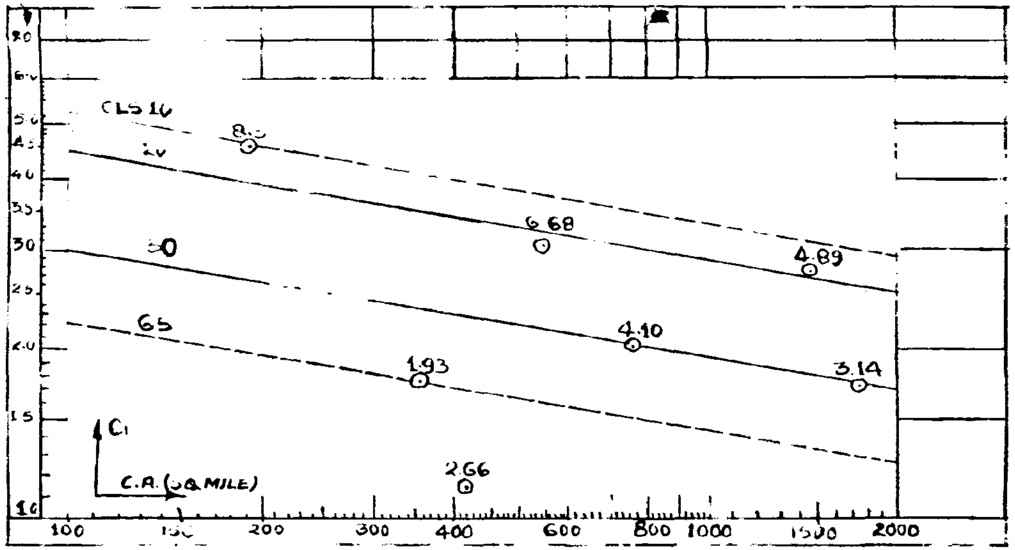


FIG.NO 4(b)-3 DETERMINATION OF C1

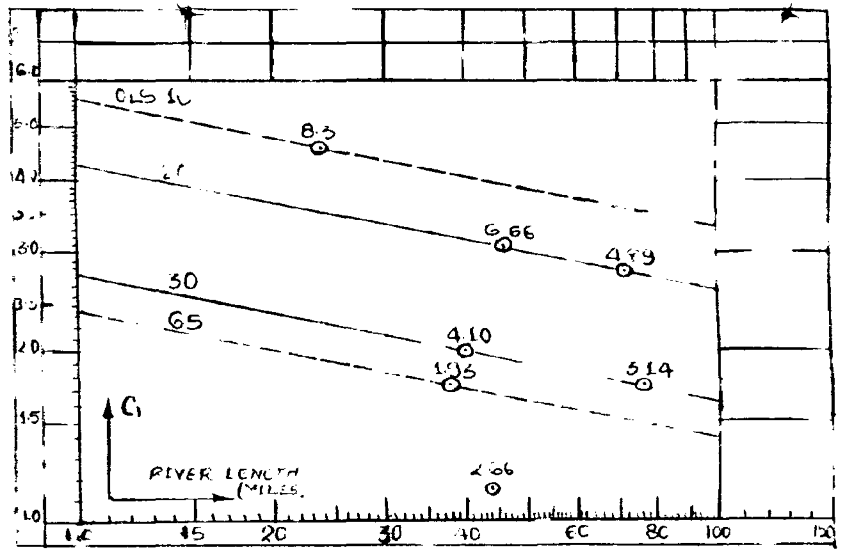


FIG.NO 4(b)-4 DETERMINATION OF C1

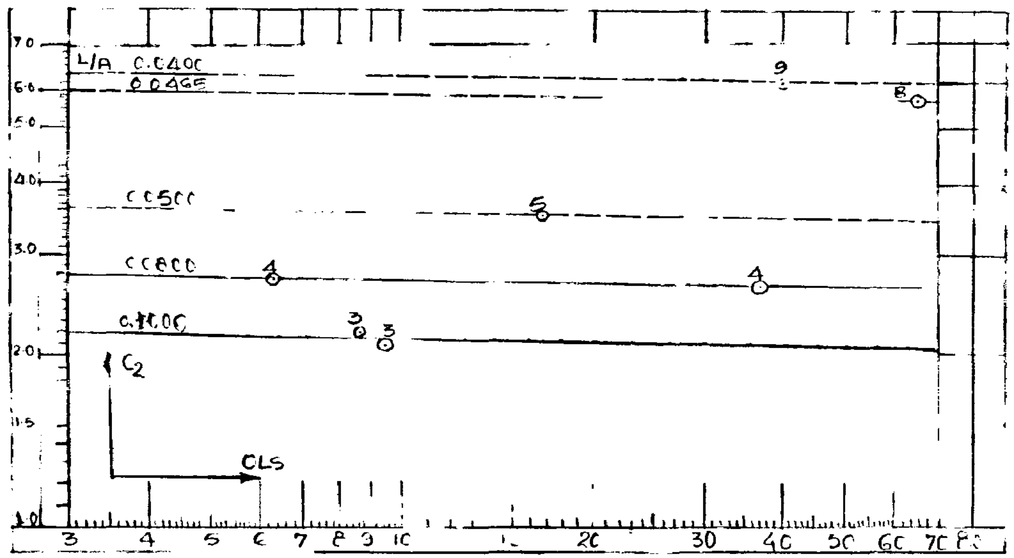


FIG NO. 4(b)-5 DETERMINATION OF C2

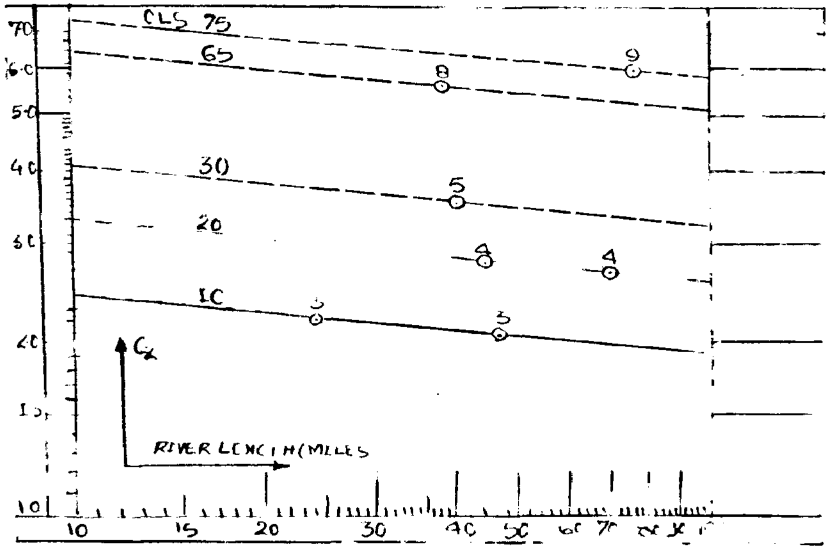


FIG.NO.4(b)-6 DETERMINATION OF C2

GRAPHS SHOWING RELATIONS BETWEEN CATCHMENT CONSTANTS C1 & C2 AND CATCHMENT CHARACTERSTICS

4 (B).3.2 (b) Conclusion Drawn:

Following conclusions may be drawn:

(i) Both lines are parallel to each other. Hence the lines drawn from other plotted points would also be parallel to these lines.

(ii) Value of C_2 will increase with the decrease in L/A (miles^{-1}) in Fig. No.4 (B)-5 while C_2 increases with the increase in OLS in Fig. No. 4 (B)-6.

(iii) The value of 4 decreases with the increase in OLS & river length (miles).

4 (B).3.2 (c) Procedure for Calculation Of C_2:

The procedure for calculation of C_2 require the knowledge of OLS, catchment area (sq. miles), length of river (miles). Following procedure adopted.

(i) with known values of L/A(mile^{-1}), fix the plot in Fig. 4 (B)-5. Similarly known value of OLS fix the plot in Fig. 4 (B)-6.

(ii) for known values of OLS & river length compute the values of C_2 from Fig. No.4 (B)-5 and 6 respectively.

(iii) Average value of C_2 is adopted if both curves are used.

4 (B)-4 DEVELOPMENT OF MODEL FOR INTERMEDIATE SUB-BASIN:

Formulation of model for intermediate sub basins has been carried out in accordance with the procedure proposed in section 4(B)-2 and section 4(B)-3, for evaluating the input function and model parameters respectively. The rest of the procedure i.e. for computing the differential responses of sub areas is same, as adopted in the modelling of gauged sub basins in Chapter IV(A). The proposed procedure is applicable to both gauged and ungauged, intermediate sub basins. Availability of gauging data at the outlet of intermediate sub basin, is helpful only in the verification of model parameters. This verification is carried out by superimposing the routed flow concentrations from the outlet of sub basin, to the contributions of the intermediate sub basin and compared the total computed flows with the observed flows at the out-let of intermediate sub basin. But the ungauged intermediate sub basin cannot be verified.

In the present section the application of proposed model is discussed in details for Choumahla intermediate sub-basin. Similar applications are extended to all the five other intermediate sub basins given below and the details of the application, are given in the appendices, mentioned in subsequent sections.

1. Kalakhedi
2. Barkheda
3. Mandsaur
4. Tumri
5. Gandhi Sagar

4 (B).4.1 Division Of Intermediate Sub-Basin:

Chøoumahla Intermediate sub-basin is covered by two raingauge stations. The influence area of each station is shown in Fig.No.3.2 by Thiessen Polygons. Therefore the basin is divided in two sub-areas. The physiographical characteristics of the sub basin has been worked out and tabulated as below in Table No.4 (B)-3.

TABLE NO.4 (B)-3 Physiographical Characteristics Of Choumahla Intermediate Sub-Basin:

Name of basin	Name of Sub-area	Thiesson weight %	Physiographical Characteristics		
			Catchment Area sq.miles	River length in miles	Overland slope in parts/10(
1	2	3	4	5	6
Choumahla		100	521	32	12.63
	(1) Pat	57	300	17	12.63
	(2) Choumahla	43	221	15	12.63

The physiographical details of sub areas of other intermediate sub basins are given in Appendix No. XIII.

4 (B).4.2 The Input Function For Choumahla Intermediate Sub-Basin:

The rainfall excess and ∅-index for intermediate sub-basin have been worked out as explained in section 4 (B)-2 using Fib. No.(B)-1 and Fig.No.4(B)-2 and thus the rainfall excess for sub areas has been calculated as explained in section 3.2. The details of the working procedure are given

…B-BASIN AND ITS

Date &	Sub-System(2) R.F. inch/Hr.	R.F. Excess inch/Hr	Observed Runoff at Choumahla: Discharge Th.Cu.	Base flow Th.Cu.	D.R.H. ORDINATE Th.cu.
1	11	12	13	14	15
18.8.7…	-	-	0.50	0.50	0
	0.56	0.41	5.00	0.50	4.50
	0.21	0.14	18.00	0.50	17.50
19.8.7…					
	0.42	0.30	30.00	1.00	29.00
	0.21	0.08	42.00	2.00	40.00
	0.16	0.11	60.30	2.30	58.00
	0.20	0.14	84.00	2.00	82.00
	0.55	0.42	112.00	2.00	110.00
	0.73	0.60	134.50	2.50	132.00
20.8.7…					
	0.19	0.12	158.00	3.00	155.00
	0.42	0.33	195.00	3.00	192.00
	0.49	0.31	208.00	3.00	205.00
			200.00	3.00	197.00
			150.00	4.00	146.00
		2.82	120.00	4.50	115.50
		11.28"	76.50	4.50	72.00
			44.00	5.00	39.00
			19.70	5.70	14.00
			15.00	6.00	9.00
			11.00	6.00	5.00
			9.00	6.00	3.00
			7.00	7.00	0

Using t…
with in…

TABLE NO.4(B)-4

STATEMENT INDICATING THE RAINFALL EXCESS FOR CHOUMAHLA INTERMEDIATE SUB-BASIN AND ITS SUB-AREAS

Date & Hrs.	Wtd.Rainfall mm/4Hr Pat 57%	Wtd.Rainfall mm/4Hr Choumahla 43%	Total W.R.F. mm/4Hr	Total W.R.F. inch/Hr	ϕ-index inch/Hr	Rainfall excess inch/Hr	Factor Col. 7 / Col. 5	Sub Sub-System(1) Rainfall inch/Hr	Sub Sub-System(1) Rainfall excess in./Hr	Sub Sub-System(2) R.F. inch /Hr.	Sub Sub-System(2) R.F. Excess inch/Hr	Observed Runoff at Choumahla Discharge Th.Cu.	Observed Runoff at Choumahla Base flow Th.Cu.	Observed Runoff at Choumahla D.R.H. ORDINATE Th.cu.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
18.8.74	4.56	1.03	5.59	0.05	0.05							0.50	0.50	0
20 Hr	13.16	24.51	37.67	0.37	0.10	0.27	0.73	0.22	0.16	0.56	0.41	5.00	0.50	4.50
24 Hr	19.95	9.37	29.32	0.29	0.10	0.19	0.65	0.34	0.22	0.21	0.14	18.00	0.50	17.50
19.8.74														
4 Hr	18.24	18.23	36.47	0.36	0.10	0.36	0.72	0.31	0.22	0.42	0.30	30.00	1.00	29.00
8 Hr	7.12	9.12	16.24	0.16	0.10	0.06	0.38	0.12	0.04	0.21	0.08	42.00	2.00	40.00
12 Hr	27.08	7.31	34.39	0.34	0.10	0.24	0.70	0.46	0.32	0.16	0.11	60.30	2.30	58.00
16 Hr	23.37	8.68	32.05	0.31	0.10	0.21	0.68	0.40	0.27	0.20	0.14	84.00	2.00	82.00
20 Hr	18.70	24.08	42.78	0.42	0.10	0.32	0.76	0.32	0.24	0.55	0.42	112.00	2.00	110.00
24 Hr	26.79	31.82	58.61	0.57	0.10	0.77	0.82	0.46	0.38	0.73	0.60	134.50	2.50	132.00
20.8.74														
4 Hr	22.23	9.56	31.79	0.30	0.10	0.20	0.66	0.38	0.25	0.19	0.12	158.00	3.00	155.00
8 Hr	29.75	18.32	48.04	0.47	0.10	0.37	0.79	0.51	0.40	0.42	0.33	195.00	3.00	192.00
12 Hr	7.01	21.50	28.51	0.28	0.10	0.18	0.64	0.12	0.08	0.49	0.31	208.00	3.00	205.00
16 Hr	0.68	5.42	6.10	0.05								200.00	3.00	197.00
20 Hr												150.00	4.00	146.00
24 Hr				3.92	1.15	2.77			2.58		2.82	120.00	4.50	115.50
				15.68"		11.08"			10.32"		11.28"	76.50	4.50	72.00
												44.00	5.00	39.00
												19.70	5.70	14.00
												15.00	6.00	9.00
												11.00	6.00	5.00
												9.00	6.00	3.00
												7.00	7.00	0

Using the curve No. 4(B)-1&2

with intensity for 48 Hr. duration = 0.3255"

Rainfall excess = 70%

ϕ - index = 30%

in Appendix No.XIV (a) to Appendix No.XIV (e).

4 (B).4.3 The Transfer Function:

This has been worked out in the following steps.

1. With the known values of catchment characteristics, as given in Table No.4 (B)-1, the value of catchment constants have been worked out, using Fig. No. 4 (B)-3 & 4 and Fig. No.'s 4 (B)-5,6 respectively.

2. With these established value of C_1 & C_2 the model parameters for each sub afea are computed using the equation Nos. 3.9 & 3.10 and are given in table No.4 (B)-5.

TABLE NO.4 (B)-5 Model Parameters of Choumahla Intermediate Sub-Basin & Its Sub-Area's:

Sub Basin / Sub area	Model Parameters		Catchment Constant	
	n	K	C_1	C_2
1	2	3	4	5
Choumahla	3	6.06	3.84	2.55
(a) Pat	3	7.10	3.84	2.55
(b) Choumahla	3	6.66	3.84	2.55

Similarly the model parameters for other intermediate sub basins are given in Appendix No. XIII.

3. With the established values of model parameters for each of the sub-areas, the instantaneous unit hydrograph have been worked out using equation

No.3.11, subesequently the unit hydrograph for each of the sub areas is computed and are given in Table No. 4 (B)-6.

Similarly the unit hydrograph for each sub areas of other intermediate sub basins are computed and given in Appendix No.XV.

TABLE NO. 4(B) 6 Unit Hydrographs for Sub-Areas Of Sub-Basin:

Hrs. / Sub Area	Unit Hydrograph Ordinate in Th. Cusecs									
	0	4	8	12	16	20	24	28	32	36
1	2	3	4	5	6	7	8	9	10	11
Sub area (1)	0	1.16	3.96	6.38	7.20	6.85	5.88	4.70	3.59	2.6
Sub area (2)	0	1.06	3.36	5.17	5.55	5.14	4.28	3.30	2.42	1.7

Hrs. / Sub Area	Unit Hydrograph Ordinate in Th. Cusecs									
	40	44	48	52	56	60	64	68	72	76
Sub area (1)	1.88	1.26	0.84	0.60	0.39	0.26	0.17	0.08	0.04	0
Sub area (2)	1.18	0.80	0.52	0.34	0.22	0.14	0.08	0.04	0.02	0

4 (B).4.4 Indentification of Model Parameters:

Knowing the rainfall excess and transfer function of each sub area of Choumahla Intermediate Sub-basin, the differential responses for each sub area are computed. These differential responses and the computed flow concentration of Pat sub basin, are superimposed, by providing the linear channel to Pat flows and response for 1st sub area of Choumahla intermediate sub basin, in such a manner, so that it can be matched agreeably with the observed record at the outlet of Choumahla intermediate sub basin. The comparison is given in Fig. No.4 (B)-7. Similarly for the responses for the Kalakhedi and the Nahargarh gauged intermediate sub-basin have been compared with the observed data and their outlets. A comparison are given in Fig.No.4 (B)-8 and Fig. No.4 (B)-9 respectively close agreement between two verify the model parameters for gauged intermediate sub-basins. Their computed direct runoff hydrograph and effective rainfall hydrographs have been given in Fig. No.4(B)-10 to Fig. No.4 (B)-12.

Ungauged intermediate sub basins (viz. Barkheda, Tumri and Gandhi Sagar) response model cannot be verified. Their direct runoff hydrograph and effective rainfall hyetograph are given in Fig. No.4 (B)-13 to Fig. No. 4 (B)-15.

4 (B).4.5 <u>Testing Of Model:</u>

For testing the model parameters, the data of the storm recorded in Aug.1977, is used. In-put function and model parameters for Transfer Function of Choumahla Intermediate sub-basin have been computed as discussed in the previous section 4 (B)-2 & 4 (B)-3.

The procedure for comparison of computed and observed responses is adopted as explained in section 4 (B)-4.4. A comparison of computed responses with observed responses at the outlet of Choumahla gauged intermediate sub basin is given in Fig. No.4 (B)-16. Similarly the comparison in computed and observed responses, for other gauge intermediate sub basin (viz. Kalakhedi and Barkheda) are given in Fig. No.4(B)-17 and Fig. No. 4 (B)-18. A close agreement between two, verify the model parameters of the gauged intermediate sub basin. Their direct runoff hydrographs are given in Fig. No.4 (B)-19 to Fig. No. 4(B)-21.

Ungauged intermediate sub basins (viz. Nahargarh and Gandhi Sagar) response model cannot be tested. Their direct runoff hydrograph and effective rainfall hydrographs are given in Fig. No.4 (B)-22 and Fig. No.4 (B)-23 respectively. Tumri ungauged intermediate sub-basin for this storm does not contribute any flow of water hence analysis could not be attempted.

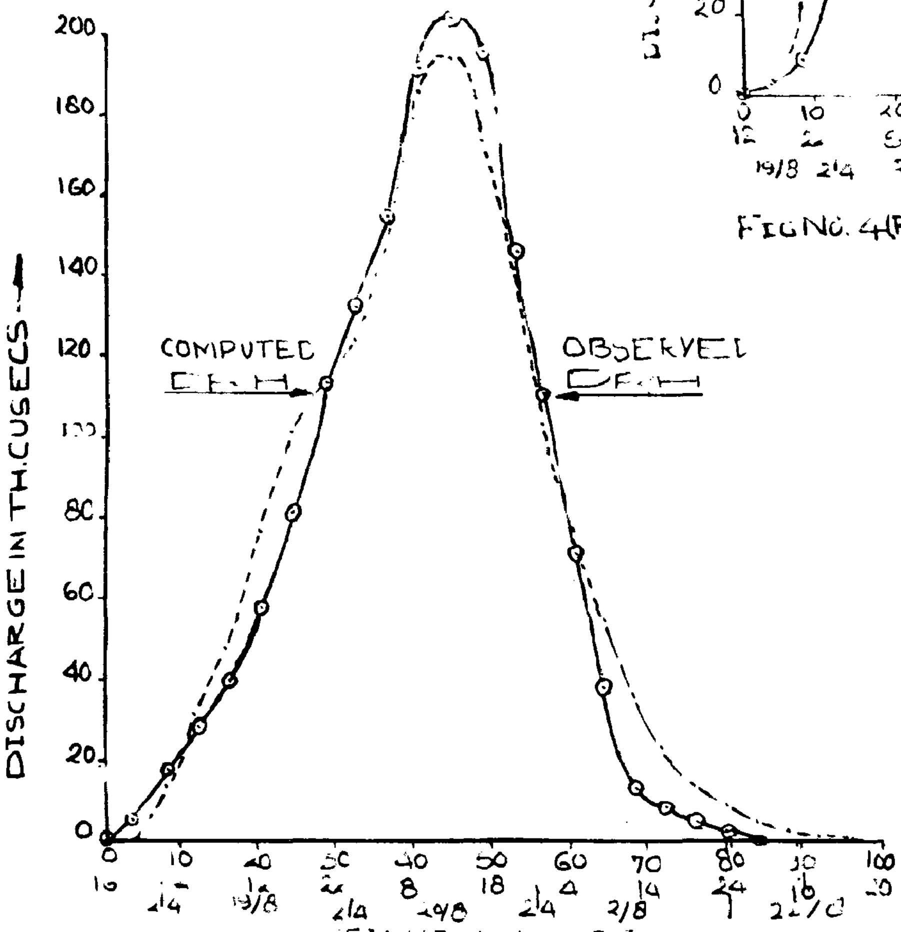


FIG. 4(B)-7. CHOUMAHLA G&D SITE

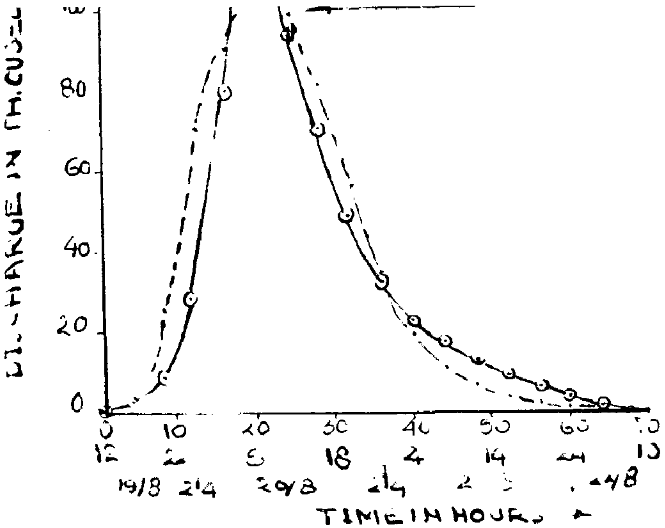


FIG NO. 4(B)-9 NAHARUAKH C.&D. SITE

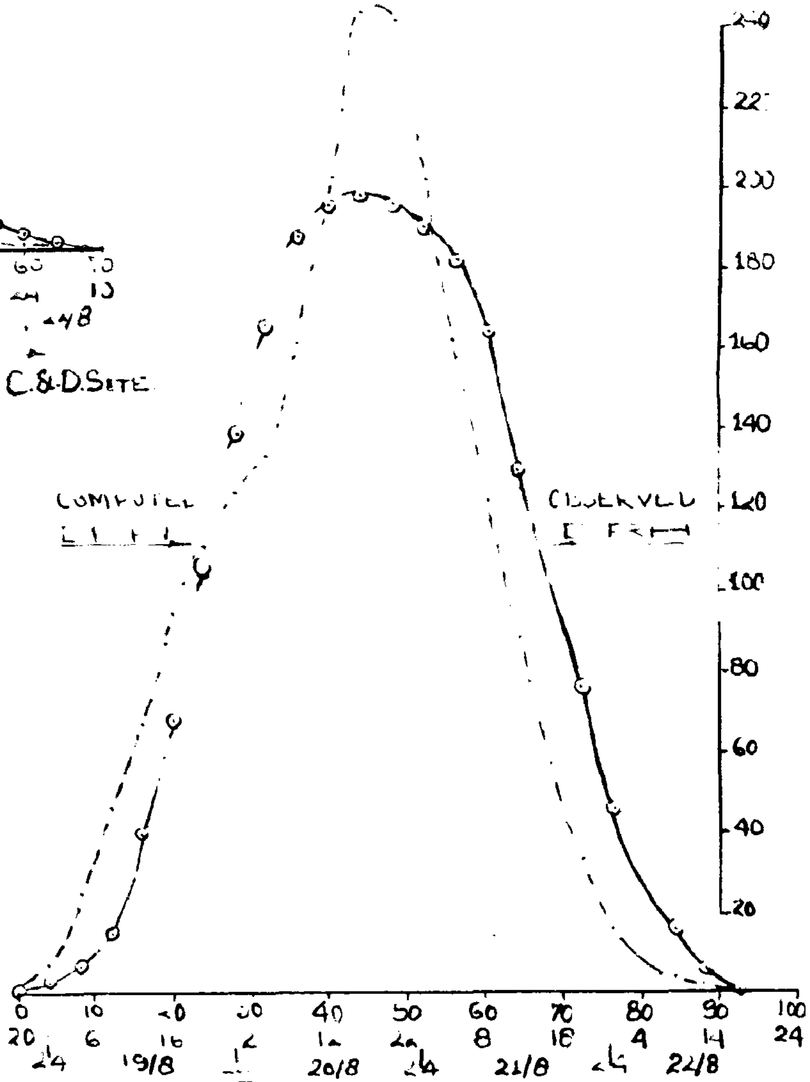
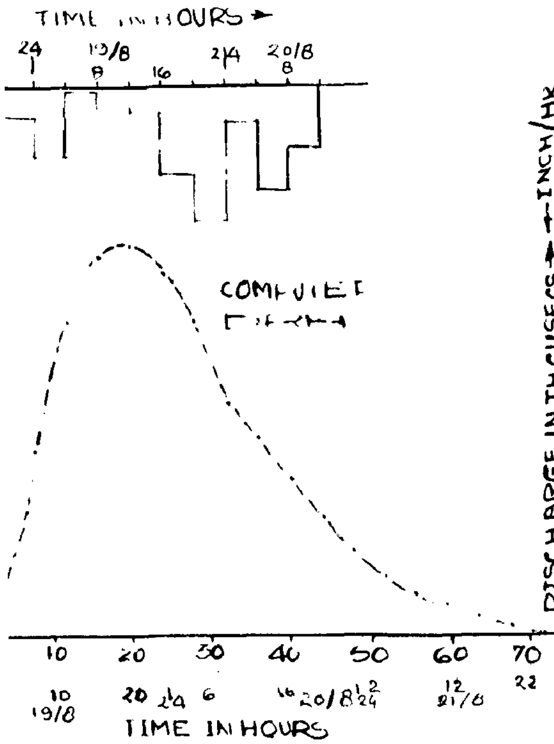


FIG NO. 4(B)-8 KALAKHELI C.&D SITE

IDENTIFICATION OF MODEL PARAMETERS FOR I.S.B's



NO. 4(B)-11 KALAKHEDI GAUGE SITE
(EXCLUDING MAHIDPUR FLOW)

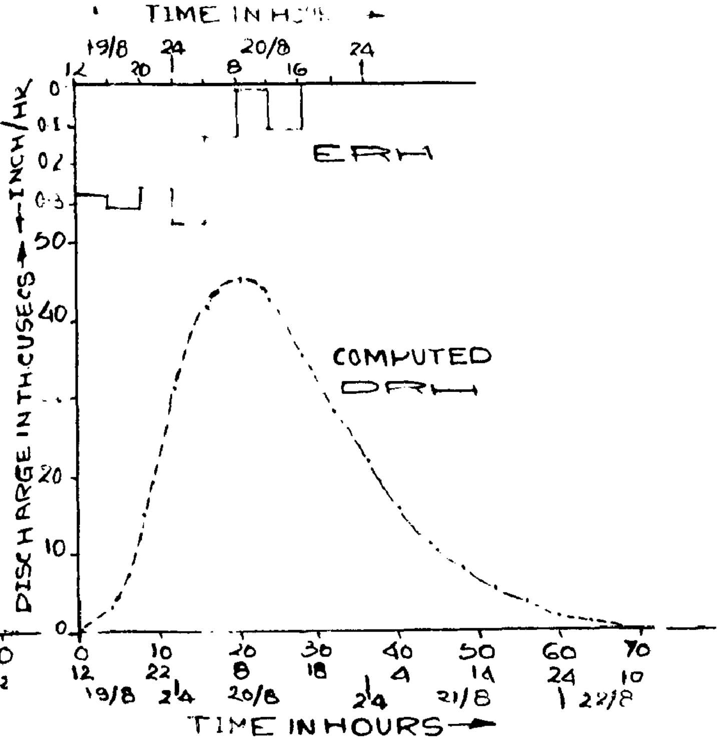


FIG.NO. 4(B)-12 NAHARGARH G&D SITE
(EXCLUDING MANDSAUR FLOW)

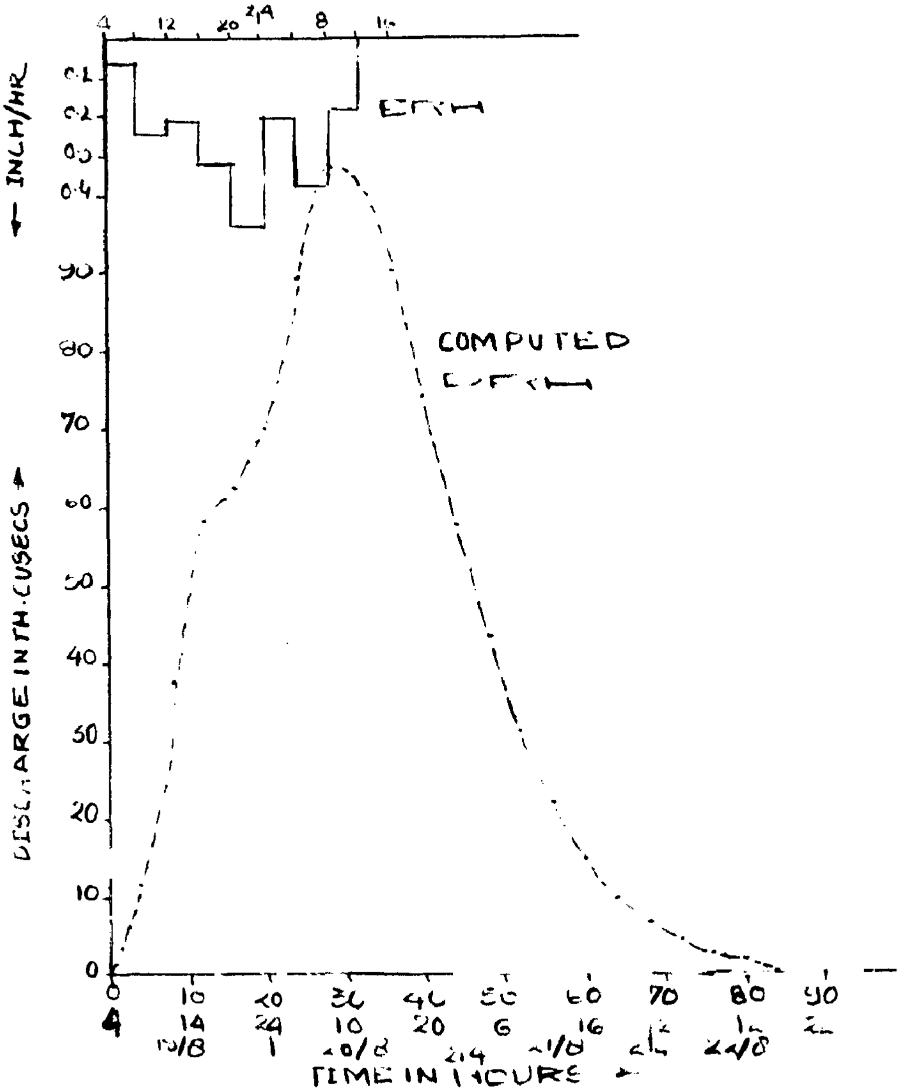


FIG.NO. 4(B)-10 CHOUMAHLA G.&D. SITE
(EXCLUDING PAT FLOW)

COMPUTATION OF DRH FOR GAUGED INTERMEDIATE SUB-BASINS

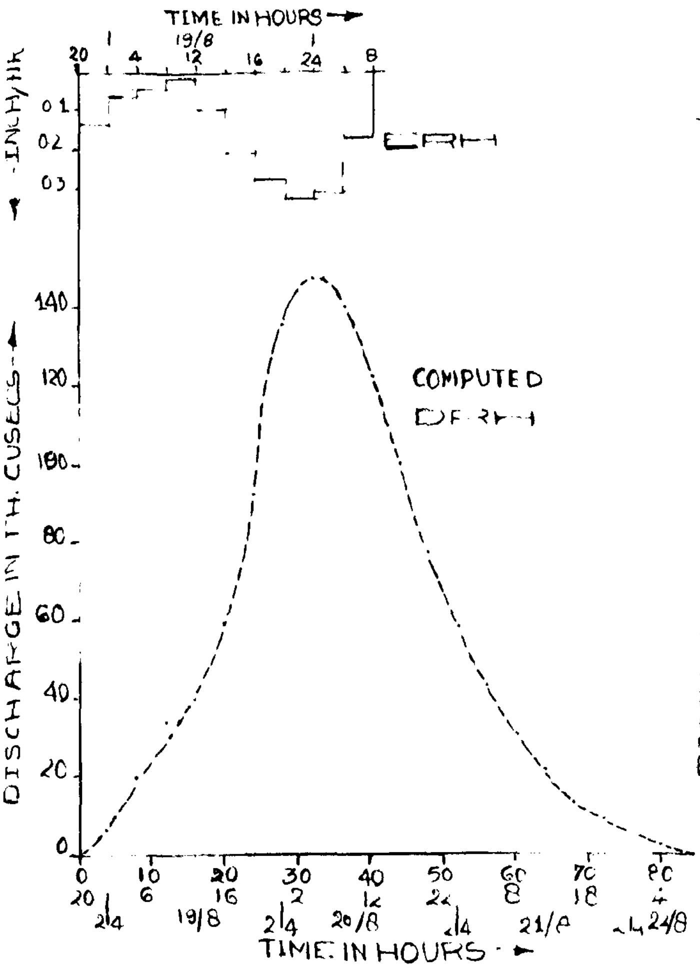


FIG No 4(b)-13 (BARKHEDA UNGAUGED SITE
(EXCLUDING NAGDA FLOW)

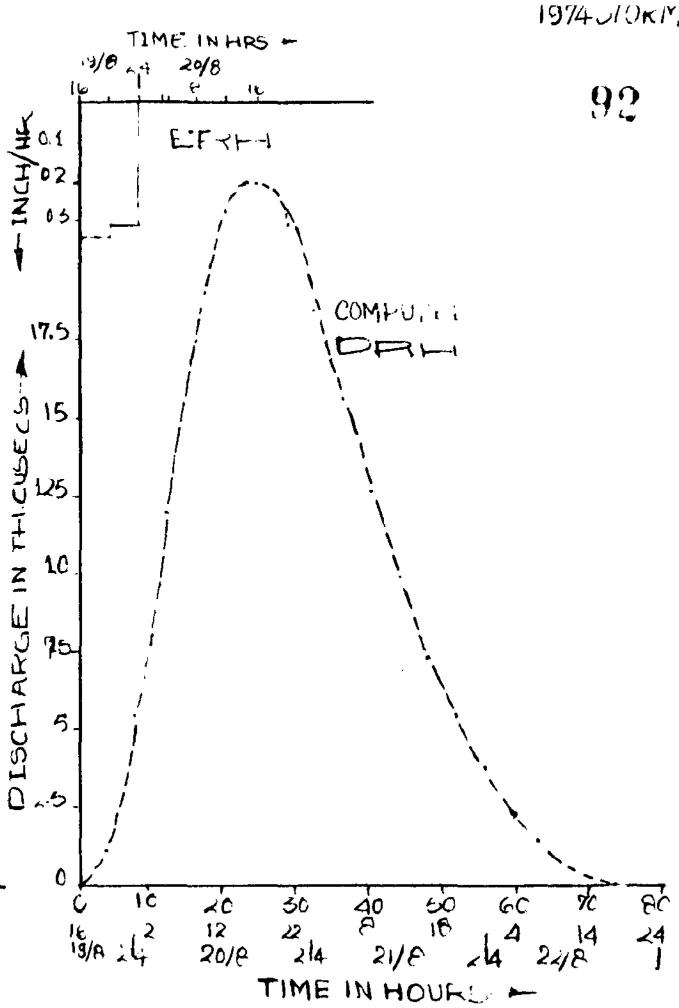


FIG NO. 4(B)-14 (TUMRI UNGAUGED SITE
(EXCLUDING CHALDU FLOW)

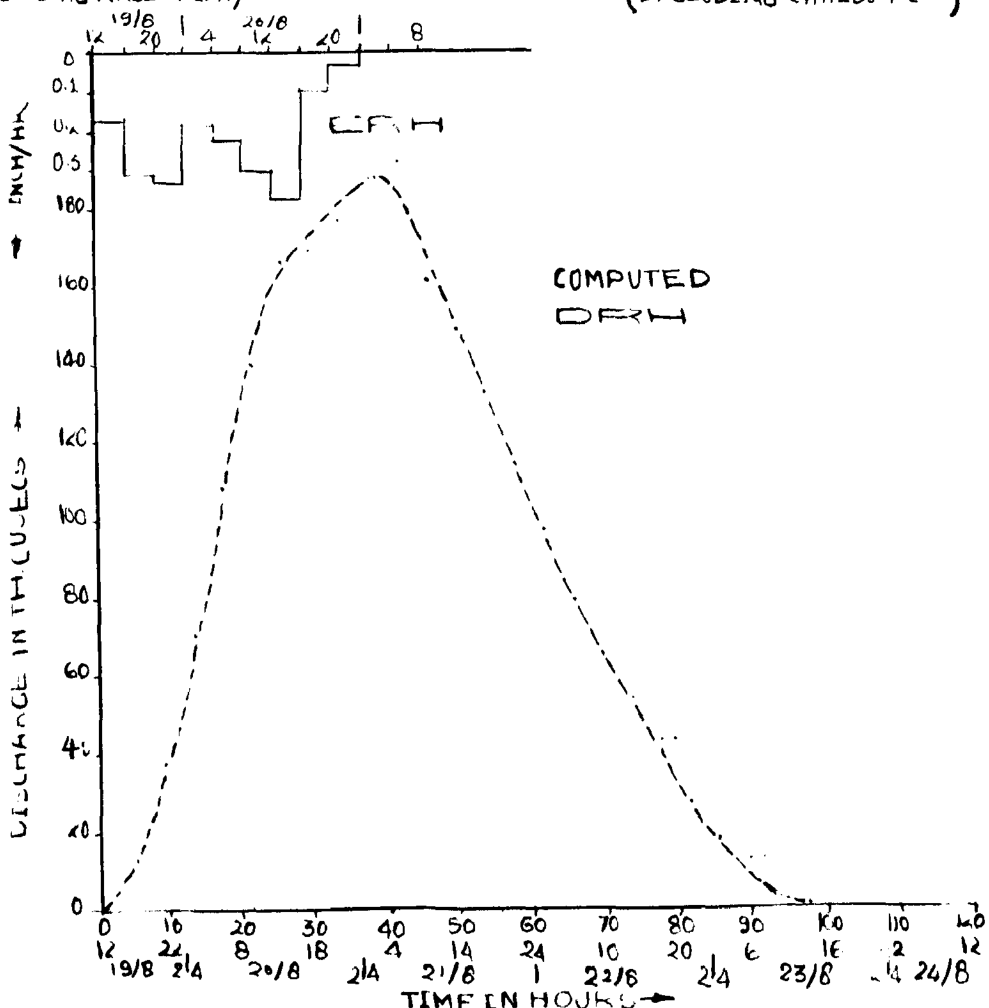


FIG NO. 4(B)-15 GANDHI SAGAR UNGAUGED SITE
(EXCLUDING OTHER U/S FLOW)

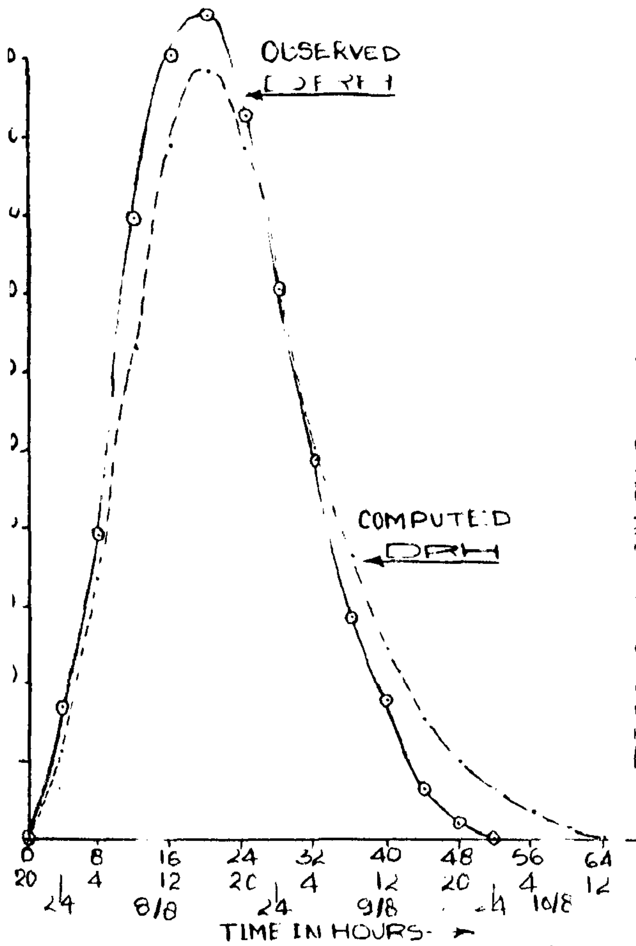


FIG No. 4(B)-16 CHOUMAHLA G&D SITE (1977 STORM)

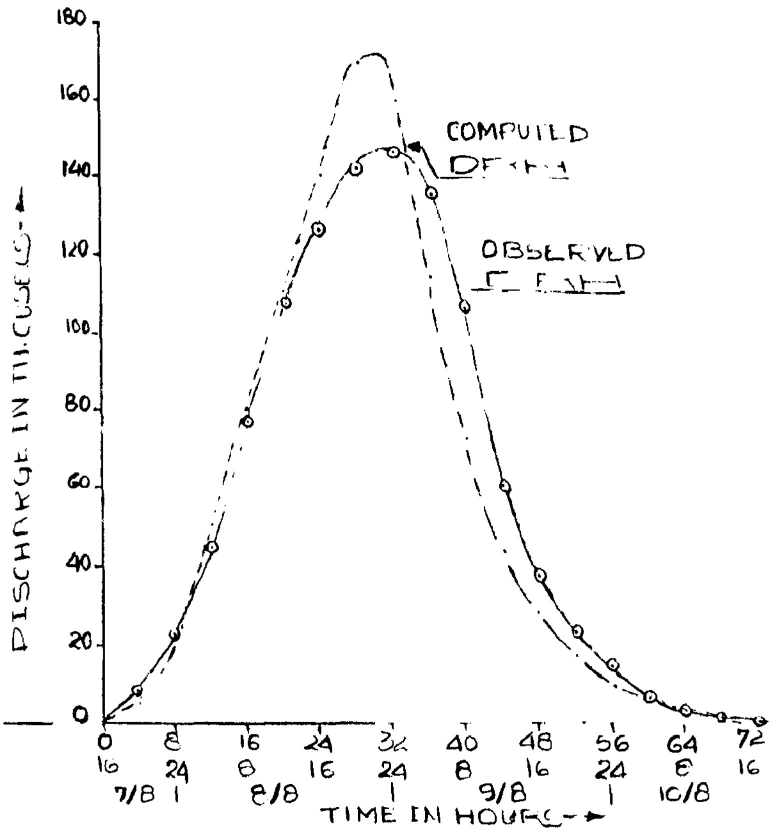


FIG No. 4(B)-17 KHALAKHEDI G&D SITE (1977 STORM)

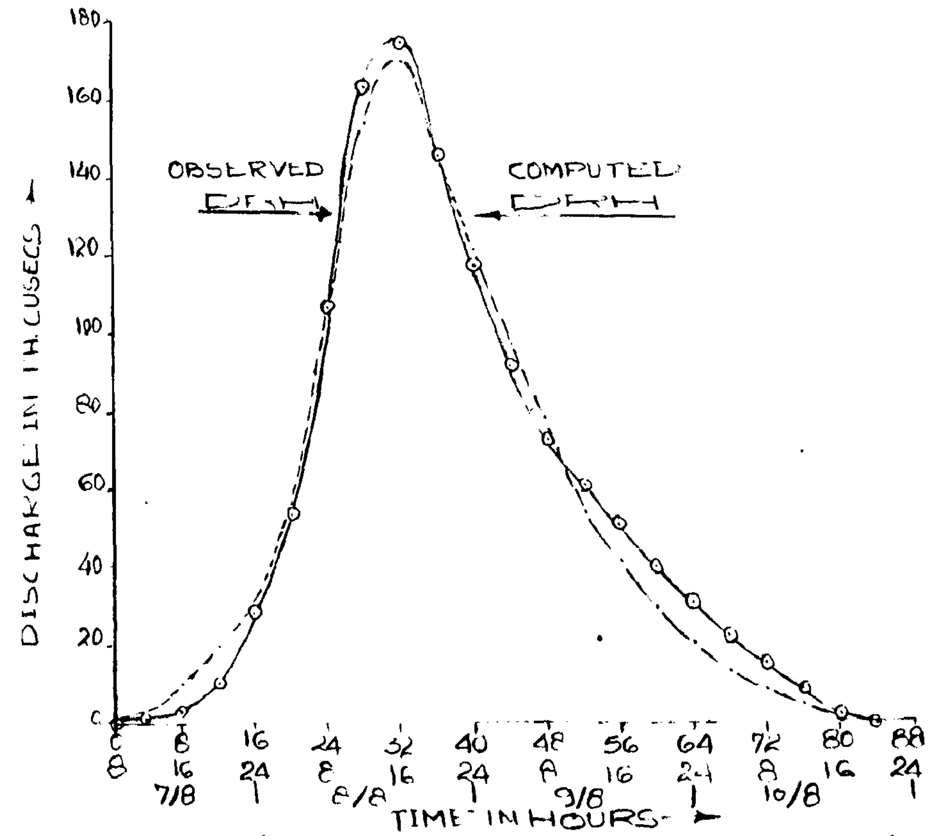


FIG No. 4(B)-18 BARKHEDA G&D SITE (1977 STORM)

TESTING OF MODELS BY 1977 STORM

(FOR INTERMEDIATE SUB-BASINS)

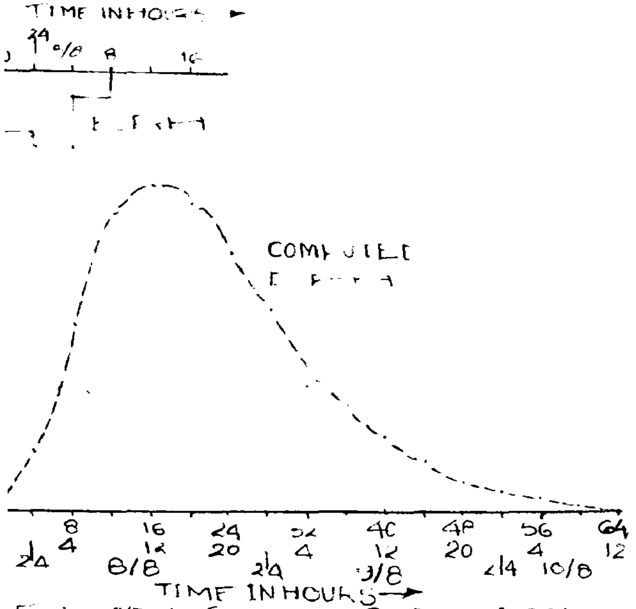


FIG. NO. 4(B)-19 CHOUMAHLA G.&D. SITE (ISB)

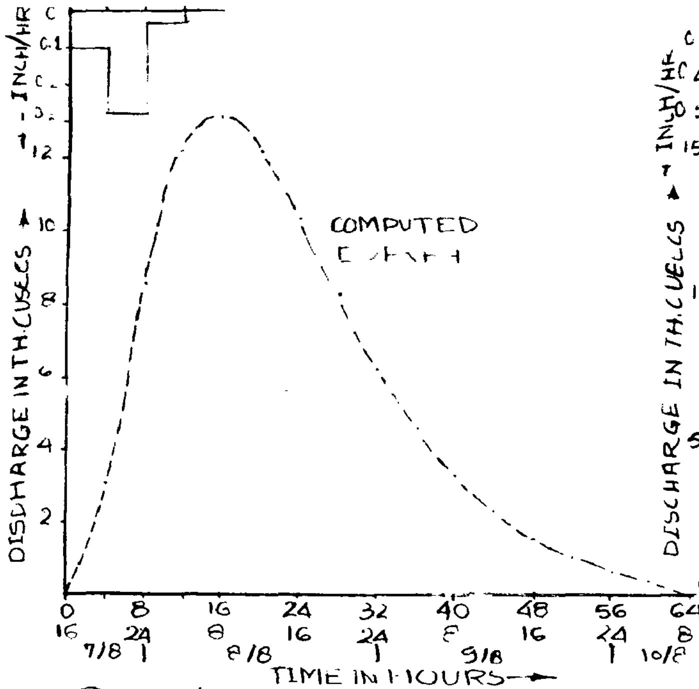


FIG. NO. 4(B)-22 NAHARGARH G.&D. SITE (ISB)

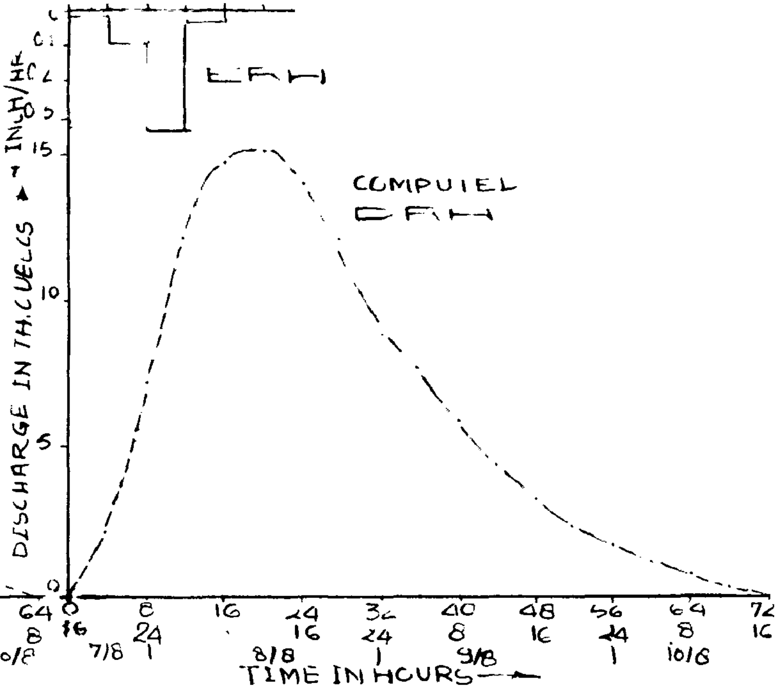


FIG. NO. 4(B)-20 KALAKHEDI G.&D. SITE (ISB)

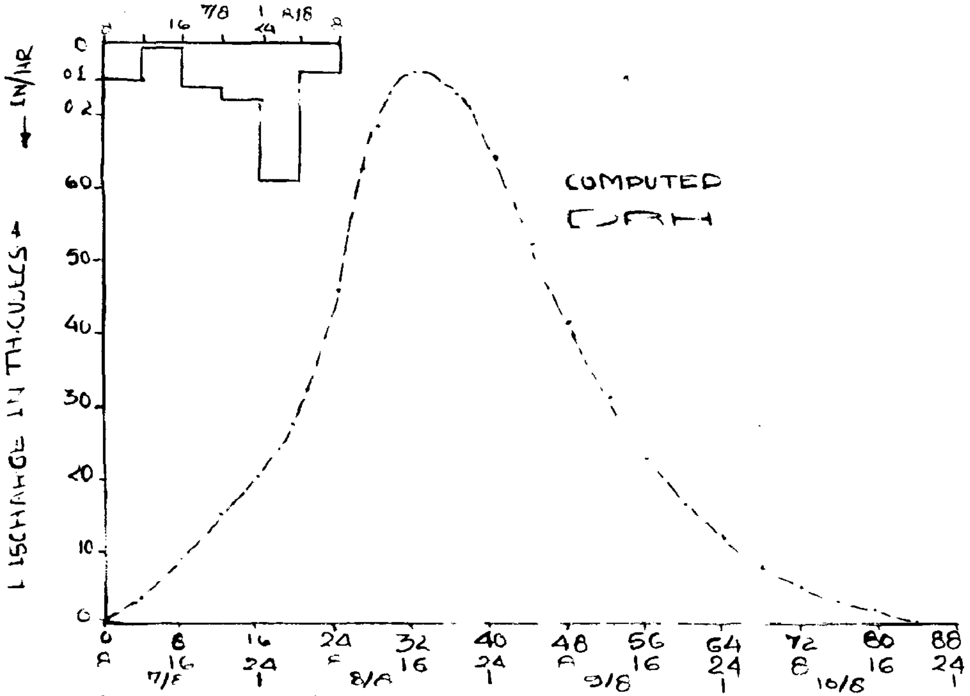


FIG. NO. 4(B)-21 BARKHEDA G.&D. SITE (ISB)

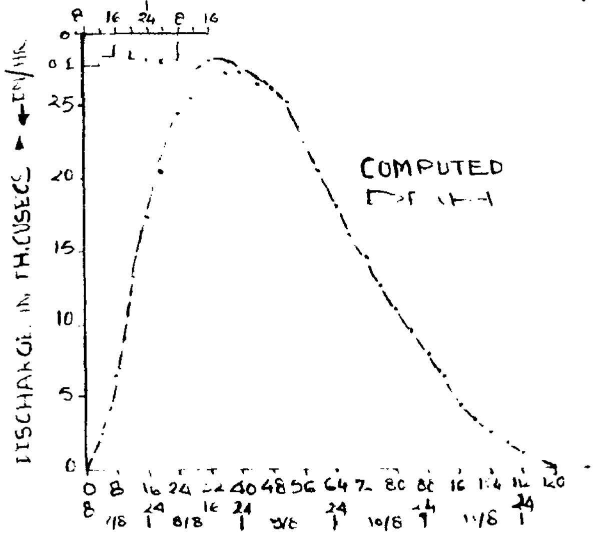


FIG. NO. 4(B)-23 GANDHISAGAR G.&D. SITE (ISB)

FIGURES SHOWING DRH & ERH FOR INTERMEDIATE-SUB-BASIN FOR 1977 STORM

CHAPTER -IV (C)

APPLICATION OF UNIT RESPONSE FLOOR ROUTING THEORY TO A LINEAR DISTRIBUTED PARAMETER MODEL

4(C).1 INTRODUCTION:

As explained earlier in Chapter 4(A), all the five sub-basins in the catchment are modelled and the computed and observed responses at the outlet are compared, To verify the model parameters.

Similarly the gauged and ungauged intermediate sub-basins in the catchment are modelled in Chapter 4(B) and the computed responses of gauged intermediate sub-basins are compared with the observed, by routing and super imposion the responses at the outlet of sub-basins to verify the model parameters.

Thus whole catchment has been modelled. In all, there are now eleven computed responses. The response from the Gandhi Sagar intermediate sub-basin will be super imposed. On the routed flow concentrations from the different outlets, to the Gandhi Sagar reservour to get the total flow at Gandhi Sagar. Flow concentration from the outlets of the following sub-basins and intermediate sub-basins, are routed upto Gandhi Sagar Reservoir.

1. Pat Sub Basin
2. Mahidpur Sub Basin
3. Nagda Sub-Basin
4. Mandsaur Sub Basin
5. Chaldu Sub Basin
6. Choumahla intermediate Sub-Basin
7. Kalakhedi intermediate Sub-Basin
8. Barkheda Intermediate Sub-Basin
9. Nahargarh intermediate Sub-Basin
10. Tumri Intermediate sub-bas:

4(C) 2 APPLICATION OF UNIT RESPONSE

The unit Response theory which has been discussed in section 2.4 & 3.5, the application of which involve the steps:

i) Analysis of the inflow hydrograph: which is to be routed.
ii) Computation of the Unit response
iii) The travel time of leading edge
iv) Routing of inflow hydrograph
v) Testing of unit response parameters.

In the present Chapter, the application of unit response theory for Pat Sub-basin is discussed in detail. Similar applications are extended to all other sub-basins and intermediate sub-basins and their findings are detailed in the appendices, mentioned in subsequent sections.

4(C).2.1 The Inflow Hydrograph

The inflow hydrograph is the computed response at the outlet of Pat sub-basin, which has been computed in Chapter 4(A) and is given in Fig. No. 4(A)-3. The hydrograph is divided into a series of flow elements as shown in Fig.No.4(c)-11. The duration of each flow element is same as the duration of Unit Response. Similarly the other inflow hydrographs are shown in Fig. No. 4(C)-13, 4(C)-15, 4(C)-17, 4(C)-19 and Fig. No. 4(C)-21 to Fig. No. 4(C)-25.

4(C).2.2 Formulation Of Unit Response:

Formulation of Unit Response for Pat Sub-Basin is carried in the following steps:

(a) Formation of Translation hydrograph
(b) Routing of translation hydrograph
(c) Derivation of Unit Response.

4(C).2.2(a) Translation Hydrograph

Formation of Translation hydrograph requires the knowledge of storage coefficient 'k' time base W and duration D.

Evaluation of 'k' require the knowledge of recession coefficient(r) and time interval Δt which can be from the recession limb of inflow hydrograph at Pat Sub-basin as explained in section 3.5. The storage coefficient is calculated by equation 3.12.

In the present case the value of time base is adopted as 0.5 K. Duration 'D' is adopted 4 Hr.

Knowing all the parameters the translation hydrograph ordinates at one hour interval are computed. The findings for Pat Sub-basin are given in Table No. 4(C)-1.

TABLE NO. 4(C)-1

TRANSLATION HYDROGRAPH AT PAT SUB-BASIN

Name of Basin	Value of K(Hrs)			W Hr	D Hr	Vol. of TH	Translation hydrograph ordinate at					
	r	t	k				0 Hr	1 Hr	2Hr	3Hr	4Hr	5Hr
1	2	3	4	5	6	7	8	9	10	11	12	13
Pat	0.673	4	10.08	0.5K 5 Hr.	4	4	0	0.80	1.60	1.07	0.53	0

The details of the working procedure of Translation hydrograph for other sub-basin and intermediate sub-basins are given in Appendix No. XVI.

4(C)2.2(b) Routing Of Translation Hydrographs:

As explained in section 3.5 the translation hydrograph is routed through a linear reservoir to obtain the instantaneous unit response. The routing constants (C_0 , C_1 , C_2) have been worked out by equation Nos. 2.26,2.27 & 2.28 respectively. The values for Pat are , $C_0 = 0.05$, $C_1 = 0.05$, $C_2 = 0.90$. Knowing the Routing constants the routing equation for Pat hydrograph is developed by equation No. 3.14.

$$Q_2 = 0.05\ I_1 + 0.05\ I_2 + 0.90\ Q_1$$

Routing period 't' is one hour. The routing of translation hydrograph is followed by assuming $I_1 = I_2 = I$ and initial value of Q_2 is equal to zero. Hence the above equation takes the form

$$Q_2 = 0.1I + 0.90\ Q_1 \qquad \ldots \quad \ldots \qquad 4(C)\text{-}1$$

Similar procedure is adopted for other inflow hydrograph for sub-basin and intermediate sub-basin , for working the routing equation, which are given in Appendix XVI.

Knowing the routing equation, the ordinates of translation hydrographs are routed to get the instantaneous unit response. The working procedure is given in Table No. 4(C)-2.

TABLE NO. 4(C)- 2

ROUTING OF TRANSLATION HYDROGRAPH FOR PAT SUB-BASIN

$$Q_2 = 0.1\ I + 0.9\ Q_1$$

Hours	Input cusecs	0.1I	$0.9Q_1$	Q_2 IUR cusecs	U.R. for 4 hour cusecs	U.R. for 8 Hours: 4 Hr. lag by 4 Hr.	U.R. for 8 Hours: cusecs
0	0	0	0	0	0		0
1	0.80	0.08	0	0.08	0.04		
2	1.60	0.16	0.07	0.23	0.16		0.16
3	1.07	0.11	0.21	0.32	0.27		
4	0.53	0.05	0.29	0.34	0.33	0	0.33
5	0	0	0.30	0.30	0.32	0.04	
6			0.27	0.27	0.29	0.16	0.45
7			0.25	0.25	0.26	0.27	
8			0.22	0.22	0.24	0.33	0.57
9			0.20	0.20	0.21	0.32	
10			0.18	0.18	0.19	0.29	0.48
11			0.16	0.16	0.17	0.26	
12			0.15	0.15	0.15	0.24	0.39
13			0.13	0.13	0.14	0.21	
14			0.12	0.12	0.13	0.19	0.32
15			0.11	0.11	0.11	0.17	
16			0.10	0.10	0.10	0.15	0.25
17			0.09	0.09	0.09	0.14	
18			0.08	0.08	0.08	0.13	0.21
19			0.07	0.07	0.07	0.11	
20			0.06	0.06	0.07	0.10	0.17
21			0.06	0.06	0.06	0.09	
22			0.05	0.05	0.05	0.08	0.13
23			0.05	0.05	0.05	0.07	
24			0.04	0.04	0.04	0.07	0.11

Similarly the routing of Translation hydrographs are made and given in Appendix No's XVII (a) to Appendix No XVII(e).

4(C)2.2(C) The Unit Response:

The duration of instantaneous unit response (worked out in previous section) is theoritically infinitesmally small. It is not possible to perform this calculation directly. Therefore it is to be transformed into unit response for required duration as explained in Section 2.4.3.

The unit response worked above is of 4 hours duration which is to be transformed into a desired duration of 8 hours The unit response for Pat sub-basin is given in Table No. 4(C)-2 and Fig. No. 4(C)-1.

Similarly the unit responses for 8 hours, have been worked out for other sub-basins and intermediate sub-basins The working procedure is given in Appendix No. XVII(a) to Appendix No. XVII (i). The corresponding unit responses are given in Fig. No. 4(C)-2 to Fig. No. 4(C)-10.

4(C).2.3 Travel Time Of Leading Edge:

In the present study, the travel time of leading edge of inflow hydrographs have been found to be insignificant as the storm have traversed in the direction of flows.

4(C).2.4 Routing Of Inflow Hydrograph:

To obtain the responses of each flow element the ordinates of the unit response for Pat Sub-Basin are multiplied with the ratio of input volume to unit flow element.

As the leading edge travel time is insignificant, all the flow responses are summed up as per their respective time period. The working procedure is given in Table No. 4(C)-3

Hours	U R f d		Total routed DRH Col. 3to13 Th.Cu.	Started from 20HR	Intermediate sub-Basin DRH Th.Cu.	Total DRH at Choumahla from Pat	Observed DRH at Choumahla Th.cu.	Time Hrs.	Date
1			14	15	16	17	18	19	20
0			0	0		0	0	16	18.8.74
4			4.95	0		0	4.50	20	
8			8.55	4.95		4.95	17.50	24	
12			16.73	8.55	0	8.55	29.00	4	
16			24.42	16.73	11.95	28.68	40.00	8	
20			31.44	24.42	37.90	62.32	58.00	12	
24			36.56	31.44	58.32	89.76	82.00	16	
28			43.35	36.56	62.60	99.16	110.00	20	
32			47.58	43.35	70.01	103.35	132.00	24	
36			60.09	47.58	89.34	136.92	155.00	4	20/8
40			67.39	60.09	103.38	163.47	192.00	8	
44			72.61	67.39	101.96	169.35	205.00	12	
48			74.17	72.61	90.32	162.93	197.00	16	
52			67.18	74.17	74.29	148.46	146.00	20	
56			59.47	67.18	57.76	124.94	115.50	24	
60			48.30	59.47	43.10	102.57	72.00	4	21/8
64			35.85	48.30	31.21	79.51	39.00	8	
68			27.81	35.85	21.98	57.83	14.00	12	
72			17.55	27.81	14.65	42.46	9.00	16	
76			13.38	17.55	9.61	27.16	5.00	20	
80			7.52	13.38	6.78	20.16	3.00	24	
84	0		5.48	7.52	4.04	11.56	0	4	22/8
88	0		3.04	5.48	2.76	8.24		8	
92	0		2.08	3.04	1.76	4.80		12	
				2.08	0	2.08		16	
						0		20	

TABLE NO. 4(c) - 3

CHANNEL ROUTING OF PAT DRH TO GANDHI SAGAR SITE

Hours	Unit Response for 8Hrs cusecs	Flow elements of Computed D.R.H. at Pat in Thousand cusecs. No. 1 15 Th. cu.	No. 2 36Th cu.	No. 3 45Th cu.	No. 4 56 Th cu.	No. 5 84Th cu.	No. 6 81 Th. cu.	No. 7 51 Th cu.	No. 8 24 Th. cu.	No. 9 10 Th cu.	No. 10 4 Th cu.	No. 11 1.5 Th cu.	Total routed DRH Col. 3to13 Th.Cu.	Started from 20HR	Intermediate sub-Basin DRH Th.Cu.	Total DRH at Choumahla from Pat	ObservedDRH at Choumahla Th.cu.	Time Hrs.	Date
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	0											0	0		0	0	16	18.8.7
4	0.33	4.95											4.95	0		0	4.50	20	
8	0.57	8.55	0										8.55	4.95		4.95	17.50	24	
12	0.39	5.85	11.88										16.73	8.55	0	8.55	29.00	4	
16	0.26	3.90	20.52	0									24.42	16.73	11.95	28.68	40.00	8	
20	0.17	2.55	14.04	14.85									31.44	24.42	37.90	62.32	58.00	12	
24	0.11	1.65	9.36	25.65	0								36.56	31.44	58.32	89.76	82.00	16	
28	0.08	1.20	6.12	17.55	18.48								43.35	36.56	62.60	99.16	110.00	20	
32	0	0	3.96	11.70	31.92	0							47.58	43.35	70.01	103.35	132.00	24	
36			2.88	7.65	21.84	27.72							60.09	47.58	89.34	136.92	155.00	4	20/8
40			0	4.95	14.56	47.88	0						67.39	60.09	103.38	163.47	192.00	8	
44				3.60	9.52	32.76	26.73						72.61	67.39	101.96	169.35	205.00	12	
48				0	6.16	21.84	46.17	0					74.17	72.61	90.32	162.93	197.00	16	
52					4.48	14.28	31.59	16.83					67.18	74.17	74.29	148.46	146.00	20	
56					0	9.24	21.06	29.07	0				59.47	67.18	57.76	124.94	115.50	24	
60						6.72	13.77	19.89	7.92				48.30	59.47	43.10	102.57	72.00	4	21/8
64						0	8.91	13.26	13.68	0			35.85	48.30	31.21	79.51	39.00	8	
68							6.48	8.67	9.36	3.30			27.81	35.85	21.98	57.83	14.00	12	
72							0	5.61	6.24	5.70	0		17.55	27.81	14.65	42.46	9.00	16	
76								4.08	4.08	3.90	1.32		13.38	17.55	9.61	27.16	5.00	20	
80								0	2.64	2.60	2.28	0	7.52	13.38	6.78	20.16	3.00	24	
84									1.92	1.70	1.56	0.50	5.48	7.52	4.04	11.56	0	4	22/8
88									0	1.10	1.04	0.90	3.04	5.48	2.76	8.24		8	
92										0.80	0.68	0.60	2.08	3.04	1.76	4.80		12	
														2.08	0	2.08		16	
																0		20	

Note: (1) Col. 2 taken from Table No. 4(c)-2 Fig.No. 4(c)-1).

(2) Col. 3 to Col. 13 taken from Fig.No. 4(c)-11

(3) Col. 16 taken from Fig.No. 4(B)-10

(4) Col. 18 is taken from Table No. 4(B)-2

The resultant will be the outflow hydrograph at Gandhi Sagar.

Similarly Routing inflow hydrograph for other basins and intermediate basins are carried out. The working procedure is given in Appendix No. XVIII(a) to Appendix No. XVIII(i)

4(C) 2.5(1) Testing Of Unit Response Parameters:

The Unit Response Parameter of Pat sub-basin is tested at the outlet of Choumahla intermediate sub-basin. For the purpose, the Choumahla intermediate flow response (which has been verified and tested) is added to the routed direct runoff hydrograph at Choumahla from Pat site, and compared with the observed inflow hydrograph at Choumahla (which include the flow upto Choumahla.) Working details are given in Table No. 4(C)-3 and comparison is given in Fig. No. 4(c)-12. Close agreement between two verify the unit response parameters for Pat Sub basin.

Similarly the unit response parameters for Mahidpur and Mandsaur have been tested. The comparison between computed and observed are shown in Fig. No. 4(C)-16 and Fig. No. 4(C)-18. Working details are given in appendix No. XVIII(a) and Appendix No. XVIII(c).

The Unit response parameter for intermediate sub-basin can not be verified. Their inflow and outflow hydrographs are shown in Fig. No. 4(C)-21 to Fig. No. 4(C)-25.

4(C) 2.5(b) Testing Of Unit Response Parameters For The Storm Recorded In August 1977.

The inflow hydrographs of gauged sub-basins (viz. Pat, Mahidpur, Nagda, Mandsaur & Chaldu) as given in Fig. No. 4(A)-8 to Fig.No. 4(A)-12 are converted into series of flow elements which are given in Fig. Nos. 4(C)-26, 4(C)-28, 4(C)-30, 4(C)-32 and Fig. No. 4(C)-34 respectively.

Similarly the computed Inflow hydrographs for intermediate sub-basins as given in Fig. Nos. 4(B)-19 to Fig. Nos. 4(B)-23 are divided into series of flow elements, which are given in Fig. Nos. 4(C)-35 to Fig. No. 4(C)-38.

Using the ordinate of unit responses given in Fig. No. 4(C)-1 to 4(C)-10, ~~one~~ are multiplied with the ratio of input volume to the unit flow element to obtain the responses of each flow element.

Unit response parameters of Pat, Mahidpur and Nagda are verified and tested as it has been done for First storm. The comparison is shown in Fig. 4(C)-27, 4(C)-29 and 4(C)-31.

The outflow hydrographs for intermediate sub-basins are shown in Fig. No. 4(C)-35 to Fig. No. 4(C)-38. There is no contribution from Tumri intermediate sub-basin.

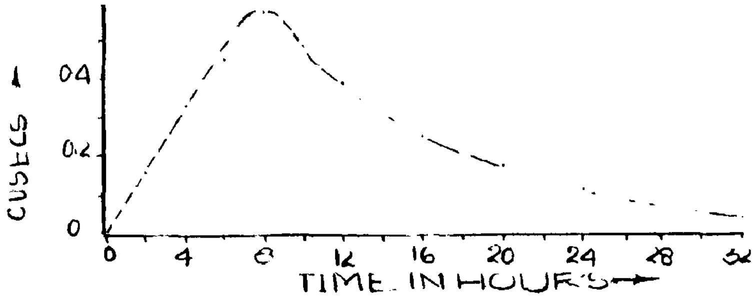


FIG NO. 4(C)-1. PAI G&D SITE

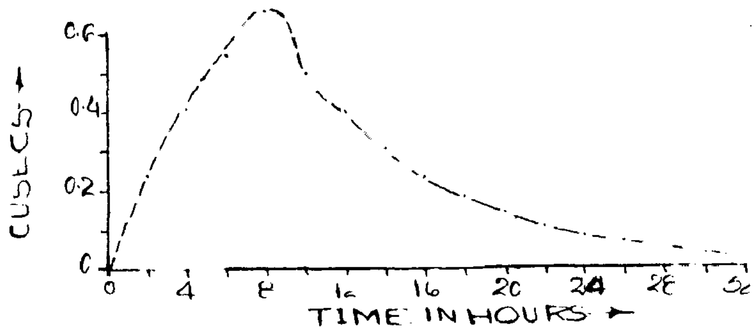


FIG NO. 4(C).2 MAHIDPUR G&D SITE

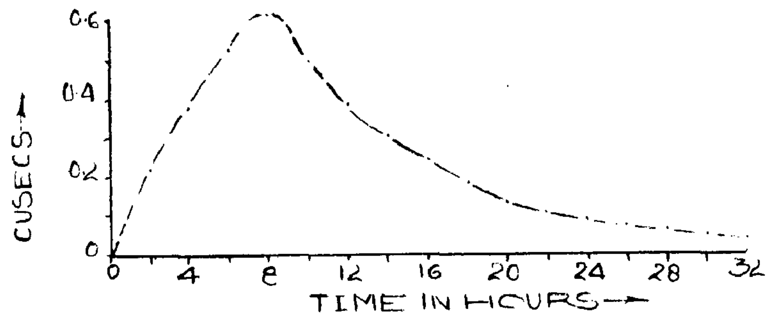


FIG. NO. 4(C).5 NAGDA G&D SITE.

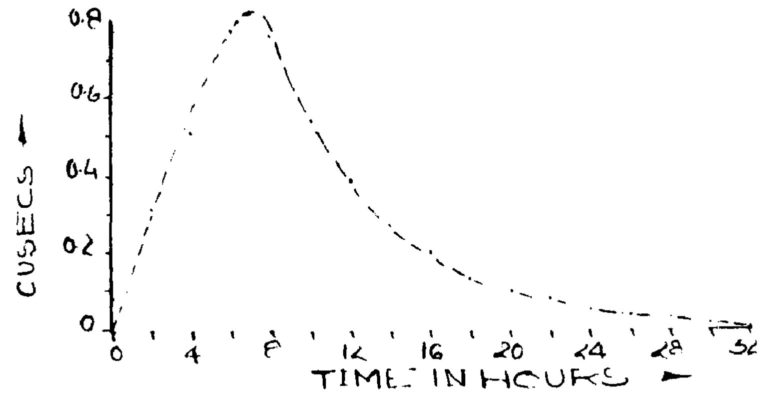


FIG. NO. 4 (C).4 MANDSAUR G&D SITE

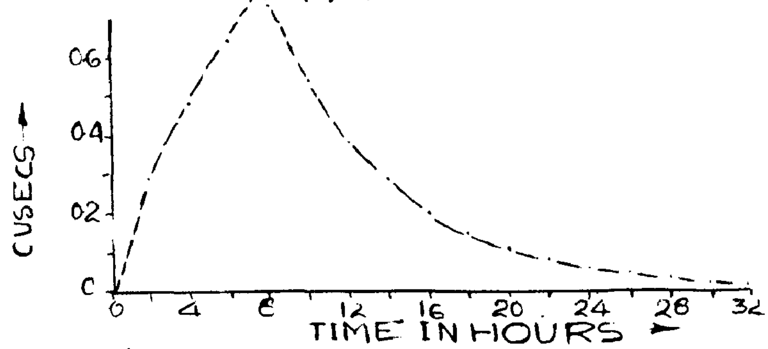


FIG. NO. 4 (C)5 CHALDU-G.&D. SITE

UNIT RESPONSE FOR 8 HOURS FOR DIFFERENT SUB-BASINS

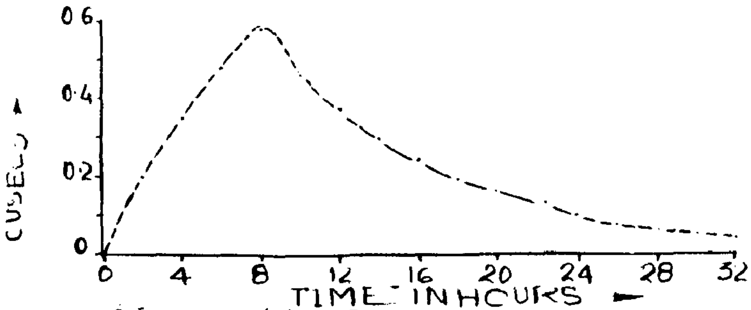


FIG No. 4(C).6 CHOUMAHLA ISB

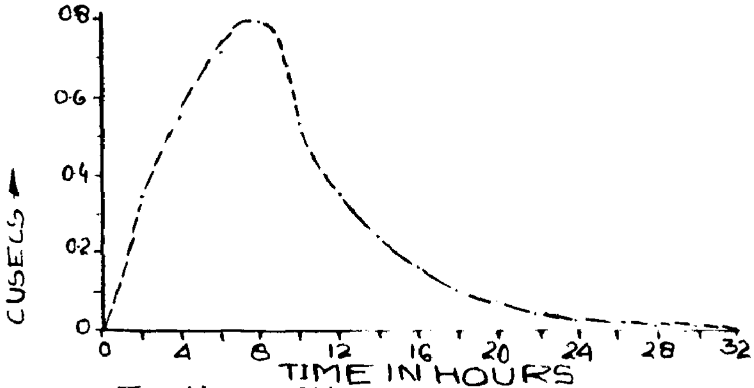


FIG. No. 4(C).7 KALAKHEDI ISB

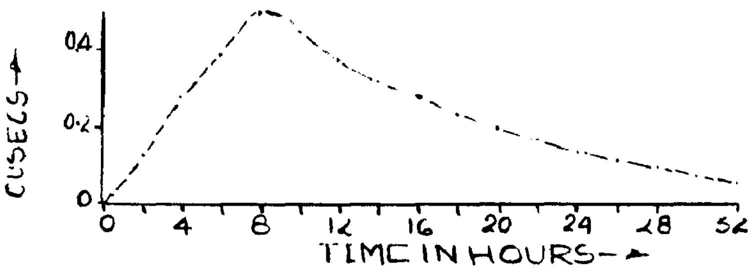


FIG. No. 4(C).8. DARKHEDA ISB

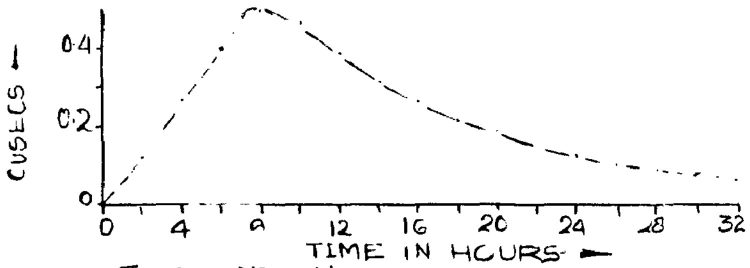


FIG No 4(C).9 NAHARGARH ISB

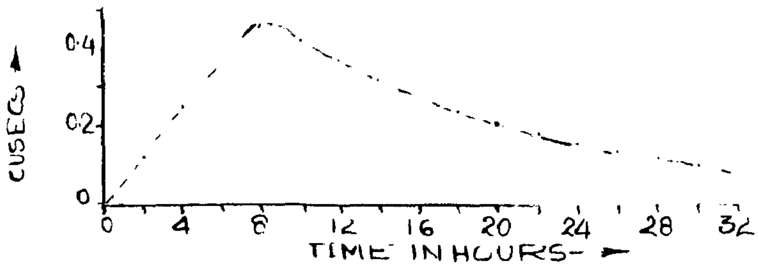
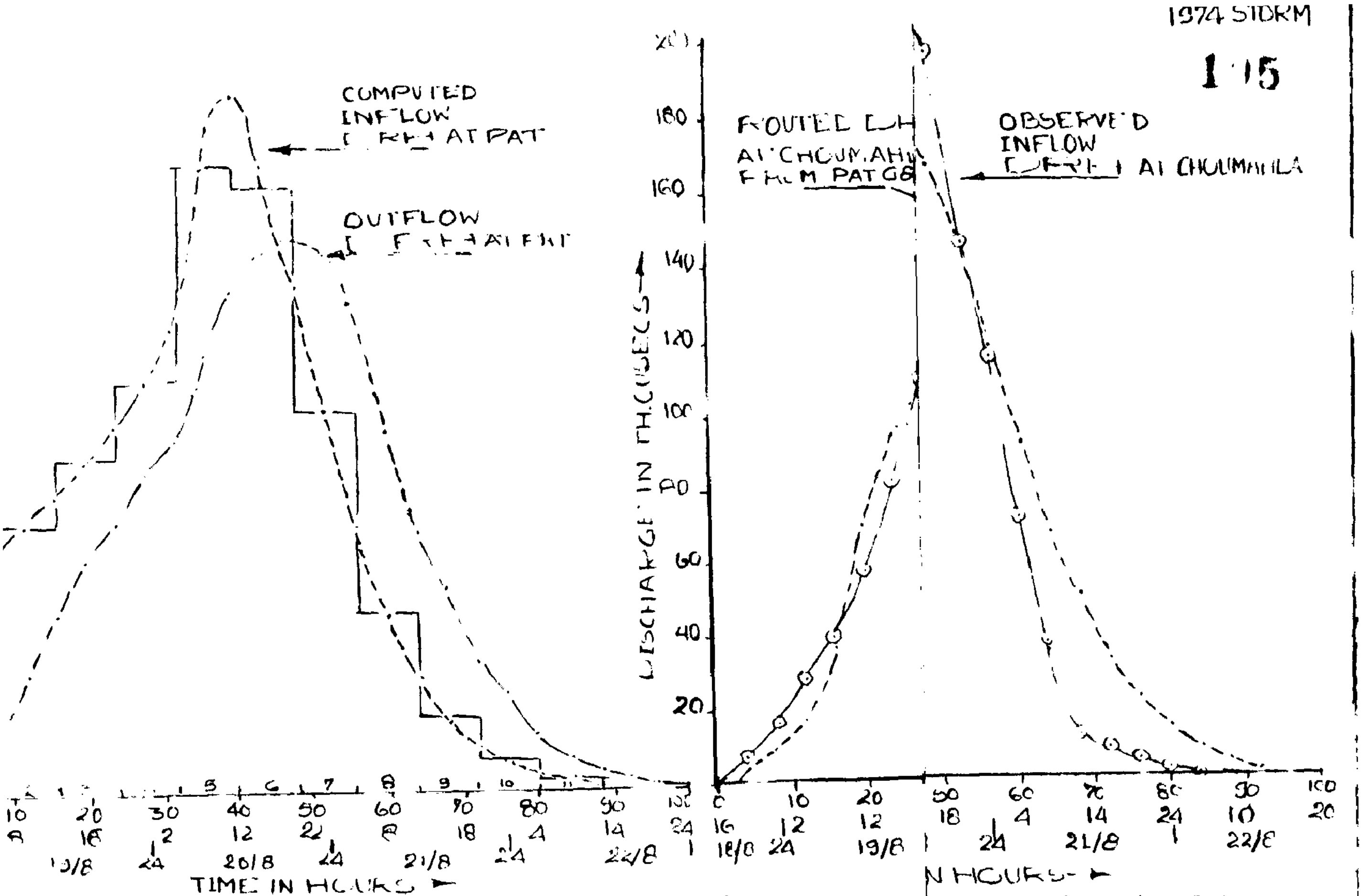


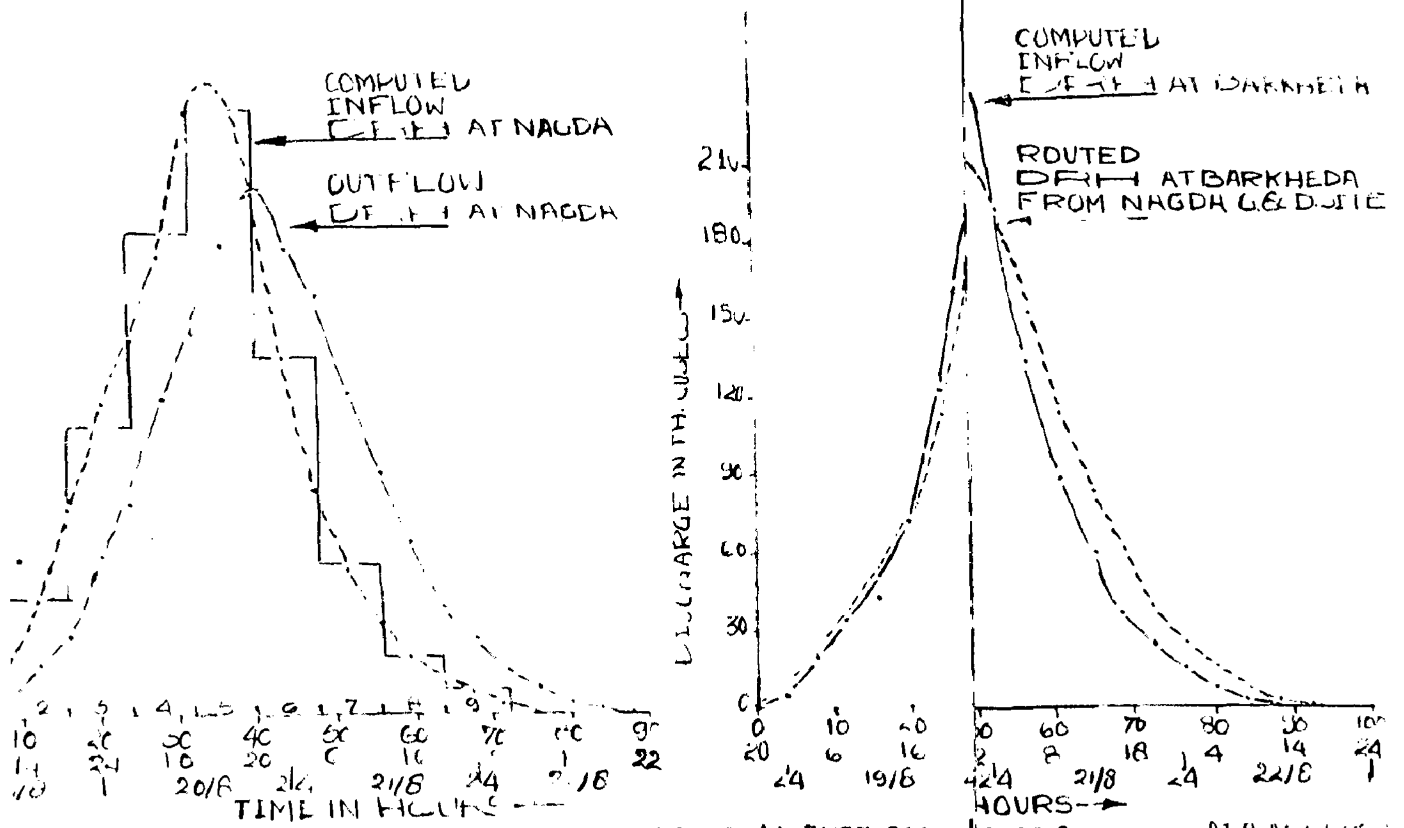
FIG. No 4(C).10 TUMKI ISB

UNIT RESPONSES FOR 8 HOURS FOR DIFFERENT INTERMEDIATE SUB-BASINS



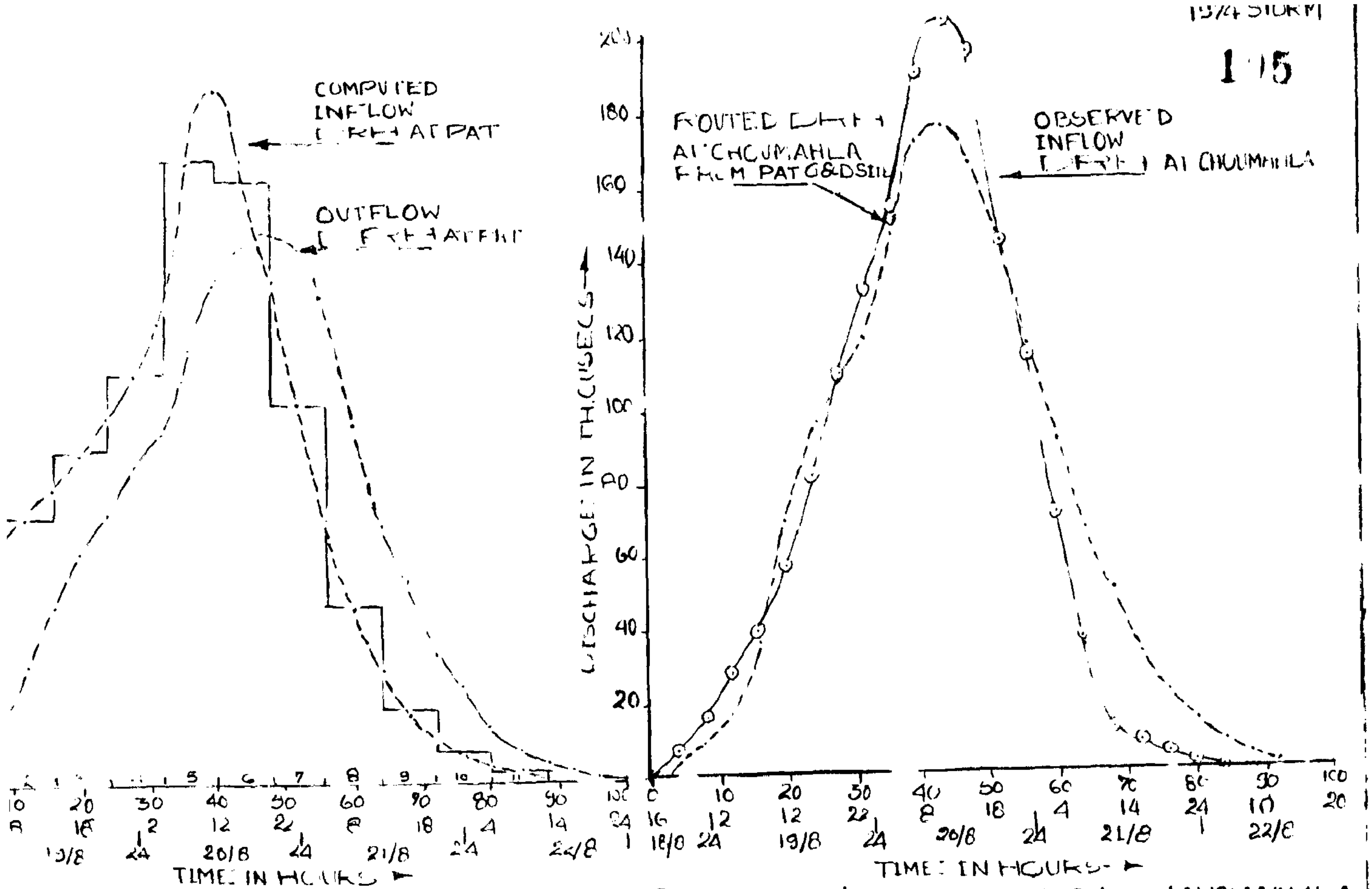
1- INFLOW AND OUTFLOW DRH AT PAT   12- INFLOW and OUTFLOW DRH at CHOUMAHLA

FIG NO 4(C)   IDENTIFICATION OF PAT UNIT RES PARAMETERS



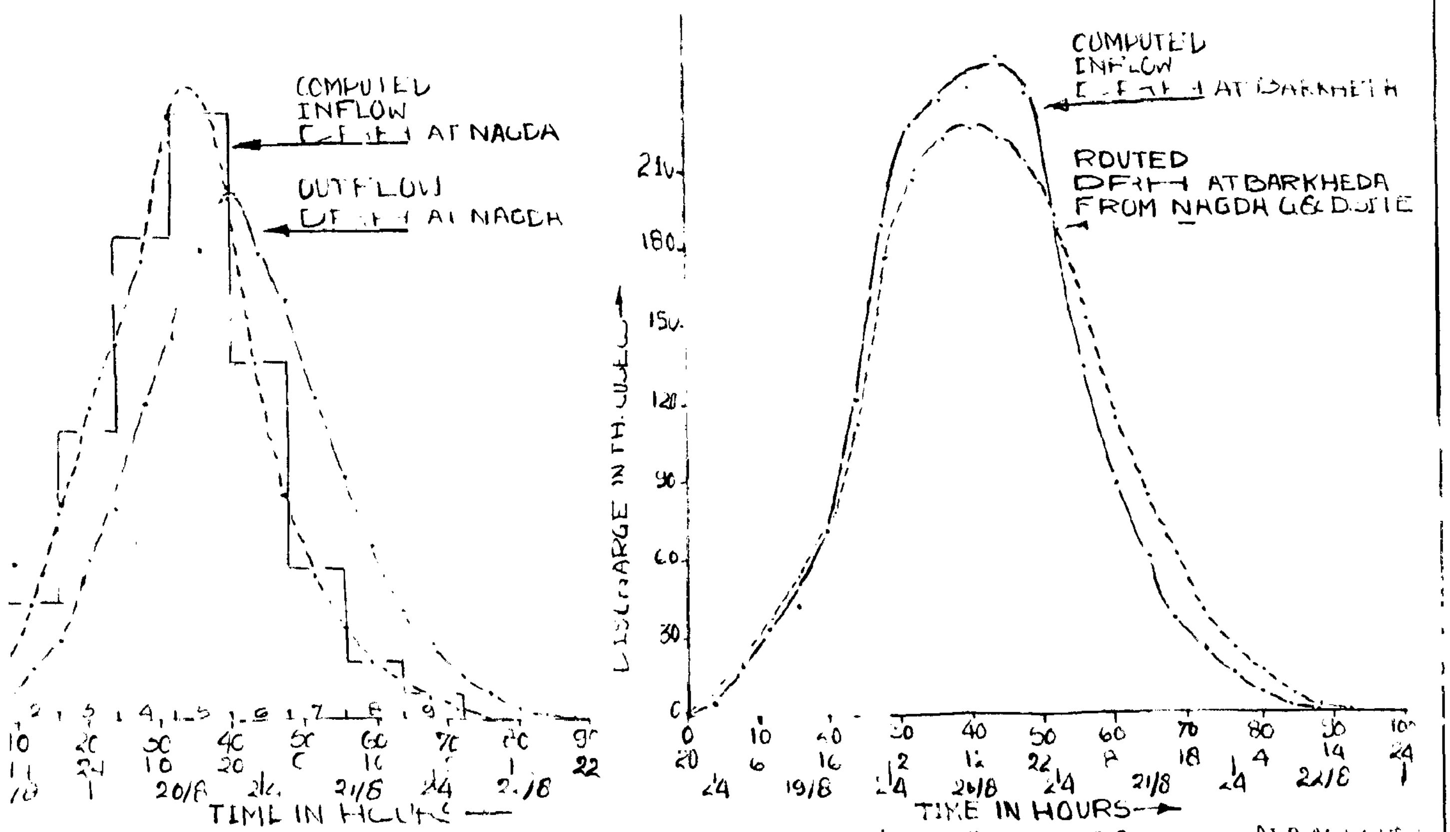
3- INFLOW AND OUTFLOW DRH AT NAGDA 14- INFLOW and OUTFLOW DRH AT BARKHEDA

FIG NO 4(C)   IDENTIFICATION OF NAGDA UNIT RES PARAMETERS



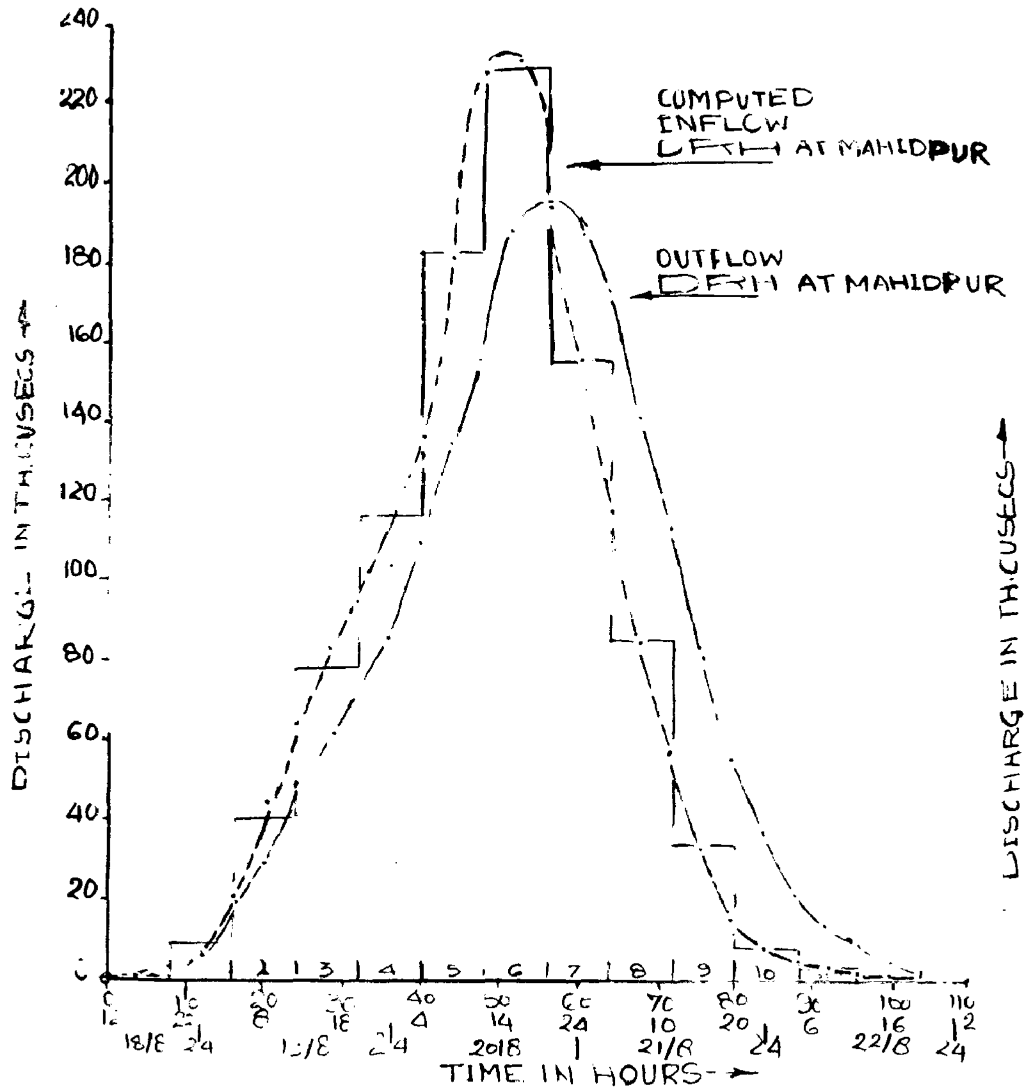
11-INFLOW AND OUTFLOW DRH AT PAT 12- INFLOW and ROUTED OUTFLOW DRH at CHOUMAHLA

FIG NO 4(C) IDENTIFICATION OF PAT UNIT RESPONSE PARAMETERS

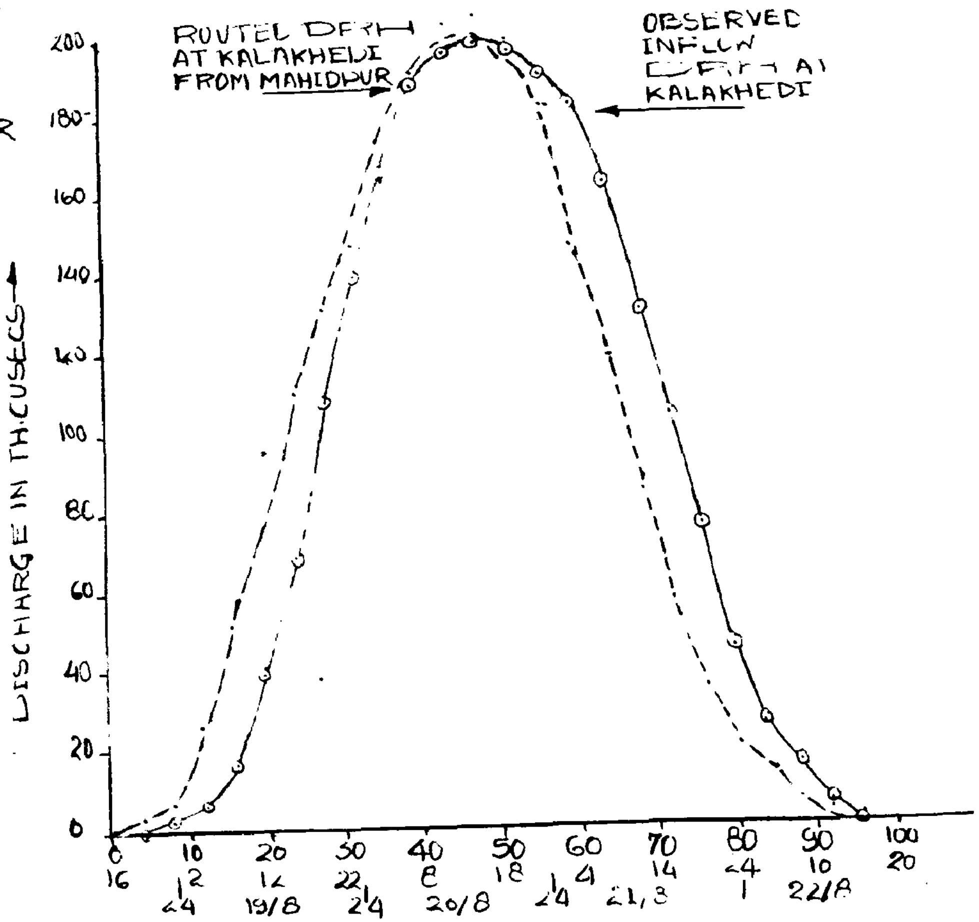


13-INFLOW AND OUTFLOW DRH AT NAGDA 14-INFLOW and ROUTED OUTFLOW DRH AT BARKHEDA

FIG NO. 4C IDENTIFICATION OF NAGDA UNIT RESPONSE PARAMETERS

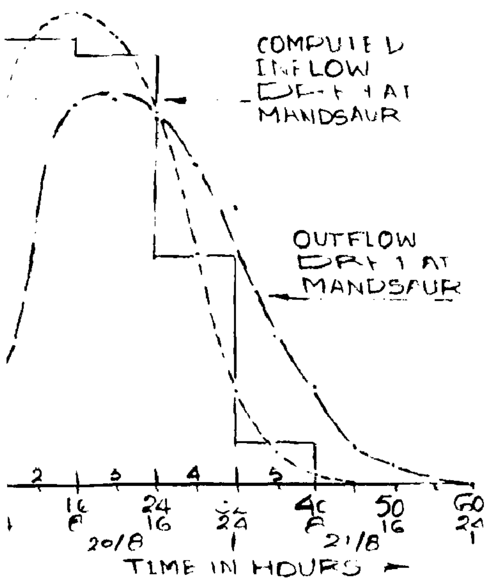


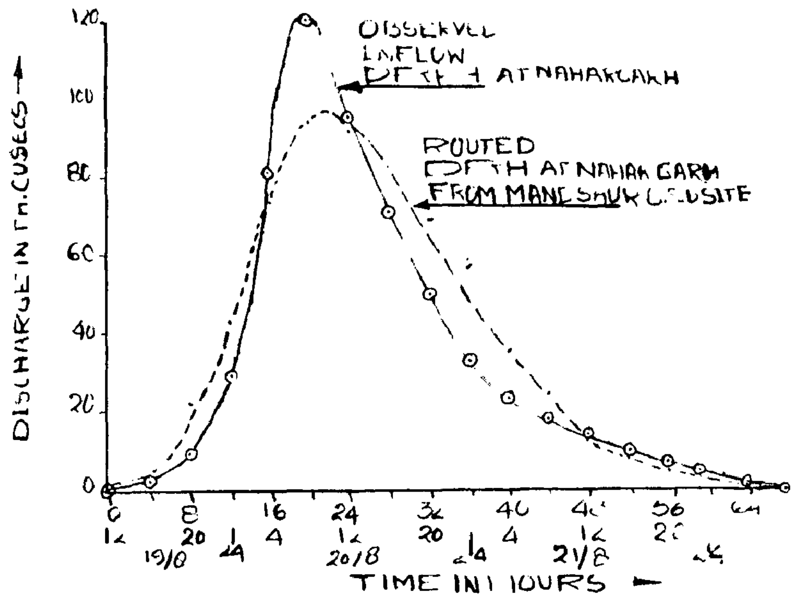
15-INFLOW AND OUTFLOW DRH AT MAHIDPUR



16-INFLOW and ROUTED OUTFLOW DRH AT KALAKHEDI

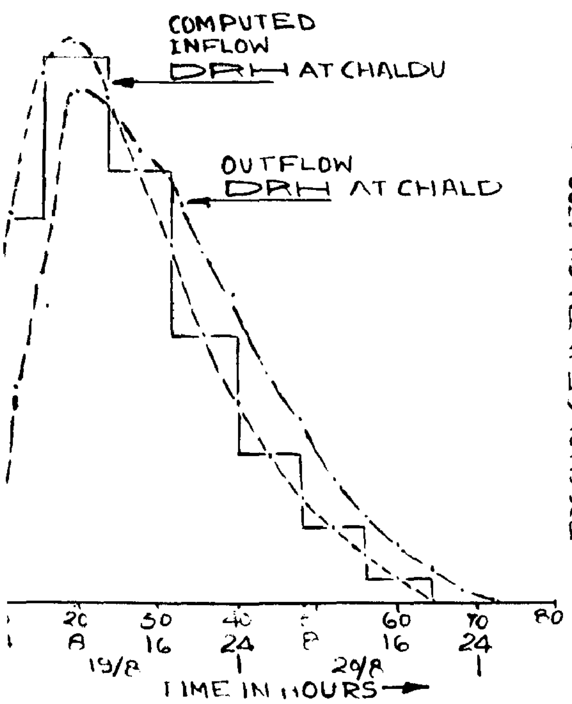
FIG.NO 4(C). IDENTIFICATION OF MAHIDPUR UNIT RESPONSE PARAMETERS.

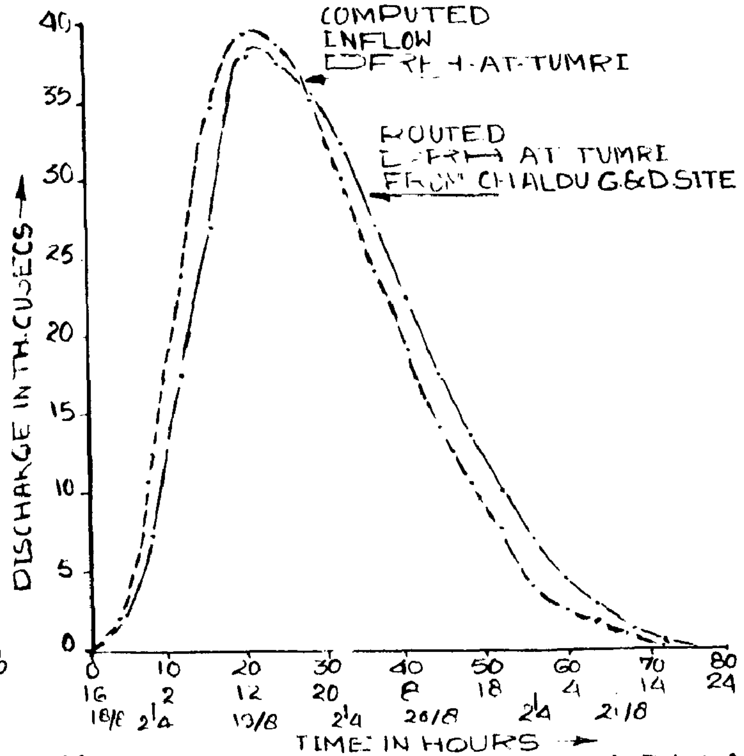




W AND OUTFLOW DRH AT MANDSAUR 18-INFLOW AND OUTFLOW(ROUTED) DRH AT NAHARGARH

FIG.NO.4(C). IDENTIFICATION-OF-MANDSAUR- UNIT-RESPONSE PARAMETERS





W-AND-OUTFLOW DRH AT CHALDU. 20-INFLOW AND ROUTED OUTFLOW DRH AT TUMRI

IO. 4(C). IDENTIFICATION-OF-CHALDU-UNIT RESPONSE PARAMETERS

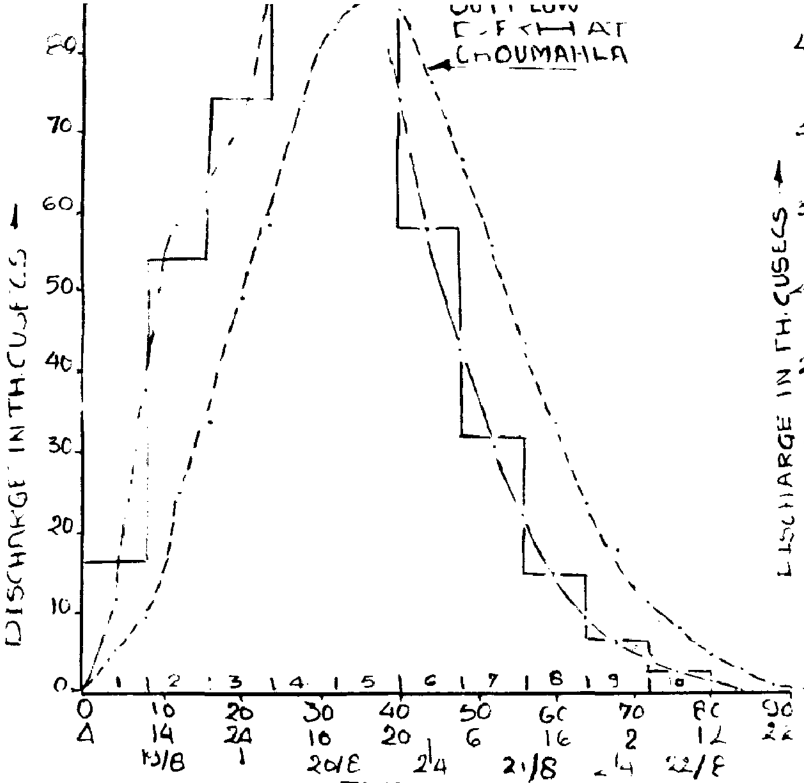


FIG NO. 4(C)-21. INFLOW AND OUTFLOW DRH AT CHOUMAHLA (ISB)

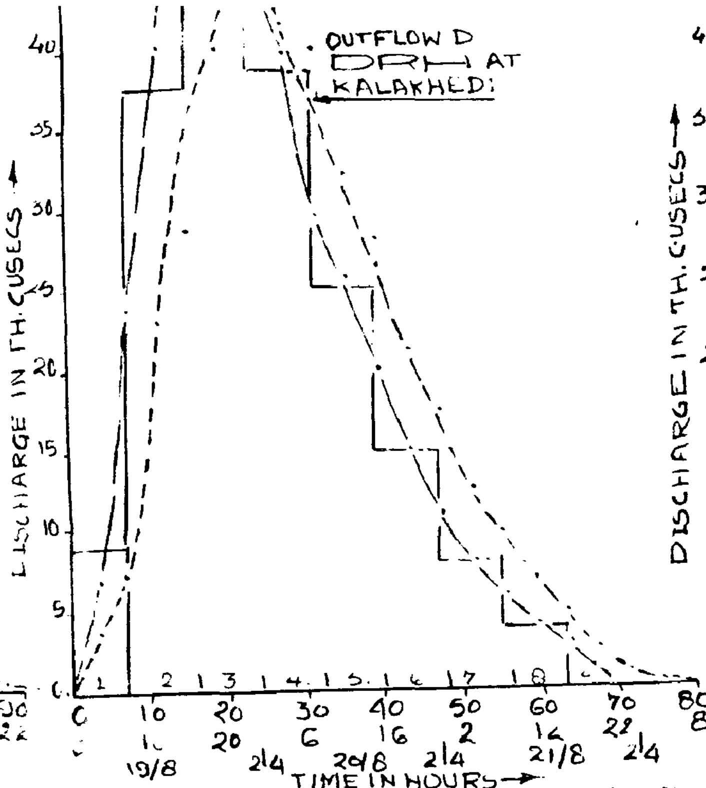


FIG NO. 4(C)-22 INFLOW AND OUTFLOW DRH AT KALAKHEDI ISB

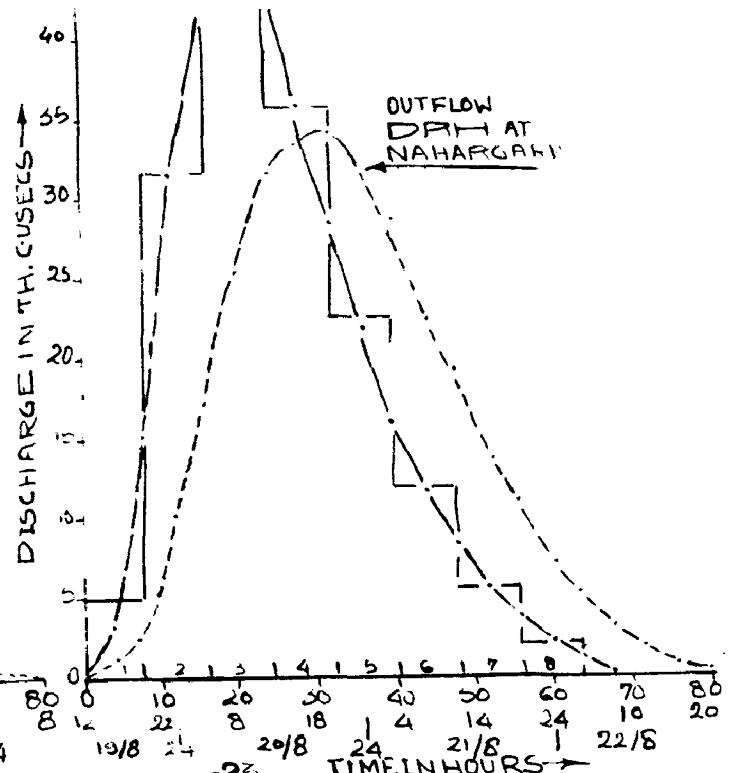


FIG NO. 4(C)-23 INFLOW AND OUTFLOW DRH AT NAHARGARH ISB

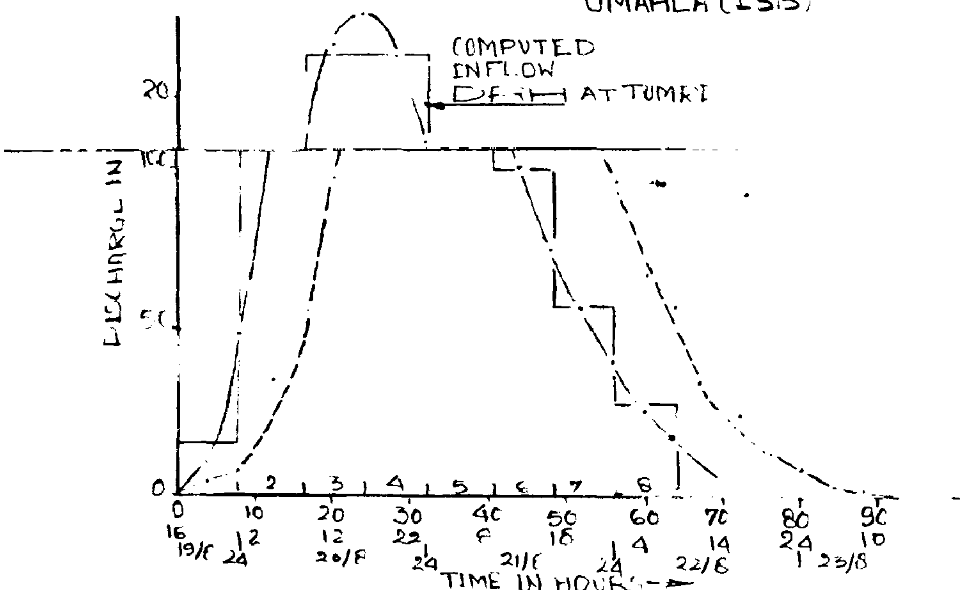


FIG NO-24 INFLOW AND OUTFLOW DRH AT TUMRI ISB

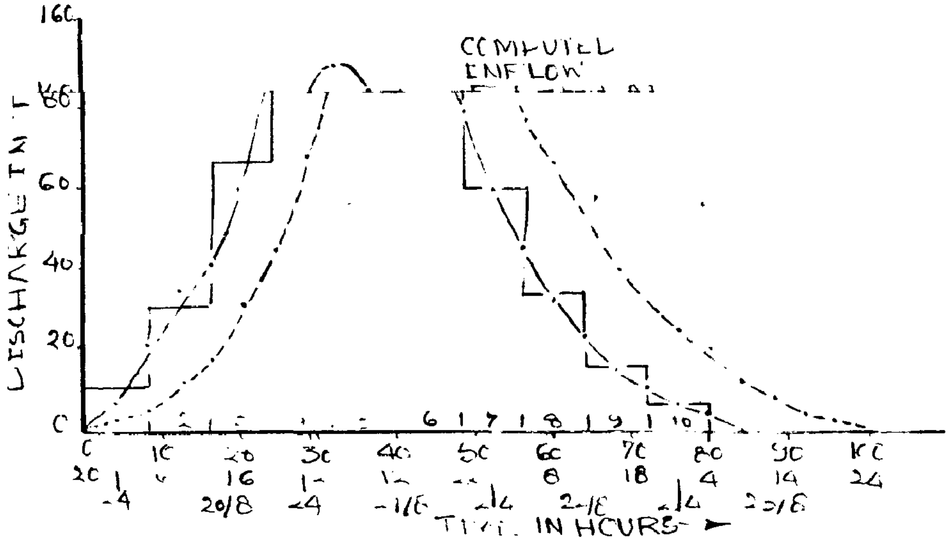
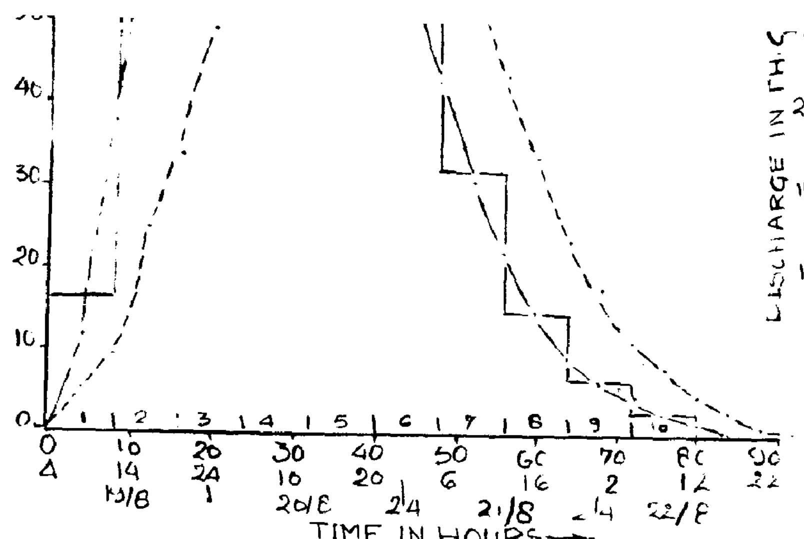


FIG NO 4(C)25 INFLOW OUTFLOW DRH AT BARKHEDI ISB



FIGNO. 4(C)-21. INFLOW-AND-OUTFLOW DRH AT CHOUMAHLA (ISB)

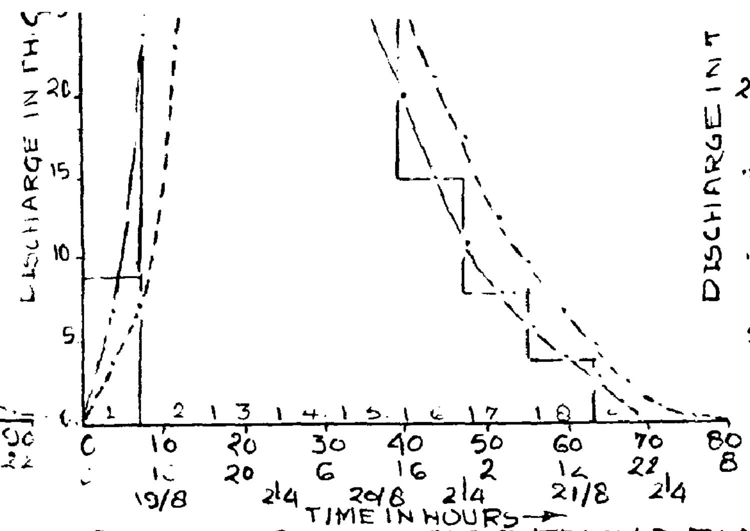


FIG No. 4(C)-22 INFLOW AND OUTFLOW DRH: AT KALAKHEDI ISB

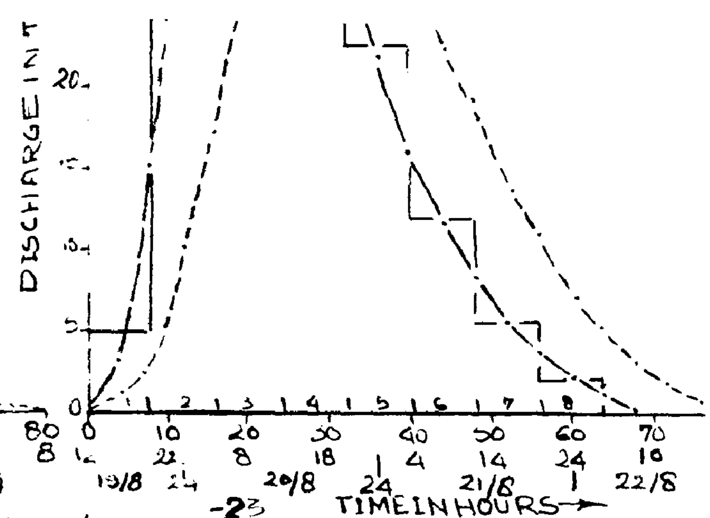
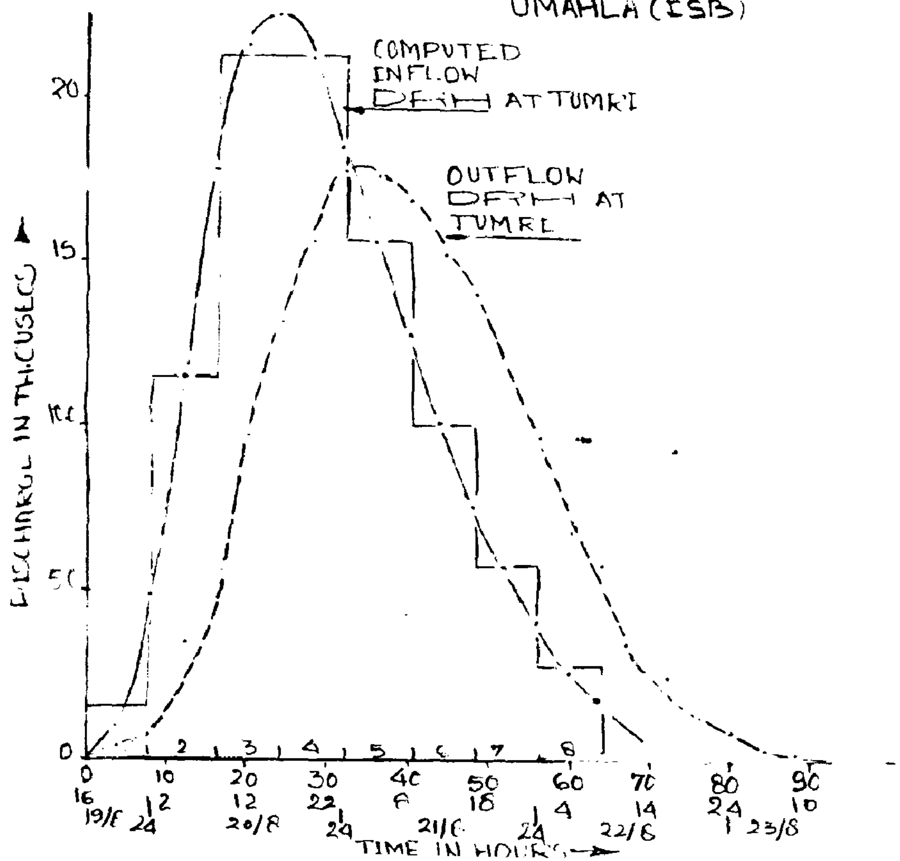
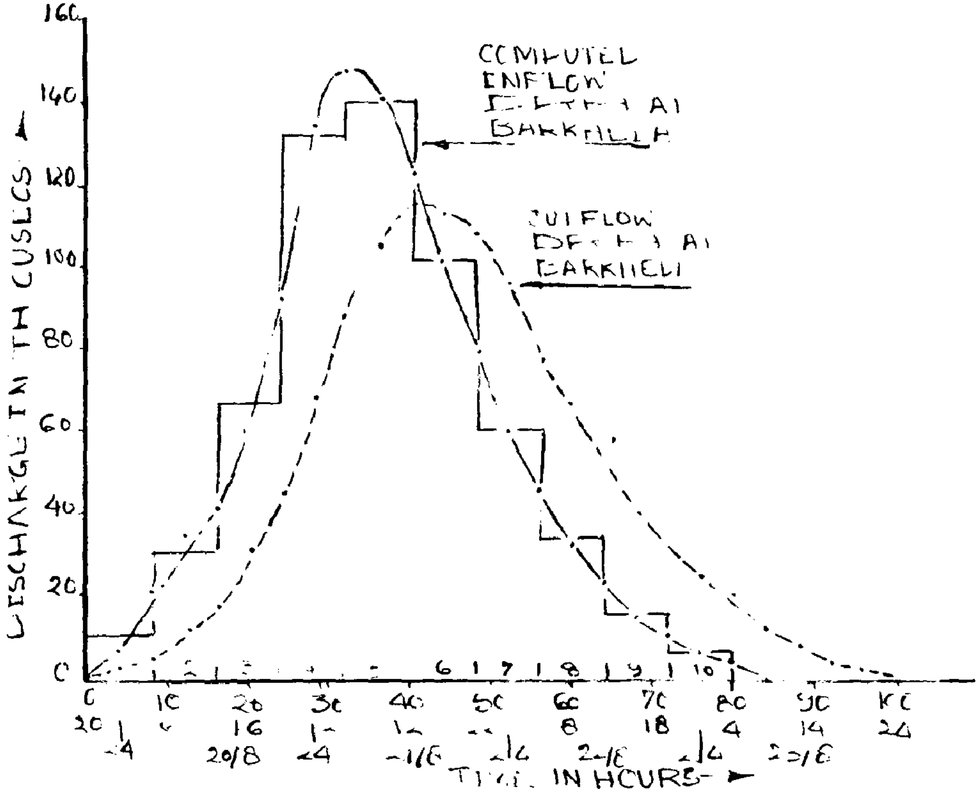


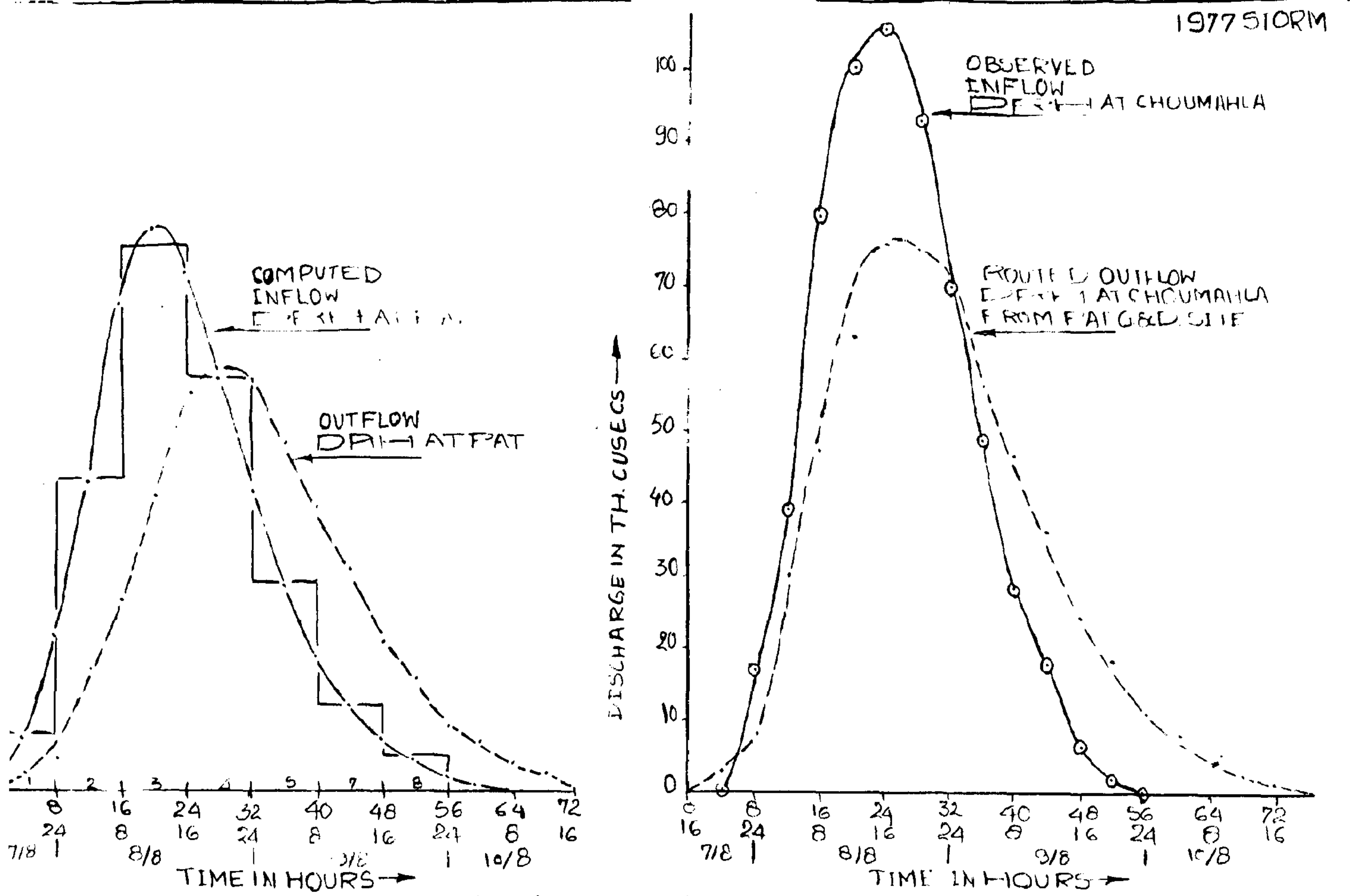
FIG No. 4(C)-23 INFLOW AND OUTFLOW DRH NAHARGARH ISB





... DRH AT BAKKHEDI ISB

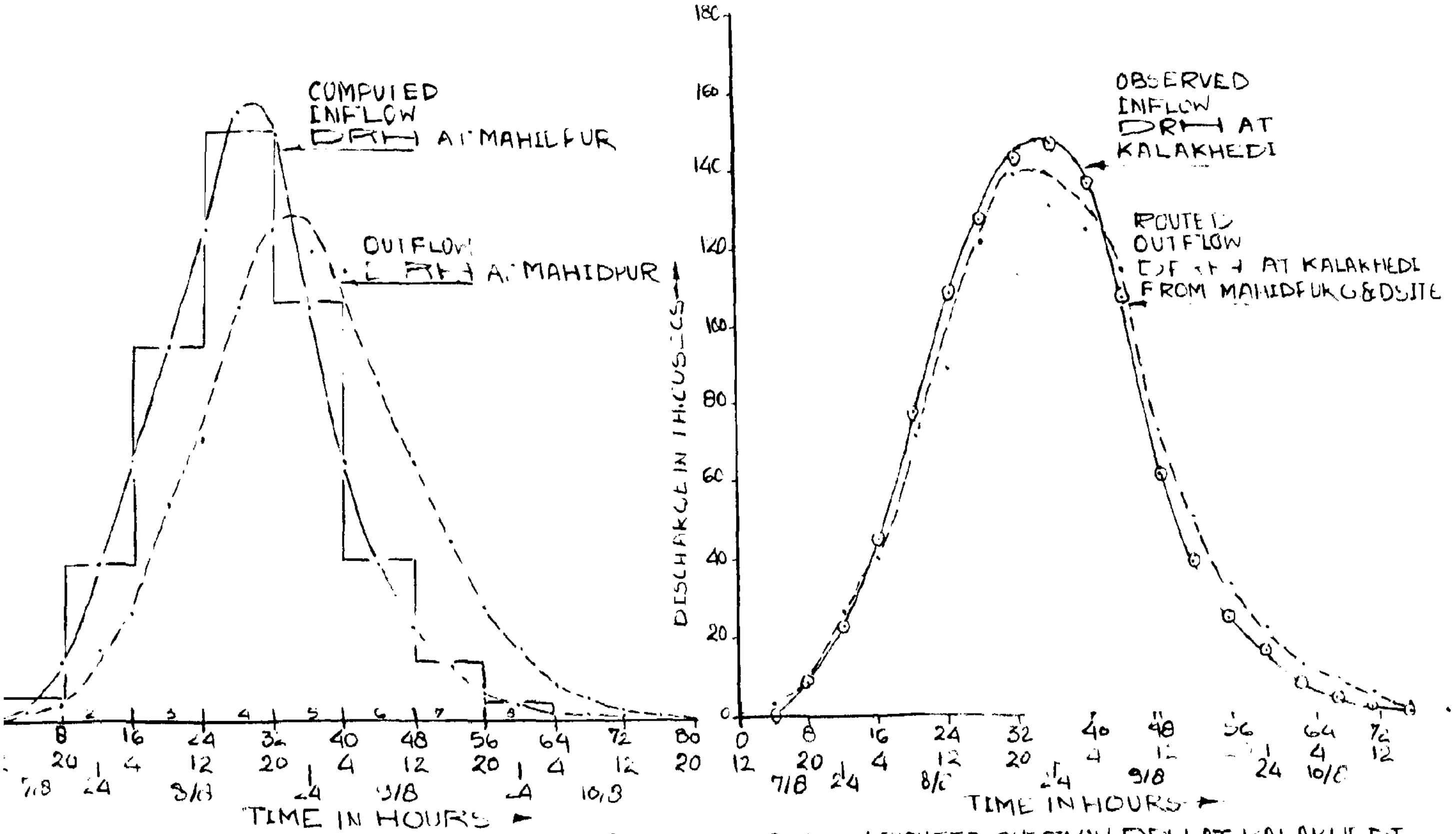
PLATE NO-27



INFLOW OUTFLOW DRH AT PAT (1977)

27- INFLOW ROUTED OUTFLOW DRH AT CHOUMAHLA

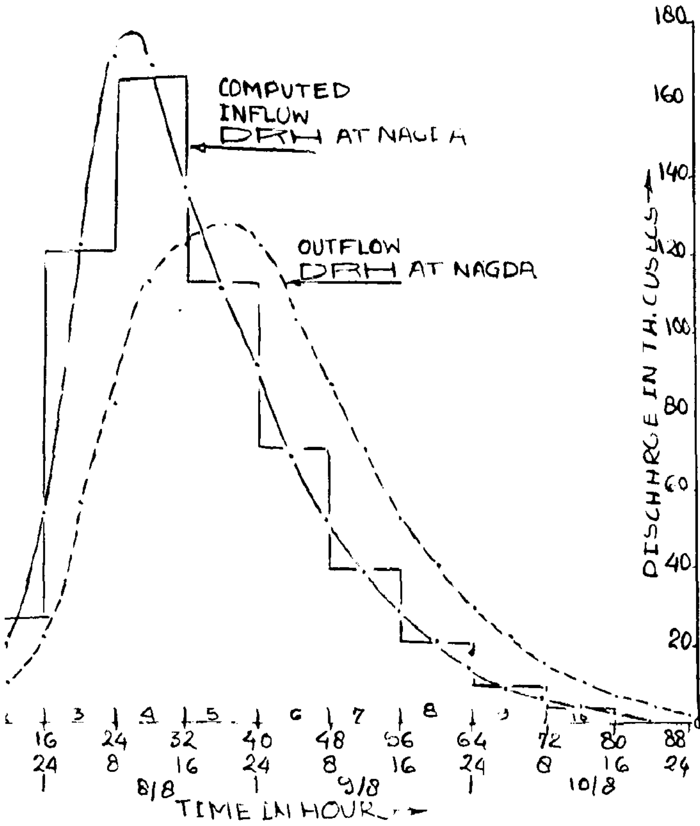
FIG.NO.4(C) TESTING OF PAT UNIT RESPONSE PARAMETERS (1977 STORM)

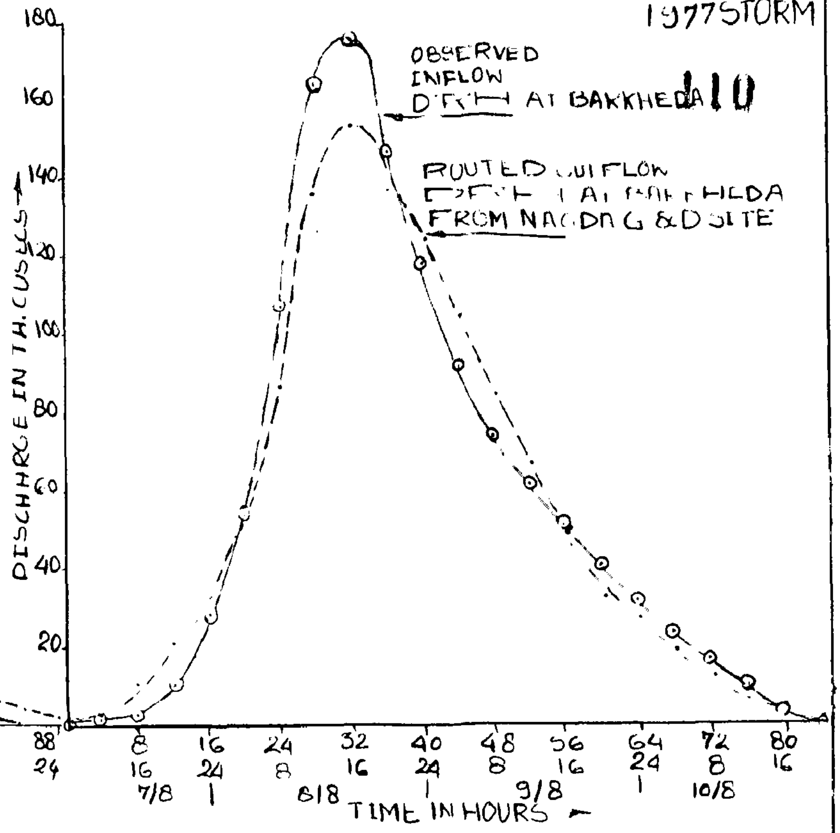


INFLOW OUTFLOW DRH AT MAHIDPUR (1977)

29- INFLOW ROUTED OUTFLOW DRH AT KALAKHEDI

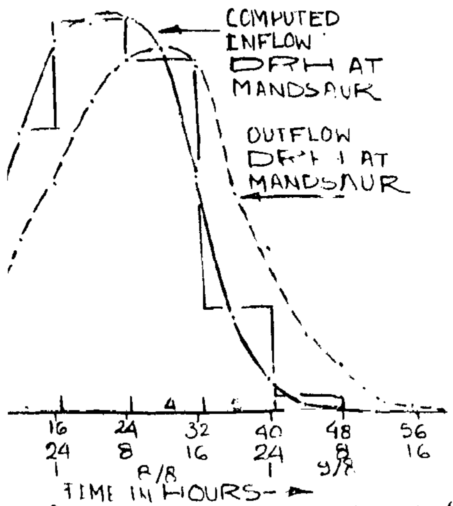
FIG.NO.4(C). TESTING OF MAHIDPUR UNIT RESPONSE PARAMETERS (1977 STORM)



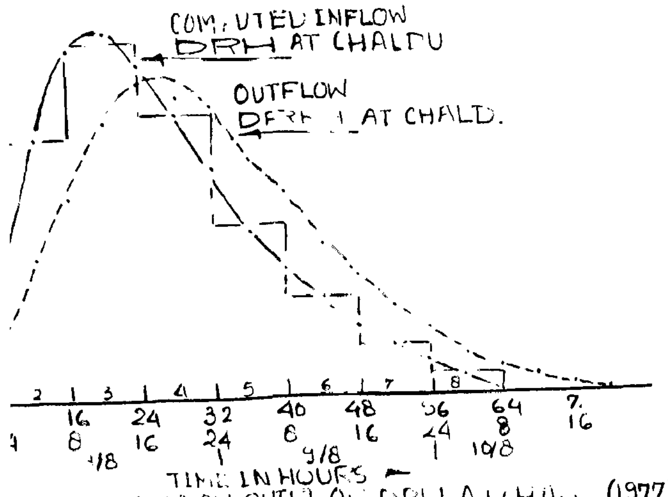


...W OUTFLOW DRH AT NAGDA (1977 STORM) 3:- INFLOW ROUTED OUTFLOW DRH AT BARKHEDA

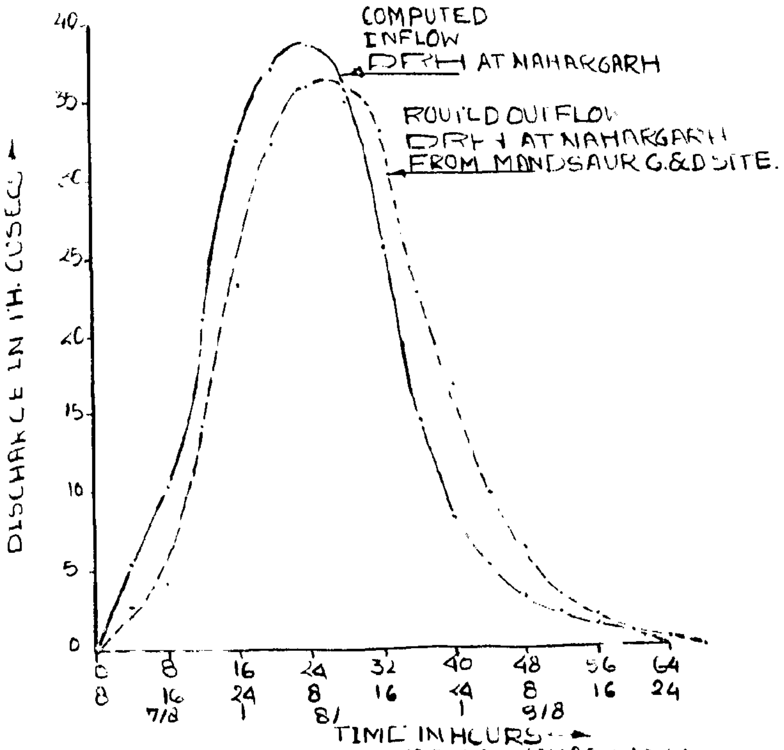
...G No 4(C). TESTING OF NAGDA UNIT RESPONSE PARAMETERS (1977 STORM)



...W OUTFLOW DRH AT MANDSAUR (1977)



...O. 4(C)-34 INFLOW OUTFLOW DRH AT CHALDU (1977)

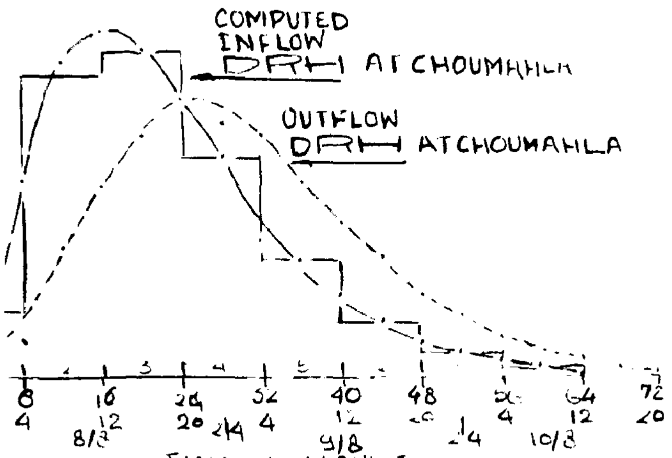


35- INFLOW ROUTED OUTFLOW DRH AT NAHARGARH

FIG NO. 4(C) · TESTING OF MANDSAUR UNIT RESPONSE PARAMETERS (1977 STORM)

PLATE NO.-29.

1977 STORM



NO 4(C)-35 CHOUMAHLA ISB

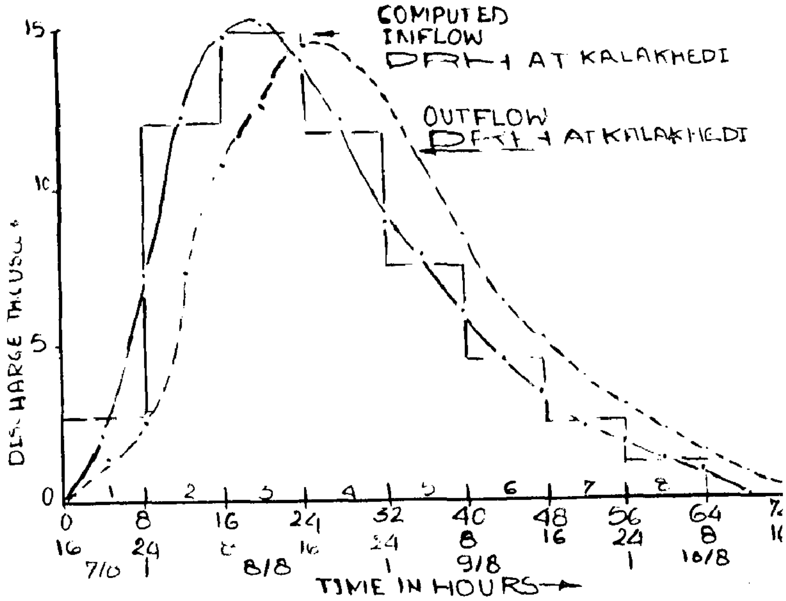


FIG NO.4(C)-36 KAKAKHEDI ISB

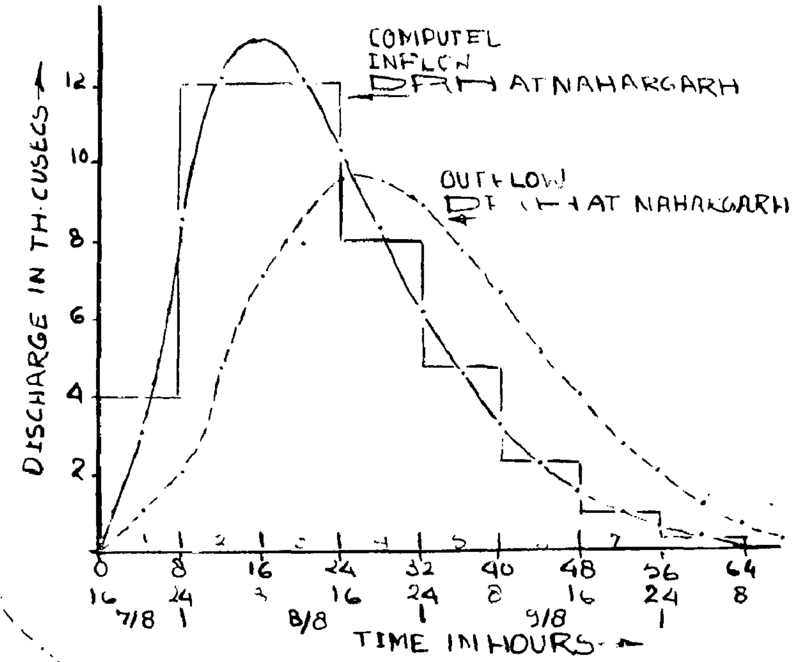


FIG.NO.4(C)-38 NAHARGARH ISB

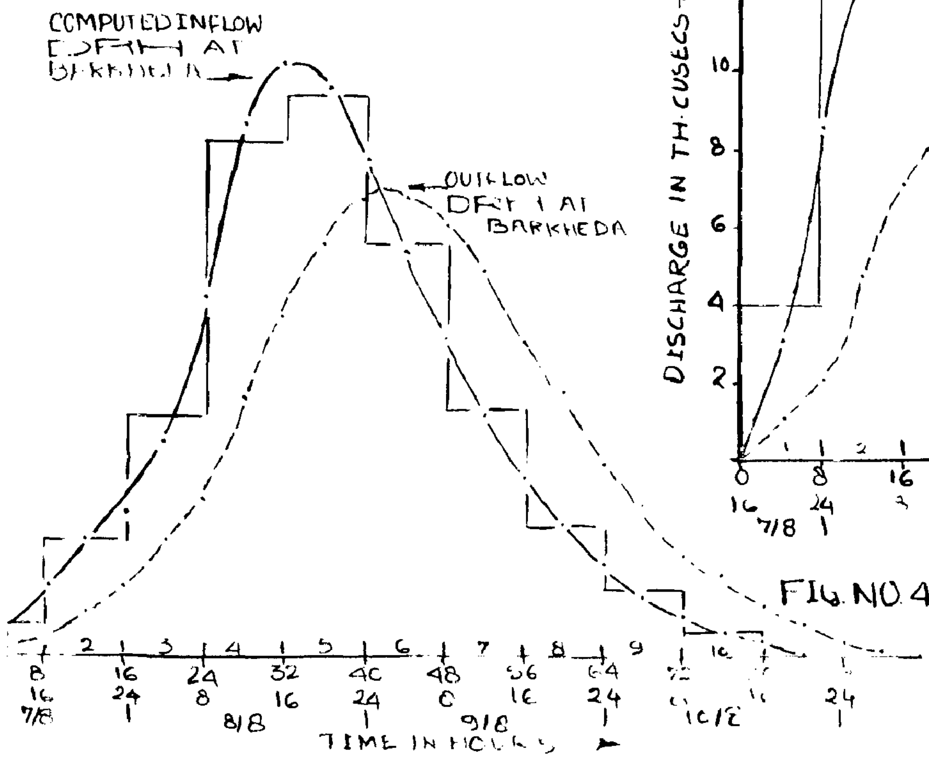


FIG NO 4(C)-37 BARKHEDA ISB

FIGURES SHOWING INFLOW-OUTFLOW DRH FOR INTERMEDIATE SUB BASINS. (1977 STORM)

4(C). 3 COMPUTATION OF FLOWS AT GANDHI SAGAR RESERVOUR

As explained in section 3.5.3, the outflow responses from all the sub-basins and intermediate sub-basins have been computed, separately and routed at the Gandhi Sagar reservoir. As the travel timings of leading edges are not significant, the routed responses are super imposed to compute the inflows to the Gandhi Sagar reservoir. To these flows are added, the flows from the Gandhi Sagar intermediate sub-basin, and also the inputs directly falling on the reservoir, to obtain the total inflows at Gandhi Sagar. The working procedure for both the storms are given in Table No. 4(C)-4 and No. 4(C)-5 respectively.

From these total inflows, the net volume of inflow at the Gandhi Sagar has been worked out. Using the area capacity relationships, the stages at the Gandhi Sagar Reservoir are computed at different times and compared with the observed stages. Working procedure for both storms are given in Table No. 4(C)-4 & 4(C)-5. The comparision for both storms are given in Fig. No. 4(C)-39 and Fig. No. 4(C)-40.

4(C).3.1 Efficiency Of Model At Gandhi Sagar Reservoir:

Efficiency of the model for both the storms have been worked using equation No. 3.15. The working procedure are given in Table No. 4(C)-6. The efficiency of the model are:

Efficiency of model for 1974 storm = 89%
Efficiency of model for 1977 storm = 81%

TABLE NO. 4(C)-4

PREDICTION AND COMPARISON OF STAGES AT GANDHI SAGAR SITE (1974 STORM)

Date/Time	Hours	Routed direct runoff hydrograph's ordinates from different G&D sites in Thousand cusecs: Pat	Mahidpur	Nagda	Mandsaur	Chaldu	Intermediate sub basins: Choumahla	Kalakhedi	Barakheda	Nahargarh	Tumri	Total col.4 to 13	G.S.Intermediate Sub basin & other sites	Inflow at Gandhisagar	Inflow at G.S in MAF	Reservoir capacity in MAF	Computed: Reservoir Level in ft.	Computed: Increase in level feet	Observed: Reservoir Level feet	Observed: Increase in level feet
1&2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
18.8.74																				
16 Hr	0		0									0		0	0	2.776	1284.28	0	1284.28	0
20 Hr	4	0	3.28						0			3.28		3.28	0.001	2.776	1284.29	0.01	1284.28	0
24 Hr	8	4.95	5.28					0	2.80			13.03		13.03	0.004	2.781	1284.33	0.04	1284.28	0
19.8.74																				
4 Hr	12	8.55	19.60	0			0	4.90	5.00			38.05		38.05	0.013	2.794	1284.45	0.12	1284.33	0.05
8 Hr	16	16.73	28.32	2.28			5.60	7.20	12.20			72.33		72.33	0.024	2.818	1284.66	0.21	1284.43	0.10
12 Hr	20	24.42	49.18	3.72			9.28	23.87	17.80	0		128.27	0	128.27	0.042	2.860	1285.07	0.41	1284.72	0.29
16 Hr	24	31.44	61.80	13.74	0	0	24.98	31.33	31.88	1.35	0	196.52	12.61	209.13	0.069	2.929	1286.04	0.97	1285.32	0.60
20 Hr	28	36.56	85.16	20.10	7.65	1.20	35.32	40.90	42.80	2.50	0.38	272.57	37.80	310.37	0.103	3.032	1287.13	1.07	1286.06	0.74
24 Hr	32	43.35	98.86	40.78	11.40	1.83	49.14	45.35	69.04	10.46	0.69	370.90	72.13	443.03	0.146	3.178	1288.55	1.42	1287.46	1.40
20.8.74																				
4 Hr	36	47.48	134.72	53.98	32.22	6.95	58.18	41.63	88.68	17.10	3.43	484.47	108.26	592.73	0.196	3.374	1290.31	1.76	1289.85	2.39
8 Hr	40	60.09	154.98	81.24	48.52	9.53	73.77	40.18	105.56	25.25	5.71	604.83	139.38	744.21	0.246	3.620	1292.62	2.31	1292.63	2.78
12 Hr	44	67.39	187.58	98.38	49.31	16.43	83.02	31.49	116.20	31.41	9.89	682.08	166.20	848.28	0.280	3.900	1295.05	2.43	1295.29	2.66
16 Hr	48	72.61	194.48	121.28	46.95	15.43	85.89	28.00	114.76	33.00	13.24	725.64	169.24	894.88	0.296	4.196	1297.49	2.44	1298.02	2.73
20 Hr	52	74.17	187.44	135.12	40.84	14.47	85.01	20.33	108.68	34.16	15.78	716.00	177.30	893.30	0.295	4.491	1299.87	2.38	1299.97	1.95
24 Hr	56	67.18	172.74	120.08	35.64	13.92	76.47	17.41	96.76	31.21	17.71	649.12	188.67	837.79	0.277	4.768	1301.85	1.98	1301.46	1.59
21.8.74																				
4 Hr	60	59.47	139.34	108.44	19.07	11.42	67.00	11.88	78.16	28.53	17.64	540.87	191.91	732.78	0.242	5.010	1303.74	1.89	1302.64	1.18
8 Hr	64	48.30	112.92	82.77	12.40	9.91	56.14	9.70	66.72	22.07	17.64	438.57	160.92	589.49	0.195	5.205	1305.15	1.41	1303.22	0.58
12 Hr	68	35.85	81.22	62.16	4.80	7.60	44.01	6.28	58.08	19.36	15.34	324.70	147.65	472.35	0.156	5.361	1306.11	0.96	1304.23	1.01
16 Hr	72	27.81	55.14	44.60	2.50	6.15	34.26	5.01	39.60	13.65	14.32	243.04	132.19	375.23	0.124	5.485	1307.03	0.92	1305.34	1.11
20 Hr	76	17.55	36.60	28.00	0.50	4.43	23.58	2.10	25.92	11.05	11.00	160.73	113.97	274.70	0.091	5.576	1307.56	0.53	1306.15	0.81
24 Hr	80	13.38	20.84	19.76	0.25	3.34	17.99	0.92	20.56	6.94	9.88	119.83	97.55	217.38	0.072	5.648	1308.00	0.44	1306.45	0.30
22.8.74																				
4 Hr	84	7.52	13.43	11.27	0	2.12	11.55	0.32	12.24	5.40	6.81	70.66	79.70	150.36	0.050	5.698	1308.32	0.32	1306.46	0.01
8 Hr	88	5.48	6.57	7.02		1.31	8.64	0.12	8.88	2.91	5.90	46.83	66.61	113.44	0.038	5.736	1308.57	0.25	1306.46	0
12 Hr	92	3.04	3.88	3.00		0.73	5.14	0	3.92	1.98	3.43	25.12	54.81	79.93	0.026	5.762	1308.75	0.18	1306.46	0
16 Hr	96	2.08	1.37	0.99		0.30	3.38		2.80	0.88	2.59	14.39	44.21	58.60	0.019	5.781	1308.87	0.12	1306.46	0
20 Hr	100	0	0	0		0.16	1.52		0	0.59	1.27	3.54	27.70	31.24	0.010	5.791	1308.94	0.07	1306.46	0
24 Hr						0.04	1.00			0.18	0.96	2.18	18.71	20.89	0.007	5.798	1309.00	0.06	1306.46	0
						0.02	0			0.12	0.33	0.47	14.71	15.18	0.005	5.803	1309.02	0.02	1306.46	0
						0				0	0.25	0.25	3.65	3.90	0.001	5.804	1309.03	0.01	1306.46	0
											0	0	1.18	1.18	0	5.804	1309.03	0	1306.46	0
													0	0	0	5.804	1309.03	0	1306.46	0

Notes 1. The references for the figures in the statement are:

Col. 4 has been taken from Table No. 4(C)-3
Col. 5 has been taken from Table No. Appendix No. XVII(a)
Col. 6 has been taken from appendix No. XVII(b)
Col. 7 has been taken from Appendix No. XVII(c)
Col. 8 has been taken from Appendix No. XVII(d)
Col. 9 has been taken from Appendix No. XVII(e)
Col. 10 -do- XVII(f)
Col. 11 -do- XVII(g)
Col. 12 -do- XVII(h)
Col. 13 -do- XVII(i)

2. Col. 14 is the total from Col. 4 to 13
3. Col. 16 has been taken from Fig. No. 4(B)-15

Note: 4 : Col. 16 is the total of column 14 and Col. 15

5 Column 17 = Col. 16 x $\frac{4 \times 60 \times 60 \times 1000}{43560 \times 10^6}$ = Col. 16 x 330.6 x 10^{-6} Million Acre ft.

6. Col. 18 worked out using area capacity relationships (Appendix No. VI)

to 20

8. Col. 21 & 22 has been taken from Appendix No. V

TABLE NO. 4(C)-5

PREDICTION AND COMPARISON OF STAGES AT GANDHI SAGAR SITE
(1977 STORM)

Dates & Period	Hours	Routed direct run off Hydrographs -Ordinates from differentG&D Sites Th.Cu.										Total Col.4 to 13	G.S. Inter mediate sub-bas in Th.Cu	Inflow at G.S Th.cu.	Inflow at Gandhi Sagar in MAF	Reserv-oir capacity in MAF	Computed		Observed	
		Pat	Mahid-pur	Nagda	Mands-aur	Chaldu	Between sub-Catchment										Reser-voir level in ft.	Incre-ase in lev el in ft.	Reserv-oir level in ft	Incre in l vel in f
							Choumah-la	Kalakh-edi	Barkheda	Naharg-arh	Tumri									
1&2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
7.8.77																				
8 Hr	0			0	0				0			0	0	0	0	3.260	1289.30	0	1289.30	0
12 Hr	4		0	0.76	2.81				1.12			4.69	2.72	7.41	0.003	3.263	1289.33	0.03	1289.30	0
16 Hr	8	0	2.46	1.24	4.18	0			2.00	0		9.88	5.07	14.95	0.005	3.268	1289.35	0.02	1289.30	0
20 Hr	12	2.64	3.96	5.72	11.27	0.34	0	0	5.72	1.08		30.73	15.57	46.30	0.015	3.283	1289.48	0.13	1289.32	0.02
24 Hr	16	4.56	18.80	8.56	14.78	0.51	1.58	1.43	8.62	2.00		60.76	22.74	83.50	0.028	3.311	1289.74	0.26	1289.34	0.02
8.8.77																				
4 Hr	20	17.31	27.84	28.19	20.14	1.85	2.61	2.17	15.18	4.80		120.09	28.74	148.83	0.049	3.360	1290.18	0.44	1289.46	0.12
8 Hr	24	26.59	56.26	40.65	22.88	2.55	8.54	7.29	20.26	7.08		192.10	33.20	225.30	0.075	3.435	1290.86	0.68	1289.60	0.14
12 Hr	28	40.88	73.50	56.76	22.78	3.54	12.44	9.95	33.66	7.98		261.49	33.42	294.91	0.098	3.533	1291.79	0.93	1290.15	0.55
16 Hr	32	54.81	107.02	67.14	23.00	4.02	15.53	12.58	43.78	9.76		337.64	36.14	373.78	0.124	3.657	1292.71	0.93	1291.10	0.95
20 Hr	36	56.00	126.96	63.64	14.37	3.84	17.56	14.00	52.94	9.48	NO WATER IS AVAILABLE	363.79	36.10	399.89	0.132	3.789	1294.08	1.37	1292.90	1.80
24 Hr	40	56.72	121.48	61.22	10.69	3.75	16.52	12.83	58.82	9.04		351.07	35.04	386.11	0.128	3.917	1295.20	1.12	1294.20	1.30
9.8.77																				
4 Hr	44	47.99	116.40	51.86	5.23	3.04	15.52	12.31	58.50	7.78		318.63	30.67	349.30	0.115	4.032	1296.20	1.00	1295.00	0.80
8 Hr	48	39.60	88.02	43.90	3.19	2.61	12.89	11.81	55.92	6.84		262.78	28.05	292.83	0.097	4.129	1296.92	0.72	1295.22	0.22
12 Hr	52	30.96	67.32	35.13	1.03	1.96	10.16	8.52	50.10	5.12		210.30	25.04	235.34	0.078	4.207	1297.58	0.66	1295.95	0.73
16 Hr	56	20.65	47.16	26.75	0.53	1.54	7.93	6.43	40.92	4.26		156.17	21.55	177.72	0.059	4.266	1298.08	0.50	1296.35	0.40
20 Hr	60	15.82	30.36	20.56	0	1.10	5.45	5.31	34.72	2.84		115.16	18.35	133.51	0.044	4.310	1298.38	0.30	1296.75	0.40
24 Hr	64	9.16	20.15	14.70		0.81	4.12	3.85	24.88	2.25		79.92	14.91	94 .83	0.031	4.341	1298.59	0.21	1297.15	0.40
10.8.77																				
4 Hr	68	6.97	10.95	11.10		0.44	2.58	3.05	20.68	1.26		57.03	12.54	69.57	0.023	4.364	1298.75	0.16	1297.38	0.23
8 Hr	72	3.76	7.32	7.60		0.34	1.96	2.11	13.74	0.87		37.70	10.26	47.96	0.016	4.380	1298.86	0.11	1297.45	0.07
12 Hr	76	2.59	3.96	5.51		0.19	1.21	1.60	11.14	0.41		26.61	08.27	34.88	0.012	4.392	1998.94	0.08	1297.45	0
16 Hr	80	1.07	2.35	3.49		0.08	0.80	0.77	6.90	0.27		15.73	5.02	20.75	0.007	4.399	1299.00	0.06	1297.45	0
20 Hr	84	0.74	0.93	2.18		0.02	0.36	0.31	5.02	0		9.56	3. 30	12.86	0.004	4.403	1299.03	0.03	1297.45	0
24 Hr	88	0.22	0.55	1.00		0	0.24	0.15	2.38			4.54	2.62	7.16	0.002	4.405	1299.05	0.02	1297.45	0
11.8.77																				
4 Hr	92	0.16	0.18	0			0.08	0.05	1.70			2.17	1.76	3.93	0.001	4.406	1299.06	0.01	1297.48	0.03
													0	0	0	4.406	1299.06	0	1297.50	0.02

No.	Increase in Reservoir level		$Q_c - Q_o$	$(Q_c - Q_o)^2$	$(Q_o - \bar{Q}_o)$	$(Q_o - \bar{Q}_o)^2$	Increase in Water level		$Q_c - Q_o$	$(Q_c - Q_o)^2$	$(Q_o - \bar{Q}_o)$	$(Q_o -$
	Observed Q_o	Computed Q_c					Observed Q_o	Computed Q_c				
1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	-0.743	0.552	0	0	0	0	-0.328	0.10
2	0	0.01	0.01	0	-0.743	0.552	0	0.03	0.03	0	-0.328	0.10
3	0	0.04	0.04	0.002	-0.743	0.552	0	0.02	0.02	0	-0.328	0.10
4	0.05	0.12	0.07	0.005	-0.693	0.480	0.02	0.13	0.16	0.026	-0.308	0.09
5	0.10	0.21	0.11	0.012	-0.643	0.413	0.02	0.26	0.24	0.058	-0.308	0.09
6	0.29	0.41	0.12	0.014	-0.453	0.205	0.12	0.44	0.32	0.102	-0.208	0.04
7	0.60	0.97	0.37	0.137	-0.143	0.021	0.14	0.68	0.54	0.292	-0.188	0.03
8	0.74	1.07	0.33	0.109	-0.003	0	0.55	0.93	0.38	0.144	0.222	0.04
9	1.40	1.42	0.02	0	0.657	0.432	0.95	0.93	-0.02	0	0.622	0.38
10	2.39	1.76	-0.63	0.397	1.647	2.713	1.80	1.37	-0.43	0.185	1.472	2.16
11	2.78	2.31	-0.47	0.221	2.037	4.149	1.30	1.12	-0.18	0.032	0.972	0.94
12	2.66	2.43	-0.23	0.053	1.917	3.675	0.80	1.00	0.20	0.040	0.472	0.22
13	2.73	2.44	-0.29	0.084	1.987	3.948	0.22	0.72	0.50	0.250	-0.108	0.01
14	1.95	2.38	0.43	0.185	1.207	1.457	0.73	0.66	-0.07	0.005	0.402	0.16
15	1.59	1.98	0.39	0.152	0.847	0.717	0.40	0.50	0.10	0.010	0.072	0.00
16	1.18	1.89	0.71	0.504	0.437	0.191	0.40	0.30	-0.10	0.010	0.072	0.00
17	0.58	1.41	0.83	0.689	-0.163	0.027	0. 40	0.21	-0.19	0.036	0.072	0.00
18	1.01	0.96	-0.05	0.003	0.267	0.071	0.23	0.16	-0.07	0.005	0.098	0.01

1	2	3	4	5	6	7	8	9	10	11	12	13
19	1.11	0.92	-0.19	0.036	0.367	0.135	0.07	0.11	0.04	0.002	-0.258	0.067
20	0.81	0.53	-0.28	0.078	0.670	0.449	0	0.08	0.08	0.006	-0.328	0.108
21	0.30	0.44	0.14	0.020	-0.443	0.196	0	0.06	0.06	0.004	-0.328	0.108
22	0.01	0.32	0.31	0.096	-0.733	0.537	0	0.03	0.03	0	-0.328	0.108
23	0	0.25	0.25	0.063	-0.743	0.552	0	0.02	0.02	0	-0.328	0.108
24	0	0.18	0.18	0.032	-0.743	0.552	0.03	0.01	0.01	0	-0.328	0.108
25	0	0.12	0.12	0.014	-0.743	0.552	0.02	0	-0.02	0	-0.328	0.108
26	0	0.07	0.07	0	-0.743	0.552						
27	0	0.06	0.06	0.004	-0.743	0.552						
28	0	0.02	0.02	0	-0.743	0.552						
29	0	0.01	0.01	0	-0.743	0.552						
30	0	0	0	0	-0.743	0.552						

$\Sigma Q_o = 22.28$ $\quad \Sigma(Q_c - Q_o)^2 = 2.91$ $\quad \Sigma(Q_o - \bar{Q}_o)^2 = 25.888$ $\quad \Sigma Q_o = 8.2$ $\quad \Sigma(Q_o - Q_o)^2 = 1.207$ $\quad \Sigma(Q_o - \bar{Q}_o)^2 = 6.277$

$\bar{Q}_o = 0.743$ $\quad \bar{Q}_o = 0.328$

Coefficient of efficiency of model

$$= \frac{\Sigma(Q_o - \bar{Q}_o)^2 - \Sigma(Q_c - Q_o)^2}{\Sigma(Q_o - \bar{Q}_o)^2}$$

$$= \frac{25.888 - 2.91}{25.888} = 0.8876$$

Efficiency = 88.76 % say 89%

Coefficient of efficiency of the model

$$= \frac{6.277 - 1.207}{6.277} = 0.8077$$

Efficiency = 80.77% Say 81%

Note:- 1. Col. 2 and Col. 3 are taken from Table No. 4(C)-4
2. Col. 8 and Col. 9 are taken from Table No. 4(C)-5

PLATE NO-30

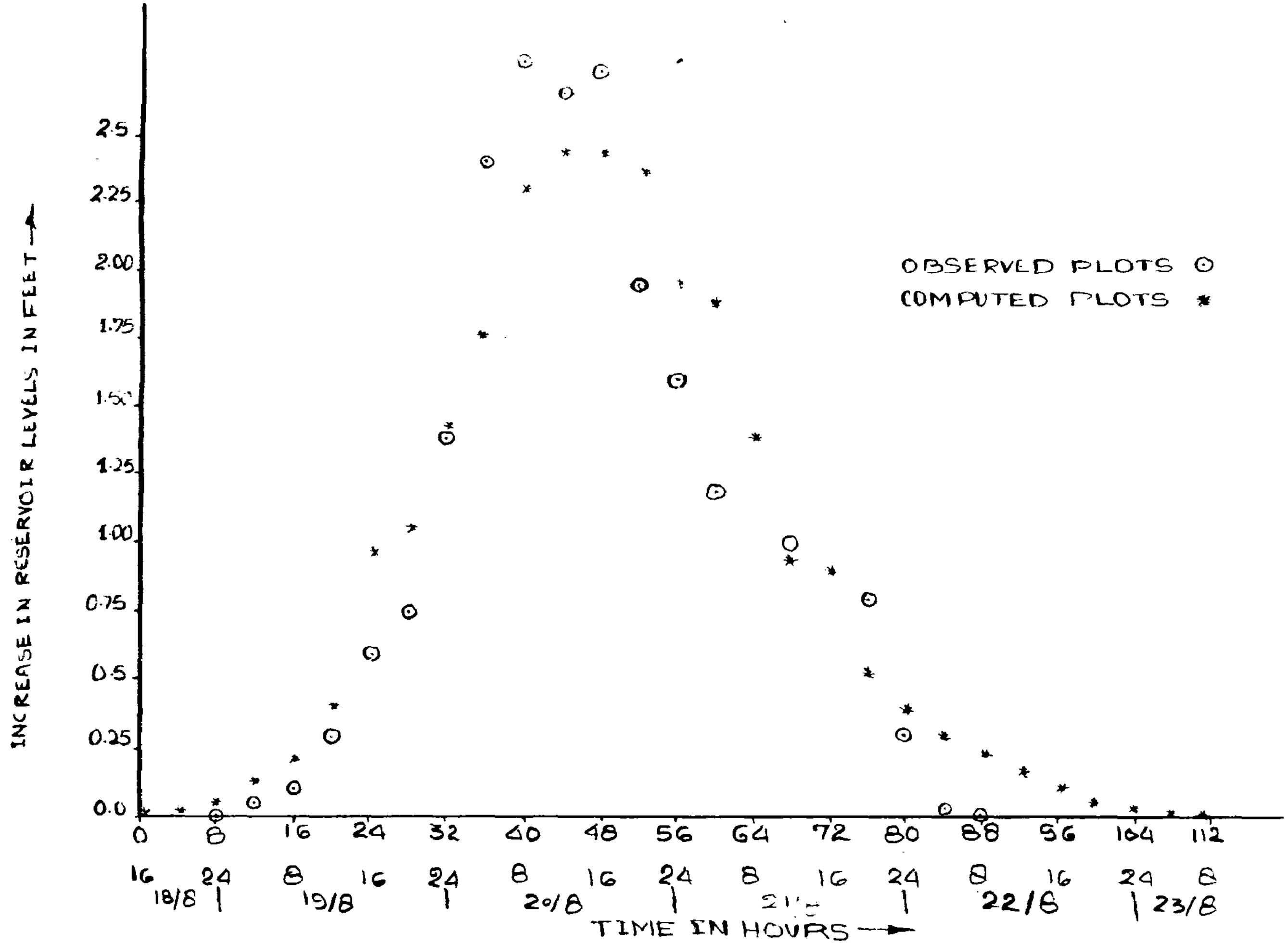


FIG.NO. 4(C)-39. COMPARISION OF COMPUTED AND OBSERVED RESERVOIR LEVELS A GANDHISAGAR USING STORM DATA OF AUGUST 1974.

PLATE NO-31

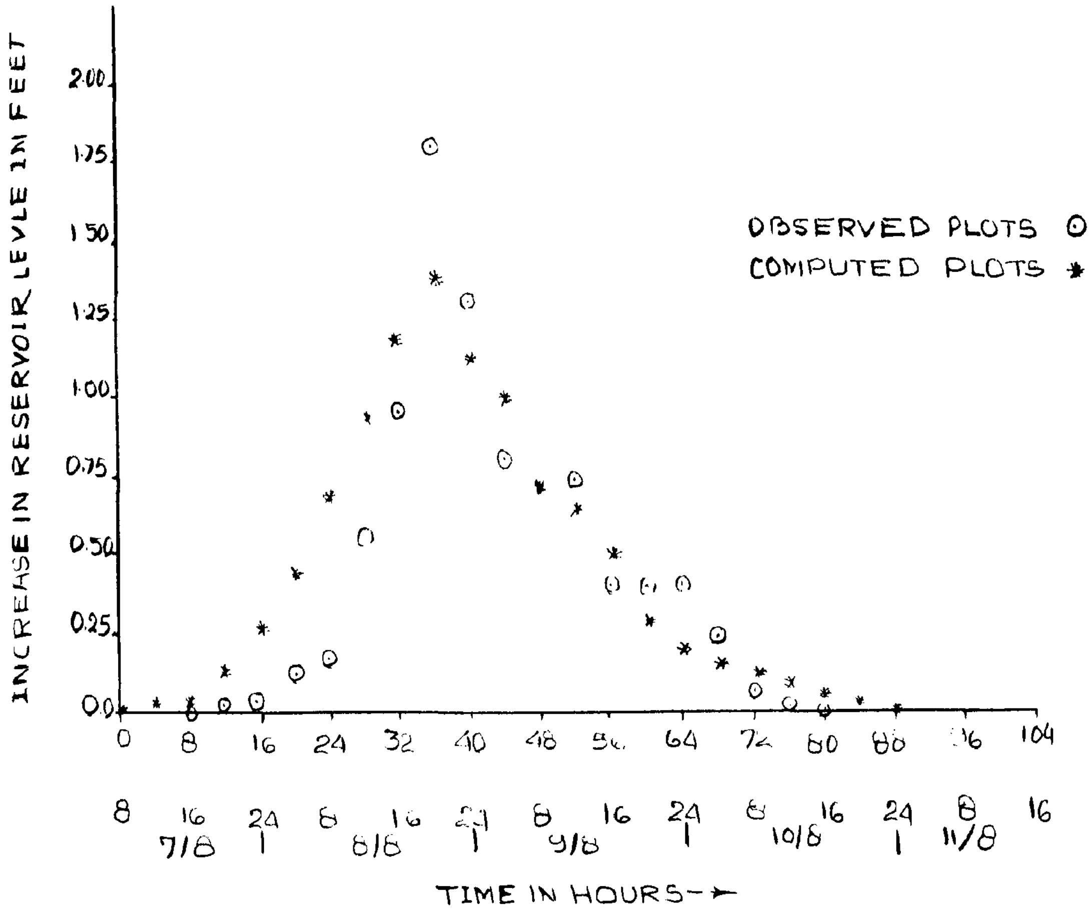


FIG. NO. 4(C)-40 COMPARISION OF COMPUTED AND OBSERVED RESERVOIR LEVELS AT GANDHISAGAR USING STORM DATA OF AUGUST 1977.

CHAPTER - V

SUMMARY OF PROPOSALS, RESULTS, DISCUSSION OF RESULTS AND PROPOSAL FOR FUTURE WORK

5.1 SUMMARY OF PROPOSALS:

The present study is aimed at simulating the direct runoff hydrograph for the Chambal River Basin at Gandhi Sagar site, using a linear distributed parameter model. The assumption of linearity ensures application of the principle of homogenity and also the principle of superimposition. In a hydrologic system the simulation of the catchment action is better taken into account, when the input is considered as distributed. In the proposed model it has been attempted by splitting the vast catchment, (having the drainage area of about 8800 square miles), into its different sub-basins and intermediate sub-basins. This is attempted, keeping in view the drainage character of the basin. Further, the non-uniformity of rainfall is taken care of by dividing them into sub-areas. These sub-areas are arrived at, keeping in view the meteorological homogenity. Thus simulation of the direct run off hydrograph for the catchment of Gandhi Sagar Reservoir, has been performed in the following steps.

- (i) To develop suitable input function
- (ii) Formulation of linear distributed parameter model for the sub-basins.
- (iii) Simulation of linear distributed parameter model for the intermediate sub-basins.
- (iv) Routing of flow concentrations from the outlets of sub-basins and intermediate sub-basins to the Gandhi Sagar site.

5.1.1 Development of Suitable Input Function:

Input to the system is considered as distributed function. This has been possible by considering different rate of abstraction for different sub basins. The rate of abstractions are considered by adopting a suitable ϕ-index. The variation in ϕ-index with in a sub basin are not considered, however aprocedure is suggested to compute the weighted effective rainfall excess for each sub area from the available rainfall excess of the sub basin.

5.1.2 Formulation Of Model For the Sub-Basin:

Using the conceptual model proposed by Nash (Nash J.E. 1957), the instantaneous unit hydrograph and subsequently unit hydrographs for each sub area is computed, which is the desired transfer function. The differential responses from each sub area are subjected to pure translation by introducing the linear channels at the outlets of each sub-area to the gauge. The linear channels account for the time lags of the differential responses from the outlets of the sub areas to the gauge. These values of the time lags are arrived at by trial and error, considering the observed record of storm runoff at the outlet of sub-basin. The comparision of computed response with the observed storm runoff at the outlet of sub basin establishes the model parameters. The model has been tested by taking the other recorded storm data.

Summarisingly the catchment action of each sub-area is characterised by a three parameter model. The parameters being 'n'- no. of linear reservoir, 'K'- the storage coefficient and the pure translation of the linear channels.

The above procedure has been extended to all the five gauged sub basins in the catchment.

5.1.3 <u>Formulation Of Model for the Intermediate Sub Basins:</u>

Intermediate sub basins are the catchment areas between the out let of a sub basin and a gauged and discharge site down stream. Separate analysis is proposed for the input function of Intermediate sub basins. To compute the input functions a graphical relationship has been arrived between intensity of weighted gross rainfall, duration of storm and ϕ-indices from the available records of gauged sub basin in the catchment. Knowing the meteorological characteristics of the storm the input function for Intermediate sub-basin and its sub areas are computed.

The transfer function, characterising the catchment action, is the same as for sub basin. But the parameters 'n' &'K' can not be obtained from the analysis of effective rainfall hyetograph and Direct Runoff Hydrograph, as the same are not available. These have been obtained from catchment characteristics (equation No.3.90 & 3.10).

Graphical relationships have been proposed between C_1 & C_2 and catchment characteristics to compute the catchment constants for intermediate sub basins. These relationships have been developed from the available records of gauged basins parts of the catchment. Thus the model parameters for the each sub areas of intermediate sub basins are derived and the transfer function i.e. the Unit Hydrographs developed.

The differential responses for sub areas of intermediate sub basins can be computed from computed rainfall excess. To these routed responses from up stream gauge are added to compute total flows at the out let of the intermediate sub basins.

The same procedure has been extended to all the six intermediate sub basins in the catchment.

5.1.4 Routing Of Flow Concentration To The Gandhi Sagar Site:

Having formulated the linear distributed parameter models for all the five gauged sub basins and six intermediate sub basins, next step is to route each flow concentration from their respective outlets to the Gandhi Sagar Site. For the purpose 'The Unite Response Theory of Open Channel Flow Routing' is adopted.

Seperate unit responses for all the five sub basins and five intermediate sub basins have been computed. The inflow hydrograph is divided into flow elements, having the same duration as that of the corresponding unit response. Routed responses of each of the flow elements have been computed at the Gandhi Sagar Reservoir. The analysis is extended to all the inflow hydrographs, using their corresponding unit responses. As the travel time of leading edge are not significant, the routed responses are superimposed to compute the inflows to the Gandhi Sagar Reservoir. To these flows, ~~one~~ are added, the flows from the Gandhi Sagar intermediate subbasin, and also the inputs directly falling on the reservoir to obtain the total inflows to the Gandhi Sagar from these total inflows, the net volume of inflow at the Gandhi Sagar is estimated. Using the area capacity relationships, the stages at the Gandhi Sagar Reservoir are computed at different times and compared with the observed stages. The procedure is repeated with the other storm data.

5.2 RESULTS, DISCUSSION OF RESULTS:

In the present section the discussion is carried out in accordance with the main tributary of river Chambal, which are - Chotti Kalisindh River, Shipra River, Shivana River and Retum River. These river basins have been modelled and compared at their outlets.

TABLE NO:5.1 Statement of Results

Name of River	River Modelled at -	Testing of Model is made at -	Reference Figure No.
1	2	3	4
1. Chambal R	(a) Nagda Site	Nagda Site	4(A)-5 & 4(A)-12
	(b) Barkheda Site (Intermediate sub-basin)	Barkheda Site (include Nagda Flow)	4(B)-18
2. Shipra R	(a) Mahidpur Site	Mahidpur Site	4(A)-4 & 4(A)-11
	(b) Kalkhedi Site (I.S.B.)	Kalakhedi Site (include Mahidpur Flow)	4(B)-8 & 4(B)-17
3. Chhotikali	(a) Pat Site	Pat Site	4(A)-3 & 4(A)-10
Sindh R	(b) Choumahla Site (I.S.B.)	Choumahla Site (include Pat Flow)	4(B)-7 & 4(B)-16
4. Shivana R	(a) Mandsaur Site	Mandsaur Site	4(A)-6 & 4(A)-8
	(b) Nahargarh Site (I.S.B.)	Nahargarh Site (include Mandsaur Flow)	4(B)-9
5. Retum R	(a) Chaldu Site	Chaldu Site	4(A)-7
	(b) Tumri Site (I.S.B.)	Tumri Site (include Chaldu Flow)	

5.2.1 Discussion Of Formulation Of Model For Sub-Basins & L.S.B.

Has considerably made the approach simpler, at the same time, the results shown above were found to be appreaciably satisfactory. Conclusions and discussions of the results are as follows:

(i) Assumption of linearity is valid.

(ii) The concepts used for computation of rainfall excess have produced satisfactory results.

(iii) The conceptual model proposed by Nash (Nash J.E. 1957) has been used to define, two parameters 'n' & 'K' of the different sub areas of the sub basins. When the Nash (Nash J.E. 1957) model as such applied to the sub basins considering the model to be lumped, in most cases, computed peak occured earlier than the observed one. This discrepency was eliminated to a great extent by considering the model to be distributed and by the application of linear channels.

(iv) For each sub area the transformation process of the hydrologic system is thus taken care of by a unit hydrographs in combination with a linear channels. The limitation of the unit hydrograph theory are not effecting the results, as the sub areas are comparatively much smaller (of the order of 70 sq. miles to 700 sq. miles).

(v) The unit hydrographs as defined in the present analysis represent the catchment action in combination with a linear channel, therefore they may not be identical to the unit hydrographs computed from the conventional approaches. However, this can only be verified when the rainfall and discharges for a sub area are available.

(vi) The rainfall excess has been computed by considering a constant rate of Ø-index for the entire sub basins where as, the rainfall excess of each sub area at different time unit is computed by using a weight factor. The weight factor represent the linear relation between excess rainfall and the gross mean rainfall for different time units. The assumption thus made have given satisfactory results.

(vii) For the input function for entire ungauged sub basins a representative relationships have been attempted between:

(a) Rainfall excess and Intensity of rainfall and its duration.

(b) Ø-index and Intensity of rainfall and its duration. Knowing the storm characteristics of the ungauged sub basins the Ø-index or rainfall excess thus directly be computed. The input function thus arrived at, has given satisfactory results.

(viii) For determination of transfer function of ungauged catchments, the model parameters 'n'& 'K' have been computed from the relationships developed between these parameters and the catchment physiographic characteristics for the entire sub basin and found the satisfactor results, which shows the usefulness of the theory developed for ungauged catchment areas.

5.2.2 Discussion of Results of Unit Response Theory:

The unit response theory for flood routing has been used to route the flow concentrations from the outlets of the sub basins and Intermediate sub basins upto Gandhi Sagar Reservoir. And the responses from sub basins out let have been tested at the outlets of intermediate sub basins and found the satisfactory results. The results are shown as follows:

The results are:

At Choumahla out let - Fig.No.'s 4(C)-12 & 4(C)-27
At Kalakhedi out let - Fig.No.'s 4(C)-16 & 4(C)-29
At Barkheda out let - Fig. No. 4(C)-31
At Nahangarh out let - Fig.No.'s 4(C)-18 & 4(C)-33
At Tumri out let - Fig. No. 4(C)-20

Discussions and conclusions made are:-

(i) The travel time of leading edge of inflow hydrographs have been found to be insignificant which may be due to the fact that the monsoon depression and cyclonic storms are traversed in the same direction as that of main river i.e. the West-North Westerly direction.

(ii) The unit responses are computed by routing a translation hydrograph to a linear reservoir, it was seen in the analysis that the shape of the unit response is not materially effected even when the time base of translation hydrograph was changed from 'K' units of time to '0.75 K', and further to '0.5K' (where K is the delay time for the area obtained by discharges in the model proposed by Clark (C.O. Clark, 1945).

(iii) The assumptions of the hypothetical channel are seldom true; however, in many open channels, the linear method yield acceptable results. Dooge and Harley (Dooge, J.C.I. & Harley, B.M., 1967) studied the effects of a non-linear channel on the attenuation and concluded that attenuation is almost independent of linearity. They suspect that it might be possible to simulate the non-linear action of a channel by two sub systems, one of which would subject to inflow to a non-linear translation, or lag and the other which would subject the translated inflow to a linear attenuation. The unit response method also includes a type of non linear attenuation.

The unit response theory and formulation of model for entire catchment has been tested at Gandhi Sagar Reservoir, by comparing the computed and observed reservoir levels. The comparision can be observed in Fig. No.'s 4(C)-39 & 4(C)-40 for both storms recorded in Aug.1974 & Aug. 1977 respectively, and found a quite close agreement between two.

The efficiency of the model for the catchment have been worked out and found as 89% and 81% for the two storms respectively.

5.3 PROPOSAL FOR FUTURE WORK:

In the light of the above discussion the following proposals have been suggested for future work on the subject.

(i) To make the theory of input function for ungauged areas more realistic by studying more storms of varied intensities and durations and by including some more parameters such as Anticipated Precipitation Index(API) etc.

(ii) To make the theory of transfer function for ungauged areas more realistic by adopting overland slope instead of river slope. This study will require the topographical maps scaled 1 inch to a mile.

(iii) A study is to be performed in the similar manner by including the upstream gauge and discharge sites which have not been included in the present study due to non-availability of the data.

(iv) Refinement in the study may be done by taking the number of linear reservoir in fraction in the Gamma function of the proposed model.

(v) Refinement in the application of input function for sub areas in the model, may be done, using the infiltration capacity curve for soil if available.

(vi) Study regarding the validity of insignificancy in the travel time of leading edge of inflow-hydrographs in the catchment is strongly suggested.

(vii) Improvement of the value of recession coefficient (r), by taking the average for several storm data, which has been worked out in the present study by considering the discharges by ~~discharging~~ considering the discharges of the recession limb beyond inflection point for only single storm. Thus improvement in storage coefficient will take place.

(viii) Last suggestion but not least in importance is that the entire simulation process starting from the rainfall to the prediction of reservoir levels at the Gandhi Sagar is computerised as the entire work is based on linear theory, which would be worth to attempt.

M

D H	t G.	Mands-aur R.G.	Dhar R.G.	Dewas R.G.	Indore R.G.	Neemuch R.G.
		10	11	12	13	14
1	00	23.60		2.40	15.24	6.50
	10	23.00	6.00	8.60	17.98	9.00
	00	11.80	6.00	5.80	27.50	
	00	0.40	20.00	27.00	51.52	1.20
1	50	1.48	19.40	100.00	16.75	1.30
	50	0.80	12.00	39.00	47.62	
	00	436.60	12.60	45.00	37.00	3.20
	80	60.00	7.80	28.00	16.30	57.20
	00	45.20	6.20	10.00	28.30	54.00
	00	54.40	14.60	40.00	11.73	18.00
2	20	31.40	10.00	45.40	16.25	22.00
	30	19.80	6.20			20.00
	20	29.20				16.50
						30.00
		2.80				10.20
2	00					5.00
		7.60	1.80		0.50	17.20
	.80	2.80	0.20			22.00
		7.00	14.00			1.20

epartment

APPENDIX NO. II

OBSERVED RAINFALL DATA FOR 1977 STORM

(All figures are in mm)

Date & Hrs	~~River~~ Rain Gauge Stations	Gandhisagar	Neemuch	Babulda	Mandsaur	Choumahla	Ratlam	Nagda	Pat	Badnagar	Ujjain	Dewas	Dhar	Indore
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
6.8.77	4 Hr						0.60	0.60			0.40			
	8 Hr				0.40	0.80	4.30			0.80				
	12 Hr					2.40	5.20		1.30					
	16 Hr				0.60		6.20	0.40	0.50			2.00		
	20 Hr							0.60	0.80			0.20		
	24 Hr									0.40				
7.8.77	4 Hr	2.80		2.20			0.20		1.00	0.80	1.20		4.20	3.50
	8 Hr	3.00		5.00		0.40	0.40	0.40	4.80	1.00	2.60	6.60	4.80	4.00
	12 Hr	32.60	6.20	25.80	6.60	15.00	8.60	22.60	19.30	26.80	31.00	32.60	42.60	19.00
	16 Hr	0.30		0.40	1.80		12.60	4.20	2.00	15.40	11.00	33.00	32.40	16.50
	20 Hr		2.00		17.20	4.00	11.40	22.60	2.50	25.80	43.60	86.60	32.40	52.00
	24 Hr	2.30		5.80	35.60	1.80	20.30	18.80	39.30	91.00	52.80	93.50	25.40	30.00
8.8.77	4 Hr	2.00	7.00	1.00	9.80	16.00	17.60	79.00	30.00	12.40	48.40	4.00	9.40	1.20
	8 Hr	1.00		1.00		24.00	31.80	1.40	1.50	2.30	0.40	1.00	6.60	3.00
	12 Hr	1.40	2.00	0.40	2.00	2.60	2.60	0.20		0.60			6.80	
	16 Hr						0.60				0.20		7.80	
	20 Hr					2.00			1.50		3.60	6.40	2.70	2.00
	24 Hr													

Note : Data has been collected from M.P. Irrigation Department

APPENDIX NO. I

OBSERVED RAIN FALL DATA FOR 1974 STORM

(All Figures are in m.m.)

Date & Hrs.	R.G. Stations	Gandhi Sagar R.G.	Babulda R.G.	Chouma-hla R.G.	Ratlam R.G.	Badnagar R.G.	Ujjain R.G.	Nagda R.G.	Pat R.G.	Mands-aur R.G.	Dhar R.G.	Dewas R.G.	Indore R.G.	Neemuch R.G.
1		2	3	4	5	6	7	8	9	10	11	12	13	14
18.8.74	12 Hrs						2.60							
	16 Hrs			2.40		1.80	1.40		8.00	23.60		2.40	15.24	6.50
	20 Hrs		2.20	57.00	0.10	4.40	44.00	3.80	23.10	23.00	6.00	8.60	17.98	9.00
	24 Hrs		1.20	21.80	45.60	40.00	23.00	20.00	35.00	1.80	6.00	5.80	27.50	
19.8.74	4 Hrs		14.00	42.40	7.80	18.40	26.00	27.20	32.00	0.40	20.00	27.00	51.52	1.20
	8 Hrs	1.50	8.00	21.20	20.40	11.40	42.00	14.60	12.50	1.48	19.40	100.00	16.75	1.30
	12 Hrs	4.80	1.80	17.00	7.50	16.40	35.00	10.60	47.50	0.80	12.00	39.00	47.62	
	16 Hrs	24.20	37.20	20.20	12.20	24.00	36.00	16.00	4 31.00	4 36.60	12.60	45.00	37.00	3.20
	20 Hrs	24.20	20.60	56.00	18.80	26.00	30.00	25.00	32.80	60.00	7.80	28.00	16.30	57.20
	24 Hrs	18.00	19.20	74.00	42.20	18.00	21.00	28.40	37.00	45.20	6.20	10.00	28.30	54.00
20.8.74	4 Hrs	21.50	33.00	19.60	65.60	39.40	25.20	25.60	39.00	54.40	14.60	40.00	11.73	18.00
	8 Hrs	5.60	37.00	32.60	48.00	21.00	32.40	38.60	52.20	31.40	10.00	45.40	16.25	22.00
	12 Hrs	32.40	57.00	50.00	26.80	13.20	7.00	26.60	12.30	19.80	6.20			20.00
	16 Hrs	70.00	128.20	12.60	4.00	5.00	1.00	2.00	1.20	29.20				16.50
	20 Hrs	15.20	58.20	0.61			0.20							30.00
	24 Hrs	9.80	37.40	4.00				1.40		2.80				10.20
21.8.74	4 Hrs	12.60	23.80	5.80	10.80		7.00	1.40	1.00					5.00
	8 Hrs	8.20	50.20	4.60	0.20		1.20	0.40		7.60	1.80		0.50	17.20
	12 Hrs	16.60	37.20	5.00	3.80				2.80	2.80	0.20			22.00
	16 Hrs	3.30	4.20	7.40		0.40				7.00	14.00			1.20

Note: Data has been collected from M.P.Irrigation Department

Da E	Ujjain	Kalakhedi	Choumahla	Nahangarh
	8	9	10	11
1	7.89	[illegible]	17.46	
1	31.06 35.10 416.51		12.79 14.50 17.46	9.67
1	736.63 1190.28 1239.87 1636.65	376.50	2536.55 1707.53 2894.73	24.53 250.34
2	2418.78 3419.88 2044.25 1544.78	5294.43 5719.98	4927.91 5867.17 4927.91	3513.62
2	403.92 123.56 96.58 60.38 48.95	5084.89	1707.53 557.70 395.22	757.13
2	34.43 45.61 82.54	752.69	205.06 195.56 97.64	260.34

APPENDIX NO. IV

OBSERVED RUN OF DATA FOR STORM 1977

All figures in cumecs

Date & Time		Badnagar	Chaldu	Mandsaur	Nagda	Balkhedey	Mahidpur	Pat	Ujjain	Kalakhedi	Choumahla
1		2	3	4	5	6	7	8	9	10	11
7.8.77	6 Hr	0.78	0.98	2.68	-	-	20.1	-	-	18.36	17.32
	12 Hr	2.14	-	2.68	-	125.91	20.1	-	-	21.19	16.76
	18 Hr	12.89	-	202.68	17.66	226.67	38.79	-	-	24.19	26.67
8.8.77	6 Hr	1593.79	7.19	835.99	2062.24	-	1763.60	-	1319.10	1687.62	1532.40
	12 Hr	1593.79	84.57	748.95	1939.24	4755.93	3544.97	-	1550.64	3129.34	2888.86
	18 Hr	1414.57	82.33	539.30	1505.66	4755.93	3727.53	78.30	1063.58	3879.96	2847.32
9.8.77	6 Hr	285.99	12.13	32.27	1713.20	2343.92	2585.27	1536.95	136.70	2556.24	1109.76
	12 Hr	44.23	7.49	11.45	1211.37	2017.70	859.93	2213.16	76.29	1831.30	567.06
	18 Hr	23.29	6.47	10.69	459.48	1457.54	278.67	2856.71	60.22	951.66	128.27
10.8.77	6 Hr	15.57	2.58	3.15	148.43	790.73	138.33	303.73	37.25	239.94	56.55
	12 Hr	15.03	2.17	3.03	131.29	793.87	86.81	179.71	19.10	154.20	54.15
	18 Hr	18.95	1.71	3.03	58.16	717.97	69.23	119.79	15.31	125.69	51.12

Note: Data have been collected from M.P.Irrigation Department

APPENDIX NO. V

STAGES AT GANDHI SAGAR RESERVOIR

Date	Period	Reservoir Level in feet	Date	Period	Reservoir Level in feet	Date	Period	Reservoir Level in feet	Date	Period	Reservoir level in feet
1	2	3	4	5	6	7	8	9	10	11	12
18.8.74	16 Hr	1284.28	21.8.74	4 Hr	1302.64	6.8.77	24 Hr	1289.34	9.8.77	12 Hr	1295.95
	20 Hr	1284.28		8 Hr	1303.22	7.8.77	4 Hr	1289.31		16 Hr	1296.35
	24 Hr	1284.28		12 Hr	1304.23		8 Hr	1289.30		20 Hr	1296.75
19.8.74	4 Hr	1284.33		16 Hr	1305.34		12 Hr	1289.30		24 Hr	1297.15
	8 Hr	1284.43		20 Hr	1306.15		126 Hr	1289.30	10.8.77	4 Hr	1297.38
	12 Hr	1284.73		24 Hr	1306.45		20 Hr	1289.32		8 Hr	1297.45
	16 Hr	1285.32	22.8.74	4 Hr	1306.46		24 Hr	1289.34		12 Hr	1297.45
	20 Hr	1286.06		8 Hr	1306.46	8.8.77	4 Hr	1289.46		16 Hr	1297.45
	24 Hr	1287.46		12 Hr			8 Hr	1289.60		20 Hr	1297.45
20.8.74	4 Hr	1289.85		16 Hr			12 Hr	1290.15		24 Hr	1297.45
	8 Hr	1292.63		20 Hr			16 Hr	1291.10	11.8.77	4 Hr	1297.48
	12 Hr	1295.29		24 Hr			20 Hr	1292.90		8 Hr	1297.50
	16 Hr	1298.02					24 Hr	1294.20		12 Hr	1297.53
	20 Hr	1299.97				9.8.77	4 Hr	1295.00		16 Hr	1297.53
	24 Hr	1301.46					8 Hr	1295.22		20 Hr	1297.55

Note: Data has been collected from M.P.Irrigation Department

APPENDIX NO. III

OBSERVED RUN OFF DATA FOR 1974 STORM

(All figures are in Cumecs)

Date & Hrs	River G & D Sites	Badnagar	Ghaldu	Mandsaur	Nagda	Mahidpur	Pat	Ujjain	Kalakhedi	Choumahla	Nahangarh
1		2	3	4	5	6	7	8	9	10	11
17.8.74	6 Hr					14.45	20.79				
	12 Hr					14.45	18.50				
	18 Hr					12.95	17.24	7.89		17.46	
18.8.74	6 Hr					12.45	16.78			12.79	9.67
	12 Hr					12.45	16.78	31.06		14.50	
	18 Hr					34.28	31.85	35.10		17.46	
	24 Hr							410.91			
19.8.74	6 Hr	19.60	12.38	1.40	108.85	452.20	858.70	736.63	376.50	2536.55	24.53
	12 Hr	45.89	4.35	0.80	653.25	1251.81	1014.77	1190.28		1707.53	
	15 Hr	72.13		46.00	895.45		1368.45	1239.87			
	18 Hr	136.08	6.13		1532.48		1930.87	1636.65		2894.73	250.34
20.8.74	0 Hr			1047.72			1730.87				
	6 Hr	664.79	428.05	1875.25	2868.12	4290.07	2101.17	2418.78	5294.43	4927.91	3513.62
	12 Hr	757.19	685.74	1860.02	5296.26	5784.94	2700.96	3419.88	5719.98	5867.17	
	15 Hr	579.03			4129.94	5926.81	1991.04	2044.25			
	18 Hr	496.40	512.31	1247.83	3401.12	5926.89	1859.06	1544.78		4927.91	
21.8.74	0 Hr					5389.00	1655.20				
	6 Hr	188.58	124.69	220.52	2589.42	4394.70	1205.80	403.92	5084.89	1707.53	757.13
	9 Hr	73.11				3637.01		123.56			
	12 Hr	28.84	205.18		1021.60	2835.64	737.12	96.58		557.70	
	15 Hr	21.33			558.17	1553.27	196.14	60.38			
	18 Hr	17.55	274.80	184.89	457.02	536.82	148.18	48.95		395.22	
22.8.74	6 Hr	5.77	33.03	183.20	159.42	166.94	127.64	34.43	752.69	205.06	260.34
	12 Hr	8.09	30.17	50.27	464.17	124.56	117.97	45.61		195.56	
	18 Hr	17.26	23.56	50.27	667.23	110.48	93.68	82.54		97.64	

APPENDIX NO.VI

AREA CAPACITY RELATIONSHIP AT GANDHI SAGAR RESERVOIR

Reservoir Level in feet	Submergence area in acres	Reservoir capacity in M.A.F.	Reservoir Level in feet	Submergence area in acres	Reservoir capacity in M.A.F.	Reservoir Level in feet	Submergence area in acres	Reservoir capacity in M.A.F.
1	2	3	4	5	6	7	8	9
1282	86200		1295	116000	3.895	1308	151200	5.650
1283	88400		1296	118600	4.005	1309	154100	5.800
1284	90400	2.745	1297	121000	4.140	1310	157000	5.955
1285	92500	2.855	1298	123600	4.255	1311	160000	6.128
1286	94700	2.925	1299	126200	4.400	1312 (F.T.L.)	163500	6.278
1287	97000	3.020	1300	128800	4.505			
1288	99000	3.115	1301	131500	4.645	1313		6.450
1289	101400	3.230	1302	134100	4.790	1314		6.638
1290	103800	3.340	1303	137000	4.910	1315		6.800
1291	106200	3.450	1304	139800	5.045	1316 (M.W.L.)		6.975
1292	108600	3.555	1305	142500	5.180			
1293	111100	3.660	1306	145400	5.345			
1294	113600	3.780	1307	148300	5.480			

Note: (1) Data is collected from M.P.Irrigation Department
(2) MAF Means Million Acre feet
(3) FTL Means Full Tank Level
(4) MWL Means Maximum Water Level

APPENDIX ~~TABLE~~ NO. VII

CATCHMENT CHARACTERISTICS & THIESSEN WEIGHTAGE OF RAINGAUGES

Sl. No.	Name of gauging site	Name of River	Length of River Miles	Catch-ment area drained sq.mile	Over land slope			Weighted Percentage of Rain Gauges Stations.													
					R.L. at farth-est point	R.L. at site ft.	OLS in parts per 10000	Gandhi sagar	Babu-lda	Neem-uch	Chou-mahla	Ratlam	Nagda	Pat	Bad-nag-ar	Ujj-ain	Dewas	Dhar	Indo-re	Mand-saur	Total percen-tage
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Pat	Choti Kali-sindh	46	553	1800	1600	9.5							35%		25%	40%				100%
2	Mahidpur	Shipra	76	1707	2950	1560	39.65						6%	3%	5%	34%	15%		37%		"
3	Nagola	Chambal	72	1477	2850	1600	37.00						15%		40%			40%	5%		"
4	Mandsaur	Shivana	45	414	1510	1380	6.15					24%								76%	"
5	Chaldu	Retum	24	193	1510	1410	8.61			20%										80%	"
6	Ujjain	Shipra	40	775	2000	1650	16.60									20%	34%		46%		"
7	Badnagar	Chamla	38	358	2850	1680	65.36								50%			50%			"
8																					

Details for Intermediate Sub-Basins

Sl. No.	Name of gauging site	Name of River	Length of River Miles	Catch-ment area drained sq.mile	R.L. at farth-est point	R.L. at site ft.	OLS in parts per 10000	Gandhi sagar	Babu-lda	Neem-uch	Chou-mahla	Ratlam	Nagda	Pat	Bad-nag-ar	Ujj-ain	Dewas	Dhar	Indo-re	Mand-saur	Total percen-tage
11	Pat & Choumahla	Choti Kali Sindh	32	521	1600	1400	12.63				43%			57%							100%
12	Nagda & Barkhedi	Maleny	63	1115	1600	1400	7.28				6%	33%	45%							16%	"
13	Mahipur & Kalakhedi	Shipra	36	390	1560	1400	10.10				41%		35%	24%							"
14	Mandsaur & Nahangarh	Shivana	24	340	1460	1320	9.47													100%	"
15	Chaldu & Tumni	Retam	30	390	1480	1320	12.38			100%											"
16	Gandhisagar & others	Chambal	32	1700	1400	1120	8.95	7%	31%	8%	34%									20%	"

NO

APPENDIX VIII

STATEMENT INDICATING THE DETAILS OF SUB-AREAS OF GAUGED SUB-BASINS

Name of Sub-System	Name of Sub-Area	Catchment area sq. mile	Thiessen weight %age	Length of River miles	Overland slope: Upstream R.L. (feet)	Overland slope: Down stream R.L.(ft.)	Overland slope: O.L.S. in Parts per 10000	Value of C_1	Value of C_2	For Sub-System: Value of n	For Sub-System: Value of k	For Sub-Area: Value of n	For Sub-Area: Value of K	Value of Time lag in Hrs.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ujjain	1. Dewas & Indore	620	42.5+57.5	30	2000	1700	20.29	2.03	2.81	5	4.1	4	3.8	24 Hr
	2. Ujjain	155	100%	10	1700	1650	7.89					4	3.8	0
Badnagar	1. Badnagar(1)	179	100%	19	2850	1730	124.78	1.74	5.63	8	1.93	8	1.43	24
	2. Badnagar (2)	179	100%	19	1730	1680	5.57					8	3.62	0
Mahidpur	1. Indore	630	100%	34	2950	1700	74.00	1.75	5.98	9	3.14	8	2.13	32
	2. Dewas	260	100%	28	1900	1700	15.20					8	2.82	40
	3. Ujjain &Badnagar	663	88+12%	36	1740	1610	8.20					8	4.24	4
	4. Pat & Nagda	153	33+67%	16	1610	1560	7.90					8	3.21	0
Nagda	1. Dhar	665	100%	28	2850	1800	90.39	2.75	2.67	4	4.89	4	6.44	24
	2. Badnagar	590	100%	32	1800	1660	8.84					4	6.44	8
	3. Nagda	222	100%	16	1660	1600	8.12					4	5.43	0
Mandsaur	1. Ratlam	100	100%	13	1510	1480	5.68	1.15	2.75	4	2.66	4	2.11	16
	2. Mandsaur (1)	157	100%	17	1480	1430	5.92					4	2.32	8
	3. Mandsaur (2)	157	100%	15	1430	1380	5.92					4	2.32	0
Chaldu	1. Mandsaur	96	100%	12	1510	1460	7.90	4.57	2.20	3	8.30	4	7.75	4
	2. Neemuch & Mandsaur	97	41+59%	12	1460	1410	9.50					4	5.95	0

APPENDIX NO. IX (a)

STATEMENT SHOWING THE RAINFALL EXCESS FOR UJJAIN SUB-BASIN & ITS SUB AREAS

Date & Time	Wtd. rainfall in mm			Total W.R.F. in mm. Col. (2+3+4)	Total W.R.F. in inch/Hr Col.5/101.6	φ-index inch/Hr	Rainfall excess inch/Hr Col.6-7	Factor Col.8/Col.6	Rainfall excess for Sub Area (1)				Sub Area (2)		Observed Runoff TH.Cusecs.		
	Ujjain 20%	Dewas 34%	Indore 46%						Dewas 42.5%	Indore 57.5%	W.R.F. in inch/Hr	R.F. excess inch/Hr. Col 9x12	W.R.F. in inch/Hr	R.F. Excess inch/Hr Col. 14x9	Discharge	Base flow	D.R.H. Ordinate
1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11	12	13	14	15	16	17	18
18.8.74															1.24	1.24	0
20 Hr	8.80	2.92	8.27	20.00	0.20	0.155	0.045	0.23	0.04	0.10	0.14	0.03	0.44	0.10	5.50	1.50	4.00
24 Hr	4.60	1.97	12.65	19.22	0.19	0.155	0.035	0.18	0.02	0.16	0.18	0.03	0.23	0.04	14.50	1.50	13.00
19.8.74																	
4 Hr	5.20	9.18	23.70	38.08	0.38	0.155	0.225	0.59	0.11	0.29	0.40	0.24	0.26	0.15	22.50	1.50	21.00
8 Hr	8.40	34.00	7.71	50.11	0.49	0.155	0.335	0.68	0.43	0.09	0.52	0.35	0.42	0.29	32.20	1.50	30.70
12 Hr	7.00	13.26	21.91	42.17	0.42	0.155	0.265	0.63	0.16	0.27	0.43	0.27	0.35	0.22	42.03	1.53	40.50
16 Hr	7.20	15.30	17.02	39.52	0.39	0.155	0.235	0.60	0.19	0.21	0.40	0.24	0.36	0.22	47.00	1.50	45.50
20 Hr	6.00	9.52	7.50	23.02	0.23	0.155	0.075	0.33	0.12	0.09	0.21	0.07	0.30	0.10	62.00	1.50	60.50
24 Hr	4.20	3.40	13.02	20.62	0.20	0.155	0.045	0.23	0.04	0.16	0.20	0.05	0.21	0.05	71.20	1.50	69.70
20.8.74																	
4 Hr	5.04	13.60	5.40	24.04	0.24	0.155	0.085	0.35	0.17	0.06	0.23	0.08	0.25	0.09	79.50	1.50	78.00
8 Hr	6.48	15.44	7.48	29.40	0.29	0.155	0.135	0.47	0.19	0.09	0.28	0.13	0.32	0.15	88.00	1.50	86.50
12 Hr	1.40			1.40	0.01	0.010									120.77	1.77	119.00
16 Hr															64.00	1.80	62.20
20 Hr				Total	3.04	1.56	1.48					1.49		1.41	43.20	1.80	41.40
24 Hr							5.92"					5.96"		5.64"	29.80	1.80	28.00
21.8.74																	
4 Hr															18.80	1.80	17.00
8 Hr															10.00	1.80	8.20
12 Hr															3.41	1.81	1.60
16 Hr															2.00	2.00	0

Note: (1) Weighted rainfall under Col. 2,3,4,10,11&14) are taken from Appendix-I

(2) Depth of run off in inches $= \dfrac{726500 \times 4 \times 60 \times 60 \times 12}{775 \times 5280 \times 5280} = 5.81"$

(3) Col. 16 the observed run off is taken from appendix-III

APPENDIX NO. IX (b)

STATEMENT INDICATING THE RAINFALL EXCESS OF BADNAGAR SUB BASIN AND ITS SUB AREAS

Date & Hrs.	Weighted R.F. mm		Total W.R.F. mm/4Hr 2+ 3	Total W.R.F. inch/Hr	Ø-index inch/Hr	Rainfall excess inch/Hr	Factor Col.7 / Col.5	Sub Area (1)		Sub Area (2)		Observed Runoff Th.Cu.		
	Badnagar 50%	Dhar 50%						R.F.in inch/Hr	R.E.in inch/Hr	R.Fall inch/Hr	R.E.E in inch/Hr	Discharge	Base Flow	D.R.H. Ordinate
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
19.8.74												0.60	0.60	0.00
8 Hr	5.70	9.70	15.40	0.15	0.07	0.08	0.53	0.11	0.06	0.19	0.10	1.00	0.55	0.45
12 Hr	8.20	6.00	14.20	0.14	0.07	0.07	0.50	0.16	0.08	0.13	0.06	1.62	0.52	1.10
16 Hr	12.00	6.30	18.30	0.13	0.07	0.06	0.46	0.20	0.11	0.12	0.06	3.00	0.50	2.50
20 Hr	13.00	3.90	16.90	0.17	0.07	0.10	0.72	0.26	0.19	0.08	0.06	7.20	0.50	6.70
24 Hr	9.00	3.10	12.10	0.12	0.07	0.05	0.42	0.18	0.07	0.06	0.03	13.00	0.45	12.55
20.8.74														
4 Hr	19.70	7.30	27.00	0.27	0.07	0.20	0.74	0.39	0.29	0.14	0.10	18.60	0.40	18.20
8 Hr	10.50	5.00	15.50	0.15	0.07	0.08	0.53	0.21	0.11	0.10	0.05	24.80	0.40	24.40
12 Hr	6.60	3.10	9.70	0.09	0.07	0.03	0.30	0.13	0.04	0.06	0.02	26.74	0.40	26.34
16 Hr	2.50		2.50	0.03	0.03							19.40	0.40	19.00
20 Hr												16.20	0.38	15.82
24 Hr			Total	1.26	0.59	0.67			0.95"		0.48	12.80	0.35	12.45
						2.68"			3.8"		1.92"			
21.8.74														
4 Hr												8.80	0.35	8.45
8 Hr												3.80	0.30	3.50
12 Hr												1.02	0.30	0.72
16 Hr												0.60	0.25	0.35
20 Hr												0.45	0.25	0.20
24 Hr												0.20	0.20	0

Note: (1) Weighted Rainfall under above are taken from appendix 4.I

(2) Depth of run off in inches $= \frac{152730 \times 4 \times 3600 \times 12}{358 \times 5280 \times 5280} = 2.64"$

(3) Observed run off under Col. 3 are taken from appendix 4.III

APPENDIX NO. IX (c)

STATEMENT INDICATING THE RAINFALL EXCESS OF MAHIDPUR SUB-BASIN & SUB AREA

Date & Time	Weighted Rainfall in mm.						Total WRF in mm. Col 2+3+4+5+6+7	Total WRF in inch/Hr Col 8/1016	Øindex inch /Hr	R.F. excess inch/Hr Col.9 -10	Factor Col.11/Col.9	Sub area(1)		Sub area(2)		Sub area(3)				Sub Area (4)				Observed Runoff Th.Cusces		
	Ujjain 34%	Indore 37%	Dewas 15%	Nagda 6%	Bad-nagar 5%	Pat 3%						WRF in. /Hr	R.E.E inch/Hr Col. 12x13	W.R.F inch /Hr	RFE Inch/Hr. Col. 15x12	Ujjain 88% mm	Bad-Nagar 12" mm	TWR inch /Hr	RFE inch /Hr	Pat 33% mm	Nagda 67% mm	TWR inc. /Hr	RFE inch /Hr	Discharge	Base flow	DRH Ordinat
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
	0.48	5.64	0.36		0.09	0.24	6.81	0.07	0.070															0.70	0.70	0
18.8.74																								1.00	1.00	2.00
20 Hr	14.96	6.65	1.29	0.23	0.22	0.69	24.04	0.24	0.116	0.124	0.52	0.18	0.09	0.08	0.42	38.72	0.53	0.38	0.20	7.62	2.50	0.10	0.05	4.50	1.50	3.00
24 Hr	7.82	10.18	0.87	1.20	2.00	1.05	23.12	0.23	0.116	0.114	0.50	0.27	0.14	0.06	0.03	20.24	4.80	0.24	0.12	11.55	13.20	0.24	0.12	8.00	2.00	6.00
19.8.74																										
4 Hr	8.84	19.06	4.05	1.63	0.92	0.96	35.46	0.35	0.116	0.234	0.67	0.51	0.34	0.26	0.17	22.90	2.21	0.25	0.17	10.56	17.95	0.28	0.19	12.50	2.00	10.50
8 Hr	14.28	6.19	15.00	0.88	0.87	0.38	37.30	0.36	0.116	0.244	0.68	0.16	0.11	0.98	0.67	37.00	1.37	0.38	0.26	4.13	9.64	0.13	0.09	22.00	2.00	20.00
12 Hr	11.90	17.62	5.85	0.64	0.82	1.43	38.26	0.38	0.116	0.264	0.69	0.47	0.32	0.38	0.26	30.80	1.97	0.32	0.22	15.67	7.00	0.22	0.015	44.20	2.00	42.20
16 Hr	12.24	13.69	6.75	0.96	1.20	1.23	36.07	0.35	0.116	0.234	0.67	0.36	0.24	0.44	0.30	31.68	2.88	0.34	0.23	13.53	10.56	0.24	0.16	62.00	2.00	60.00
20 Hr	10.20	6.03	4.20	1.50	1.30	0.98	24.21	0.24	0.116	0.124	0.52	0.16	0.08	0.27	0.14	26.40	3.12	0.29	0.15	10.82	16.50	0.28	0.15	88.20	2.20	86.00
24 Hr	7.14	10.47	1.50	1.70	0.90	1.41	23.12	0.23	0.116	0.114	0.80	0.28	0.14	0.10	0.05	18.48	2.16	0.20	0.10	15.51	18.74	0.34	0.17	110.00	2.20	107.80
20.8.																										
4 Hr	8.57	4.34	6.00	1.54	1.97	1.17	23.59	0.23	0.116	0.114	0.50	0.11	0.05	0.39	0.19	22.18	4.73	0.26	0.13	12.07	16.90	0.29	0.15	136.00	2.20	133.80
8 Hr	11.02	6.01	6.81	2.32	1.05	1.57	28.78	0.28	0.116	0.164	0.59	0.16	0.09	0.25	0.28	28.51	2.52	0.30	0.18	17.23	25.48	0.49	0.25	178.00	2.20	175.80
12 Hr	2.38			1.60	0.66	0.37	5.01	0.05	0.050															204.30	2.29	202.00
16 Hr	0.34			0.12	0.25	0.04	0.75	0.01	0.010															210.00	2.50	207.50
20 Hr							Total	3.03	1.30	1.73			1.6		2.49				1.76"				1.48	204.00	2.50	201.50
24 Hr										6.92"			6.4"		9.96"				7.04"				5.92"	190.37	3.37	187.00
21.8.																										
4 Hr																								169.00	3.50	165.50
8 Hr																								140.00	3.50	136.50
12 Hr																								100.14	3.14	96.50
16 Hr																								46.00	3.50	42.50
20 Hr																								14.00	3.70	10.30
24 Hr																								9.00	3.80	5.30
22.8																										
4 Hr																								6.00	4.00	2.00
8 Hr																								5.00	4.00	1.00
12 Hr																								4.00	4.00	0
																										1904.70

Note: (1) Weighted rainfall in the above columns are taken from appendix 4.I

(2) Depth of runoff in inches $= \frac{1904700 \times 4 \times 60 \times 60 \times 12}{1707 \times 5280 \times 5280} = 6.92"$

(3) Col. 25 - the observed runoff is taken from appendix [illegible]III

APPENDIX NO.IX(d)

STATEMENT INDICATING THE RAINFALL EXCESS FOR NAGDA SUB-BASIN & ITS SUB-AREA

Date & Time	Wtd.Rainfall in mm. Nagda 15%	Bad Nagar 40%	Dhar 40%	Indore 5%	Total WRF in inch /Hr	ϕ-index inch /Hr	Rain fall excess in inch/ Hr	Factor Col.8 / Col.6	Dhar Sub-area (1) Rain fall inch /Hr	Rain fall excess inch /Hr	(2) Sub-Area Bad Nagar Rain fall inch /Hr	Rain fall excess inch /Hr	3rd Sub-Area Nagda R.E.in inch /Hr	R.F. EXCESS INCH/Hr	Observed Runoff Th.Cusecs Discharge	Base Flow	DRH Ordinate
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19.8.74															2.00	2.00	0.00
8 Hr	2.19	4.56	7.76	0.84	0.15	0.025	0.125	0.83	0.19	0.16	0.112	0.09	0.144	0.12	10.00	2.00	8.00
12 Hr	1.59	6.56	4.80	2.38	0.15	0.025	0.125	0.83	0.12	0.10	0.161	0.13	0.104	0.09	23.07	2.07	21.00
16 Hr	2.40	9.60	5.04	1.85	0.19	0.025	0.165	0.87	0.124	0.11	0.236	0.21	0.157	0.14	38.00	2.50	35.50
20 Hr	3.75	10.40	3.12	0.82	0.18	0.025	0.155	0.86	0.077	0.07	0.256	0.22	0.246	0.21	60.00	3.00	57.00
24 Hr	4.26	7.20	2.48	1.42	0.15	0.025	0.125	0.83	0.061	0.05	0.177	0.15	0.279	0.23	78.00	3.00	75.00
20.8.74 4 Hr	3.84	15.76	5.84	0.59	0.26	0.025	0.235	0.90	0.144	0.13	0.388	0.35	0.242	0.23	93.00	3.00	90.00
8 Hr	5.79	8.40	4.00	0.81	0.19	0.025	0.165	0.87	0.098	0.009	0.206	0.18	0.380	0.33	118.00	3.00	115.00
12 Hr	3.99	5.28	2.48		0.12	0.025	0.095	0.79	0.061	0.05	0.130	0.10	0.262	0.21	157.72	3.22	148.50
16 Hr	0.30	2.00			0.02	0.020									139.50	3.50	136.00
20 Hr															116.00	3.50	113.50
				Total	1.41	0.22	1.19			0.76		1.43		1.56			
24 Hr							4.76"			3.04"		5.78"		6.24"	107.00	3.50	103.50
21.8.74 4 Hr															96.00	3.70	92.30
8 Hr															84.00	4.00	80.00
12 Hr															36.08	4.08	32.00
16 Hr															18.00	4.00	14.00
20 Hr															12.50	4.00	8.50
24 Hr															8.00	4.00	4.00
															4.00	4.00	0
																	1133.80

Note: (1) Weighted Rainfall in the above table have been taken from appendix 4.I

(2) Depth of runoff in inches $= \frac{1133800 \times 4 \times 60 \times 60 \times 12}{1477 \times 5280 \times 5280} = 4.76$ inches

(3) Observed runoff in col. 16 are taken from appendix 4.III

APPENDIX NO. IX (e)

Statement indicating the rainfall excess for Mandsaur sub-Basin & its Sub-area

Date & Time	Wtd. R.F. in mm		Total Wtd.R.F in mm. Col. 2 + 3	Total W.R.F in inch/Hr	ϕ-index inch/Hr	Rainfall excess inch/Hr	Factor Col.7 / Col. 5	Sub-Area(1)		Sub-Area (1 & 2)			Observed Run Off Th.Cusecs		
	Mandsaur 76%	Ratlam 24%						Ratlam inch/Hr.	R.F. excess inch/Hr	Rainfall inch/Hr	R.F. excess inch /Hr	Rainfall excess inch /Hr	Discharge	Base Flow	D.R.H. ordinate
1.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
19.8.74													1.63	1.63	0
20 Hr	45.60	4.50	50.10	0.49	0.18	0.31	0.63	0.18	0.11	0.59	0.37	0.37	15.00	2.00	13.00
24 Hr	34.15	10.13	44.48	0.44	0.18	0.26	0.59	0.21	0.24	0.45	0.27	0.27	37.00	2.50	34.50
20.8.74															
4 Hr	41.34	15.74	57.07	0.56	0.18	0.38	0.68	0.65	0.44	0.53	0.36	0.36	55.00	3.00	52.00
8 Hr	23.86	11.52	35.38	0.35	0.18	0.17	0.48	0.47	0.23	0.31	0.15	0.15	67.00	3.00	64.00
12 Hr	15.04	6.43	21.47	0.21	0.18	0.03	0.14	0.26	0.04	0.19	0.03	0.03	65.69	3.69	62.00
16 Hr	22.19	0.96	23.15	0.23	0.18	0.05	0.22	0.04	0.01	0.29	0.06	0.06	54.00	4.00	50.00
20 Hr			Total	2.28	1.08	1.20			1.07		1.24	1.24	35.00	4.00	31.00
24 Hr						4.80"			4.28"		4.96"	4.96"	20.00	4.50	15.50
21.8.74															
4 Hr													9.00	5.00	4.00
8 Hr													7.00	5.00	2.00
12 Hr													6.50	6.50	0
															328.00

Note: 1. Weighted rainfall under col. (2,3,9,10) are taken from appendix 4.I

2. Depth of run off in inches $= \frac{32800 \times 4 \times 60 \times 60 \times 12}{414 \times 5280 \times 5280} = 4.91''$

3. The observed runoff in col. 14 is taken from appendix 4.3III

APPENDIX NO. IX (f)

STATEMENT INDICATING THE RAINFALL EXCESS FOR CHALDU SUB-BASIN AND ITS SUB-AREA

Date & Time	Wtd.rainfall in mm		Total W.R.F. in mm.	Total Wtd. W.R.F. in inch/Hr	ϕ-index inch/Hr	Rainfall exdess in inch/Hr	Factor Col.7/Col.5	Sub-Area(1)		Sub-Area (2)			Observed Runoff in Th.Cusecs.			
	Neemuch 20%	Mandsaur 80%						Mandsaur inch/Hr	R.F. excess inch/Hr	Mansaur mm 41%	Neemuch mm 59%	Total WRF in inch/Hr	Rainfall	Discharge	Base Flow	D.R.H. ordinate
1	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
19.8.74														0.22	0.22	0
20 Hr	11.44	48.00	59.44	0.58	0.20	0.38	0.655	0.59	0.39	24.60	33.60	0.57	0.37	3.00	0.50	2.50
24 Hr	10.80	36.16	46.96	0.46	0.20	0.26	0.565	0.44	0.25	18.50	32.00	0.50	0.28	7.00	0.60	6.40
20.8.74 4 Hr	3.60	43.52	47.12	0.46	0.20	0.26	0.565	0.53	0.30	22.30	10.60	0.32	0.18	11.00	1.50	9.50
8 Hr	4.40	25.12	29.12	0.29	0.20	0.09	0.310	0.31	0.10	12.90	13.00	0.25	0.08	17.00	2.00	15.00
12 Hr	4.00	8.64	12.64	0.13	0.13			0.11		4.40	11.80	0.16		24.22	2.22	22.00
16 Hr	3.20	23.36	26.36	0.26	0.20	0.06	0.231	0.29	0.07	12.00	9.40	0.21	0.05	21.00	2.50	18.50
20 Hr	6.00		6.00	0.06	0.06									15.00	2.50	12.50
24 Hr	2.04	2.24	4.24	0.04	0.04									9.00	2.00	7.00
21.8.74 4 Hr	1.00		1.00	0.01	0.01									5.00	1.00	4.00
8 Hr	3.44	5.60	9.04	0.09	0.09									5.50	1.00	4.50
12 Hr	4.40		4.40	0.04	0.04									7.25	1.25	6.00
16 Hr						1.05			1.11				0.96	9.00	1.00	8.00
20 Hr						4.20			4.44				3.84"	7.50	1.00	6.50
24 Hr														4.00	1.00	3.00
22.8.74 4 Hr														1.00	1.00	0
																129.40

Note: 1. Weighted Rainfall under Columns 2,3,9,11&12 are taken from appendix 4.I

2. Depth of runoff in inches $= \frac{129400 \times 4 \times 60 \times 60 \times 72}{193 \times 5280 \times 5280} = 4.16"$

3. The observed runoff under Col. 15 are taken from appendix 4.III

APPENDIX NO. X

UNIT HYDROGRAPHS OF EACH SUB-AREA OF GAUGED SUB-BASINS

(All figures are in Th. Cusecs)

Hrs.	Ujjain Sub-Basin		Badnagar Sub-Basin		Mahidpur Sub-Basin				Nagda Sub-Basin			Mandsaur Sub-Basin			Chaldu Sub-Basin	
	Dewas& Indore (1)	Ujjain (2)	Badnagar (1)	Badnagar (2)	Indore (1)	Dewas (2)	Ujjain & Bad nagar (3)	Pat & Nagda (4)	Dhar (1)	Badnagar (2)	Nagda (3)	Ratlam (1)	Mandsaur 1 (2)	Mandsaur 2 (3)	Mandsaur (1)	Mandsaur & Neemuch (2)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3.56	5.02	0.66	0	0.25	0.02	0.01	0.01	5.66	0.65	0.43	2.61	2.35	2.35	3.10	0.38
8	13.53	18.95	5.76	0.09	4.92	0.52	0.13	0.15	19.18	3.37	2.00	5.81	8.16	8.16	1.09	1.25
12	21.19	30.29	10.38	0.60	14.84	2.52	0.98	0.83	27.26	7.80	4.15	4.78	7.65	7.65	1.82	2.00
16	21.45	30.23	7.71	1.77	24.19	5.79	3.21	2.27	23.39	11.10	5.52	2.13	4.05	4.05	2.10	2.32
20	16.44	23.18	3.14	3.24	24.19	8.14	6.85	3.80	14.36	13.44	5.66	0.71	1.64	1.64	2.03	2.23
24	10.60	14.95	0.86	4.33	15.86	8.14	9.85	4.49	7.50	13.58	5.01	0.21	0.55	0.55	1.82	1.91
28	6.20	8.74	0.18	4.64	8.13	6.46	10.70	4.15	4.14	11.42	4.01	0.05	0.17	0.17	1.55	1.55
32	3.38	4.79	0	4.33	3.46	4.62	12.63	3.26	1.92	9.44	2.94	0.01	0.05	0.05	1.23	1.20
36	1.76	2.48		3.50	1.77	2.88	13.70	2.27	0.88	7.35	2.08	0	0.01	0.01	0.93	0.88
40	0.88	1.24		2.47	0.86	1.38	11.77	1.44	0.37	5.54	1.41		0	0	0.70	0.63
44	0.40	0.56		1.67	0.14	0.69	9.42	0.85	0.15	4.09	0.90				0.51	0.44
48	0	0		1.06	0.05	0.44	7.06	0.47	0.05	2.91	0.57				0.36	0.30
52				0.69	0.01	0.30	4.97	0.25	0.01	1.98	0.35				0.25	0.21
56				0.31	0.	0.13	3.23	0.12	0	1.34	0.21				0.17	0.14
60				0.20		0.04	2.10	0.06		0.91	0.13				0	0
64				0		0	1.35	0.03		0.59	0.07					
68							0.84	0.01		0.38	0					
72							0.50	0		0.25						
76							0.27			0.16						
80							0.15			0.10						
88							0			0						
92																

APPENDIX NO. XI

COMPARISON OF OBSERVED AND COMPUTED DIRECT RUNOFF
ALL GAUGED SUB-BASINS

(All figures are in Th. cusecs)

Date & Period	Hours	Ujjain Sub-Basin Observed	Ujjain Sub-Basin Computed	Badnagar Sub-Basin Observed	Badnagar Sub-Basin Computed	Pat Sub-Basin Observed	Pat Sub-Basin Computed	Mahidpur Sub-Basin Observed	Mahidpur Sub-Basin Computed	Nagda Sub-Basin Observed	Nagda Sub-Basin Computed	Mandsaur Sub-Basin Observed	Mandsaur Sub-Basin Computed	Chaldu Sub-Basin Observed	Chaldu Sub-Basin Computed
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
18.8.74 12 Hr	0							0	0						
16 Hr	4	0	0			0		2.00	0.03						
20 Hr	8	4.00	5.02			6.00	0	3.00	0.88						
24 Hr	12	13.00	8.00			17.00	13.46	6.00	5.79						
19.8.74 4 Hr	16	21.00	13.00	0	0	25.00	32.00	10.50	20.34	0	0				
8 Hr	20	30.70	18.00	0.45	0	30.50	36.00	20.00	45.10	8.00	2.68				
12 Hr	24	40.50	24.00	1.10	0.35	34.50	40.00	42.20	64.70	21.00	12.51				
16 Hr	28	45.50	34.00	2.50	2.28	41.00	44.00	60.00	84.14	35.50	29.62	0	0	0	0
20 Hr	32	60.50	50.00	6.70	6.73	51.00	49.00	86.00	94.61	57.00	53.68	13.00	11.63	2.50	1.44
24 Hr	36	69.70	85.43	12.55	12.31	59.50	55.00	107.80	103.90	75.00	79.94	34.50	40.45	6.40	6.17
20.8.74 4 Hr	40	78.00	131.16	18.20	17.71	68.00	62.21	133.80	136.40	90.00	94.69	52.00	49.57	9.50	12.51
8 Hr	44	86.50	129.08	24.40	28.69	79.00	84.02	175.80	183.03	115.00	118.20	64.00	60.45	15.00	16.97
12 Hr	48	119.00	98.54	26.34	37.38	93.50	97.90	202.00	229.02	148.50	154.26	62.00	57.23	22.00	17.80
16 Hr	52	62.20	63.18	19.00	28.10	67.00	84.69	207.50	231.02	136.00	161.20	50.00	47.59	18.50	16.31
20 Hr	56	41.40	36.95	15.82	15.42	61.00	68.17	201.50	194.79	113.50	133.89	31.00	29.38	12.50	14.04
24 Hr	60	28.00	20.15	12.45	8.00	56.00	51.02	187.00	156.15	103.50	91.27	15.50	12.06	7.00	11.48
21.8.74 4 Hr	64	17.00	10.49	8.45	4.38	47.50	35.49	165.50	118.05	92.30	58.00	4.00	3.95	4.00	8.79
8 Hr	68	8.20	5.25	3.50	2.62	36.00	23.42	138.50	85.22	80.00	38.19	2.00	1.10	4.50	6.50
12 Hr	72	1.60	2.38	0.72	1.18	23.50	15.00	96.50	57.32	32.00	22.84	0	0	6.00	4.75
16 Hr	76	0	0	0.35	0.76	3.00	9.41	42.50	32.78	14.00	14.74			8.00	3.40
20 Hr	80			0	0	2.00	5.91	10.30	15.60	8.50	9.26			6.50	2.40
24 Hr	84					0	3.51	5.30	7.95	4.00	5.68			3.00	1.64
22.8.74 4 Hr	88						2.06	2.00	4.30	0	3.52			0	0.75
8 Hr	92						1.27	1.00	2.99		0				0
12 Hr	96						0	0	1.25						
16 Hr	100								0.44						
20 Hr	104								0						
24 Hr	108														

APPENDIX NO. XII

TESTING OF MODELS BY 1977 STORM

COMPARISION OF OBSERVED AND COMPUTED DIRECT RUN OFF HYDROGRAPHS

(All figures are in Th. cusecs)

Date	Period	Hrs	Pat Sub-Basin		Mahidpur Sub-Basin		Nagda Sub-Basin		Mandsaur Sub-Basin		Chaldu Sub-Basin	
			Observed DRH	Computed DRH	Observed DRH	Computed DRH	Observed DRH	Computed DRH	Observed DRH	Computed DRH	Observed DRH	Computed DRH
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
7.8.77	8 Hr	0	0		0	0	0	0	0	0		
	12 Hr	4	0.77		1.71	0.07	0.62	1.03	2.00	5.52		
	16 Hr	8	3.30	0	7.50	2.82	3.00	4.80	4.40	10.50		0
	20 Hr	12	8.30	7.49	19.00	15.24	9.00	9.96	10.30	18.05		0.41
	24 Hr	16	22.00	21.96	36.00	39.67	48.50	26.83	17.30	24.00	NOT AVAILABLE	1.69
8.8.77	4 Hr	20	39.20	42.92	51.00	67.02	69.00	61.18	27.30	25.00		3.34
	8 Hr	24	59.50	67.28	83.00	96.45	71.00	85.51	28.00	25.51		4.47
	12 Hr	28	75.00	77.55	123.70	127.25	67.00	84.50	26.15	23.67		4.68
	16 Hr	32	95.30	71.21	130.00	157.35	58.50	68.16	22.00	15.27		4.25
	20 Hr	36	80.80	57.22	128.00	151.40	48.00	55.25	15.20	6.35		3.64
	24 Hr	40	46.50	42.08	116.00	106.94	38.50	45.89	7.20	2.08		2.97
9.8.77	4 Hr	44	15.00	28.92	105.00	67.20	33.50	34.30	2.10	0.61		2.17
	8 Hr	48	5.00	18.97	76.00	40.23	27.00	26.14	0	0		1.68
	12 Hr	52	2.80	12.05	28.37	25.66	20.50	19.37				1.23
	16 Hr	56	1.00	7.60	13.00	15.28	17.00	14.16				0.88
	20 Hr	60	0	4.72	7.00	8.24	13.00	10.25				0.62
	24 Hr	64		2.46	5.00	5.00	8.50	7.15				0.42
10.8.77	4 Hr	68		1.00	3.50	3.03	4.50	4.75				0.18
	8 Hr	72		0	2.50	1.76	3.00	3.24				0
	12 Hr	76			1.00	0.95	2.64	2.18				
	16 Hr	80			0	0	0	1.42				
	20 Hr	84						0				
	24 Hr	88										
		92										

APPENDIX NO. XIII

STATEMENT INDICATING THE DETAILS OF SUB-AREA'S OF UNGAUGED & GAUGED INTERMEDIATE SUB-BASINS

Name of Sub-System	Name of Sub-Area	Catchment area sq.miles	Thiessen weight percentage	Length of River miles	Overland slopes			For Sub Basin				For Sub area		Value of Time lag Hrs.
					U/S R.L. feet	D/S R.L. feet	OLS in parts per 10000	Value of C_1	Value of C_2	Value 'n'	Value of 'K'	Value of n	Value of 'K'	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Kalakhedi	Choumahla	390	100	36	1560	1400	10.10	4.10	2.10	3	8.21			8
Nahargarh	(1) Mandsaur (1)	200	100	20	1460	1380	9.47	4.15	2.10	3	8.19	3	7.47	4
	(2) Mandsaur (2)	140	100	14	1380	1320	9.47					3	7.08	0
Barkheda	(1) Ratlam	368	100	19	1600	1530	8.28					3	7.5	16
	(2) Nagda	500	100	30	1530	1440	7.10	3.40	2.35	3	9.25	3	7.85	16
	(3) Mandsaur & Chaumahla	247	74.5+ 25.5	14	1440	1400	5.41					3	7.85	0
Tumri	(1) Neemuch (1)	290	100	18	1480	1380	11.83	4.15	2.70	4	7.91	4	8.75	0
	(2) Neemuch (2)	100	100	12	1380	1320	13.26					4	5.95	0
Gandhisagar	(1) Choumahla & Mandsaur	720	80.6 + 19.4	32	1400	1290	6.51	3.90	4.10	6	10.44	6	10.44	0
	(2) Mandsaur	200	100	27	1400	1290	7.72	4.475	2.15	3	8.38	3	8.38	0
	(3) Neemuch	140	100	17	1550	1330	13.37	4.70	2.20	3	7.10	3	7.10	0
	(4) Babulda & G.S.	570	92 + 8	27	1290	1160	9.12	4.00	3.50	5	9.27	5	9.27	0
	(5) Gandhisagar	70	100	10	1160	1120	7.58	6.00	2.28	3	8.69	3	8.69	0

APPENDIX NO. XIV (a)

STATEMENT INDICATING RAINFALL EXCESS FOR KALAHEDI (INTERMEDIATE) SUB-BASIN

Date	Time	Wtd. Rainfall in mm			Total W.R.F. in mm /4Hr.	Total W.R.F inch /Hr.	φ-Index inch /Hr.	Rainfall excess	Observed Runoff in Kalakhedi		
		Pat 24%	Nagda 35%	Choum-ahla 41%					Dischar-ge Th.cu.	Base flow Th cu.	D.R.H. Ordienat Th.cu.
1	2	3	4	5	6	7	8	9	10	11	12
18.8.74	16 Hr	1.92		1.00	2.94	0.03	0.03		4.00	4.00	0
	20 Hr	5.54	1.33	23.37	30.24	0.30	0.17	0.13	4.00	4.00	0
	24 Hr	8.40	7.00	8.94	24.34	0.24	0.17	0.07	7.00	4.00	3.00
19.8.74	4 Hr	7.68	9.52	17.38	34.58	0.34	0.17	0.17	11.00	4.00	7.00
	8 Hr	3.00	5.11	8.69	16.80	0.16	0.16		21.00	4.00	17.00
	12 Hr	11.40	3.71	6.97	22.08	0.22	0.17	0.05	44.00	4.00	40.00
	16 Hr	9.84	5.60	8.28	23.72	0.23	0.17	0.06	72.00	4.00	68.00
	20 Hr	7.87	8.75	22.96	39.58	0.39	0.17	0.22	110.00	4.00	106.00
	24 Hr	11.28	9.94	30.34	51.56	0.51	0.17	0.34	144.00	4.00	140.00
20.8.74	4 Hr	9.36	8.96	8.04	26.36	0.26	0.17	0.09	170.00	4.00	166.00
	8 Hr	12.52	13.51	17.47	43.50	0.43	0.17	0.26	192.00	4.00	188.00
	12 Hr	2.95	9.31	20.50	32.76	0.32	0.17	0.15	200.00	4.00	196.00
	16 Hr	0.30	0.70	5.17	6.17	0.06	0.06		202.00	4.00	198.00
	20 Hr					3.49	1.95	1.54	200.00	4.00	196.00
	24 Hr							6.16"	195.00	4.00	191.00
21.8.74	4 Hr								187.00	4.00	183.00
	8 Hr								167.00	4.00	163.00
	12 Hr								134.00	4.00	130.00
	16 Hr								108.00	4.00	104.00
	20 Hr								80.00	4.00	76.00
	24 Hr								50.00	4.00	46.00
22.8.74	4 Hr								30.00	4.00	26.00
	8 Hr								20.00	4.00	16.00
	12 Hr.								10.00	4.00	6.00
	16 Hr								4.00	4.00	0

Considering the maximum rain in 48 Hrs = 3.52
Intensity of rain = 0.288 inches/Hr.
Rainfall excess = 45%
φ - index = 55%

Note: For R.F. Fig.No.4(B)-1 is used
For φ- index Fig.No. 4(B)-2 is used

APPENDIX NO. XIV (b)

STATEMENT INDICATING RAINFALL EXCESS FOR BARKHEEDA INTERMEDIATE SUB BASIN AND ITS SUB-AREA'S

Date & Period	Wtd.Rainfall in mm				Total W.R.F in inch / Hr	ϕ-Index inch /Hr.	Rainfall excess inch/Hr	Factor Col.8 / Col.6	Sub-area (1)		Sub-Catchment (2)		Sub-area No. 3			Rainfall excess in inch/Hr.
	Mandsaur 16%	Choumahla 6%	Nagda 45%	Ratlam 33%					R.F. inch/ Hr.	Rainfall excess inch/Hr	R.F. in inch/Hr	R.F. excess inch/Hr.	Rainfall Mandsaur 74.5%	in mm Choumah-la 25.5%	Total in inch /Hr.	
1.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
18.8.74																
12 Hr.																
16 Hr	3.78	0.14			0.04	0.04										
20 Hr	3.68	3.42	1.71	0.03	0.09	0.09										
24 Hr	0.29	1.31	9.00	15.05	0.23	0.09	0.14	0.61	0.45	0.28	0.20	0.12	1.30	5.50	0.07	0.04
19.8.74																
4 Hr	0.06	2.54	12.24	2.57	0.16	0.09	0.07	0.44	0.08	0.04	0.27	0.12	0.30	10.60	0.11	0.05
8 Hr	0.24	1.27	6.57	6.73	0.14	0.09	0.05	0.36	0.20	0.07	0.14	0.05	1.10	5.30	0.06	0.02
12 Hr	0.13	1.02	4.77	2.48	0.10	0.09	0.01	0.10	0.07		0.10	0.01	0.06	4.25	0.04	
16 Hr	7.46	1.21	7.20	4.03	0.19	0.09	0.10	0.53	0.12	0.06	0.16	0.09	34.72	5.15	0.39	0.21
20 Hr	9.60	3.36	11.25	6.20	0.30	0.09	0.21	0.70	0.19	0.13	0.24	0.17	44.70	14.28	0.58	0.41
24 Hr	7.23	4.44	12.60	13.93	0.37	0.09	0.28	0.76	0.41	0.31	0.27	0.21	33.67	18.87	0.52	0.40
20.8.74																
4 Hr	8.70	1.18	11.52	21.65	0.42	0.09	0.33	0.79	0.64	0.51	0.25	0.20	40.53	5.00	0.45	0.36
8 Hr	5.02	2.56	17.37	15.84	0.40	0.09	0.31	0.78	0.47	0.37	0.30	0.23	23.39	10.86	0.34	0.27
12 Hr	3.17	3.00	11.97	8.84	0.26	0.09	0.17	0.65	0.26	0.17	0.26	0.17	14.75	12.75	0.27	0.18
16 Hr	4.67	0.76	0.90	1.32	0.07	0.07										
					2.77	1.10	1.67			1.94		1.37				1.94
										7.76"		5.38"				7.76"

Considering the 40 Hr storm intensity = 0.257"

Rainfall excess 65% } From fig No's 4(B)-1&2

ϕ - Index 35% }

APPENDIX NO. XIV (C) &(D)

STATEMENT INDICATING RAINFALL EXCESS FOR TUMRI AND NAHARGARH INTERMEDIATE SUB-BASIN THEIR SUB AREA

Date & Time	Tumri Sub catchment Neemuch				Nahargarh subcatchment				Observed discharge at Nahargarh			
	Rainfall mm /4Hr	Rainfall inch/Hr	ϕ-Index	Rainfall excess	Rainfall of Mandsaur mm/4Hr	Inch /Hr	ϕ-index inch /Hr	Rainfall excess inch /Hr	Discharge Th.Cu	Base Flow Th. cu.	DRH ordinate Th.Cu	Date & Time
1	2	3	4	5	6	7	8	9	10	11	12	13
19.8.74									2.80	2.80	0	12 Hr
16 Hr					46.60	0.46	0.18	0.28	5.00	3.00	2.00	16 Hr
20 Hr	57.20	0.56	0.22	0.34	60.00	0.59	0.18	0.31	13.00	3.50	9.50	20 Hr
24 Hr	54.00	0.53	0.22	0.31	45.20	0.44	0.18	0.26	32.50	3.50	29.00	24 Hr
20.8.74												
4 Hr	18.00	0.17	0.17		54.40	0.53	0.18	0.35	85.00	4.00	81.00	4 Hr
8 Hr	22.00	0.22	0.22		31.40	0.31	0.18	0.13	124.08	4.08	120.00	8
12 Hr	20.00	0.19	0.19		19.80	0.19	0.18	0.01	100.00	5.00	95.00	12
16 Hr	16.00	0.16	0.16		29.20	0.29	0.18	0.11	76.50	5.50	71.00	16 Hr
20 Hr	30.00	0.29	0.22	0.09					55.50	5.50	50.00	20
24 Hr	10.20	0.10	0.10						38.50	5.50	33.00	24
21.8.74												
4 Hr	5.00	0.05	0.05						29.50	6.00	23.50	4
8 Hr	17.10	0.17	0.17						25.00	6.50	18.50	8
12 Hr	22.00	0.22	0.22						21.50	7.00	14.50	12
16 Hr									17.50	7.50	10.00	16
		2.66	1.92	0.74 =2.96"		2.72	1.26	1.46 =5.84"	15.00	8.00	7.00	20
									12.50	8.00	4.50	24
									10.00	8.50	1.50	22.8 4Hr
									9.00	9.00	0.00	8

Note :-(1) ϕ-Index for Tumri adopted on the basis of Chaldu
Rainfall excess = 28% ϕ - Index = 72%
(2) Hence for sub ~~sub-catchment~~ one the rainfall excess will be 2.96"
(3) Assuming ϕ-index on the basis of Mandsaur as RE = 53% ϕ - index = 47%
(4) Hence for the sub ~~sub-system~~ same of Nahangarh ~~sub~~ sub-~~system~~ basin the rainfall excess will same = 5.84 "

APPENDIX NO. XIV (e)

STATEMENT SHOWING THE RAINFALL EXCESS FOR GANDHISAGAR INTERMEDIATE SUB-BASIN & ITS SUB-AREA'S

Date & Time	Wtd.Rainfall in mm/4 Hrs. Choumahla 34%	Mand-saur 20%	Neem-uch 8%	Babula 31%	Gandhi Sagar 7%	Total W.R.F mm/4Hr	Total W.R.F inch/Hr	Φ-Index Inch /Hr	Rain Fall excess inch/Hr	Factor Col.10 / Col.8	Sub-Area (1) Mand saur 19.4% mm	Choumahla 80.6% mm	Total in inch /Hr	Rainfall excess inch/Hr	Sub-Area(2) Mand saur inch /Hr	R.F. excess inch /Hr.	Sub-Area(3) Neem uch inch /Hr	R.F. excess inch /Hr	Sub-Area(4) Babulda 92% mm	G.S 8% mm	Total inch /Hr.	Rain fall excess inch /Hr	Sub-Area(5) G.S inch /Hr	Rain Fall excess inch /Hr.
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
19.8. 12 Hr.	5.78	0.16		0.56	0.34	6.84	0.07	0.07																
16 Hr	6.87	9.32	0.25	11.53	1.69	29.66	0.29	0.12	0.17	0.59	9.04	16.28	0.25	0.15	0.46	0.27	0.03	0.02	34.22	1.94	0.36	0.21	0.24	0.14
20 Hr	19.04	12.00	4.58	6.39	1.69	43.70	0.43	0.12	0.31	0.72	11.64	45.14	0.56	0.40	0.60	0.43	0.56	0.40	18.95	1.94	0.20	0.14	0.24	0.17
24 Hr	25.16	9.04	4.32	5.95	1.26	45.73	0.45	0.12	0.33	0.73	8.77	59.64	0.67	0.49	0.45	0.33	0.53	0.39	17.66	1.44	0.19	0.14	0.18	0.13
20.8. 4 Hr	6.66	10.88	1.44	10.23	1.50	30.71	0.30	0.12	0.18	0.60	10.55	15.80	0.26	0.16	0.54	0.32	0.18	0.11	30.36	1.72	0.32	0.19	0.21	0.13
8 Hr	14.48	6.28	1.76	11.47	0.35	34.34	0.34	0.12	0.22	0.64	6.09	34.33	0.40	0.26	0.31	0.20	0.22	0.14	34.04	0.40	0.34	0.22	0.05	0.03
12 Hr	17.00	3.96	1.60	17.67	2.27	42.50	0.42	0.12	0.30	0.71	3.84	40.30	0.43	0.31	0.19	0.14	0.20	0.14	52.44	2.59	0.55	0.39	0.32	0.23
16 Hr	4.28	5.84	1.32	33.54	4.90	49.88	0.49	0.12	0.37	0.76	5.66	10.16	0.16	0.12	0.29	0.22	0.16	0.12	99.50	5.60	1.00	0.76	0.69	0.52
20 Hr	0.02		2.40	18.09	1.06	21.52	0.21	0.12	0.09	0.43		0.49					0.30	0.13	53.54	1.22	0.54	0.02	0.15	0.06
24 Hr	1.36	0.56	0.82	11.59	0.69	15.72	0.15	0.12	0.03	0.20	0.54	0.32			0.04		0.10	0.02	34.41	0.78	0.35	0.07	0.01	
21.8. 4 Hr	2.00		0.40	7.38	0.88	10.66	0.10	0.10									0.05							
8 Hr	1.56	1.52	1.38	15.10	0.57	20.66	0.21	0.12	0.09	0.33	1.47	3.70	0.05	0.02	0.08	0.03	0.17	0.06	46.18	0.66	0.46	0.16	0.08	0.03
12 Hr	1.70	0.56	1.76	11.53	1.16	16.31	0.16	0.12	0.04	0.25	0.60	4.00	0.05	0.02	0.30	0 .09	0.22	0.06	34.20	1.33	0.35	0.10	0.16	0.0[illegible]
		Total					3.62	1.49	2.13					1.93		2.03						2.40		
														7.72"		8.12"						9.60"		

Note:(1) For 0.3% Per Hour and 48 Hr duration

From curve R.F.Excess = 60%
Φ = Index = 40%

(2) Ror R.E. Fig.No. 4(B) - 1 is used

APPENDIX NO. XV

UNIT HYDROGRAPH OF EACH SUB AREA OF INTERMEDIATE SUB - BASINS

All Figures are in Thousand Cusecs

Hrs	Bara Kheda Sub Basin			Tumri Sub-Basin		Gandhi Sagar Sub-Basin					Kalakhedi S.B.	Nahargarh Sub-Basin	
	Ratlam (1)	Nagda (2)	Mandsaur & Choumahla (3)	Neemuch (1)	Neemuch (2)	Choumahla & Mandsaur (1)	Mandsaur (2)	Neemuch (3)	Babulda & G.S. (4)	Gandhi Sagar (5)	Nagda & Pat (1)	Mandsaur (1)	Mandsaur (2)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1.30	1.59	0.79	0.17	0.14	0	0.55	0.56	0.19	0.17	1.12	0.73	0.56
8	3.39	5.43	2.68	0.95	0.71	0.23	1.91	1.81	0.37	0.62	3.87	2.42	1.86
12	7.13	9.08	4.48	2.36	1.53	0.46	3.20	2.94	0.83	1.06	6.52	3.93	2.97
16	8.36	10.79	5.33	3.86	2.16	1.70	4.01	3.15	1.94	1.32	7.85	4.62	3.29
20	8.23	10.76	5.31	4.92	2.41	3.79	4.15	3.13	3.07	1.39	8.05	4.52	3.15
24	7.25	9.72	4.80	5.33	2.27	6.22	3.83	2.76	5.58	1.30	7.49	3.92	2.76
28	5.93	8.17	4.04	5.26	1.92	7.28	3.31	2.18	6.20	1.16	6.46	3.24	2.19
32	4.63	6.56	3.25	4.82	1.49	8.04	2.75	1.65	7.17	0.98	4.30	2.54	1.66
36	3.56	5.06	2.50	4.19	1.12	9.04	2.24	1.23	7.65	0.79	4.19	1.89	1.23
40	2.61	3.79	1.87	3.50	0.81	9.65	1.68	0.88	7.70	0.63	3.23	1.41	0.87
44	1.83	2.82	1.39	2.83	0.55	11.01	1.26	0.58	7.45	0.47	2.43	1.01	0.60
48	1.30	2.04	1.00	2.21	0.36	9.41	1.04	0.40	6.95	0.36	1.78	0.70	0.41
52	0.92	1.42	0.70	1.68	0.24	8.78	0.70	0.27	6.36	0.28	1.27	0.48	0.28
56	0.62	1.00	0.49	1.26	0.15	8.04	0.44	0	5.64	0.20	0.93	0.33	0.19
60	0.41	0.70	0.35	0.90	0	7.14	0.32		4.86	0.15	0.66	0.22	0.12
64	0.28	0.48	0.24	0.66		6.14	0		4.12	0	0.46	0	0
68	0	0	0	0		5.20			3.44		0		
72						4.35			2.83				
76						3.58			2.28				
80						2.89			1.84				
84						1.30			1.48				
88						0.58			1.12				
92						0.52			0.83				
						0.27			0				

APPENDIX NO. XVI

DETAILS OF TRANSLATION HYDROGRAPHS FOR ALL TEN SUB-BASINS

Sl. No.	Name of Sub-Basin	Reference for computed D.R.H. Fig. No.	Value of K(Hrs) r	Value of K(Hrs) Δt Hrs	Value of K(Hrs) K	Value of W in Hrs	D.Hrs	Volume of T.H. Cu.-Hrs.	Translation Hydrograph ordinates at 0 Hr	1 HR	2 Hr	3 Hr	4 Hr	5 Hr	Routing Constants C_o+C_1	C_2	Equation of Routing
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Pat	4(A)-3	0.673	4	10.08	0.5K(5)	4	4	0	0.80	1.60	1.07	0.53	0	0.10	0.90	$Q_2 = 0.1I + 0.9Q_1$
2	Mahidpur	4(A)-4	0.593	4	7.65	0.5K(4)	4	4	0	1.00	2.00	1.00	0		0.12	0.88	$Q_2 = 0.12I + 0.88\ Q_1$
3	Nagda	4(A)-5	0.632	4	8.71	0.5K(4)	4	4	0	1.00	2.00	1.00	0		0.11	0.89	$Q_2 = 0.11I + 0.89\ Q_1$
4	Mandsaur	4(A)-6	0.493	4	5.65	0.7K(4)	4	4	0	1.00	2.00	1.00	0		0.16	0.84	$Q_2 = 0.16I + 0.84Q_1$
5	Chaldu	4(A)-7	0.533	4	6.35	0.7K(4)	4	4	0	1.00	2.00	1.00	0		0.15	0.85	$Q_2 = 0.15I + 0.85Q_1$
	Intermediate sub-catchment																
6	Choumahla	4(B)-10	0.680	4	10.33	0.4K(4)	4	4	0	1.00	2.00	1.00	0		0.10	0.90	$Q_2 = 0.1I + 0.9\ Q_1$
7	Kalakhedi	4(B)-11	0.747	4	5.35	0.6K(4)	4	4	0	1.00	2.00	1.00	0		0.18	0.82	$Q2 = 0.18I + 0.82\ Q_1$
8	Barkheda	4(B)-13	0.714	4	11.88	0.4K(5)	4	4	0	0.80	1.60	1.07	0.53	0	0.08	0.92	$Q_2 = 0.08\ I + 0.92\ Q1$
9	Nahargarh	4(B)-12	0.698	4	11.14	0.5K(6)	4	4	0	0.67	1.33	1.00	0.67	0.33	0.09	0.91	$Q_2 = 0.09I + 0.91\ Q_1$
10	Tumri	4(B)-14	0.744	4	13.51	0.4K(5)	4	4	0	0.80	1.60	1.07	0.53	0	0.07	0.93	$Q_2 = 0.07\ I + 0.93Q_1$

Note :
1. For Col. (6) used equation No. 2.29
2. For Col. (9) = Cusecs x Col.(8)
3. For Col. (9) used equation No. 2.30
4. Translation hydrograph Maximum ordinate = $\frac{2\ D}{2} = \frac{2 \times Col.(8)}{Col.(7)}$
5. For Col. (16 & 17) Used equation Nos. 2.26 & 2.27
6. For Col. 18 used equation No. 3.7

APPENDIX NO. XVII (a)

ROUTING OF TRANSLATION HYDROGRAPH FOR MAHIDPUR SUB BASIN

$$Q_2 = 0.12\ I + 0.88\ Q_1$$

Hours	Input Cusecs	0.1I Cusecs	0.9 Q_1 Cusecs	Q_2 IUR Cusecs	U.R. for 4 hrs. Cusecs	U.R. for 8 Hours: UR for 4 hr. lag by 4 hr. Cusecs	U.R. for 8 Hours: UR for 8 hours Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0
1	1	0.12	0	0.12	0.06		
2	2	0.24	0.11	0.35	0.24		0.24
3	1	0.12	0.31	0.43	0.39		
4.	0	0	0.38	0.38	0.41	0	0.41
5			0.33	0.33	0.36	0.06	
6			0.29	0.29	0.31	0.24	0.55
7			0.26	0.26	0.28	0.39	
8			0.23	0.23	0.25	0.41	0.66
9			0.20	0.20	0.22	0.36	
10			0.18	0.18	0.19	0.31	0.50
11			0.16	0.16	0.17	0.28	
12			0.14	0.14	0.15	0.25	0.40
13			0.12	0.12	0.13	0.22	
14			0.11	0.11	0.12	0.19	0.31
15			0.09	0.09	0.10	0.17	
16			0.08	0.08	0.09	0.15	0.24
17			0.07	0.07	0.08	0.13	
18			0.06	0.06	0.07	0.12	0.19
19			0.06	0.06	0.06	0.10	
20			0.05	0.05	0.06	0.09	0.15
21			0.04	0.04	0.05	0.08	
22			0.04	0.04	0.04	0.07	0.11
23			0.03	0.03	0.04	0.06	
24			0.03	0.03	0.03	0.06	0.09

APPENDIX NO. XVII (b)

ROUTING OF TRANSLATION HYDROGRAPH FOR NAGDA SUB BASIN

$$Q_2 = 0.11I + 0.89\ Q_1$$

Hours	Input cusecs	0.11 I cusecs	0.89 Q_1 cusecs	Q_2 IUR cusecs	U.R. for 4 Hours cusecs	U.R. for 8 Hours: U.R. for 4 Hrs. lag by 4 Hrs	U.R. for 8 Hours: U.R. for 8 Hrs. Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	1	0.11	0	0.11	0.06		
2	2	0.22	0.10	0.32	0.22		0.22
3	1	0.11	0.29	0.40	0.36		
4	0	0	0.36	0.36	0.38	0	0.38
5			0.32	0.32	0.34	0.06	
6			0.29	0.29	0.31	0.22	0.53
7			0.25	0.25	0.27	0.36	
8			0.23	0.23	0.24	0.38	0.62
9			0.20	0.20	0.21	0.34	
10			0.18	0.18	0.19	0.31	0.50
11			0.16	0.16	0.17	0.27	
12			0.14	0.14	0.15	0.24	0.39
13			0.13	0.13	0.13	0.21	
14			0.11	0.11	0.12	0.19	0.31
15			0.10	0.10	0.11	0.17	
16			0.09	0.09	0.10	0.15	0.29
17			0.08	0.08	0.09	0.13	
18			0.07	0.07	0.07	0.12	0.19
19			0.06	0.06	0.06	0.11	
20			0.06	0.06	0.06	0.10	0.16
21			0.05	0.05	0.06	0.09	
22			0.04	0.04	0.04	0.07	0.11
23			0.04	0.04	0.04	0.06	
24			0.03	0.03	0.04	0.06	0.10

APPENDIX NO. XVII (c)

ROUTING OF TRANSLATION HYDROGRAPH FOR MANDSAUR SUB BASIN

$$Q_2 = 0.16\ I + 0.84\ Q_1$$

Hours	Input Cusecs	0.16 I Cusecs	$0.84\ Q_1$ Cusecs	Q_2 I U R Cusecs	U.R. for 4 Hrs. Cusecs	U.R. for 8 Hours	
						U.R. for 4 Hrs. lag by 4 Hrs.	U.R. for 8 Hrs. Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	1	0.16	0	0.16	0.08		
2	2	0.32	0.14	0.46	0.31		0.31
3	1	0.16	0.39	0.55	0.51		
4	0	0	0.46	0.46	0.51	0	0.51
5			0.39	0.39	0.43	0.08	
6			0.33	0.33	0.36	0.31	0.77
7			0.27	0.27	0.30	0.51	
8			0.23	0.23	0.25	0.51	0.76
9			0.19	0.19	0.21	0.43	
10			0.16	0.16	0.18	0.36	0.54
11			0.14	0.14	0.15	0.30	
12			0.11	0.11	0.13	0.25	0.38
13			0.10	0.10	0.11	0.21	
14			0.08	0.08	0.09	0.18	0.27
15			0.07	0.07	0.08	0.15	
16			0.06	0.06	0.07	0.13	0.20
17			0.05	0.05	0.06	0.11	
18			0.04	0.04	0.04	0.09	0.13
19			0.03	0.03	0.04	0.08	
20			0.03	0.03	0.03	0.07	0.10
21			0.02	0.02	0.02	0.06	
22			0.02	0.02	0.02	0.04	0.08
23			0.02	0.02	0.02	0.04	
24			0.01	0.01	0.02	0.03	0.05

APPENDIX NO. XVII (d)

ROUTING OF TRANSLATION HYDROGRAPH CHALDU SUB BASIN

$$Q_2 = 0.15\ I + 0.85\ Q_1$$

Hours	Input	0.15I	0.85 Q_1	Q_2 I U R	U.R. for 4 Hrs.	U.R. for 8 Hours	
						U.R. for 4 Hr. lag by 4 Hr.	U.R. for 8 Hrs.
	Cusecs	Cusecs	Cusecs	Cusecs	Cusecs		Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	1	0.15	0	0.15	0.08		
2	2	0.30	0.13	0.43	0.29		0.29
3	1	0.15	0.37	0.52	0.48		
4	0	0	0.44	0.44	0.48	0	0.48
5			0.38	0.38	0.41	0.08	
6			0.32	0.32	0.35	0.29	0.64
7			0.27	0.27	0.30	0.48	
8			0.23	0.23	0.25	0.48	0.73
9			0.20	0.20	0.22	0.41	
10			0.17	0.17	0.19	0.35	0.54
11			0.14	0.14	0.16	0.30	
12			0.12	0.12	0.13	0.25	0.38
13			0.10	0.10	0.11	0.22	
14			0.09	0.09	0.10	0.19	0.29
15			0.07	0.07	0.08	0.16	
16			0.06	0.06	0.07	0.13	0.20
17			0.05	0.052	0.06	0.11	
18			0.05	0.05	0.05	0.16	0.15
19			0.04	0.04	0.05	0.08	
20			0.03	0.03	0.04	0.07	0.11
21			0.03	0.03	0.03	0.06	
22			0.02	0.02	0.03	0.05	0.08
23			0.02	0.02	0.02	0.05	
24			0.02	0.02	0.02	0.04	0.06

APPENDIX NO. XVII (e)

ROUTING OF TRANSLATION HYDROGRAPH FOR CHAUMAHLA INTERMEDIATE SUBBASIN

$$Q_2 = 0.1 I + 0.9 Q_1$$

Hours	Inflow Cusecs	0.10 I Cusecs	0.90 Q_1 Cusecs	Q_2 IUR Cusecs	U.R. for 4 Hrs. Cusecs	U.R. for 8 Hours: U.R. for 4 Hrs. lag by 4 Hr. Cusecs	U.R. for 8 Hours: U.R. for 8 Hrs. Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	1	0.10	0	0.10	0.05		
2	2	0.20	0.09	0.29	0.20		0.20
3	1	0.10	0.26	0.36	0.33		
4	0	0	0.33	0.33	0.35	0	0.35
5			0.29	0.29	0.31	0.05	
6			0.26	0.26	0.28	0.20	0.48
7			0.24	0.24	0.25	0.33	
8			0.21	0.21	0.23	0.35	0.58
9			0.19	0.19	0.20	0.31	
10			0.17	0.17	0.18	0.28	0.46
11			0.16	0.16	0.17	0.25	
12			0.14	0.14	0.15	0.23	0.38
13			0.13	0.13	0.14	0.20	
14			0.11	0.11	0.12	0.18	0.30
15			0.10	0.10	0.11	0.17	
16			0.09	0.09	0.10	0.15	0.25
17			0.08	0.08	0.09	0.14	
18			0.08	0.08	0.08	0.12	0.20
19			0.07	0.07	0.08	0.11	
20			0.06	0.06	0.07	0.10	0.17
21			0.06	0.06	0.06	0.09	
22			0.05	0.05	0.06	0.08	0.14
23			0.04	0.04	0.05	0.08	
24			0.04	0.04	0.04	0.07	0.11

APPENDIX NO. XVII (f)

ROUTING OF TRANSLATION HYDROGRAPH FOR KALAKHEDI INTERMEDIATE SUB BASIN

$$Q_2 = 0.18\ I + 0.82\ Q_1$$

Hours	Input Cusecs	0.18I Cusecs	$0.82\ Q_1$ Cusecs	Q_2 IUR Cusecs	U.R. for 4 Hrs. Cusecs	U.R. for 8 Hrs.: U.R. for 4 Hrs. lag by 4 Hrs.	U.R. for 8 Hrs.: U.R. for 8 Hrs. Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	1	0.18	0	0.18	0.09		
2	2	0.36	0.15	0.51	0.35		0.35
3	1	0.18	0.42	0.60	0.56		
4	0	0	0.49	0.49	0.55	0	0.55
5			0.40	0.40	0.45	0.09	
6			0.33	0.33	0.37	0.35	0.72
7			0.27	0.27	0.30	0.56	
8			0.22	0.22	0.25	0.55	0.80
9			0.18	0.18	0.20	0.45	
10			0.15	0.15	0.17	0.37	0.54
11			0.12	0.12	0.13	0.30	
12			0.10	0.10	0.11	0.25	0.36
13			0.08	0.08	0.09	0.20	
14			0.07	0.07	0.08	0.17	0.25
15			0.06	0.06	0.07	0.13	
16			0.05	0.05	0.06	0.11	0.17
17			0.04	0.04	0.05	0.09	
18			0.03	0.03	0.03	0.08	0.11
19			0.03	0.03	0.03	0.07	
20			0.02	0.02	0.02	0.06	0.08
21			0.02	0.02	0.02	0.05	
22			0.01	0.01	0.02	0.03	0.05
23			0.01	0.01	0.01	0.03	
24			0.01	0.01	0.01	0.02	0.03

APPENDIX NO. XVII (g)

ROUTING OF TRANSLATION HYDROGRAPH FOR BARKHEDA (INTERMEDIATE) SUB BASIN

$$Q_2 = 0.08\ I + 0.92\ Q_1$$

Hours	Input Cusecs	0.08 I Cusecs	$0.92\ Q_1$ Cusecs	Q_2 IUR Cusecs	U.R. for 4 Hrs. Cusecs	U.R. for 8 Hrs: U.R. for 4 Hr. lag by 4 Hr.	U.R. for 8 Hrs: U.R. for 8 Hrs. Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	0.80	0.06	0	0.06	0.03		
2	1.60	0.13	0.06	0.19	0.13		0.13
3	1.07	0.09	0.18	0.27	0.23		
4	0.53	0.04	0.25	0.29	0.28	0	0.28
5	0.0	0	0.27	0.27	0.28	0.03	
6			0.25	0.25	0.26	0.13	0.39
7			0.23	0.23	0.24	0.23	
8			0.21	0.21	0.22	0.28	0.50
9			0.17	0.19	0.20	0.28	
10			0.18	0.18	0.19	0.26	0.45
11			0.16	0.16	0.07	0.24	
12			0.15	0.15	0.16	0.22	0.38
13			0.14	0.14	0.19	0.20	
14			0.13	0.13	0.14	0.19	0.33
15			0.12	0.12	0.13	0.07	
16			0.11	0.11	0.12	0.16	0.28
17			0.10	0.10	0.11	0.19	
18			0.09	0.10	0.10	0.14	0.24
19			0.08	0.08	0.09	0.13	
20			0.08	0.08	0.08	0.12	0.20
21			0.07	0.07	0.08	0.11	
22			0.06	0.06	0.07	0.10	0.17
23			0.06	0.06	0.06	0.09	
24			0.06	0.06	0.06	0.09	0.14

APPENDIX NO. XVII (h)

ROUTING OF TRANSLATION HYDROGRAPH FOR NAHARGARH (INTERMEDIATE) SUB BASIN

$$Q_2 = 0.09\ I + 0.91\ Q_1$$

Hours	Input	0.09 I	0.91 Q_1	Q_2 IUR	U.R. for 4 Hrs.	U.R. for 8 Hrs.	
						U.R. for 4 Hour lag by 4 Hour	U.R. for 8 Hrs.
	Cusecs	Cusecs	Cusecs	Cusecs	Cusecs	Cusecs	Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	0.67	0.06	0.06	0.06	0.03		
2	1.33	0.12	0.96	0.18	0.12		0.12
3	1.00	0.09	0.16	0.25	0.22		
4	0.67	0.06	0.23	0.29	0.27	0	0.27
5	0.33	0.03	0.26	0.29	0.29	0.03	
6	0	0	0.26	0.26	0.18	0.12	0.40
7			0.24	0.24	0.25	0.22	
8			0.22	0.22	0.23	0.27	0.50
9			0.20	0.20	0.21	0.29	
10			0.18	0.18	0.19	0.28	0.47
11			0.16	0.16	0.17	0.25	
12			0.15	0.15	0.16	0.23	0.39
13			0.14	0.14	0.15	0.21	
14			0.12	0.12	0.13	0.19	0.32
15			0.11	0.11	0.12	0.17	
16			0.10	0.10	0.11	0.16	0.27
17			0.09	0.09	0.10	0.15	
18			0.09	0.09	0.09	0.13	0.22
19			0.08	0.08	0.09	0.12	
20			0.07	0.07	0.08	0.11	0.19
21			0.06	0.06	0.07	0.10	
22			0.06	0.06	0.06	0.09	0.15
23			0.05	0.05	0.06	0.09	
24			0.05	0.05	0.05	0.08	0.13

APPENDIX NO. XVII (i)

ROUTING OF TRANSLATION HYDROGRAPH FOR TUMRI (INTERMEDIATE) SUB BASIN

$$Q_2 = 0.07\ I + 0.93\ Q_1$$

Hours	Input Cusecs	0.07 I Cusecs	$0.93\ Q_1$ Cusecs	Q_2 IUR Cusecs	U.R. for 4 Hours Cusecs	U.R. for 8 Hrs. U.R. for 4 Hr. lag by 4 Hrs Cusecs	U.R. for 8 Hours Cusecs
1	2	3	4	5	6	7	8
0	0	0	0	0	0		0
1	0.80	0.06	0	0.06	0.03		
2	1.60	0.11	0.06	0.17	0.12		0.12
3	1.07	0.08	0.16	0.24	0.21		
4	0.53	0.04	0.22	0.26	0.25	0	0.25
5	0	0	0.25	0.25	0.26	0.03	0
6			0.23	0.23	0.24	0.12	0.36
7			0.21	0.21	0.22	0.21	
8			0.20	0.20	0.21	0.25	0.46
9			0.18	0.18	0.19	0.26	
10			0.17	0.17	0.18	0.24	0.42
11			0.16	0.16	0.17	0.22	
12			0.15	0.15	0.16	0.21	0.37
13			0.14	0.14	0.15	0.19	
14			0.13	0.13	0.14	0.18	0.32
15			0.12	0.12	0.13	0.17	
16			0.11	0.11	0.12	0.16	0.28
17			0.10	0.10	0.11	0.15	
18			0.10	0.10	0.10	0.14	0.24
19			0.09	0.09	0.10	0.13	
20			0.08	0.08	0.09	0.12	0.21
21			0.08	0.08	0.08	0.11	
22			0.07	0.07	0.08	0.10	0.18
23			0.07	0.07	0.07	0.10	
24			0.06	0.06	0.07	0.09	0.16

APPENDIX NO. XVIII (a)

CHANNEL ROUTING OF MAHIDPUR DRH UPTO GANDHI SAGAR SITE

Hours	Unit Response for 8 Hr cusecs	Flow elements of computed DRH at Mahidpur in Th.Cusecs No. 1 8Th.Cu.	No.2 40Th. cu.	No. 3 78Th. cu.	No.4 116Th cu.	No.5 182Th. cu.	No.6 228 Th. cu.	No. 7 154Th. cu.	No. 8 84 Th. cu.	No. 9 32 Th. cu.	No.10 8.5Th. cu.	No. 11 2.5 Th. cu.	Total Routed D.R.H Col.3to13 Th.Cu.	Intermediate sub-basin D.R.H. Th.Cu.	Total D.R.H. at Kalakhedi Routed from Mahidpur Th.cu.	Observed D.R.H. at Kalakhedi Th.Cu.	Date & Time
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	0											0		0		16 Hr 18/8
4	0.41	3.28											3.28		3.28	0	20
8	0.66	5.28	0										5.28	0	5.28	3.00	24
12	0.40	3.20	16.40										19.60	6.90	26.50	7.00	4 19/8
16	0.24	1.92	26.40	0									28.32	23.84	52.16	17.00	8
20	0.15	1.20	16.00	31.98									49.18	40.16	89.34	40.00	12
24	0.09	0.72	9.60	51.48	0								61.80	48.36	101.16	68.00	16
28	0.05	0.40	6.00	31.20	47.56								85.16	49.59	134.75	106.00	20
32	0	0	3.60	18.72	76.56	0							98.86	46.14	155.00	140.00	24
36			2.00	11.70	46.40	74.62							134.72	39.79	174.51	166.00	4 20/8
40			0	7.02	27.84	120.12	0						154.98	29.57	194.55	188.00	8
44				3.90	17.40	72.80	93.48						187.58	25.81	203.39	196.00	12
48				0	10.44	43.68	140.48	0					194.48	19.90	204.38	198.00	16
52					5.80	27.30	91.30	63.14					187.44	14.96	202.40	196.00	20
56					0	16.38	54.72	101.64	0				172.74	10.96	183.70	191.00	24
60						9.10	34.20	61.60	34.44				139.34	7.82	147.16	183.00	4 21/8
64						0	20.52	36.96	55.44	0			112.92	5.73	118.65	163.00	8
68							11.40	23.10	33.60	13.12			81.22	4.06	85.28	130.00	12
72							0	13.86	20.16	21.12	0		55.14	2.83	57.97	104.00	16
76								7.70	12.60	12.80	3.50		36.60	0	36.60	76.00	20
80								0	7.56	7.68	5.60	0	20.84		20.84	46.00	24
84									4.20	4.80	3.40	1.03	13.43		13.43	26.00	4 22/8
88									0	2.88	2.04	1.65	6.57		6.57	16.00	8
92										1.60	1.28	1.00	3.88		3.88	6.00	12
96										0	0.77	0.60	1.37		1.37	0	16
													0		0	0	20

Note: (1) Col. (2) has been taken from Fig.4(c)-2
(2) Col. (3) to (13) are taken from Fig.4(C)-15
(3) Col. (15) is taken from Fig.No.4(B)-11
(4) Col. (17) is taken from Appendix No.14(i)

APPENDIX NO. XVIII (b)

CHANNEL ROUTING OF NAGDA D.R.H. UPTO GANDHI SAGAR SITE

Hours	Unit Response for 8 Hrs cusecs	Flow elements of computed D.R.H. at Nagda in Th. Cusecs									Total routed D.R.H. Col. (3to11)	Intermediate Sub Basin		Computed D.R.H. at Barkheda	Period & Date
		No. 1 6 Th.Cu.	No. 2 30 Th.Cu.	No. 3 74 Th. cu.	No. 4 124 Th. cu.	No. 5 156 Th. cu.	No. 6 92 Th. cu.	No. 7 38 Th. cu.	No. 8 15 Th. cu.	No. 9 6 Th. cu.		D.R.H. Th. Cu.	Total D.R.H. at Barkheda Routed from Nagda		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
												0	0	0	20 Hr. 18/8
												6.13	6.13	6.13	24 Hr.
0	0	0									0	20.80	20.80	20.80	4 Hr. 19/8
4	0.38	2.28									2.28	34.77	37.05	34.77	8 "
8	0.62	3.72	0								3.72	41.36	45.08	44.00	12 "
12	0.39	2.34	11.40								13.74	59.86	73.60	72.37	16 "
16	0.25	1.50	18.60	0							20.10	92.77	112.87	122.45	20 "
20	0.16	0.96	11.70	28.12							40.78	135.53	176.31	189.21	24 "
24	0.10	0.60	7.50	45.88	0						53.98	148.16	202.15	228.11	4 " 20/8
28	0.06	0.36	4.80	28.86	47.12						81.24	141.16	222.40	235.85	8 "
32	0	0	3.20	18.50	76.88	0					98.38	123.07	222.45	241.27	12 "
36			1.80	11.84	48.36	59.28					121.28	100.79	222.17	255.05	16 "
40			0	7.40	31.00	96.72	0				135.12	79.00	214.17	240.20	20 "
44				4.44	19.84	60.84	34.96				120.08	60.27	180.35	194.16	24 "
48				0	12.40	39.00	57.04	0			108.44	44.45	152.89	135.72	4 " 21/8
52					7.44	34.96	35.88	14.44			82.77	32.10	114.82	90.10	8 "
56					0	15.60	23.00	23.56	0		62.16	22.96	85.12	61.15	12 "
60						9.36	14.72	14.82	5.70		44.60	14.78	59.38	37.62	16 "
64						0	9.20	9.50	9.30	0	28.00	10.19	38.19	24.93	20 "
68							5.52	6.08	5.85	2.28	19.73	6.97	26.70	16.23	24
72							0	3.80	3.75	3.72	11.27	4.78	16.05	10.46	4 22/8
76								2.28	2.40	2.43	7.02	0	7.02	3.52	8 Hr.
80								0	1.50	1.50	3.00		3.00	0	12 Hr.
84									1.09	0.90	0.99		0.99		16 "
													0		20 "

Note:- (1) Col.(2) has been taken from Fig. No. 4(c)-3

(2) Col.(3) to (11) has been taken from Fig. No. 4(c)-13

(3) Col. (13) has been taken from Fig.No. 4 (B)-13

(4) Col. (15) has been taken from Fig.No.4(c)-14

APPENDIX NO. XVIII (C)

CHANNEL ROUTING OF MANDSAUR D.R.H. UPTO GANDHISAGAR SITE

Hours	Unit Response Th.8 Hrs cusecs	Flow elements of computed DRH at Mandsaur in Th.cusecs No. 1 15 Th. cu.	No. 2 57 Th. cu.	No. 3 55 Th. cu.	No. 4 29 Th. cu.	No. 5 5 Th. cu.	Total routed D.R.H. Col. (6to7)	Intermediate sub-basin D.R.H. Th. Cu.	Total D.R.H. At Nahar garh routed from Mandsaur	Period	Date	Observ DR.H. at Nahar garh
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
0	0	0						0	0	12 Hr	19.8.	0
							0	3.27	3.27	16 Hr		2.00
4	0.51	7.65					7.65	15.12	22.77	20 Hr		9.50
8	0.76	11.40	0				11.40	31.47	42.87	24 "		29.00
12	0.38	5.70	26.52				32.22	42.16	74.38	4 "	20.8.74	81.00
16	0.20	3.00	46.52	0			48.52	45.40	93.92	8 "		120.00
20	0.10	1.50	19.76	28.05			49.31	42.50	91.90	12 "		95.00
24	0.05	0.75	8.40	37.80	0		46.95	35.70	82.65	16 "		71.00
28	0	0	5.20	20.90	14.79		40.84	28.60	69.44	20 "		50.00
32			2.60	11.00	22.04	0	35.64	22.03	57.67	24 "		33.00
36			0	5.50	11.02	2.55	19.07	16.13	35.15	4 "	21.8.74	23.50
40				2.80	5.80	3.80	12.40	11.73	24.13	8 "		18.50
44				0	2.90	1.90	4.80	8.30	11.60	12 "		14.50
48					1.50	1.00	2.50	5.70	8.20	16 "		10.00
52					0	0.50	0.50	3.90	4.40	20 "		7.00
56						0.25	0.25	2.00	2.83	24 "		4.50
60						0	0	1.30	1.30	4 "	22.8.74	1.50
								0	0	8 "		0

Note: Col.(2) has been taken from Fig.No. 4(c)-4
Col. (3) to Col. (7) have been taken from Fig. No. 4 (c)-17
Col. (9) has been taken from Fig. No. 4(B)-12
Col. (13) has been taken from Appendix No. 14(iv)

APPENDIX NO. XVIII (d)

CHANNEL ROUTING OF CHALDU D.R.H. UPTO GANDHISAGAR SITE

Hours	Unit Response for 8 Hr cusecs	Flow elements of computed D.R.H. at Chaldu in Th.Cusecs								Total Routed D.R.H. Col.(3) to(10)	Intermediate sub-basin D.R.H.	Total D.R.H. at Tumri routed from Chaldu	Computed D.R.H.at Tumri	Period & Date
		No. 1 2.5 Th. cu.	No. 2 12.5 Th. cu.	No. 3 17.5 Th. cu.	No. 4 13.25 Th.Cu.	No. 5 8.5 Th. cu.	No. 6 5.0 Th. cu.	No. 7 2.5 Th. cu.	No. 8 0.75 Th cu.					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0								0	0	0	0	16 Hr 19.8.74
4	0.48	1.20								1.20	0.91	2.11	2.35	20 "
8	0.73	1.83	0							1.83	4.91	6.74	11.08	24 "
12	0.38	0.95	6.00							6.95	11.53	18.48	24.04	4 " 20/8
16	0.20	0.50	9.13	0						9.53	17.83	27.36	34.80	8 "
20	0.11	0.28	5.75	10.40						16.43	21.69	38.12	39.57	12 "
24	0.06	0.15	2.50	12.78	0					15.43	22.50	37.93	38.81	16 "
28	0.03	0.08	1.38	6.65	6.36					14.47	21.25	35.72	35.29	20 "
32	0	0	0.75	3.50	9.67	0				13.92	18.69	32.61	30.17	24 "
36			0.37	1.93	5.04	4.08				11.42	15.72	27.14	24.51	4 " 21/8
40			0	1.05	2.65	6.21	0			9.91	12.76	22.67	19.26	8 "
44				0.53	1.45	3.23	2.40			7.60	10.01	17.62	14.26	12 "
48				0	0.80	1.70	3.65	0		6.15	7.60	13.75	11.00	16 "
52					0.40	0.93	1.90	1.20		4.43	5.71	10.34	8.10	20 "
56					0	0.51	1.00	1.83	0	3.34	2.66	7.51	4.17	24 "
60						0.26	0.55	0.95	0.38	2.12	1.95	4.78	2.64	4 " 22/8
64						0	0.30	0.50	0.51	1.31	0	3.26	1.95	8 "
68							0.15	0.28	0.30	0.73		0.73	0	12 "
72							0	0.15	0.15	0.30		0.30		16 "
76								0.08	0.08	0.16		0.16		20 "
80								0	0.04	0.04		0		24 "
84									0.02	0.02				
88									0	0				

Note: (1) Col. 2 has been taken from Fig. 4(C)-5
(2) Col. 3 to 10 have been taken from Fig. 4(c)-19
(3) Col. 12 has been taken from Fig. 4(B)-14
(4) Col. 14 has been taken from Fig. 4(c)-20

APPENDIX NO. XVIII (e)

CHANNEL ROUTING OF CHOUMAHLA (INTERMEDIATE) DRH UPTO G.S.

Hours	Unit Response for 8 Hrs cusecs	Flow elements of computed D.R.H. at Choumahla (Intermediate Subbasin) in Th. cusecs										Total Routed DRH Col.3 to 12	Period & Date
		No. 1 16 Th. cu.	No. 2 54 Th. cu.	No. 3 74 Th. cu.	No. 4 101Th. cu.	No. 5 89 Th. cu.	No. 6 58 Th. cu.	No.7 32 Th. cu.	No. 8 15 Th. cu.	No. 9 7 Th. cu.	No.10 3 Th cu.		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	0	0										0	4 Hr 19.8.74
4	0.35	5.60										5.60	8 "
8	0.58	9.28	0									9.28	12 "
12	0.38	6.08	18.90									24.48	16 "
16	0.25	4.00	31.32	0								35.32	20 "
20	0.17	2.72	20.52	25.90								49.14	24 "
24	0.11	1.76	13.50	42.92	0							58.18	4 "
28	0.07	1.12	9.18	28.12	35.35							73.77	8 "
32	0	0	5.94	18.50	58.58	0						83.02	12 "
36			3.78	12.58	38.38	31.15						85.89	16 "
40			0	8.14	25.25	51.62	0					85.01	20 "
44				5.18	17.17	33.82	20.30					76.47	24 "
48				0	11.11	22.25	33.64	0				67.00	4 " 21/8
52					7.07	15.13	22.04	11.90				56.14	8 "
56					0	9.79	14.50	19.72	0			44.01	12 "
60						6.23	9.86	12.92	5.25			34.26	16 "
64						0	6.38	8.50	8.70	0		23.58	20 "
68							4.06	5.78	5.70	2.45		17.99	24 "
72							0	3.74	3.75	4.06	0	11.55	4 " 22/8
76								2.38	2.55	2.66	1.05	8.64	8 "
80								0	1.65	1.75	1.74	5.14	12 "
84									1.05	1.19	1.14	3.38	16 "
88									0	0.77	0.75	1.52	20 "
92										0.49	0.51	1.00	24 "
												0	4 "23/8

Note: (1) Col.(2) has been taken from Fig.No.4(c)-6

(2) Col.(3) to (12) have been taken from Fig.No. 4(c)-21

APPENDIX NO. XVIII (b)

CHANNEL ROUTING OF KALAKHEDI (INTERMEDIATE) D.R.H. UPTO GANDHISAGAR

Hours	Unit Response for 8 Hr cusecs	Flow elements of computed DRH at Kalakhedi between Catchment No. 1 9 Th. cu.	No. 2 37.5 Th.Cu.	No. 3 48.5 Th.Cu.	No. 4 38.5 Th.Cu.	No. 5 25 Th. cu.	No. 6 15 Th. cu.	No. 7 8 Th. cu.	No. 8 4 Th. cu.	Total routed D.R.H. Col.3 to 10	Period & Date
1	2	3	4	5	6	7	8	9	10	11	12 & 13
0	0	0								0	24 Hr.18
4	0.55	4.90								4.90	4 " 19/
8	0.80	7.20	0							7.20	8 "
12	0.36	3.24	20.63							23.87	12 "
16	0.17	1.53	30.00	0						31.33	16 "
20	0.08	0.72	13.50	26.68						40.90	20 "
24	0.03	0.27	6.38	38.80	0					45.35	24 "
28	0	0	3.00	17.46	21.17					41.63	4 " 20/
32			1.13	8.25	30.80	0				40.18	8 "
36			0	3.88	13.86	13.75				31.49	12 "
40				1.46	6.54	20.00	0			28.00	16 "
44				0	3.08	9.00	8.25			20.33	20 "
48					1.16	4.25	12.00	0		17.41	24 "
52					0	2.00	5.40	4.40		11.80	4 "21/8
56						0.75	2.55	6.40	0	9.70	8 "
60						0	1.20	2.88	2.20	6.28	12 "
64							0.45	1.36	3.20	5.01	16 "
68							0	0.64	1.44	2.10	20 "
72								0.24	0.68	0.92	24 "
76								0	0.32	0.32	4 "
80									0.12	0.12	8 "
84									0	0	12 "

Note: 1. Col. 2 has been taken from Fig.No. 4(c)-7
2. Col. 3 to 10 have been taken from Fig. No. 4 (c)-22

APPENDIX NO. XVIII (g)

CHANNEL ROUTING OF BARKHEDA (INTERMEDIATE) D.R.H. TO G.S.

Hours	Unit Response for 8 Hr cusecs	Flow elements of computed D.R.H. at Barkheda(~~Between~~ ISB) in Th.Cu.										Total routed DRH Col.3 to 12	Period & Date
		No. 1 10 Th cu.	No. 2 30 Th. cu.	No. 3 66 Th. cu.	No. 4 132 Th cu.	No. 5 140 Th. cu.	No. 6 102 Th.Cu	No. 7 60 Th cu	No. 8 34 Th cu.	No. 9 16Th. cu.	No.10 6 Th. cu.		
1	2	3	4	5	6	7	8	9	10	11	12	13	14&15
0	0	0										0	20 Hr.18/8
4	0.28	2.80										2.80	24 " /74
8	0.50	5.00	0									5.00	4 " 19/8
12	0.38	3.80	8.40									12.20	8 "
16	0.28	2.80	15.00	0								17.80	12 "
20	0.20	2.00	11.40	18.48								31.88	16 "
24	0.14	1.40	8.40	33.00	0							42.80	20 "
28	0.10	1.00	6.00	25.08	36.96							69.04	24 "
32	0	0	4.20	18.48	66.00	0						88.68	4 " 20/8
36			3.00	13.20	50.16	39.20						105.56	8 "
40			0	9.24	36.96	70.00	0					116.20	12 "
44				6.60	26.40	53.20	28.56					114.76	16 "
48				0	18.48	39.20	51.00	0				108.68	20 "
52					13.20	28.00	38.56	16.80				96.76	24 "
56					0	19.60	28.56	30.00	0			78.16	4 " 21/8
60						14.00	20.40	22.80	9.52			66.72	8 "
64						0	14.28	16.80	17.00	0		58.08	12 "
68							10.20	12.00	12.92	4.48		39.60	16 "
72							0	8.40	9.52	8.00	0	25.92	20 "
76								6.00	6.80	6.08	1.68	20.56	24 "
80								0	4.76	4.48	3.00	12.24	4 "
84									3.40	3.20	2.28	8.88	8 "
88									0	2.24	1.68	3.92	12 "
92										1.60	1.20	2.80	16 "
												0	20 "

Note: 1 Col(2) has been taken from Fig. No. 4(c)-8

2. Col. (3) to (12) have been taken from Fig. No. 4(c)-25

APPENDIX NO. XVIII (h)

CHANNEL ROUTING OF NAHARGARH (INTERMEDIATE) D.R.H. UPTO G.S.

Hours	Unit Response for 8 Hrs cusecs	Flow elements of computed D.R.H. at Nahargarh (Between ISB) in Th. cusecs. No. 1 5 Th. cu.	No. 2 31.5Th cu.	No. 3 44.5 Th.Cu.	No. 4 35.5 Th.Cu.	No. 5 22.5 Th cu.	No. 6 12.5 Th.Cu.	No. 7 5.5 Th.Cu.	No. 8 2 Th. cu.	Total routed D.R.H. Col.(3) to(10)	Period & Date
1	2	3	4	5	6	7	8	9	10	11	12&13
0	0	0								0	12 Hr.19/8/
4	0.27	1.35								1.35	16 "
8	0.50	2.50	0							2.50	20 "
12	0.39	1.95	8.51							10.46	24 "
16	0.27	1.35	15.75	0						17.10	4 " 20/8/7
20	0.19	0.95	12.29	12.01						25.25	8 "
24	0.13	0.65	8.51	22.25	0					31.41	12 "
28	0.09	0.45	5.60	17.35	9.60					33.00	16 "
32	0.06	0.30	4.10	12.01	17.75	0				34.16	20 "
36	0	0	2.84	8.45	13.84	6.08				31.21	24 "
40			1.89	5.79	9.60	11.25	0			28.53	4 " 21.8.7
44			0	4.00	6.75	8.78	3.24			22.07	8 "
48				2.67	4.61	6.08	6.00	0		19.36	12 "
52				0	3.20	4.28	4.68	1.49		13.65	16 "
56					2.13	2.93	3.24	2.75	0	11.05	20 "
60					0	2.03	2.28	2.09	0.54	6.94	24 "
64						1.35	1.56	1.49	1.00	5.40	4 Hr 22.8.
68						0	1.08	1.05	0.78	2.91	8 "
72							0.72	0.72	0.54	1.98	12 "
76							0	0.50	0.38	0.88	16 "
80								0.33	0.26	0.59	20 "
84								0	0.18	0.18	24 "
88									0.12	0.12	4 " 23.8.7
92									0	0	8 "

Note:1. Col. No.(2) has been taken from Fig. No. 4 (c)-9

2. Col. No. (3) to (10) have been taken from Fig. No. 4(c)-23

APPENDIX NO. XVIII (1)

CHANNEL ROUTING OF TUMRI (INTERMEDIATE) D.R.H. UPTO G.S.

Hours	Unit Response for 8 Hrs cusecs	Flow elements of computed DRH at Tumri ISP in Th. cusecs. No. 1 1.5Th cu.	No. 2 11.5 Th cu.	No.3 21.25 Th.Cu.	No. 4 21.25 Th.Cu	No. 5 15.75 Th.Cu	No. 6 10 Th cu.	No.7 5.75 Th. Cu.	No.8 2.75 Th. cu.	Total routed D.RH. Col.3 to 10	Period	Date
1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	0								0	16 Hr	19.8.7
4	0.25	0.38								0.38	20 "	
8	0.46	0.69	0							0.69	24 "	
12	0.37	0.55	2.88							3.43	4 "	20.8.7
16	0.28	0.42	5.29	0						5.71	8 "	
20	0.21	0.32	4.26	5.31						9.89	12 "	
24	0.16	0.24	3.22	9.78	0					13.24	16 "	
28	0.12	0.18	2.41	7.86	5.31					15.78	20 "	
32	0.09	0.14	1.84	5.95	9.78	0				17.71	24 "	
36	0	0	1.38	4.46	7.86	3.94				17.64	4 "	21.8.74
40			1.04	3.40	5.95	7.25	0			17.64	8 "	
44			0	2.55	4.46	5.83	2.50			15.34	12 "	
48				1.91	3.40	4.41	4.60	0		14.32	16 "	
52				0	2.55	3.31	3.70	1.44		11.00	20 "	
56					1.91	2.52	2.80	2.65	0	9.38	24 "	
60					0	1.89	2.10	2.13	0.69	6.81	4 "	22.8.74
64						1.42	1.60	1.61	1.27	5.90	8 "	
68						0	1.20	1.21	1.02	3.43	12 "	
72							0.90	0.92	0.77	2.59	16 "	
76							0	0.69	0.50	1.27	20 "	
80								0.52	0.44	0.96	24 "	
84								0	0.33	0.33	4 "	23.8.74
88									0.25	0.25	8 "	
92									0	0	12 "	

Note: (1) Col. 2 has been taken from Fig.No. 4(C)-10
(2) Col. 3 to 10 have been taken from Fig.No. 4(C)-24

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