# STUDY OF WATER AVAILABILITY FOR RAMGANGA BASIN UPTO KALAGARH

A DISSERTATION

*submitted in partial fulfilment of the requirements*
*for the award of the degree*
*of*

MASTER OF ENGINEERING
*in*
HYDROLOGY

*By*
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# S Y N O P S I S

The establishment of relationship between rainfall and runoff is one of the basic problem in hydrology. Such relationships involving various factors affecting runoff are useful for extending runoff records by using rainfall records which are generally available for longer periods. The relationships range from simple rainfall versus runoff plots for different periods such as storm, monthly, or annual to very complicated rainfall runoff model.

In the present study, the monthly rainfall-runoff relationships have been established for Ramganga river basin upto Kalagarh gauge site, for estimating the water availability using flow duration analysis procedure. The catchment area of Ramganga river upstream of the Kalagarh dam site is 3097.60 sq.km. Most of the area extends over a rugged and hilly terrain. The monthly average basin rainfall obtained from 5 external raingauge was available for 60 years. The relationships between average basin rainfall obtained from 5 external raingauge station and corresponding average basin rainfall obtained from internal raingauge station is established, to develop 60 years average basin rainfall.

The monthly rainfall-runoff relationships is estimated using two methods (i) Linear regression analysis (ii) Multiple linear regression analysis.

In the method of simple linear regression analysis the monthly rainfall data (X mm) and monthly runoff data (Y mm) were used and the straight regression is fitted analytically by the method of least square in the form $Y = A + B X$ to establish monthly rainfall-runoff relationship.

In the method of multiple linear regression analysis the rainfall of the previous month has been taken ($X_2$ mm) into consideration along with the monthly rainfall ($X_1$ mm) to the resulting monthly runoff ( Y mm). The equation of the form $Y = A + BX_1 + C X_2$. This correlation was established for the month of July, August, September and October as the affect of monthly rainfall for the month of May is very less on the runoff for month of June.

The procedure has been developed for computation of 60 years runoff series. For estimating the water availability, flow duration analysis procedure has been taken by using the annual runoff series obtained by linear regression analysis and by multiple linear regression analysis.

In this study an attempt has also been made to represent the ~~two~~ time series of structures of available daily runoff data by a simple stochastic model. Such model or some similar model could be used to generate a number of alternative sequences which can be then used for arriving at realistic information regarding flow availability. However these will involve generation of large amount of number of random numbers. This can be achieved only on very big high speed digital computer. In view of this present study the generation of daily flow sequence has not been attempted.

C O N T E N T S

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LIST OF TABLES

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# C E R T I F I C A T E

Certified that the dissertation entitled 'STUDY OF WATER AVAILABILITY FOR RAMGANGA BASIN UPTO KALAGARH' b being submitted by Abdul Wasif, in 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 guidance. 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 certify that Abdul Wasif has worked for a period of 8 months since April 1978, in the preparation of this dissertation under my guidance.

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A C K N O W L E D G E M E N T

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ABDUL WASIF

# CHAPTER - 1

## INTRODUCTION

The main step in water resources planning isto assess the water availability. The hydrologic appraisal of water resources is the basic requirement for planning, designing, constructing, and operating water resources projects. Its objective is to determine the source, extent time distribution and dependability of supply and the quality of water on which an evaluation of control and utilization is to be based. The design of irrigation and hydel project often requires a complete analysis of stream flow possibilities with respect to runoff not only from individual storm but for extended period as well. The efficient operation of many irrigation and power and flood control developments require that some estimate be made of the stream flow to be expected during coming month, season or year.

When long term runoff data are not available at the project site, indirect determination of runoff may be employed. This runoff may be determined by extension of short term runoff record by using long term rainfall record.

Generally in the project site long term rainfall data are available from which some indirect method is applied to estimate the water availability by computing runoff series from the available long term rainfall data. Defficient hydrologic data may result in the danger of under and over-designing. Generally in the water resources project where the long term data of runoff is not available the long term monthly rainfall is used to compute runoff series after developing monthly rainfall runoff relationships with available data.

The relationships between rainfall and runoff is usually complex. These relationships is influenced by various factors such as storm pattern, antecedent condition and basin characteristics. Since the most recent rainfall has greatest effect on soil moisture, precipitation values used in an antecedent precipitation index should be weighted according to time of concurrence. But soil moisture is not, the only influencing factor. Thus more parameters are needed to completely explain the scatter of points in rainfall runoff plot. These parameters could be duration of storm, time of year, distribution of characteristics of rainfall, evaporation loss etc.

As we consider bigger size of catchment the process is affected more by channel characteristics and many factors which are important, for small catchment these factors are less important. As we go from short time interval say one hour, two hours, three hours, day to month, season or year it becomes possible to develop suitable and simple rainfall-runoff relation.

The basic objective of this study is to make water availability study for Ramganga basin upto Kalagarh.

Ramganga river is the first main tributary of Ganga river ont its left, after river enters the plains. Ramganga river rises in the Lower Himalayas north of the hill station of Ranikhet, where a no. of small tributaries join it. Ramganga catchment upstream of multipurpose dam at Kalagarh extends over a rugged and hilly terrain of 3097.60 sq.km. Nearly 50 percent of drainage area is covered with forestwhile above 30 percent is under cultivation with terraced field. Average annual precipitation is 1552 mm out of which 262 mm during non-monsoon period.

Weighted monthly mean rainfall was available for 60 years from (June 1901 to May 1961). These mean were derived 5 external raingauge. Monthly rainfall data was available from 12 internal raingauge station inside the catchment for the period 1957 to 1967.

Daily flow data was available at Kalagarh gauge site from 1957 to 1967.

This study will be done in the following stages -

(1) Computation of average basin rainfall series of 60 years.

(2) Development of suitable month rainfall - runoff relationships.

(3) Computation of monthly and annual flow series.

(4) Water availability study using flow duration analysis procedure.

(5) Examining the possibility of development of a stochastic model of daily runoff.

# CHAPTER - 2

## A BRIEF REVIEW OF LITERATURE

### 2.1 INTRODUCTION

In hydrologic analysis, it is often useful to develop relationships between rainfall and runoff, for water availability analysis. Such relations are useful for generation of runoff from longer period of rainfall which are generally available.

The estimation of water availability is necessary in water resources development not only for economic appraisal of the project but also for checking the reliability and general pattern of availability of water from year to year.

So when rainfall data is available for longer periods and runoff data is available for shorter period, it is necessary to develop rainfall-runoff relation to compute runoff series. The relationships between rainfall and runoff is usually complex. These relationship is influenced by various factors such as storm pattern, antecedent conditions and basin characteristics etc. Due to these complexities and the frequent paucity of adequate data many formulae which have been developed are only approximate. Following rainfall-runoff relations are generally developed for computing runoff series depending upon particular requirements and data.

(a) Annual and seasonal rainfall-runoff relation

(b) Monthly rainfall-runoff relation

(c) Storm rainfall-runoff relation

These relations are attempted through linear or nonlinear regression models or through conceptual models.

## 2.2 REGRESSION MODELS

### 2.2.1 Annual and Seasonal rainfall-runoff relation

In humid climates, annual yield of small water sheds may be much smaller than those of rivers because the later contain high base flow. In arid and semi-arid climate annual yield of smaller water shed may be greater than those of large streams and rivers that have channel transmission losses and no base flow.

Some methods of annual and seasonal rainfall runoff relationships are discussed below -

(a) Binnies Method

Sir Alexander Binnie was probably among the first who try to develop relationship of Rainfall and Runoff. In his study, he has taken Amajheri reservoir on Nag river in Madhya Pradesh, which has a catchment area of 6.6 square mile.

The characteristics of the catchment to which Binnie applied for developing the relation is as follow -

(i) In Ambajhari catchment, only the wet season rainfall is normally effective in producing the year's runoff.

(ii) The catchment area maintain the same condition of dryness of surface at the beginning of each successive wet season and

(iii) The catchment is small, steep and almost impermeable.

(b) Barlow's Method

Mr. T.G.Barlow has studied the actual flow from catchments of various sizes mostly under 50 square miles in the United Provinces and propounded a system of estimating runoff. He divided the catchment into five classes and to each class he assigned a figure representing the percentage of Runoff to Rainfall for an 'average year'. These percentages based on average type of monsoon were to be modified by the application of certain co-efficient according to the 'nature of the season'. The figures of percentages for an average year and the co-efficient depending upon the nature of the season are given in Tables 1 and 2.

TABLE - 1

BARLOW'S PERCENTAGE FOR DIFFERENT TYPES OF CATCHMENT

| Class | Percentage of runoff | Description of Catchment |
|---|---|---|
| A | 10 | Flat, cultivated and black cotton soil |
| B | 15 | Flat, partly cultivated, various soil |
| C | 20 | Average (probably undulating with moderate slopes), greater part cultivated. |
| D | 35 | Hills and Plains with little cultivation. |
| E | 50 | Very hilly and steep with hardly any cultivation |

TABLE -.2

CO-EFFICIENT OF BARLOW

| Nature of season | A | B | C | D | E |
|---|---|---|---|---|---|
| Light rain, no heavy down pour | 0.70 | 0.80 | 0.80 | 0.80 | 0.80 |
| Average year, varying rainfall, no continuous down pour | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Continuous down pour | 1.50 | 1.50 | 1.60 | 1.70 | 1.80 |

The above two tables may be combined into a single one and is tabulated in Table - 3.

TABLE - 3

RUNOFF - RAINFALL PERCENTAGES BY BARLOW

| No. | Nature of Season | Class of Catchment | | | | |
|---|---|---|---|---|---|---|
| | | A | B | C | D | E |
| 1. | Light rains, no heavy downpour | 7.0 | 12.0 | 16.0 | 24.0 | 40.0 |
| 2. | Average year | 10.0 | 15.0 | 20.0 | 35.0 | 50.0 |
| 3 | Continuous downpour | 15.0 | 22.5 | 32.0 | 59.5 | 90.0 |

The method gives quick results when only a very rough idea of the available runoff is required provided the classification of the type of the catchment and the nature of the season can be judged correctly.

(c) Lacey's Method

Gerald Lacey worked out a formula for seasonal runoff, taking into account rainfall, nature of the catchment and the duration of the monsoon.

$$R/P \text{ percentage} = \frac{100}{1 + \frac{120}{PS} f}$$

Where

R = Monsoon Runoff in inches

P = Monsoon Rainfall in inches

S = A catchment factor

f = Monsoon Duration factor

(d) Justin's Formula

Mr. Joel D.Justin drew logarithmic curves of rainfall and runoff for nineteen catchment in Eastern United States and came to the conclusion that the relation between rainfall and runoff must conform to the general shape.

$$R = K P^n$$

Where R is annual runoff in inches

P is the annual rainfall in inches

K and n are constants

He observed that the value of 'n' in all cases nearly equal to two.

He also tabulated the value of catchment slope S the mean annual temperature T and the value of K in fourteen catchments, with varying characteristics.

(e) Parker Study

Parker presented the rainfall-runoff relationship as

$$R = P - L \qquad \ldots \qquad (i)$$

Where $R$ = Annual runoff in inches

$P$ = Annual rainfall in inches

$L$ = Annual rainfall in inches

He gave the rainfall loss L in an individual year by equation

$$L = a + b\,P \qquad \ldots \qquad (ii)$$

According to him the equation of the type

$$L = a + b_s\,P_s + b_w\,P_w$$

Where $P_s$ is the rainfall in summer and $P_w$ the rainfall in winter, would be better than equation (ii). On considerations of practical convenience, however, he used to former equation itself (i.e. equation for purposes of computations). From a study of the data of catchments in British Isles, Germany and Eastern United States, he found the value of 'b' to be 0.16. In deriving this value of 'b' he neglected the data of all years in which the rainfall was more than 1.2 times the mean annual rainfall of the catchment, for the reason that a practical engineer is more concerned with only an analyses of the dry years. He stated that the formula so found, i.e.

$$L = a + 0.16\,P$$

"will be correct for all temperate and non-continental climates provided the mean annual rainfall does not greatly exceed 60 inches".

None of the methods enumerated above either for the estimation of surface or ground water can be applied to a given situation without a study of its specific features and deciding upon the most suitable approach. For an accurate determination of available supplies, surface or ground, most of the methods require either long term records or experimental analysis involving a certain amount of cost, time and certain minimum laboratory facilities. In the ultimate analyses, such methods would no doubt be necessary for the sake of accuracy. But, if there be a method that could indicate the order of available supplies. It will serve as a basis for a preliminary forecast and for judging the desirability or otherwise of taking up more expensive investigations and analyses.

2.2.2 Monthly Rainfall-Runoff Relation

When monthly rainfall is available for long period and runoff is available for short period, then to compute runoff series for water availability analysis. Suitable and monthly rainfall - runoff relationships can be developed. Usual methods are graphical correlation by plotting the direct rainfall and runoff value, the linear regression analysis and multiple regression analysis.

In the linear regression analysis the straight line is generally fitted by method least square method in the form

$$Y = A + BX$$

Where A is the intercept and

B is the regression co-efficient of dependent variable Y and independent variable X. In order to establish monthly rainfall-runoff relationship with this proces s Y is taken as monthly runoff and X is taken as monthly rainfall. This relationships developed by linear regression analysis cannot properly account for base flow contribution which is influenced by rainfall in preceeding months also.

In order to establish the monthly rainfall runoff relationships considering the effect of rainfall of previous month on the resulting runoff, the multiple regression analysis can be used in the form

$$Y = A + BX_1 + CX_2$$

Where Y is dependent variable and $X_1$ and $X_2$ are externally independent variable. In this equation there are three parameter to be determined. The parameter A is the intercept, B is the multiple correlation co-efficient of Y on $X_1$ when $X_2$ is kept constant and the parameter C is the multiple correlation co-efficient of Y on $X_2$ when $X_1$ is kept constant. With the help of this method monthly rainfall-runoff relationships can be develop by considering the effect of previous month rainfall also. Where Y is taken as the monthly runoff and $X_1$ is the monthly rainfall of the same month and $X_2$ for the previous month rainfall.

The multiple linear regression method can also be used to develop monthly rainfall-runoff relationships by considering the effect of more that one previous month rainfall.

Some more methods used to develop monthly rainfall runoff relations are discussed below -

(a) Methods used in Ramganga Project

In the Ramganga project the monthly rainfall-runoff relationships has been developed in the form

$$R = K\ P^N$$

and $R = P - k\ P^n$

Where $R$ = runoff in inches

$P$ = rainfall in inches

$K, k, N, n$ are constants are better suited for computing runoff from relatively short period rainfall when contribution of ground water to runoff is minor.

This relationships were used for the month of June, July, August and for the non-monsoon month (November to May). For the month of September and October the monthly relationships has been developed in the form

$$R_i = a\ P_{(i-1)} + b\ P_i$$

Subscript (i-1) refers to the preceding month. The constant a and b are fitted by method of least squares. The above method shows, when rainfall is zero, runoff is also zero.

(b) Vermeule's formula

In 1894 C.C.Vermeule put forward a formula which expressed a relationships between evaporation rainfall and mean temperature. He worked out monthly loss in the form

$$I = a + b_p$$

Where $I$ = monthly losses in inches

$p$ = month rainfall in inches

Vermeule's were derived from specific catchments which have a mean annual temperature 94.70. To make them applicable to other catchments he introduced another multiplication factor (0.05 T - 1.48) where is the mean annual temperature. Parker tested the multiplication factor and found it correct for catchment in United States, but in applicable to British and German. Later Vermeule develop in the form

$$R = P - (11-0.29\ P)\ (0.035\ T - 0.65)$$

2.2.3 Storm Rainfall-Runoff Relation

The rainfall-runoff relation correlates storm rainfall, antecedent basin conditions, storm duration, and the resulting runoff. As in any statistical correlation the basic data being used to develop runoff relation must be as consistant and reliable as possible. Only that storm rainfall which produced the runoff being considered should be included small showers which occured after the hydrograph had started to recede and should not be included if they have little effect upon the amount of runoff. Similarly, showers occuring sometime before the storm should be excluded from the storm rainfall and included in antecedent precipitation if such an index is utilized. Rainfall duration need not be determined critically unless one is interested in making accurate small amount of rainfall.

The basic technique used by the U.S. Weather Bureau is the Co-axial graphic al method. Such relation is developed using data for one or more head water areas in the basin where forecast are required. Studies must be limited to areas for which the runoff can be evaluated (from the hydrograph ) for each individual storm event. Factors such as soil type, land use, ground cover etc. are also considered.

In this rainfall runoff relations the antecedent basin condition are represented by two variables. The first is an antecedent precipitation index (API), which is essentially the summation of precipitation amount occuring prior to the storm weighed according to time of occurance. The API for to-day equal to K times the API for yesterday plus the average basin precipitation observed for the intervening day. The value of K used by the U.S.Weather Bureau river forecast centre is 0.90. The second variable is week of the year in which the storm occurs (As for example Ist week of Jan. being 1 etc.) Week of the year introduces the average interception and evapotranspiration characteristics of each season which when combined with antecedent precipitation index provided an index of antecedent soil conditions.

Besides this there are some other approach also such as the infiltration approach by using infiltration indices etc.

## 2.3 CONCEPTUAL MODEL

In recent years, a number of mathematically sophisticated methods of hydrologic analysis have been developed. All these methods and those proposed in the earlier years for hydrologic design are essentially techniques of hydrologic modelling. The complicated hydrologic phenomenon can be better approximated by modelling only. A brief description of the modelling approaches of rainfall runoff process used in hydrologic models are being discussed below -

### 2.3.1 Principle of Conceptual Models

The process of modelling a physical system can be divided into the following three phases -

1. Model formulation
2. Model calibration and
3. Model verification

Execution of the modelling process is part art and part science. The designer must combine existing knowledge of the physical processes with conceptual representations of unknown principles underlying the process being modeled.

2.3.2 Requirements in a Model

If a model were required solely to forecast the flow from a particular basin, it would probably be adequate to specify the models form and parametric values such that the computed output was a sufficiently close reproduction of the observed output. If the model is also to help us to understand the process of converting rainfall into discharge and the relative importance of different elements in this process, and particularly if it is hoped eventually to use the model for basins without records by establishing relation between the model parameters and basin characteristics, it is essential to obtain some guide to the relative significance of model parts and the accuracy of parametric values.

Although simplification of the operation of a basin is necessary, especially in terms of variability over the area, it is desirable that the model should reflect the physical reality as closely as possible. If it is hoped to transfer the model to an ungauged basin the parametric values can be determined only by measuring the physical characteristics of the basin. Therefore the further the operation of the model departs from known physical laws the more tenuous is likely to be the relationship between model parameters and the basin characteristics. On the other hand if the model parameters are to be fixed by optimisation on comparison of computed and observed outputs, the more detailed and complex the model the more difficult it becomes to establish the values of the parameters, particularly if these are interdependent. This conflict cannot be resolved entirely, but there should be no unnecessary large number of parameters to be optimised and model parts with similar elements should not be combined.

All systems are analyzed with the aid of mathematical methods. These fall into two categories -

(1) Analytic or direct approach

and

(2) the trial and error or non analytical approach.

Analytical solution are the most desirable, since they yield the wanted result directly. Unfortunately the equations describing hydrologic system are often so complex and numerous that direct solutions are impossible and non analytic and trial and error solution must be resorted to. The principle advantage of the trial and error method is that relatively simple equations are usually involved.

However, a separate trial is reouire of each combination of system parameters.

From the above discussion it is clear that as we consider bigger catchment the process is effected more by channel characteristics and many factors which are important and less for the small catchment. As we go from short time interval to-day to months, season or year it becomes possible to develop suitable and simple rainfall runoff relations.

# CHAPTER - 3

# RAM GANGA BASIN AND DATA AVAILABLE

## 3.1 INTRODUCTION :

The first main tributory of Ganga River is Ramganga, which is on its left, after the river enters the plains Ramganga River rises in the lower Himalayas north of the hill station of Ranikhet, where number of small tributories join the river. At Kalagarh the river emerges into the plain after flowing through a long and narrow gorge, and about 160 KM in the hilly terrain. The main tributaries are the Mandal, the Madalati and the Sona Nadi which joins the river before it enters the gorge. The total catchment area of the Ramganga basin is 82,800 sq.km.

Ramganga river project in Uttar Pradesh (Latitude $28^{o}$ 30' and Longitude $78^{o}$ 45') is built up, which is a multi-purpose project with Irrigation and Power.

## 3.2 CATCHMENT OF RAMGANGA RIVER PROJECT :

Ramganga catchment upstream of multipurpose dam at Kalagarh extends over a rugged and hilly terrain of 3097.60 sq. km. as shown in Figure 3.2.1. in a typical shoe shape fashion. It lies in Almora, Nainital, Chamoli and Garhwal districts. Nearly 50% of the drainage area is covered with forest while above 30% is under cultivation with terraced field. Most of the area falls in the outer middle Himalayan Regions but a smaller part of it right upstream of the reservoir, is in

Himalayan foot hills and Siwaliks. The predominant slope is 50 to 60 percent. The catchment lies between the elevation 262 and 2927 metre.

The Ramganga drains through the geologically unstable Himalayan formation. This area led to an accelerated soil erosion due to heavy rainfall, indistriminate felling of trees, continuous and heavy pressure of grazing, faulty method of agriculture and indiscriminate excavation of hill sides for road construction.

The most of the streams heavily charged with silt, sand and boulders etc. during rains and the flow with torrential velocities lead to heavy damage to adjoining land. Due to frequent change of course of some big rivers like Ramganga, Bin- Gragas etc. wash away some of the best agriculture land in the catchment.

To maintain of the effective span of reservoir life period the most pressing watershed management need of Ramganga river valley project was, therefore, to reduce rate of siltation. A centrally sponsored scheme of soil conservation in the catchment of the Ramganga river valley was started in 1962, to check the problem at its source. The execution of soil conservation measures was entrusted to the forest department Uttar Pradesh with headquarter at Raniket and at Ramnagar. The quantitative estimate of silt load contributed by different subcatchment is being observed by the measurement of discharge of water and the amount of silt in it during the various part of the year.

## 3.3. CLIMATE

The catchment falls in Himalayan subtropical zone of climate with mean annual temperature of 24°c and average annual precipitation is 1552 mm out of which 262 mm during non-monsoon period. At the ridges and places of elevation about 1500 metres, occasional snow fall occurs in winter, but does not stay for long. Winter frosts are common in the valley from December to February and its intensity varies moderate to severe i.e. from April to June but monsoon rain mainly occur from July to early part of October. In the early December/January or early February winter rain also occur, but very little contribution to the total rainfall. Some of the climatic data related to Ramganga catchment in Table 3.1.

## 3.4. PHYSICAL CHARACTERISTICS OF THE CATCHMENT AREA

The catchment area of Ramganga river valley project has been subdivided into small units to accelerate the work of soil conservation and water shed management. The important subcatchments of Ramganga river project are as below -

| | | | |
|---|---|---|---|
| (a) | Mahalchouri | (g) | Choukhtia |
| (b) | Kedar | (h) | Naula |
| (c) | Bhikiasain | (i) | Kaprah |
| (d) | Bhoura | (j) | Machulla on Ramganga river |
| (e) | Marchulla on Deota River | (k) | Swepdulli |
| (f) | Beharbadi | (l) | Kalagarh |

## 3.5. RAINGAUGE STATION AND GAUGE SITE

One gauge site at Kalagarh and 5 nos. of Raingage Station outside the catchment and 15 nos. raingauge inside the catchment. The name of the raingauge stations is mentioned below and their positions shown in the Figure 3.1.

External Stations:

(a) Karan prayag

(b) Ranikhet

(c) Ramnagar

(d) Lansdown

(e) Kotdwara

Internal Stations:

1. Bungidhar
2. Chaukhtia
3. Chitresware
4. Papra
5. Sinaura
6. Harora
7. Koerala
8. Naula
9. Dungri
10. Badiar gaon
11. Rath Wadah
12. Khubani
13. Silgaon
14. Bhikiasain
15. Deghat

## 3.6. RAINFALL DATA

Weighted monthly mean rainfall was available for 60 years from June 1901 to May 1961. These mean were derived from five out side raingauge station namely Ranikhet, KaranPrayag, Kotdwara, Lansdown and Ramnagar (Table 3.2).

The monthly rainfall data was available for the individual raingauge of 4 station outside the catchment from 1957 to 1967.

Monthly rainfall data was available from 12 nos. raingauge station inside the catchment for the common period from 1957 to 1967.

The position of these 12 nos. raingauge station are shown in Figure 3.2.

3.7. RUNOFF DATA

Daily flow data was available at Kalagarh gauge site from 1957 to 1967.

3.8. REMARKS

For the purpose of water availability study since only the monthly data is available for rainfall, monthly series of runoff can be computed using appropriate relationship for conversion monthly rainfall data to monthly Runoff data. As the rainfall data, rain gauge station situated within the catchment is for limited period for the remaining period of about 50 years or so such computation will have to rely on data for outside rain gauge station. The availability of daily runoff data for about 10 years period provides a means for development of some stochastic model which could be used for data generation. However such a approach for data generation will require lot of computer time.

TABLE 3.1

NORMAL MONTHLY VALUES OF SOME CLIMATIC FACTORS AT KALAGARH DAM SITES ON RAMGANGA RIVER

| MONTH | TEMPERATURE Maximum | TEMPERATURE Minimum | Relative Humidity | Wind velocity | Evaporation |
|---|---|---|---|---|---|
| | °C | °C | % | MPH | mm |
| January | 20.90 | 6.8 | 76.3 | 5.02 | 107.8 |
| Feb. | 22.70 | 9.2 | 70.1 | 5.38 | 162.4 |
| March | 28.20 | 14.2 | 62.3 | 6.54 | 266.4 |
| April | 34.0 | 20.3 | 42.8 | 7.00 | 387.0 |
| May | 36.8 | 24.5 | 37.3 | 8.78 | 474.3 |
| June | 36.2 | 26.1 | 59.0 | 6.76 | 333.0 |
| July | 32.2 | 25.8 | 78.6 | 5.49 | 133.3 |
| August | 31.7 | 25.4 | 81.9 | 5.03 | 111.6 |
| Sept. | 31.0 | 23.8 | 79.0 | 4.57 | 138.0 |
| Oct. | 29.8 | 19.6 | 67.5 | 5.11 | 164.3 |
| Nov. | 25.6 | 13.4 | 65.2 | 5.41 | 147.0 |
| Dec. | 22.40 | 7.4 | 72.0 | 5.24 | 108.5 |

TABLE 3.2

WEIGHTED MONTHLY MEAN RUN-OFF (1901-1960)

(FROM EXTERIOR STATION)

| YEAR | JUNE mm | JULY mm | AUG. mm | SEPT. mm | OCT. mm | NOV.- MAY mm |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1901-2 | 27.63 | 364.23 | 704.34 | 144.78 | 17.52 | 144.52 |
| 2-3 | 128.01 | 413.76 | 365.25 | 187.70 | 16.76 | 140.46 |
| 3-4 | 60.19 | 248.92 | 474.73 | 213.10 | 42.92 | 199.39 |
| 4-5 | 128.52 | 495.55 | 403.09 | 207.01 | 3.55 | 405.34 |
| 5-6 | 72.13 | 314.96 | 319.53 | 106.68 | - | 215.64 |
| 6-7 | 194.05 | 307.08 | 573.78 | 243.58 | 5.08 | 503.93 |
| 7-8 | 46.73 | 336.55 | 393.39 | 11.17 | - | 164.49 |
| 8-9 | 83.82 | 474.22 | 526.03 | 58.92 | 0.50 | 222.25 |
| 9-10 | 316.74 | 660.90 | 513 08 | 148.59 | 33.78 | 213.86 |
| 10-11 | 216.15 | 540.76 | 683.51 | 283.46 | 363.73 | 336.04 |
| 11-12 | 144.52 | 67.56 | 342.64 | 296.42 | 10.41 | 301.98 |
| 12-13 | 99.31 | 368.30 | 496.82 | 317.24 | - | 320.29 |
| 13-14 | 215.90 | 346.20 | 137.41 | 47.24 | 12.44 | 368.30 |
| 14-15 | 98.29 | 613.41 | 357.37 | 502.41 | 19.05 | 360.42 |
| 15-16 | 154.43 | 373.38 | 552.19 | 165.35 | 12.44 | 124.15 |
| 16-17 | 314.96 | 362.96 | 408.17 | 253.49 | 70.61 | 392.43 |
| 17-18 | 234.44 | 608.33 | 354.07 | 391.66 | 141.73 | 213.86 |
| 18-19 | 195.32 | 168.91 | 313.69 | 195.32 | 5.33 | 359.92 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1919-20 | 190.75 | 401.32 | 316.23 | 307.84 | 12.44 | 217.93 |
| 20-21 | 225.55 | 454.91 | 258.82 | 69.85 | 9.14 | 193.44 |
| 21-22 | 426.21 | 356.10 | 655.57 | 657.60 | 62.99 | 105.41 |
| 22-23 | 112.52 | 497.33 | 704.34 | 318.77 | 4.06 | 254.51 |
| 23-24 | 27.94 | 347.72 | 331.47 | 210.56 | 28.44 | 267.97 |
| 24-25 | 26.41 | 526.28 | 422.65 | 656.59 | 134.87 | 201.93 |
| 25-26 | 257.73 | 553.46 | 371.85 | 64.77 | 6.85 | 294.21 |
| 26-27 | 24.38 | 397.51 | 419.10 | 176.02 | 5.08 | 250.44 |
| 27-28 | 166.62 | 286.76 | 655.57 | 128.27 | 171.45 | 311.91 |
| 28-29 | 58.42 | 492.50 | 248.66 | 12.70 | 0.25 | 151.43 |
| 29-30 | 122.17 | 246.38 | 38.04 | 40.38 | 44.19 | 359.66 |
| 30-31 | 147.06 | 483.61 | 315.21 | 93.72 | 13.71 | 219.20 |
| 31-32 | 46.48 | 392.17 | 454.91 | 140.18 | 94.48 | 115.06 |
| 32-33 | 88.64 | 367.53 | 529.08 | 360.17 | 10.71 | 346.20 |
| 33-34 | 285.75 | 557.53 | 371.60 | 176.53 | 113.79 | 185.67 |
| 34-35 | 225.55 | 434.34 | 485.64 | 89.66 | - | 246.63 |
| 35-36 | 30.48 | 342.39 | 253.74 | 203.45 | 1.27 | 247.65 |
| 36-37 | 379.98 | 625.85 | 392.93 | 261.36 | 15.74 | 374.65 |
| 37-38 | 152.65 | 438.65 | 458.72 | 318.77 | 8.63 | 318.77 |
| 38-39 | 328.93 | 591.05 | 411.98 | 90.93 | 18.79 | 166.11 |
| 39-40 | 231.64 | 399.03 | 204.97 | 215.90 | 22.35 | 308.86 |
| 40-41 | 150.62 | 489.20 | 378.90 | 91.18 | 0.25 | 256.28 |
| 41-42 | 228.09 | 181.61 | 440.18 | 117.35 | 27.68 | 27.68 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1942-43 | 236.47 | 599.94 | 567.69 | 187.70 | - | 243.07 |
| 43-44 | 73.66 | 264.41 | 760.22 | 213.61 | - | 302.51 |
| 44-45 | 197.32 | 429.00 | 200.35 | 161.24 | 8.38 | 231.14 |
| 45-46 | 79.75 | 254.76 | 395.98 | 400.05 | 73.66 | 283.97 |
| 46-47 | 223.26 | 691.38 | 426.97 | 108.90 | 69.08 | 216.40 |
| 47-48 | 138.93 | 417.83 | 357.12 | 504.71 | 11.43 | 240.03 |
| 48-49 | 48.51 | 334.26 | 721.61 | 260.35 | 38.51 | 273.05 |
| 49-50 | 86.10 | 590.04 | 450.08 | 205.74 | 14.47 | 259.08 |
| 50-51 | 266.44 | 597.66 | 605.53 | 191.51 | 1.77 | 245.36 |
| 51-52 | 61.72 | 246.38 | 412.49 | 280.92 | 15.24 | 317.75 |
| 52-53 | 303.02 | 366.26 | 434.34 | 62.73 | 12.19 | 205.99 |
| 53-54 | 200.40 | 690.88 | 271.78 | 143.76 | - | 352.29 |
| 54-55 | 70.86 | 501.65 | 542.29 | 219.71 | 223.52 | 228.60 |
| 55-56 | 115.57 | 337.05 | 466.34 | 279.40 | 371.09 | 241.55 |
| 56-57 | 187.70 | 411.73 | 436.37 | 149.08 | 410.72 | 316.48 |
| 57-58 | 170.68 | 422.14 | 217.93 | 351.28 | 314.90 | 225.04 |
| 58-59 | 85.34 | 591.82 | 571.75 | 270.76 | 91.69 | 296.16 |
| 59-60 | 90.17 | 525.01 | 450.34 | 259.08 | 102.87 | 264.41 |
| 60-61 | 105.66 | 681.99 | 507.49 | 209.29 | 84.58 | 264.41 |

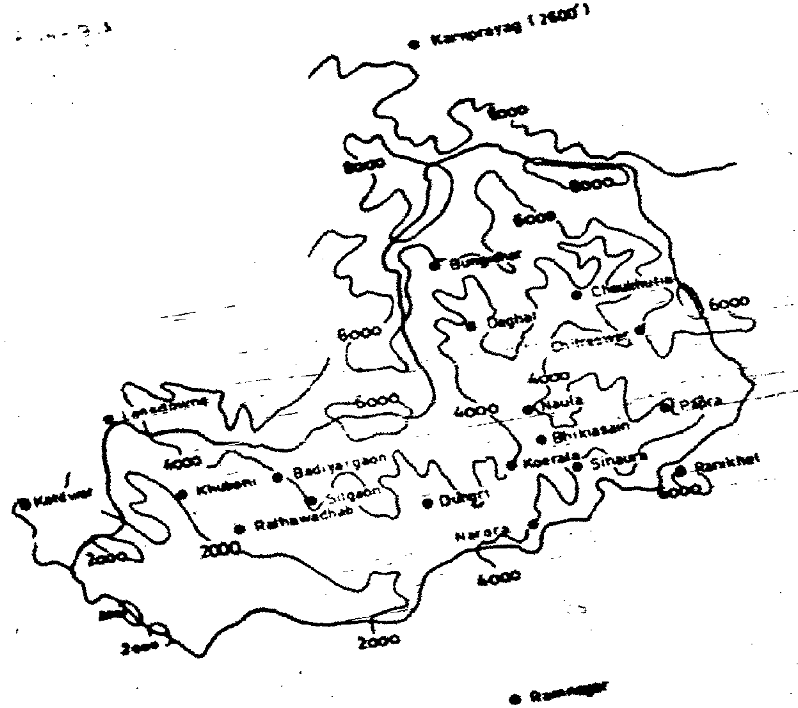


FIG. 3.1

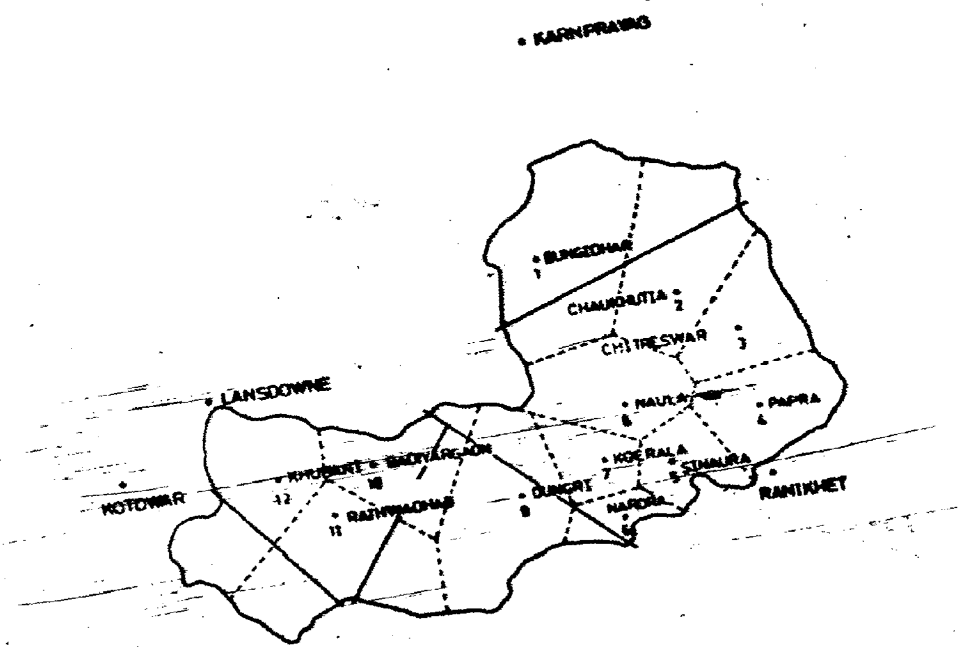


FIG. 3.2 THIESSEN POLYGON OF INTERNAL (----) AND EXTERNAL (——) RAINGAUGE STATION

# CHAPTER - 4

# COMPUTATION AND ANALYSIS OF RUNOFF SERIES

## 4.1 INTRODUCTION

For the assessment of water availability in appraising water resources detailed stream flow data are required. In planning the utilization of water resources, the magnitude of the available water dictates the location and its distribution dictates the scope and size of the various structures. For this reason the availability of quantity of water at any time within a year and the total quantity of water available for certain period are required to be estimated.

The runoff data is available generally for a limited period only whereas the rainfall data is available for a longer period. In such cases to estimate flow series for a longer period it is necessary to correlate rainfall and runoff using some type of correlation analysis using the available data of rainfall and runoff for concurrent period.

The usual methods for developing such relationships are :

(1) Graphical correlation using the method of deviation

(2) Graphical correlation using coaxial methods.

(3) Simple linear Regression and Multiple regression analysis.

In this study relationship have been developed between monthly rainfall and monthly runoff using statistical procedures of simple linear regression and Multiple Regression Analysis.

4.1.2. Simple Linear Regression and Correlation :

The straight regression line is generally fitted analytically by method of least squares of the departure from the line. For the regression line Y vs X the departures are $y_i$ along the ordinate. The equation of the form

$$Y = A + BX$$

Where B is the regression coefficient of dependent variable Y and independent variable X, A is the intercepts for the the regression line. If $\bar{x}$ and $\bar{y}$ are the mean values of x and y for the sample size N, then

$$B = \frac{\Sigma X_i Y_i - N \bar{X} \bar{Y}}{\Sigma X_i^2 - N \bar{X}^2} = \frac{\Sigma (\Delta X_i)(\Delta Y_i)}{\Sigma (\Delta X_i)^2}$$

Where $\Delta X_i = (x - \bar{x})$ and $\Delta Y_i = (y - \bar{y})$,
and the intercept

$$A = \bar{Y} - B \bar{X}$$

Above analysis procedure has been adopted to correlate (1) Monthly Rainfall of external raingauge station (X) as independent variable and Average Basin rainfall over its Thiessen Polygon obtained from inside Raingauge Station (Y) as dependent variable (2) Average monthly Basin Rainfall obtained from five external raingauge stations (x) and Average monthly Basin Rainfall obtained from 12 internal raingauge stations and (3) Average monthly Ischyetal mean Rainfall obtained from Inside raingauge stations (x) and Monthly Runoff (y).

4.1.3. Multiple Regression and Correlation :

The association of three or more variables can be investigated by multiple regression and correlation analysis.

The multiple - regression may be expressed in the form

$$Y = f\ (x_1,\ x_2, \ldots\ x_m)$$

Where, Y is dependent variable and $x_1,\ x_2, \ldots\ x_m$ are independent variables.

If the above equation is linear, the regression is referred to as multiple linear regression and the association is multiple linear correlation. The non-linear relations in hydrology are often transformed to linear relation for multiple regression analysis.

The linear regression for three variables is

$$Y = A + BX_1 + C\ X_2$$

Where Y is the dependent variables and $X_1$ and $X_2$ are externally independent variables. In this equation there are three parameters to be determined. The parameter A is the intercept, B is the multiple regression co-efficient of Y on $X_1$ when $X_2$ is kept constant. The parameter C is the multiple regression co-efficient of Y on $X_2$ when $X_1$ is kept constant.

In this the correlation between monthly runoff (Y) with the monthly rainfall of the same month ($X_1$) and the monthly rainfall of the previous month ($X_2$) has been developed using the above mentioned analysis.

The development of linear regression and multiple linear regression relationships between monthly rainfall and monthly runoff has been described in the following sections. This involves computation of monthly average basin rainfall using available records of raingauge stations. Using the relationships thus developed monthly runoff series have been calculated for 60 years and analysed for water availability study. Besides this an attempt has been made to develop a stochastic model structure for available daily runoff data at Kalagarh gauge site. The procedures and results of the study are discussed in following sections.

## 4.2 COMPUTATION OF MONTHLY AVERAGE BASIN RAINFALL SERIES

### 4.2.1. Thiessen Polygons for Internal and External Raingauge Stations:

The Thiessen polygon of five nos. of external station has been drawn and the areas of Thiessen polygon as per these 5 station were found out. Similarly weighted areas of Thiessen polygon from the 12 Nos. internal Raingauge Station were found out. (Fig. 3.2).

The computed areas and weights of different polygons of External and Internal Raingauge Stations are tabulated in Table No.4.1.

4.2.2. Development of Relationship between Rainfall Data of External and Internal Raingauges:

Out of 15 nos. internal raingauge stations, data from 3 nos. raingauge stations are available for the period 1968 to 1976 for which rainfall data of external stations are not available. So only the rainfall data of 12 nos. internal raingauge stations has been taken for analysis as it has relatively larger period of data for which data of external rain gauge stations are available.

As discussed in Chapter-3 the rainfall data for 5 nos. external raingauge station is available for 60 years (1901-1960) where as for internal stations only 12 stations have reasonable length of data for the concurrent period. In order to obtain flow series of 60 years it is essential to know rainfall series for 60 years an attempt has been made to establish relationship between monthly rainfall for each five external raingauge stations and corresponding average rainfall over their respective Thiessen Polygon for the concurrent period. So that using these relationship average basin rainfall could be computed for entire 60 years period. For Kotdwara external station concurrent period of rainfall data has been obtained by corresponding period rainfall for Kalagarh raingauge station situated nearby. The procedure and results for this study has been discussed in Sections 4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4 and 4.2.2.5.

4.2.2.1. Weights of Internal Raingauge Stations within Thiessen Polygon of External Station :

Areas of Thiessen Polygon of internal raingauge stations within each external raingauge station, Thiessen Polygon has been found out along with their weightage. The figures is tabulated in Table No. 4.2.

4.2.2.2. Monthly Rainfall of Kotdwara Station:

The rainfall of Kotdwara station was not available for which Thiessen Polygon have been drawn including this as an external station, for the period 1957 to 1967, for which rainfall data was available of the internal stations. However in the same period the rainfall data of the raingauge station Kalagarh were available which is close to the Thiessen Polygon area of the Kotdwara station.

Relation as linear proportionate was assumed for each month (June to October and November to May combined) between Kalagarh and Kotdwara stations for which concurrent rainfall data of period 1968 to 1976 were available.

The following relations were established which were used to get the rainfall figures for Kotdwara station during 1957 to 1967.

Y = Monthly rainfall of Kotdwara (mm)

X = Monthly rainfall of Kalagarh (mm)

| | |
|---|---|
| June | Y = 1.15 x |
| July | Y = 1.08 x |
| August | Y = 1.14 x |
| Sept. | Y = 1.13 x |
| Oct. | Y = 0.86 x |
| Nov.-May | Y = 1.49 x |

4.2.2.3. Correlation Between the Monthly External Station Rainfall and Weighted Average Rainfall from the internal station - within the Thiessen Polygon Area of External Station :

The weighted average rainfall as per internal stations were calculated and tabulated along with each rainfall of external station in Table No.4.3.

4.2.2.4. Relation from Simple Graph:

By plotting on single graph relationship was established between rainfall of exterior and the average rainfall within the Thiessen Polygon area of external station for the month of June, July, August, September, October and November-May. The results are tabulated below in the Table No.4.4.

TABLE - 4.4

| Month | Relation with Karan-prayag | Relation with Ranikhet | Relation with Lansdown | Relation with Ramnagar |
|---|---|---|---|---|
| Jun | Y=.66x | Y=0.66x | Y=1.28x | Y=0.8x |
| Jul | Y=0.79x | Y=0.64x | Y=0.85x | Y=0.84x |
| Aug. | Y=1.07x | Y=0.55x | Y=0.7x | Y=1.4x |
| Sept. | Y=0.53x | Y=0.62x | Y=0.87x | Y=1.16x |
| Oct. | Y=1.6x | Y=0.60x | Y= x | Y=0.5x |
| Nov-May | Y=1.4x | Y=0.80x | Y=0.75x | Y=0.75x |

Y = Rainfall of external stations (in mm)

x = Average rainfall over their respective Thiessen Polygon (in mm).

4.2.2.5. Regression Analysis and Correlation Co-efficient:

Correlations were established between rainfall of external stations (Y in mm) and average rainfall over their respective Thiessen Polygon (X in mm) with curve fitting (By least square method) in the form

$$Y = A + BX$$

The correlation co-efficient and the linear relation of different month is tabulated in the Table No.4.5. The Computer programme was used to established the relation. The programme is listed and shown in Appendix.I

From the above results it is observed that except for the external raingauge station Lansdown, the correlation coefficients are very low. Furthermore longer period rainfall data of the internal raingauge stations is not available. There the relation which are obtained above have not been adopted for computation of rainfall series for the catchment.

4.2.3. Development of Relation between Average Basin Rainfall for External and Internal Raingauge :

4.2.3.1 Average Basin Rainfall as per Isohyetal Method compared to that from Normal Thiessen Polygon Method:

The average basin rainfall computed from isohyetal maps for different months for three years choosing one as average rainfall year (1962), one low flow year and one wettest year (1963).

Mean ratio of monthly rainfall as per Isohyetal method and as per Thiessen Polygon method has been computed and the monthly ratio shown below:

| Month | Jun | July | Aug. | Sept. | October | November-May |
|---|---|---|---|---|---|---|
| Mean Ratio | 1.013 | 0.976 | 1.015 | 1.021 | 0.945 | 0.974 |

Above mentioned three years Isohyetal maps has been shown in Appendix - III.

The above ratios were used to convert Thiessen polygon mean rainfall to Isohytal mean of the other years which were used to develop rainfall runoff relationship. This is done because it is possible to estimate the precipitation with a fair degree of accuracy by a simple inspection. It is also advantageous as the catchment is mountaneous.

4.2.3.2. Relation between average basin rainfall obtained from external station and internal station:

For establishing correlation between the monthly mean calculated from the out side station rainfall data and the monthly mean rainfall calculated from inside Rain gauge station rainfall data only the years in which complete data for exterior and interior station available have been taken here and tabulated in the Table No.4.6.

By using these data the straight regression line is fitted analytically by the method of least squares. The equation of the form

$$Y = A + BX$$

Here Y is taken as Average basin rainfall obtained from external station ( in mm ) and X is taken as Average basin rainfall obtained from internal station ( in mm ).

Computer programme was made to establish the relation programme. Co-relation coefficient between them is also found out.

The results of the relation established is tabulated below along with correlation co-efficient for the month of June, July, August, September, October and November-May. These relationships have high correlation coefficient and hence have been adopted.

| Month | Relation | Corelation coefft. |
|---|---|---|
| June | Y = 15.14+0.8004 X | 0.82 |
| July | Y = 177.7386 + 0.5278 X | 0.80 |
| Aug. | Y = 51.63 + 0.7005 X | 0.91 |
| Sept. | Y = 24.14 + 0.6629 X | 0.85 |
| Oct. | Y = 2.82 + 0.7272 X | 0.87 |
| Nov. - May | Y = -8.328 + 0.732 X | 0.94 |

4.2.4. Computation of Rainfall Series:

The relation obtained in section 4.2.3.2. between average basin rainfall obtained from five external stations and average basin rainfall obtained from 12 internal stations have been used to convert 60 years monthly basin rainfall series obtained from external stations to average monthly basin rainfall. Thus 60 years monthly average basin rainfall series have been computed and tabulated in Table 4.7.

4.2.5. Comparison of computed rainfall series with rainfall series computed in the project report memorandum:

In the project report, conversion of average basin rainfall for out side station to average basin rainfall for internal station has been done by taking 75% average basin rainfall obtained from outside raingauges stations.

The statistical parameters Mean and Standard Deviation of computed rainfall series and the rainfall series computed in the project were calculated for each month from June to October and for total rainfall for November to May. The comparison of two series is shown in Fig.4.1. The mean, standard deviation and coefficient of variation of rainfall series computed in present study and that for the series computed in project report is tabulated below:

| | Month | June | July | Aug. | Sept. | Oct. | Nov.-May |
|---|---|---|---|---|---|---|---|
| Computed rainfall series | Mean (mm) | 141.53 | 408.10 | 353.04 | 167.55 | 40.41 | 183.51 |
| | Standard deviation (mm) | 75.15 | 72.31 | 102.40 | 89.50 | 64.81 | 57.10 |
| | Co-efficient of variation | 0.53 | 0.177 | 0.29 | 0.535 | 1.60 | 0.311 |
| Rainfall series computed in project report | Mean | 117.17 | 321.65 | 321.17 | 163.17 | 44.75 | 195.92 |
| | Standard deviation | 70.77 | 101.70 | 108.92 | 101.71 | 70.66 | 59.17 |
| | Co-efficient of variation | 0.603 | 0.316 | 0.339 | 0.623 | 1.57 | 0.302 |

The comparison of statistical parameter for two rainfall series as well constant obtained for relationship between average basin rainfall and from external and internal raingauges for different months clearly shows that a constant factor of 75% is not correct such a constant factor would give considerable variation in monthly rainfall values, though it might maintain total annual rainfall to a realistic value in the computation of monthly rainfall series for 60 years could be improved further if sufficient data is available for developing relationship between rainfall and value recorded by an external raingauge station and corresponding average value over its Thiessen polygon as obtained from internal raingauge stations.

## 4.3. RAINFALL RUNOFF RELATION

### 4.3.1. Rainfall-Runoff data:

Rainfall runoff relation was based on the data of rainfall and runoff for the period 1957 to 1967.

Weighted monthly average for the basin was calculated from 12 nos. internal raingauge stations for the above mentioned period. These monthly means were converted to Isohyetal mean by applying the factors, mean ratios of monthly rainfall as per Isohyetal method and as per thiessen polygon method (4.2.3.1)

Monthly runoff data was also found out from the available daily flow of the same period, which are tabulated along with monthly Ischyetal mean rainfall converted from Thiessen polygon mean as discussed above in Table No.4.9.

### 4.3.2. Rainfall-Runoff Relation Using Simple Linear Regression analysis :

By using the monthly rainfall data ( X mm) and monthly runoff data (Y mm) mentioned in section 4.3.1. the straight regression is fitted analytically by the method of least squares in the form

$$Y = A + BX$$

A computer programme was written to establish rainfall-runoff relations and to compute with correlation co-efficients for these relationships (Appendix I ).

### 4.3.3. Results of Linear Regression:

The regression relation which were established at 4.3.2. are tabulated below with their correlation co-efficients for the month of June, July, August, Sept. Oct. and November-May in Table No.4.10

TABLE 4.10

| Month | Relation | Correlation in coefficient |
|---|---|---|
| June | $Y = -4.3789 + 0.2756\ X$ | 0.77 |
| July | $Y = -19.3243 + 0.5869\ X$ | 0.52 |
| August | $Y = 52.89 + 0.6912\ X$ | 0.80 |
| Sept. | $Y = 160.274 + 0.0925\ X$ | 0.93 |
| Oct. | $Y = 13.44 + 0.1367\ X$ | 0.95 |
| Nov.-May • | $Y = -40.9448 + 1.177\ X$ | 0.76 |

X = Monthly rainfall in mm

Y = Monthly runoff in mm

### 4.3.4. Rainfall runoff relation using Multiple regression analysis:

In the monthly rainfall runoff relation established at 4.3.3. gives monthly run off values from the same months rainfall. There may be considerable amount of effect on the runoff from the previous month rainfall also. So an attempt has been made to establish rainfall run off relationship considering rainfall for previous month also.

For this multiple regression analysis was used. The equation is of the form $Y = A + B X_1 + CX_2$ as discussed in section 4.1.3.

Here Y is taken as the monthly runoff in mm and $X_1$ is the monthly rainfall of the same month and $X_2$ is the monthly rainfall of the previous month.

This correlation was established only for the month of July, August, Sept. and October as the effect of monthly rainfall for the month of May is very less on the runoff for month of June.

The computer programme was written to establish rainfall runoff relations and to compute multiple correlation coefficients for these relationships (Appendix II)

4.3.5. Result of multiple Linear Regression :

The multiple regression relationship for the month of July, August, September and October are given in Table No.4.11 along with their correlation co-efficient. Thus monthly runoff Y (mm) is related to monthly rainfall $X_1$(mm) for the same month and monthly rainfall $X_2$(mm) for the previous month.

These relationships gives somewhat better correlation as compared to those for linear regression. Particularly for the month of July considerably improvement is there in correlation coefficient.

TABLE 4.11

| Month | Relation | Multiple correlation co-efft. |
|---|---|---|
| July | $Y = 0.513\ X_1 + 0.57\ X_2 - 6.07$ | 0.721 |
| Aug. | $Y = 0.65\ X_1 - 0.274\ X_2 + 164.338$ | 0.834 |
| Sept. | $Y = 0.064\ X_1 - 0.081\ X_2 + 38.35$ | 0.936 |
| Oct. | $Y = 1.36 X_1 - 0.047 X_2 + 21.59$ | 0.957 |

4.4. RUNOFF SERIES

4.4.1. Computation of Runoff series:

The monthly average weighted rainfall series for 60 years as obtained from the monthly average basin rainfall series from out side station (4.2.4) were converted to monthly Isohyetal mean applying the mean ratio as obtained in section 4.2.3.1.

After converting the rainfall series to monthly Isohyetal average rainfall series, the same has been used to compute monthly runoff series for 60 years with the linear regression relationships established at 4.3.3 for the month of June to October and November-May (combined) and tabulated in Table No.4.13A.

The multiple linear regression relationships established at 4.3.5. were also used and the monthly runoff series for the months from July to October was computed and tabulated in Table No.4.12.

4.4.2. Non Monsoon runoff ( November to May ) :

In order to divide the total non monsoon runoff (November-May) into that for individual months ratios were established between individual months runoff to total runoff for seven monmonsoon months(Nov.-May) 1947-48 to 1960-61 which was available. These ratios are tabulated below:

| Month | Nov. | Dec. | Jan. | Feb. | March. | April | May | Total |
|---|---|---|---|---|---|---|---|---|
| Fraction of Total flow | 0.24 | 0.18 | 0.16 | 0.17 | 0.11 | 0.08 | 0.06 | 1.00 |

Using the above ratios monthly runoff series for 60 years of non-monsoon flow of Nov. to May was divided into different months and is tabulated in Table 4.13.

After converting the rainfall series to monthly Isohyetal average rainfall series, the same has been used to compute monthly runoff series for 60 years with the linear regression relationships established at 4.3.3 for the month of June to October and November-May (combined) and tabulated in Table No.4.13A.

The multiple linear regression relationships established at 4.3.5. were also used and the monthly runoff series for the months from July to October was computed and tabulated in Table No.4.12.

4.4.2. Non Monsoon runoff ( November to May ) :

In order to divide the total non monsoon runoff (November-May) into that for individual months ratios were established between individual months runoff to total runoff for seven nonmonsoon months(Nov.-May) 1947-48 to 1960-61 which was available. These ratios are tabulated below:

| Month | Nov. | Dec. | Jan. | Feb. | March. | April | May | Total |
|---|---|---|---|---|---|---|---|---|
| Fraction of Total flow | 0.24 | 0.18 | 0.16 | 0.17 | 0.11 | 0.08 | 0.06 | 1.00 |

Using the above ratios monthly runoff series for 60 years of non-monsoon flow of Nov. to May was divided into different months and is tabulated in Table 4.13.

4.4.3. COMPARISON OF RUNOFF SERIES

Statistical parameter comparison:

The mean, standard deviation and co-efficient of co-variance have been calculated for the computed monthly runoff series (Table 4.13A, 4.13B and 4.12) and for the monthly runoff series computed by Central Design Directorate, Irrigation Department, Uttar Pradesh which are tabulated below in Table No. 4.14, 4.15 and 4.16. Fig. 4.3.

From the above results it is seen that monthly mean and standard deviation in nearly all the months is higher for the series obtained in the present study in comparison to the monthly mean and standard deviation of the monthly runoff series obtained in project report. Thus it is seen that monthly runoff series obtained by using proper statistical relationships for converting external raingauge average basin rainfall to average basin rainfall and regression relations for rainfall-runoff conversion differs considerable from that obtained in project report. This in turn will influence the design of project.

4.5. WATER AVAILABILITY ANALYSIS

The objective of this study is to estimate the availability of water with specified levels of probability. In order to evolve economic design of the Hydraulic structures to the water availability study is essential.

In order to estimate water availability for Irrigation and Power for the Ramganga Project the runoff series which have been computed, have been analysed and flow duration curves have been plotted. This analysis has been made for annual series only. For this the monthly runoff data which was computed in mm has been converted to annual flows in Million Cubic Metre.

4.5.1. Flow-Duration Analysis :

When the values of Hydrologic events are arranged in descending order, the percent of time for each magnitude to be equalled or exceeded can be computed. A plotting magnitude as ordinates against the corresponding percent of time as abscissa results is so called duration curve. If the magnitude to be plotted is the runoff of a stream, the duration curve is known as flow-duration curve. In the present study two annual series has been computed for 60 years. One from linear regression relation between monthly rainfall and runoff and other from multiple linear regression relation ( for monsoon months of July to Oct.).

4.5.2. Flow Duration Comparison :

Flow duration analysis was made for 3 annual series:

(1) Annual runoff (M.Cum) series as per project report (Vide Table 4.17)

(2) Present computed two annual runoff series (Vide Table 4.18 and 4.19)

The flow duration curves were plotted as shown in Fig.4.2. for all three series. The following yield values have been estimated and tabulated for comparison.

| Sl.No. | Series | 75% dependable runoff in Mcum | 90% dependable runoff in Mcum |
|---|---|---|---|
| 1. | As per project report | 1700 | 1360 |
| 2. | As per present computation with linear regression analysis | 2460 | 2150 |
| 3. | As per Multiple linear regression analysis | 2150 | 1960 |

4.5.3. Remarks

In the previous section the procedure has been developed for computation of 60 years of monthly runoff series for Ramganga catchment using available data. This has involved establishment of suitable relationship to convert monthly average basin rainfall obtained from 5 external raingauge station for which 60 years data was available, to monthly average basin rainfall as indicated by limited data available for 12 internal rain gauge station. An attempt was made to relate monthly rainfall recorded by external raingauge station to the average rainfall over its Thiessen Polygon as recorded by appropriate internal raingauge station. However due to limited data available satisfactory relationship could not be established. As such relationship between average monthly basin rain fall obtained by using data of external raingauge stations and corresponding average basin rainfall obtained from internal raingauge station, was developed and used for obtaining 60 years series of average monthly basin rainfall.

The results of above analysis are thus affected by the extent of representativeness of external raingauge station and also the adequancy of relationships developed by using about 10 years of concurrent period of data.

The monthly rainfall runoff relationships developed by using linear regression analysis could not properly account for base flow contribution which is influenced by rainfall in preceeding months also. The multiple regression analysis using previous month also deals with this particular aspect to some extent. However as the monthly rainfall runoff data consists of totals for the calendar months it is subject to error due to rainfall occuring during last few days of a month being accounted in that month while the resulting run off being accounted in next month.

The nonmonsoon runoff has been estimated as a total for the entire seven months period ( Nov. to May ) and then redistributed in constant proportion to individual months. This procedure was adopted due to non availability of suitable data.

The water availability study for three cases viz. (1) annual runoff series obtained by linear regression analysis (2) annual run off series obtained by multiple linear regression analysis for monsoon month and (3) annual run of series used in project, clearly shows that the decision regarding water availability is effected by the method used to estimate the runoff series.

It is therefore necessary that while estimating runoff series a best possible used is made of all available data in a scientific manner.

## 4.6. STOCHASTIC MODEL FOR DAILY FLOW SERIES

### 4.6.1. Introduction

In the previous section the monthly runoff series for 60 years has been obtained by using available rainfall data and deterministic relationship developed between monthly rainfall and runoff data. However the runoff series thus obtained represents a sequence which is not likely to repeat in the same order in future. As such the decision arrived at using these sequence may lead to over design on under-design. To help overcome this defficiency the modelling technique developed in the field of stochastic hydrology are employed to generate a number of stream flow sequences of desired length using statistical information of available observation data. These sequences which are equally likely to occur in future can be utilised to evolve a rational design of the water resources project.

In this section an attempt has been made to represent the two series of structures of available daily runoff data by a simple stochastic model. Such model or some similar model could be used to generate a number of alternative sequences which can be then used for arriving at realistic information regarding flow availability. However these will involve generation of large amount of number of random numbers, for example to general one 60 years series of daily flows 60 x 12 x 365 normal independent random nos.

will have to be generated. This can be achieved only on very big high speed digital computer. In view of this present study the generation of daily flow sequence has not be attempted.

4.6.2. Component of daily flow series

Component of daily flow series can be represented by an additive model of the form

$$Q_t = \bar{Q} + Q_d + Z_t$$

Where $Q_t$ = observed daily flow

$\bar{Q}$ = mean of all available daily flows

$Q_d$ = mean of $(Q_t - \bar{Q})$ for each day of year thus representing periodic component of time series.

$Z_t$ = Stochastic component which consists of dependent and independent components.

In this representation both $\bar{Q}$ and $Q_d$ constitute deterministic component. The removal of mean $\bar{Q}$ from the time series makes it homogeneous and then the removal of periodic component $Q_d$ makes the remaining series $Z_t$ a stationary stochastic series. In this approach the periodicities in standard deviation and other higher moment have been assumed to be non existant. The periodic component $Q_d$ which consists of 365 values of daily means could be represented by significant harmonic within the annual cycle. A maximum of 173 harmonics could be present in case of daily flows whereas a maximum of 6 harmonics could be present in case of periodic component of monthly flows. Generally it has been found that in case of daily flows also the periodic component can be represented by 5 or 6 harmonics needing 10 or 12 parameters only.

The stochastic component $Z_t$ can be represented by a Ist order Markov model

$$Z_t = a_1 Z_{t-1} + \varepsilon_t$$

where $a_1 = r_1$ = Lag one correlation coefficient.

$\varepsilon_t$ = Independent stochastic component.

Best fit statistical distribution of $\varepsilon_t$ for given data can be found using Chi square test and then the time series model can be used to generate a number of sequences of data of required length by generating $\varepsilon_t$ having same statistical distribution and adding dependent stochastic component and deterministic component $\bar{Q}$ and $Q_d$ i.e. mean and periodic component.

In this study an attempt has been made to represent available 8 years data of daily flows by time series model structures discussed above.

4.6.3. Determination of $Q_t$ (Daily flow )

Data of daily flow was available for 8 years from 1960 to 1967 in which 6 to 8 observation were recorded at a regular interval of time on each day. The average of these observation for each day has been calculated and in this way the $Q_t$ series of 8 years of daily flow has been computed. The $Q_t$ values for 1963 which is wettest year out of 8 years have been plotted in figure -4(A)

4.6.4. Determination of $\bar{Q}$

The mean $\bar{Q}$ of all available daily flow data for 8 years has been calculated by summing up all daily flow values of the $Q_t$ series for 8 years and dividing by the number of days in 8 years. The mean daily flow of each year has also been calculated and tabulated below -

| AR | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|
| tal ily ow umec) | 31733.63 | 35781.25 | 34607.08 | 36718.56 | 35239.39 | 24315.19 | 41951.45 |
| an | 86.94 | 98.03 | 94.81 | 100.59 | 96.54 | 66.61 | 114.93 |

| .R | 1967 | Total for 8 years |
|---|---|---|
| al ly w mec) | 31399.74 | 359035.90 |
| n | 86.02 | $\bar{Q}$ = 983.66 |

4.6.5. Determination of $Q_d$

The mean $\bar{Q}$ of the daily flow data of 8 years is substracted from $Q_t$ (daily flow). The values of $Q_t - \bar{Q}$ have been plotted for

1963 in Fig.4C. Then the flow $(Q_t-\bar{Q})$ are added for the respective day of each year and the summation has been divided by the number of years i.e. 8. For example $Q_d$ for Ist January obtained by summing all Ist January $(Q_t-\bar{Q})$ values. of each year and then divided by number of years. In the same manner $Q_d$ is found out for 365 days i.e. 365 number of $Q_d$ values. The $Q_d$ represent the deterministic periodic component of time series. The 365 values of $Q_d$ have been plotted in figure 4.B. This figure clearly indicates the periodic nature of $Q_d$, which can be represented by suitable small number of significant harmonics.

4.6.6. Determination of $Z_t$

Stochastic component which consists of dependent and independent component is found out after removing deterministic component $\bar{Q}$ and corresponding $Q_d$ from the daily flow $Q_t$ i.e.

$Z_t = Q_t - \bar{Q} - Q_d$ The figure 4.D shows a plot of $Z_t$ values for 1963.

This stochastic component $Z_t$ could then be represented by a Markov Model. The simplest would be Ist order Markov Model as below

$$Z_t = a_1 \; Z_{t-1} + \varepsilon_t$$

where $\varepsilon_t$ is independent stochastic ( random ) component.

4.6.7. Calculation of $a_1$ and $\varepsilon_t$ for 1963 data

The co-efficient $a_1 = r_1$, where $r_1$ is Lag one serial co-relation co-efficient which is calculated from the equation given below -

$$r_1 = \frac{\frac{1}{N-1} \sum_{t=1}^{N-1} Z_t \cdot Z_{t+1} - \frac{1}{(N-1)^2} \left( \sum_{t=1}^{N-1} Z_t \right) \left( \sum_{t=1}^{N-1} Z_{t+1} \right)}{\left[ \frac{1}{N-1} \sum_{t=1}^{N-1} Z_t^2 - \frac{1}{(N-1)^2} \left( \sum_{t=1}^{N-1} Z_t \right)^2 \right]^{1/2} \left[ \frac{1}{N-1} \sum_{t=1}^{N-1} Z_{t+1}^2 - \frac{1}{(N-1)^2} \left( \sum_{t=1}^{N-1} Z_{t+1} \right)^2 \right]^{1/2}}$$

Auto co-relation analysis is used to determine the linear dependence among the successive values of a series that are given lag apart. In case of two series, the lag cross co-relation, with the positive or negative lag, gives the linear dependence of the successive values of the two series that are given lag apart. A measure of this is given by the serial correlation co-efficient.

The serial co-relation co-efficient is analogous to the product moment co-relation co-efficient for two sets of data.

$Z_t$ and $Z_{t+1}$ are considered here two sets of data. The values of the above equation are calculated from $Z_t$ series which are given below

i) $N = 364$

ii) $\sum_{t=1}^{363} Z_t = 0.11262 \times 10^4$ cumec

iii) $\sum_{t=1}^{363} Z_{t+1} = 0.11097 \times 10^4$ cumec

iv) $\sum_{t=1}^{363} Z_t^2 = 0.13612 \times 10^8 \text{ (cumec)}^2$

v) $\sum_{t=1}^{363} Z_{t+1}^2 = 0.13611 \times 10^8 \text{ (cumec)}^2$

vi) $\sum_{t=1}^{363} Z_t \, Z_{t+1} = 0.09246 \times 10^8 \text{ (cumec)}^2$

Substituting these values in the above equation $r_1$ comes to

$r_1 = 0.6791$

4.6.7.1. Test of Significance

A test of significance for social co-relation co-efficient $r_k$ has been proposed by Anderson, is based on circular series approach and the confidence limits which is modified by Yevjevich (38) for open series approach is given by the equation.

$$r_k(\alpha) = \left( \frac{-1 \pm n_\alpha \sqrt{N-K-1}}{N-K} \right)$$

Where N is the number of observed value in the time series, K is the lag and $n_\alpha$ is the normal standard deviate from standard normal distribution for a two tail test and at the significance level $\alpha$.

$\alpha$ at 95 percent $n_\alpha = 1.96$

Substituting the value of $n_\alpha$ and N in the above equation

$$r_1(\alpha) = \frac{-1 \pm 1.96\sqrt{364-1-1}}{364-1}$$

$$= -0.105 \text{ and } + 0.099$$

Therefore the $r_1 = 0.6791$ (4.6.7) is highly significant for 364 data values.

4.6.7.2. Determination of $\varepsilon_t$

Knowing $a_1$ ( i.e. $r_1$ ) and $Z_t$ , the independent stochastic component was calcvlated as below

$$\varepsilon_t = Z_t - a_1 Z_{t-1}$$

The values of $\varepsilon_t$ for 1963 has been plotted in figure 4.E.

4.6.8. Testing fore fit of Normal distribution of $\varepsilon_t$ series

For independent stochastic component i.e. $\varepsilon_t$ series normal distribution was fitted. The values of parameter of Normal Distribution i.e. mean and standard deviation were obtained as Mean = 1.75 cumec Standard deivation = 141.66 cumec.

The goodness of fit Normal distribution was tested by dividing the 364 values of $\varepsilon_t$ into 28 classes having equal probability. The class interval limits for equal probability were obtained by using normal distribution table. The observed frequency for each class limit was obtained and Chi square was calculated as given in Table No.4.6.10.

The Chi square comes as 2181.354 the Degrees of Freedom in this case is 28-1-1 i.e. 25 for which tabulated values of Chi square at 95 percent confident level is 377 this shows that Normal Distribution does not fit $\varepsilon_t$ series. The reason for this is clearly indicated by class limit No.14 and figure 4.E. where a large number of negative values of nearly equal magnitude occur during non monsoon reason. It appears that typical seasonal value of Indian climate, monsoon and non-monsoon season have to be dealt separately, and normal distribution could be tried for monsoon season data.

Therefore generation of data of such cases will also have to be dealt by taking to separate model for monsoon and non monsoon period after evaluating their respective parameters.

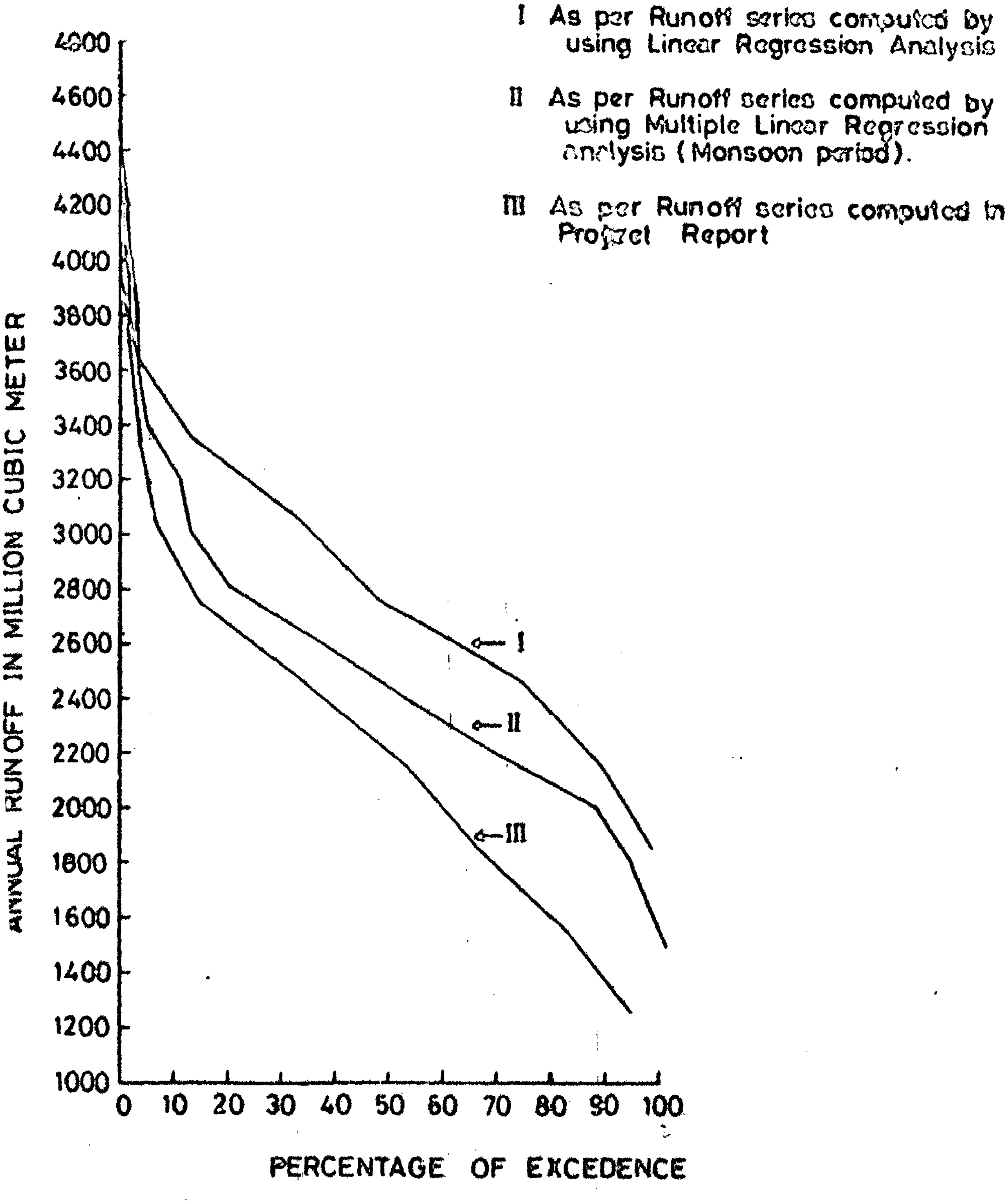


FIG.4.2 FLOW DURATION CURVES

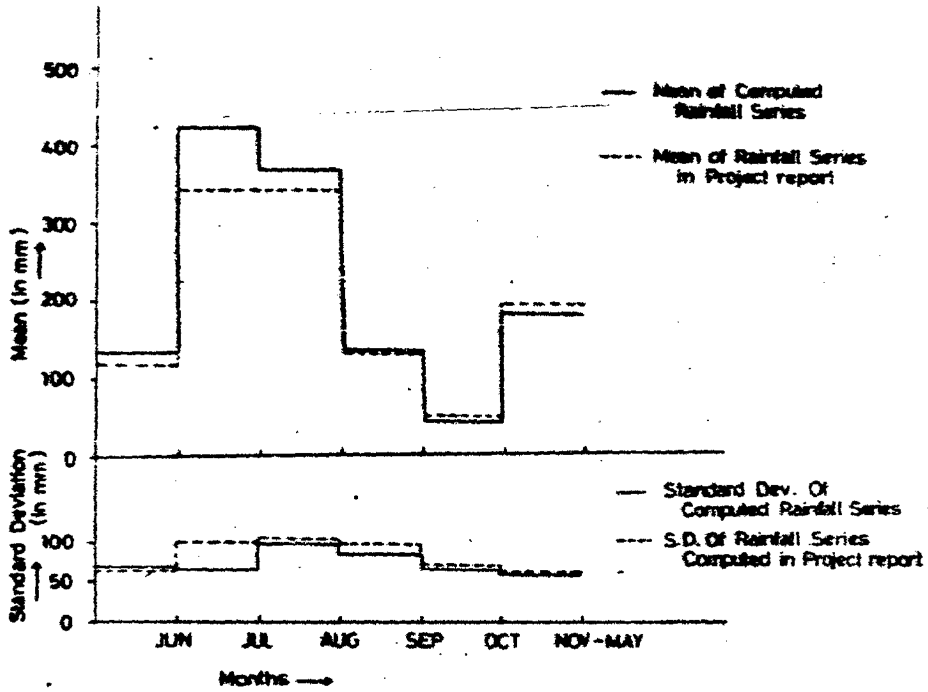
Mean of Computed Rainfall Series
Mean of Rainfall Series in Project report
Standard Dev. Of Computed Rainfall Series
S.D. Of Rainfall Series Computed in Project report
Mean (in mm)
Standard Deviation (in mm)
500
400
300
200
100
0
50
JUN
JUL
AUG
SEP
OCT
NOV-MAY
Months

FIG.4.1

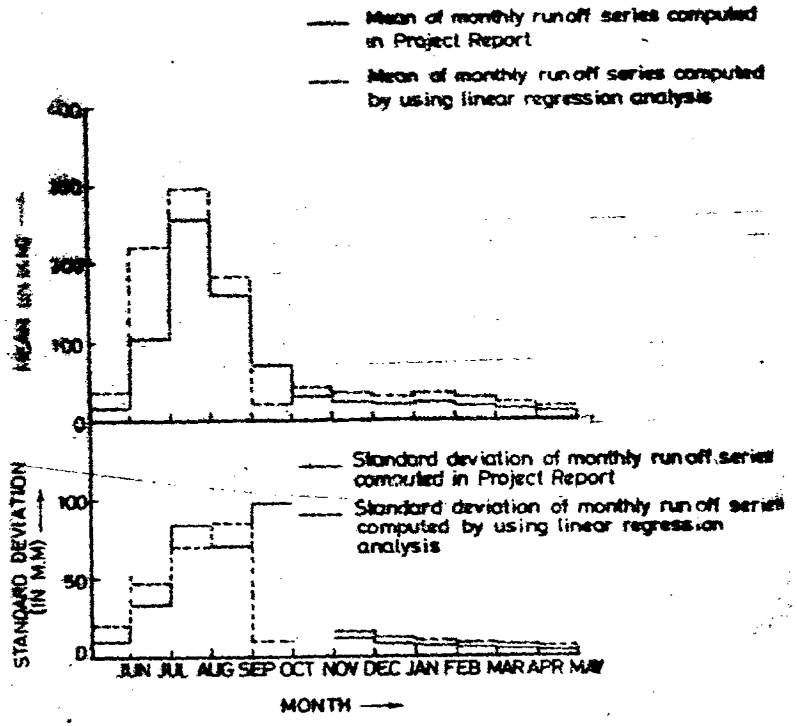
Mean of monthly run off series computed in Project Report
Mean of monthly run off series computed by using linear regression analysis
Standard deviation of monthly run off series computed in Project Report
Standard deviation of monthly run off series computed by using linear regression analysis
STANDARD DEVIATION (IN M.M)
100
50
0
JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
MONTH

FIG.4.3

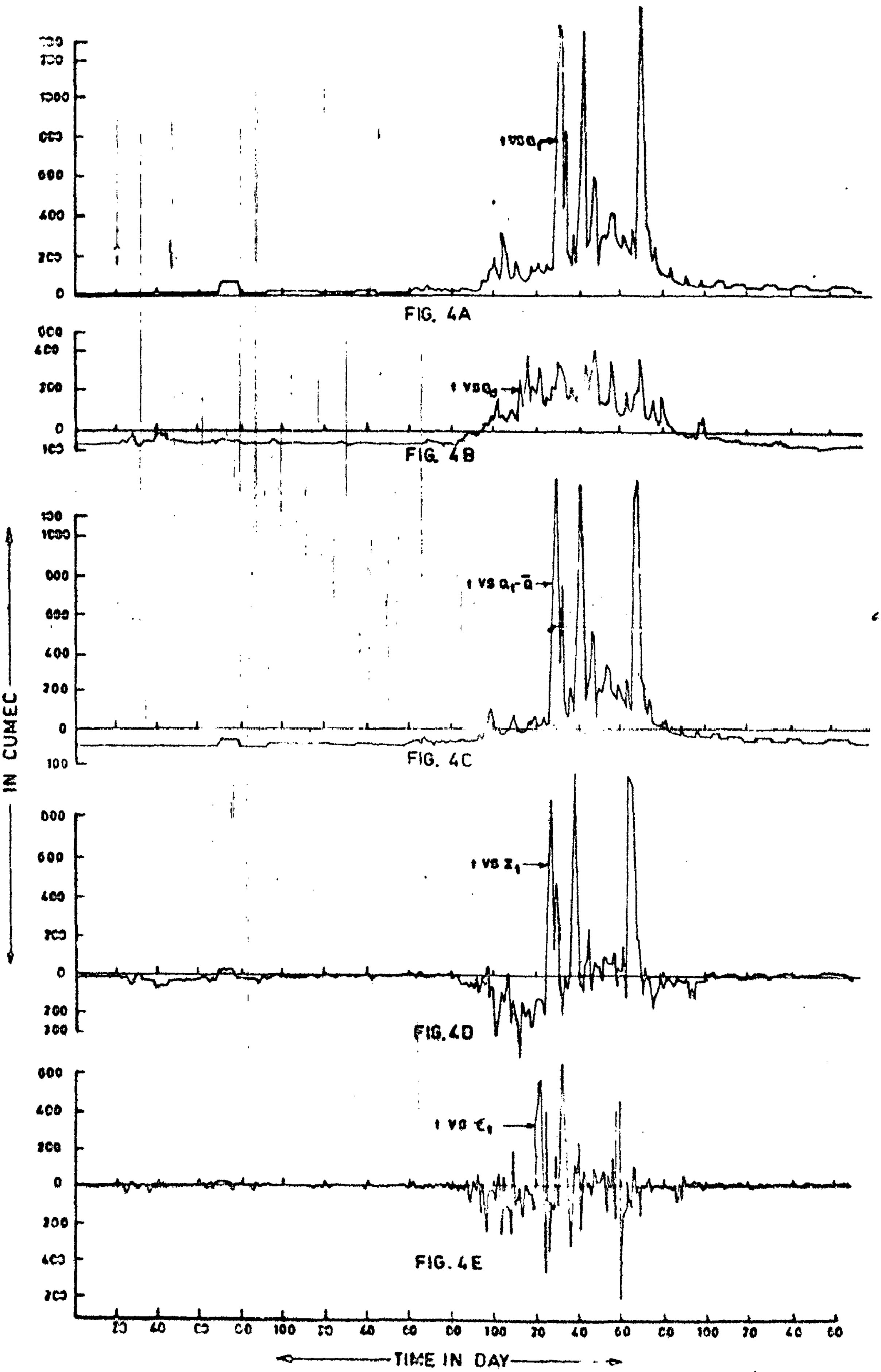


FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

FIG. 4E

TABLE-4.6.10

| Sl.No. | Class Limits | Expected Frequency E | Observed Frequency $O_t$ | $\frac{(O_i - E)^2}{E}$ |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 1 | -∞ to - 8942 | 13 | 7 | 2.769 |
| 2 | -8942 to-7241 | 13 | 2 | 9.307 |
| 3 | -7241 to-6640 | 13 | 0 | 13.00 |
| 4 | -6640 to- 5243 | 13 | 4 | 6.230 |
| 5 | -5243 to-4539 | 13 | 6 | 3.769 |
| 6 | -4539 to-3890 | 13 | 3 | 7,692 |
| 7 | -3890 to-3291 | 13 | 4 | 6,23 |
| 8 | -3291 to-2741 | 13 | 3 | 7,692 |
| 9 | -2741 to 2240 | 13 | 6 | 3,769 |
| 10 | -2240 to -1741 | 13 | 5 | 4,923 |
| 11 | -1741 to -1290 | 13 | 7 | 2,769 |
| 12 | -1290 to - 838 | 13 | 11 | 0.307 |
| 13 | -838 to - 383 | 13 | 27 | 15.076 |
| 14 | -383 to + 62 | 13 | 164 | 1753.92 |
| 15 | 62 to 507 | 13 | 68 | 232.69 |
| 16 | 507 to 962 | 13 | 15 | 0.307 |
| 17 | 962 to 1414 | 13 | 2 | 9.307 |
| 18 | 1414 to 1865 | 13 | 3 | 7.692 |
| 19 | 1865 to 2364 | 13 | 4 | 6.230 |
| 20 | 2364 to 2865 | 13 | 2 | 9.307 |
| 21 | 2865 to 3415 | 13 | 3 | 7.692 |
| 22 | 3415 to 4013 | 13 | 1 | 15.07 |
| 23 | 4013 to 4663 | 13 | 3 | 7.692 |
| 24 | 4663 to 5367 | 13 | 1 | 15.07 |
| 25 | 5367 to 6764 | 13 | 2 | 9.307 |
| 26 | 6764 to 7366 | 13 | 2 | 9.307 |
| 27 | 7366 to 9066 | 13 | 0 | 13.00 |
| 28 | 9066 to | 13 | 9 | 1.23 |
| | | = | 364 | Chi Square=2181.354 |

TABLE 4.1

THIESSEN POLYGON AREA OF EXTERNAL STATION AND INTERNAL STATION

Area in sq.km.

| Sl. No. | Name of out side Station | Area | Weightage of total basin | Sl. No. | Name of Inside station | Area | Weightage of total basin |
|---|---|---|---|---|---|---|---|
| 1. | KaranPrayak | 502.19 | 0.162 | 1. | Bungidhar | 453.88 | 0.1465 |
| 2. | Ranikhet | 1382.96 | 0.446 | 2. | Chaukhtia | 483.26 | 0.0982 |
| 3. | Ramnagar | 500.33 | 0.162 | 3. | Chitreswar | 245.65 | 0.0793 |
| 4. | Lansdown | 438.65 | 0.142 | 4. | Papra | 197.40 | 0.0637 |
| 5. | Kotdwara | 273.47 | 0.088 | 5. | Sinawea | 164.38 | 0.0531 |
| | | | | 6. | Harora | 70.48 | 0.0227 |
| | | | | 7. | Koerala | 126.29 | 0.0408 |
| | | | | 8. | Naula | 245.58 | 0.0793 |
| | | | | 9. | Dungri | 372.62 | 0.1203 |
| | | | | 10. | Badiargaon | 210.09 | 0.0678 |
| | | | | 11. | Kathwadhab | 385.32 | 0.1244 |
| | | | | 12. | Khubani | 321.85 | 0.1039 |
| | Total | 3097.60 | 1.00 | | | 3097.60 | 1.00 |

TABLE 4.2

AREAS OF THIESSEN POLYGONS OF INSIDE RAIN GAUGE STATIONS WITHIN EACH OUTSIDE RAINGAUGE STATION THIESSEN POLYGON

Area in Sq. Km.

| Sl. No. | Name of out-side station | Area for outside station T.P. | Sl. No. | Inside Rain Gauge T.P. Winlni | Area of inside station T.P. included in outside station TP | Weighage |
|---|---|---|---|---|---|---|
| 1. | Karanprayag | 502.19 | 1 | Bunghidhar | 360.29 | 0.7174 |
| | | | 2 | Chaukhtia | 141.90 | 0.2826 |
| | | | | Total | 502.19 | 1.0000 |
| 2. | Ranikhet | 1382.96 | 1 | Bungidhar | 93.59 | 0.0677 |
| | | | 2 | Chaukhtia | 162.15 | 0.1172 |
| | | | 3. | Chitreswar | 245.65 | 0.1776 |
| | | | 4 | Papra | 197.39 | 0.1427 |
| | | | 5 | Sinaura | 164.38 | 0.1188 |
| | | | 6 | Horora | 41.80 | 0.0322 |
| | | | 7 | Koerala | 126.29 | 0.0913 |
| | | | 8 | Naula | 245.58 | 0.1778 |
| | | | 9 | Dungri | 88.88 | 0.0643 |
| | | | 10 | Badiyargaon | 173.38 | 0.0124 |
| | | | | Total | 1382.96 | 1.0000 |
| 3 | Ramnagar | 500.33 | 6 | Horora | 28.67 | 0.0573 |
| | | | 7 | Dungri | 283.74 | 0.5671 |
| | | | 10 | Badiyargaon | 88.88 | 0.1776 |
| | | | 11 | Rathwadhab | 99.04 | 0.1980 |
| | | | | Total | 500.33 | 1.0000 |
| 4 | Lansdown | 438.65 | 10 | Badiyargaon | 103.98 | 0.2370 |
| | | | 11 | Rathwadhab | 154.63 | 0.3525 |
| | | | 12 | Khubani | 180.04 | 0.4105 |
| | | | | Total | 438.65 | 1.0000 |
| 5 | Kotdwara | 273.47 | 11 | Rathwadhab | 131.67 | 0.4815 |
| | | | 12 | Khubani | 141.80 | 0.5185 |
| | | | | Total | 273.47 | 1.0000 |

TABLE 4.3

DATA USED FOR CORRELATION BETWEEN MONTHLY RAINFALL OUTSIDE RAINGAUGE STATION (X mm) AND AVERAGE RAINFALL OVER ITS THIESSEN POLYGON OBTAINED FROM INSIDE RAINGAUGE STATIONS (Y mm)

OUTSIDE STATION KARANPRAYAG

| YEAR | JUNE | | JULY | | AUGUST | |
|---|---|---|---|---|---|---|
| | X mm | Y mm | X mm | Ymm | X mm | Y mm |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1960 | 168.33 | 64.44 | 305.14 | 190.60 | 340.57 | 171.64 |
| 1962 | 136.70 | 122.16 | 494.10 | 341.44 | 301.20 | 720.52 |
| 1963 | 160.14 | 110.00 | 0.0 | 220.56 | 512.90 | 539.24 |
| 1964 | 189.50 | 74.00 | 221.20 | 485.32 | 318.20 | 229.18 |
| 1965 | 101.90 | 154.52 | 303.60 | 284.52 | 208.80 | 229.68 |
| 1966 | 252.90 | 208.41 | 313.40 | 229.24 | 216.10 | 239.36 |
| 1967 | 114.30 | 87.84 | 233.80 | 250.12 | 511.70 | 224.88 |
| OUTSIDE STATION RANIKHET | | | | | | |
| 1960 | 107.38 | 70.63 | 393.29 | 375.27 | 375.00 | 145.13 |
| 1961 | 0.0 | 103.84 | 483,10 | 182.24 | 298.70 | 127.69 |
| 1962 | 245.90 | 117.54 | 385.10 | 330.80 | 360.70 | 234.62 |
| 1963 | 107.38 | 135.53 | 270.60 | 179.39 | 596.40 | 351.52 |
| 1964 | 136.10 | 56.84 | 380.70 | 408.47 | 184.10 | 195.45 |
| 1965 | 28.50 | 68.79 | 382.70 | 246.99 | 294.60 | 194.89 |
| 1966 | 192.40 | 126.18 | 292.20 | 214.87 | 360.70 | 220.09 |
| 1967 | 41.40 | 79.65 | 479.70 | 187.87 | 551.40 | 294.38 |
| OUTSIDE STATION RAM NAGAR | | | | | | |
| 1960 | 135.66 | 96.22 | 445.70 | 373.26 | 265.71 | 394.94 |
| 1961 | 132.30 | 59.50 | 0.0 | 575.58 | 0.0 | 310.44 |
| 1962 | 192.60 | 230.40 | 563.40 | 611.90 | 336.0 | 260.80 |

Contd.

TABLE CONTD.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1963 | 135.66 | 136.30 | 452.20 | 386.74 | 407.50 | 704.08 |
| 1964 | 91.50 | 58.62 | 469.40 | 507.06 | 89.70 | 284.94 |
| 1965 | 18.0 | 21.18 | 421.40 | 243.18 | 208.0 | 254.80 |
| 1966 | 229.0 | 427.82 | 361.20 | 452.24 | 402.40 | 470.66 |
| 1967 | 150.80 | 147.70 | 854.60 | 506,38 | 417,30 | 577.64 |
| | | | OUTSIDE STATION LANSDOWN | | | |
| 1960 | 147.33 | 76.25 | 632.57 | 342.05 | 625.51 | 581,35 |
| 1961 | 74.30 | 150.20 | 987.20 | 486.75 | 681.50 | 421.05 |
| 1962 | 147.00 | 225.40 | 866.90 | 718.35 | 603.50 | 314.60 |
| 1963 | 147.33 | 195.10 | 547.70 | 516.45 | 641.60 | 559.45 |
| 1964 | 112.60 | 144.10 | 554.70 | 508.65 | 560.60 | 357.00 |
| 1965 | 55.30 | 24.35 | 417.60 | 334.15 | 432.50 | 433.45 |
| 1966 | 359.90 | 485.55 | 407.50 | 784.25 | 983.50 | 634 50 |
| 1967 | 135.80 | 149.25 | 647.90 | 719.50 | 892.20 | 672.65 |
| | | | OUTSIDE STATION KOTDWARA | | | |
| 1960 | 52.79 | 65.56 | 242.55 | 420.36 | 463.70 | 379.28 |
| 1961 | 125.90 | 251.81 | 278.28 | 540.14 | 390.30 | 690.58 |
| 1962 | 149.50 | 280.12 | 536.50 | 409.60 | 230.70 | 200.38 |
| 1963 | 153.40 | 241.38 | 434.50 | 231.65 | 438.10 | 631.24 |
| 1964 | 151.60 | 232.44 | 377.20 | 682.52 | 269.85 | 269.86 |
| 1965 | 19.05 | 6.85 | 265.00 | 674.61 | 344.85 | 430.86 |
| 1966 | 379.35 | 552.79 | 721.05 | 259.90 | 502.70 | 337.12 |
| 1967 | 111.05 | 395.28 | 338.40 | 451.20 | 519.25 | 418.82 |

TABLE 4.5

Y = Monthly rainfall of external station in mm

X = Average monthly rainfall over their respective Thiessen Polygon

| Month | Relation with Karan-Prayag | Correlation co-efficient | Relation with Ranikhet | Correlation co-efficient | Relation with Lansdown | Correlation co-efficient |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| June | 71.08 + 0.26 X | 0.27 | Y=80.05+0.13X | 0.39 | -21.67+0.14X | 0.92 |
| July | 298.30-0.09 X | -0.16 | Y=156.99+0.27X | 0.25 | 509.17+0.66X | 0.78 |
| August | 183.66+0.36X | 0.20 | Y=61.57+0.42X | 0.78 | 137.16+0.532 | 0.71 |
| Sept. | 40.91 +0.42X | 0.47 | Y=8.85+0.63X | 0.83 | 121.14+0.42X | 0.77 |
| Oct. | 10.67+0.85 X | 0.68 | Y=4.15+0.98X | 0.78 | 10.67+0.32X | 0.82 |
| Nov.-May | 110.50+0.45X | 0.32 | Y= 73.23 +0.4X | 0.42 | 102.71+0.23X | 0.62 |

| | Relation with Ramnagar | Correlation coefficient | Relation with Kotdwara | Correlation co-efficient |
|---|---|---|---|---|
| 1 | 8 | 9 | 10 | 11 |
| | Y=81.8 +1.77 X | 0.89 | 4.014 +0.55X | 0.87 |
| | Y=274.18+0,32X | 0.44 | 667.45-0.58X | -0.60 |
| | Y=110.45+1.02X | 0.72 | 287.91+0.25X | 0.40 |
| | Y=41.46+0.86X | 0.88 | 72.97 +0.54X | 0.92 |
| | Y=3.68 +0.2 X | 0.64 | 7.44 +0.38 X | 0.49 |
| | Y= 130.16-0.02X | -0.04 | 88.83 +0.19X | 0.37 |

TABLE 4.6

DATA USED FOR GENERATING RELATION BETWEEN OUTSIDE MEAN(RAINFALL)AND INSIDE MEAN (RAINFALL)

| YEAR | JUNE | | JULY | | AUG. | | SEPT. | |
|---|---|---|---|---|---|---|---|---|
| | Outside mean in mm | Inside mean in mm | Outside mean in mm | Inside mean in mm | Outside mean in mm | Inside mean in mm | Outside mean in mm | Inside mean in mm |
| 1960 | 142.03 | 70.86 | 395.18 | 427.66 | 398.88 | 299.21 | 213.61 | 171.70 |
| 1961 | 88.28 | 112.01 | - | - | 338.53 | 232.41 | 146.50 | 115.57 |
| 1962 | 207.69 | 157.22 | 502.52 | 481.03 | 367.55 | 329.69 | 325.37 | 217.42 |
| 1963 | 143.12 | 144.52 | 289.87 | 299.37 | 560.76 | 497.58 | 308.31 | 324.10 |
| 1964 | 142.13 | 84.83 | 460.12 | 445.51 | 251.02 | 255.52 | 362.70 | 211.58 |
| 1965 | 41.16 | 73.91 | 380.25 | 298.17 | 286.82 | 268.47 | 55.18 | 71.12 |
| 1966 | 260.61 | 273.30 | 308.10 | 391.61 | 427.62 | 356.36 | 119.74 | 77.21 |
| 1967 | 112.33 | 114.80 | 526.13 | 421.65 | 559.62 | 409.19 | 177.48 | 137.40 |

| YEAR | OCT. | | NOV.-MAY | |
|---|---|---|---|---|
| | Outside mean in mm | Inside mean in mm | Outside mean in mm | Inside mean in mm |
| 1960 | 22.05 | 43.18 | 166.59 | 162.05 |
| 1961 | 75.33 | 54.61 | 194.16 | 145.79 |
| 1962 | 0.67 | 0.0 | 213.06 | 177.80 |
| 1963 | 0.0 | 0.0 | 214.83 | 165.01 |
| 1964 | 1.6 | 0.0 | 329.13 | 271.80 |
| 1965 | 38.66 | 22.86 | 167.59 | 106.33 |
| 1966 | 27.62 | 25.4 | 108.13 | 66.87 |
| 1967 | 10.53 | 4.82 | 348.54 | 203.88 |

TABLE CONTD.

| YEAR | SEPT. X mm | SEPT. Ymm | OCT. X mm | OCT. Y mm | NOV.-MAY X mm | NOV.-MAY Y mm |
|---|---|---|---|---|---|---|
| 1 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1960 | 212.57 | 122.44 | 40.40 | 59.06 | 164.0 | 174.24 |
| 1962 | 297.40 | 102.44 | 0.9 | 1.44 | 182.85 | 152.84 |
| 1963 | 318.30 | 319.24 | 0.0 | 0.0 | 156.60 | 211.80 |
| 1964 | 262.30 | 131.44 | 0.0 | 0.0 | 177.30 | 260.30 |
| 1965 | 47.80 | 110.32 | 44.40 | 35.76 | 228.10 | 330.72 |
| 1966 | 110.00 | 28.56 | 9.0 | 20.22 | 103.60 | 158.08 |
| 1967 | 178.20 | 157.84 | 0.0 | 0.90 | 167.0 | 82.67 |
| 1960 | 194.60 | 114.48 | 27.99 | 66.42 | 138.30 | 140.98 |
| 1961 | 100.80 | 62.42 | 112.90 | 69.14 | 362.70 | 143.28 |
| 1962 | 310.60 | 219.48 | 1.50 | 0.0 | 220.60 | 163.10 |
| 1963 | 253.40 | 262.27 | 0.0 | 0.0 | 251.30 | 211.85 |
| 1964 | 358.90 | 184.84 | 0.0 | 0.0 | 188.60 | 161.69 |
| 1965 | 51.80 | 60.30 | 36.60 | 19.64 | 274.00 | 304.81 |
| 1966 | 126.00 | 52.73 | 27.10 | 16.19 | 172.60 | 82.14 |
| 1967 | 160.70 | 94.76 | 17.80 | 1.26 | 170.20 | 104.36 |
| 1960 | 184.86 | 231.22 | 17.29 | 12.89 | 161.71 | 190.06 |
| 1961 | 0.0 | 131.17 | 0.0 | 17.64 | 285.20 | 102.92 |
| 1962 | 211.10 | 275.14 | 0.0 | 0.0 | 83.10 | 158.96 |

Contd.

TABLE CONTD.

| 1 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| 1963 | 360.20 | 443.45 | 0.0 | 0.18 | 88.56 | 118.56 |
| 1964 | 394.0 | 318.52 | 10.0 | 1.12 | 177.30 | 127.23 |
| 1965 | 38.0 | 54.42 | 65.0 | 10.66 | 228.10 | 110.42 |
| 1966 | 40.80 | 82.22 | 39.8 | 19.70 | 103.60 | 79.40 |
| 1967 | 249.80 | 163.10 | 6.0 | 9.0 | 167.0 | 97.64 |
| 1960 | 275.18 | 260.45 | 51.17 | 20.45 | 258.14 | 193.65 |
| 1961 | 225.80 | 213.63 | 167.20 | 63.85 | 402.60 | 171.70 |
| 1962 | 582.70 | 357.00 | 0.00 | 0.0 | 353.50 | 266.00 |
| 1963 | 316.00 | 378.85 | 0.0 | 0.0 | 122.70 | 127.00 |
| 1964 | 503.00 | 275.00 | 0.0 | 0.0 | 163.20 | 126.40 |
| 1965 | 94.80 | 119.05 | 6.30 | 35.85 | 396.50 | 171.15 |
| 1966 | 195.20 | 156.75 | 15.20 | 29.90 | 293.50 | 130.45 |
| 1967 | 183.00 | 206.80 | 5.00 | 13.50 | 76.20 | 124.20 |
| 1960 | 205.15 | 221.76 | 12.95 | 28.56 | 158.10 | 184.78 |
| 1961 | 201.30 | 285.60 | 55.80 | 22.80 | 129.15 | 326.25 |
| 1962 | 273.95 | 250.88 | 0.0 | 0.0 | 210.20 | 253.93 |
| 1963 | 333.05 | 474.88 | 0.0 | 0.0 | 75.87 | 226.75 |
| 1964 | 197.15 | 295.68 | 0.0 | 0.0 | 99.45 | 198.58 |
| 1965 | 98.25 | 53.76 | 27.05 | 42.28 | 140.95 | 210.30 |
| 1966 | 129.65 | 131.04 | 21.50 | 68.85 | 110.95 | 89.60 |
| 1967 | 139.95 | 120.96 | 9.0 | 10.87 | 91.50 | 73.45 |

TABLE 4.7

COMPUTED AVERAGE BASIN RAINFALL SERIES

| YEAR | JUNE mm | JULY mm | AUG. mm | SEPT. mm | OCT. mm | NOV.-MAY mm |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1901-2 | 37.24 | 370.00 | 544.66 | 119.69 | 15.60 | 97.60 |
| 2-3 | 117.54 | 396.15 | 307.30 | 148.02 | 15.05 | 94.62 |
| 3-4 | 93.57 | 309.13 | 383.94 | 164.78 | 34.15 | 137.81 |
| 4-5 | 117.95 | 439.32 | 333.79 | 160.82 | 5.41 | 286.20 |
| 5-6 | 72.84 | 343.99 | 275.30 | 94.54 | - | 149.73 |
| 6-7 | 170.38 | 339.84 | 453.27 | 184.90 | 6.52 | 361.04 |
| 7-8 | 52.52 | 355.93 | 327.00 | 31.51 | - | 149.54 |
| 8-9 | 82.19 | 428.06 | 419.85 | 63.02 | 3.18 | 154.73 |
| 9-10 | 268.53 | 526.61 | 410.78 | 122.20 | 27.48 | 148.43 |
| 10-11 | 188.06 | 463.19 | 530.08 | 210.92 | 268.34 | 237.98 |
| 11-12 | 130.75 | 213.40 | 291.47 | 219.77 | 10.41 | 213.03 |
| 12-13 | 94.58 | 370.81 | 399.40 | 233.51 | - | 224.57 |
| 13-14 | 187.86 | 360.48 | 147.81 | 55.31 | 11.90 | 261.62 |
| 14-15 | 93.77 | 501.54 | 301.78 | 355.73 | 16.72 | 255.85 |
| 15-16 | 138.68 | 374.83 | 438.16 | 133.27 | 11.90 | 82.52 |
| 16-17 | 267.10 | 369.33 | 337.34 | 191.44 | 54.36 | 279.37 |
| 17-18 | 202.69 | 525.67 | 299.47 | 282.63 | 106.28 | 148.43 |
| 18-19 | 171.39 | 266.90 | 271.21 | 153.05 | 6.71 | 255.48 |
| 19-20 | 195.58 | 389.58 | 272.99 | 227.31 | 11.90 | 151.41 |
| 20-21 | 195.58 | 417.87 | 232.80 | 70.24 | 9.49 | 93.88 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1921-22 | 356.10 | 365.71 | 510.53 | 458.15 | 48.80 | 68.93 |
| 22-23 | 105.15 | 440.26 | 544.66 | 234.52 | 5.78 | 178.22 |
| 23-24 | 37.49 | 361.29 | 283.65 | 163.10 | 23.58 | 188.08 |
| 24-25 | 36.26 | 455.55 | 347.48 | 457.48 | 101.27 | 134.68 |
| 25-26 | 221.32 | 469.89 | 311.92 | 66.88 | 7.82 | 210.98 |
| 26-27 | 34.64 | 387.57 | 345.00 | 140.31 | 6.52 | 175.24 |
| 27-28 | 148.43 | 329.11 | 510.53 | 108.79 | 115.97 | 220.29 |
| 28-29 | 61.87 | 437.71 | 225.69 | 32.52 | 3.00 | 104.86 |
| 29-30 | 112.87 | 307.79 | 78.25 | 50.79 | 35.07 | 255.29 |
| 30-31 | 132.78 | 433.02 | 272.27 | 85.99 | 12.82 | 152.34 |
| 31-32 | 52.32 | 384.75 | 370.06 | 116.65 | 71.79 | 76.00 |
| 32-33 | 86.05 | 371.75 | 421.98 | 261.85 | 10.63 | 245.80 |
| 33-34 | 243.74 | 472.04 | 311.75 | 140.64 | 85.88 | 127.76 |
| 34-35 | 195.58 | 407.01 | 391.57 | 83.31 | - | 172.44 |
| 35-36 | 39.52 | 357.13 | 229.24 | 158.41 | 3.74 | 173.19 |
| 36-37 | 319.12 | 508.11 | 326.68 | 196.63 | 14.31 | 266.28 |
| 37-38 | 137.26 | 409.29 | 372.73 | 2[illegible]4.52 | 9 .12 | 225.32 |
| 38-39 | 278.28 | 489.74 | 340.01 | 84.15 | 16.53 | 113.43 |
| 39-40 | 200.45 | 388.37 | 195.10 | 166.63 | 49.13 | 218.06 |
| 40-41 | 135.63 | 435.97 | 316.90 | 84.84 | 3.00 | 179.52 |
| 41-42 | 197.60 | 273.60 | 359.75 | 101.59 | 23.02 | 230.34 |
| 42-43 | 204.31 | 494.43 | 449.01 | 148.02 | - | 169.84 |
| 43-44 | 74.06 | 317.31 | 583.78 | 165.12 | - | 213.40 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1944-45 | 172.99 | 404.19 | 191.87 | 130.59 | 8.93 | 161.09 |
| 45-46 | 78.94 | 446.30 | 328.82 | 288.17 | 56.59 | 199.81 |
| 46-47 | 193.74 | 542.70 | 350.59 | 96.01 | 53.24 | 150.29 |
| 47-48 | 126.28 | 398.30 | 301.61 | 357.90 | 11.16 | 167.60 |
| 48-49 | 53.94 | 354.18 | 556.75 | 195.97 | 38.23 | 191.81 |
| 49-50 | 84.02 | 489.20 | 366.69 | 159.92 | 13.38 | 181.57 |
| 50-51 | 228.29 | 493.22 | 475.50 | 150.53 | 4.11 | 171.51 |
| 51-52 | 64.51 | 308.32 | 340.37 | 209.54 | 13.94 | 224.57 |
| 52-53 | 257.55 | 371.85 | 355.66 | 65.54 | 11.71 | 142.04 |
| 53-54 | 175.46 | 543.90 | 241.87 | 119.02 | - | 248.84 |
| 54-55 | 71.82 | 443.61 | 431.23 | 169.14 | 165.97 | 158.55 |
| 55-56 | 107.59 | 356.37 | 378.06 | 208.54 | 273.71 | 168.00 |
| 56-57 | 165.30 | 392.95 | 357.07 | 122.53 | 302.64 | 222.70 |
| 57-58 | 151.68 | 401.47 | 204.18 | 255.98 | 25.80 | 155.94 |
| 58-59 | 83-42 | 491.40 | 451.85 | 202.84 | 69.75 | 207.86 |
| 59-60 | 87.27 | 445.99 | 366.87 | 195.13 | 77.91 | 184.68 |
| 60-61 | 99.66 | 539.19 | 406.87 | 162.27 | 64.56 | 184.68 |

TABLE 4.9

DATA USED FOR CORRELATION BETWEEN MONTHLY ISOHYETAL MEAN RAINFALL ( Xmm) AND MONTHLY RUNOFF (Ymm)

| YEAR | JUNE | | JULY | | AUGUST | |
|---|---|---|---|---|---|---|
| | (X)mm | (Y)mm | (X)mm | (Y)mm | (X) mm | (Y)mm |
| 1957 | 91.44 | 10.92 | 401.32 | 130.81 | 209.8 | 190.5 |
| 58 | 61.72 | 12.95 | 374.65 | 169.67 | 468.12 | 373.63 |
| 60 | 70.87 | 5.08 | 314.96 | 213.36 | 299.21 | 282.19 |
| 61 | 112.01 | 24.89 | 298.20 | 206.25 | 232.41 | 304.55 |
| 62 | 157.23 | 28.96 | 448.31 | 247.65 | 329.69 | 201.16 |
| 63 | 144.53 | 18.80 | 260.10 | 70.10 | 497.59 | 401.83 |
| 64 | 84.84 | 18.29 | 437.13 | 208.79 | 255.52 | 225.55 |
| 65 | 73.91 | 49.28 | 294.89 | 113.54 | 268.48 | 161.04 |
| 66 | 273.30 | 81.03 | 378.71 | 314.96 | 356.36 | 318.77 |
| 67 | 114.81 | 32.51 | 362.46 | 227.33 | 409.19 | 369.06 |

| YEAR | SEPTEMBER | | OCTOBER | | NOV.- MAY | |
|---|---|---|---|---|---|---|
| | X(mm) | (Y)mm | (X)mm | (Y)mm | (X)mm | (Y)mm |
| 1957 | 264.92 | 242.57 | 17.02 | 35.31 | 163.07 | 123.19 |
| 58 | 159.00 | 176.53 | 92.71 | 150.11 | 105.16 | 60.96 |
| 60 | 171.70 | 204.98 | 43.18 | 59.18 | 162.65 | 112.27 |
| 61 | 115.57 | 192.53 | 54.61 | 90.42 | 145.8 | 173.74 |
| 62 | 217.42 | 236.73 | 37.08 | 62.48 | 177.8 | 187.45 |
| 63 | 324.10 | 333.25 | 37.08 | 48.51 | 178.05 | 146.30 |
| 64 | 211.58 | 252.98 | 37.08 | 70.36 | 162.31 | 204.72 |
| 65 | 71.12 | 78.49 | 22.86 | 48.41 | 228.35 | 220.73 |
| 66 | 77.22 | 80.77 | 25.4 | 39.88 | 99.31 | 351.28 |
| 67 | 137.41 | 111.76 | 4.83 | 38.1 | 94.49 | 166.12 |

TABLE 4.12

COMPUTED MONTHLY RUNOFF SERIES FROM JULY TO OCT.

| YEAR | July mm | August mm | September mm | October mm |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 1901-2 | 203.93 | 418.13 | 1.61 | 36.74 |
| 2-3 | 263.04 | 256.79 | 22.3 | 34.57 |
| 3-4 | 204.99 | 330.09 | 17.17 | 59.7 |
| 4-5 | 285.28 | 262.34 | 20.95 | 20.82 |
| 5-6 | 216.95 | 250.07 | 23.65 | -4.73 |
| 6-7 | 264.44 | 366.86 | 12.83 | 21.12 |
| 7-8 | 205.46 | 280.45 | 13.73 | -1.58 |
| 8-9 | 259.16 | 321.32 | 8.19 | 22.66 |
| 9-10 | 415.63 | 288.83 | 12.47 | 52.76 |
| 10-11 | 337.42 | 383.49 | 8.25 | 375.99 |
| 11-12 | 177.36 | 295.84 | 27.87 | 24.67 |
| 12-13 | 237.02 | 323.49 | 20.06 | -11.68 |
| 13-14 | 284.92 | 162.75 | 29.49 | 34.91 |
| 14-15 | 303.36 | 224.74 | 35.2 | 24.45 |
| 15-16 | 264.21 | 347.6 | 10.95 | 31.02 |
| 16-17 | 334.61 | 283.55 | 22.5 | 85.85 |
| 17-18 | 377.62 | 216.73 | 31.0 | 151.91 |
| 18-19 | 227.81 | 268.23 | 25.48 | 22.98 |
| 19-20 | 304.17 | 236.25 | 29.8 | 26.31 |
| 20-21 | 318.59 | 202.5 | 23.59 | 30.9 |
| 21-22 | 383.49 | 397.1 | 24.65 | 64.96 |
| 22-23 | 278.47 | 399.16 | 8.5 | 17.63 |

Contd.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 1923 -24 | 199.63 | 252.84 | 25.1 | 45.41 |
| 24 -25 | 247.0 | 266.86 | 37.65 | 136.36 |
| 25 -26 | 357.24 | 239.88 | 17.06 | 28.8 |
| 26 -27 | 211.4 | 283.61 | 18.82 | 23.35 |
| 27 -28 | 246.46 | 406.98 | 29.69 | 173.78 |
| 28 -29 | 252.5 | 192.52 | 21.89 | 23.95 |
| 29 -30 | 215.31 | 131.76 | 34.79 | 66.66 |
| 30 -31 | 290.52 | 224.06 | 21.38 | 34.64 |
| 31-32 | 220.04 | 300.66 | 15.9 | 113.3 |
| 32-33 | 232.64 | 337.92 | 19.95 | 22.87 |
| 33 -34 | 373.67 | 194.98 | 21.5 | 131.27 |
| 34 -35 | 313.06 | 181.24 | 11.67 | -4.17 |
| 35 -36 | 198.67 | 93.26 | 29.16 | 18.67 |
| 36 -37 | 441.04 | 234.24 | 23.67 | 31.13 |
| 37 -38 | 280.98 | 142.71 | 22.25 | 22.17 |
| 38 -39 | 402.39 | 213.65 | 15.85 | 39.77 |
| 39 -40 | 306.33 | 189.43 | 32.39 | 39.19 |
| 40 -41 | 293.65 | 134.45 | 17.74 | 21.34 |
| 41 -42 | 246.17 | 218.57 | 15.32 | 47.73 |
| 42 -43 | 363.62 | 163.3 | 2.08 | -7.40 |
| 43 -44 | 198.04 | 126.47 | 1.2 | -8.26 |
| 44 -45 | 298.74 | 167.31 | 30.49 | 27.11 |
| 45 -46 | 266.6 | 94.81 | 28.98 | 84.06 |
| 46 -47 | 381.21 | 143.4 | 15.71 | 89.11 |

Contd.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 1947-48 | 269.11 | 252.51 | 35.34 | 18.79 |
| 48-49 | 205.38 | 430.26 | 5.22 | 63.69 |
| 49-50 | 291.38 | 270.27 | 18.26 | 31.7 |
| 50-51 | 375.67 | 239.91 | 8.99 | 19.56 |
| 51-52 | 188.01 | 301.99 | 23.48 | 29.98 |
| 52-53 | 330.44 | 294.78 | 13.78 | 34.15 |
| 53-54 | 371.4 | 179.37 | 25.79 | -5.95 |
| 54-55 | 261.18 | 324.53 | 13.65 | 238.76 |
| 55-56 | 237.08 | 313.52 | 20.27 | 382.35 |
| 56-57 | 290.15 | 289.19 | 16.78 | 426.96 |
| 57-58 | 285.21 | 188.32 | 37.03 | 43.79 |
| 58-59 | 292.16 | 325.02 | 14.02 | 106.22 |
| 59-60 | 271.19 | 282.05 | 20.36 | 117.7 |
| 60-61 | 325.8 | 282.89 | 15.19 | 101.19 |

TABLE 4.13A

COMPUTED MONTHLY RUN-OFF SERIES

| YEAR | JUNE mm | JULY mm | AUG. mm | SEPT. mm | OCT. mm | NOV.-MAY mm |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1901-2 | 5.67 | 195.27 | 428.70 | 170.71 | 15.62 | 73.24 |
| 2-3 | 27.35 | 210.44 | 264.92 | 173.32 | 15.85 | 69.76 |
| 3-4 | 20.88 | 159.97 | 317.80 | 174.76 | 18.22 | 120.29 |
| 4-5 | 27.46 | 235.48 | 283.20 | 174.40 | 14.19 | 293.91 |
| 5-6 | 15.28 | 180.18 | 242.84 | 168.58 | 13.44 | 134.24 |
| 6-7 | 41.62 | 177.78 | 365.64 | 176.56 | 14.35 | 381.47 |
| 7-8 | 9.80 | 187.11 | 278.52 | 164.95 | 13.44 | 134.01 |
| 8-9 | 17.81 | 228.95 | 342.58 | 165.67 | 13.88 | 140.12 |
| 9-10 | 68.12 | 285.87 | 336.33 | 170.99 | 17.28 | 132.72 |
| 10-11 | 46.39 | 249.32 | 418.64 | 160.90 | 51.00 | 237.49 |
| 11-12 | 30.72 | 104.44 | 254.00 | 179.71 | 14.89 | 208.30 |
| 12-13 | 21.15 | 195.38 | 328.47 | 180.97 | 13.44 | 221.80 |
| 13-14 | 46.34 | 189.75 | 154.87 | 164.95 | 15.10 | 265.15 |
| 14-15 | 20.93 | 271.56 | 261.12 | 191.55 | 15.75 | 258.40 |
| 15-16 | 33.06 | 198.07 | 355.22 | 171.97 | 15.10 | 55.60 |
| 16-17 | 67.73 | 194.88 | 285.58 | 177.19 | 21.05 | 285.91 |
| 17-18 | 50.34 | 285.56 | 259.52 | 185.38 | 28.31 | 132.72 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1918-19 | 41.89 | 135.47 | 240.02 | 171.32 | 14.38 | 257.96 |
| 19-20 | 48.42 | 206.63 | 241.25 | 180.43 | 15.10 | 136.20 |
| 20-21 | 48.42 | 223.04 | 213.52 | 166.32 | 17.76 | 68.89 |
| 21-22 | 91.76 | 192.78 | 405.15 | 201.22 | 20.27 | 39.70 |
| 22-23 | 24.01 | 236.02 | 428.70 | 181.06 | 14.25 | 167.57 |
| 23-24 | 5.74 | 190.22 | 248.60 | 171.82 | 16.74 | 179.11 |
| 24-25 | 5.41 | 244.89 | 292.87 | 201.13 | 27.61 | 122.48 |
| 25-26 | 55.37 | 253.21 | 268.11 | 166.02 | 14.53 | 205.90 |
| 26-27 | 4.97 | 205.46 | 290.94 | 169.79 | 14.35 | 164.08 |
| 27-28 | 35.69 | 171.55 | 405.15 | 16[illegible].72 | 29.67 | 216.79 |
| 28-29 | 12.32 | 234.54 | 208.61 | 162.88 | 13.86 | 81.74 |
| 29-30 | 26.09 | 159.19 | 106.88 | 164.50 | 18.35 | 257.74 |
| 30-31 | 31.47 | 231.82 | 240.75 | 167.70 | 15.23 | 137.29 |
| 31-32 | 9.74 | 203.83 | 308.23 | 170.44 | 23.49 | 47.97 |
| 32-33 | 18.85 | 196.29 | 344.05 | 183.49 | 14.92 | 246.64 |
| 33-34 | 61.43 | 254.45 | 267.99 | 172.60 | 25.46 | 108.53 |
| 34-35 | 48.42 | 216.74 | 323.07 | 167.47 | 13.44 | 160.81 |
| 35-36 | 6.29 | 187.81 | 211.06 | 168.81 | 13.96 | 161.68 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1936-37 | 81.78 | 275.37 | 278.29 | 177.69 | 15.44 | 270.60 |
| 37-38 | 32.68 | 389.96 | 310.07 | 181.06 | 14.71 | 222.68 |
| 38-39 | 70.75 | 264.72 | 287.49 | 167.56 | 15.75 | 91.77 |
| 39-40 | 49.74 | 205.93 | 187.51 | 174.94 | 16.12 | 214.18 |
| 40-41 | 32.24 | 252.86 | 271.55 | 167.56 | 13.86 | 169.09 |
| 41-42 | 48.97 | 139.36 | 301.11 | 169.09 | 16.66 | 228.55 |
| 42-43 | 50.78 | 267.44 | 362.70 | 173.32 | 13.44 | 157.76 |
| 43-44 | 15.61 | 164.71 | 455.69 | 174.85 | 13.44 | 208.73 |
| 44-45 | 42.32 | 215.10 | 185.28 | 171.70 | 14.69 | 147.53 |
| 45-46 | 17.20 | 239.53 | 279.77 | 185.92 | 21.36 | 192.83 |
| 46-47 | 47.93 | 295.44 | 294.79 | 168.68 | 20.89 | 134.83 |
| 47-48 | 29.27 | 211.69 | 261.00 | 192.13 | 15.00 | 155.14 |
| 48-49 | 10.18 | 186.10 | 437.04 | 177.55 | 18.79 | 183.47 |
| 49-50 | 18.30 | 264.41 | 305.90 | 174.31 | 15.31 | 171.49 |
| 50-51 | 57.25 | 266.74 | 380.98 | 173.50 | 14.01 | 159.72 |
| 51-52 | 13.03 | 159.50 | 287.74 | 178.81 | 15.39 | 221.80 |
| 52-53 | 65.15 | 196.35 | 298.29 | 165.85 | 15.04 | 125.24 |
| 53-54 | 42.99 | 296.13 | 219.78 | 170.71 | 13.44 | 250.19 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1954-55 | 15.01 | 237.96 | 350.43 | 175.20 | 36.67 | 144.55 |
| 55-56 | 24.67 | 187.37 | 313.75 | 178.72 | 51.75 | 155.61 |
| 56-57 | 40.25 | 210.32 | 299.26 | 170.98 | 55.81 | 219.61 |
| 57-58 | 36.57 | 213.52 | 193.77 | 182.95 | 17.05 | 141.50 |
| 58-59 | 18.14 | 265.68 | 364.66 | 178.18 | 23.20 | 202.25 |
| 59-60 | 19.18 | 239.34 | 306.03 | 177.50 | 24.34 | 175.13 |
| 60-61 | 22.52 | 293.40 | 336.63 | 177.58 | 22.47 | 175.13 |

TABLE 4.13B

COMPUTED MONTHLY RUN-OFF SERIES(NON MONSOON PERIOD)

| YEAR | NOV. mm | DEC. mm | JAN. mm | FEB. mm | MAR. mm | APR. mm | MAY mm |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1901-2 | 17.57 | 13.18 | 11.72 | 12.45 | 8.05 | 5.85 | 4.39 |
| 2-3 | 16.74 | 12.55 | 11.16 | 11.86 | 7.67 | 5.58 | 4.18 |
| 3-4 | 28.86 | 21.60 | 19.20 | 20.40 | 13.20 | 9.60 | 7.20 |
| 4-5 | 70.53 | 52.92 | 47.04 | 49.98 | 32.33 | 23.44 | 17.64 |
| 5-6 | 32.22 | 24.12 | 21.44 | 22.78 | 14.76 | 10.72 | 8.04 |
| 6-7 | 91.55 | 68.58 | 60.96 | 64.77 | 41.91 | 30.48 | 22.86 |
| 7-8 | 32.16 | 24.12 | 21.44 | 22.77 | 14.74 | 10.72 | 8.01 |
| 8-9 | 33.60 | 25.20 | 22.40 | 23.80 | 15.40 | 11.20 | 8.40 |
| 9-10 | 31.92 | 23.76 | 21.12 | 22.44 | 14.52 | 10.56 | 7.92 |
| 10-11 | 56.88 | 42.66 | 37.92 | 40.29 | 26.07 | 18.96 | 14.22 |
| 11-12 | 49.92 | 37.44 | 33.28 | 35.36 | 22.88 | 16.64 | 12.48 |
| 12-13 | 53.04 | 39.96 | 35.52 | 37.74 | 24.42 | 17.76 | 13.32 |
| 13-14 | 63.60 | 47.70 | 42.40 | 45.05 | 29.15 | 21.20 | 15.90 |
| 14-15 | 61.92 | 46.44 | 41.28 | 43.86 | 28.38 | 20.64 | 15.48 |
| 15-16 | 13.20 | 9.90 | 8.89 | 9.35 | 6.05 | 4.40 | 3.30 |
| 16-17 | 68.40 | 51.48 | 45.74 | 48.45 | 31.45 | 22.87 | 17.16 |
| 17-18 | 31.68 | 23.94 | 21.12 | 22.44 | 14.52 | 10.56 | 7.92 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 1918-19 | 61.68 | 46.08 | 40.96 | 43.87 | 28.37 | 20.64 | 15.47 |
| 19-20 | 32.60 | 24.48 | 21.76 | 23.12 | 14.96 | 10.88 | 8.16 |
| 20-21 | 16.56 | 12.24 | 10.88 | 11.56 | 7.48 | 5.44 | 4.08 |
| 21-22 | 9.60 | 7.02 | 6.24 | 6.63 | 4.29 | 3.12 | 2.34 |
| 22-23 | 40.08 | 30.06 | 26.72 | 28.39 | 18.37 | 13.36 | 10.02 |
| 23-24 | 42.96 | 32.22 | 28.64 | 30.43 | 19.69 | 14.32 | 10.74 |
| 24-25 | 29.28 | 21.96 | 19.52 | 20.74 | 13.42 | 9.76 | 7.32 |
| 25-26 | 49.20 | 36.90 | 38.80 | 34.85 | 22.55 | 16.40 | 12.30 |
| 26-27 | 39.36 | 29.52 | 26.24 | 27.88 | 18.09 | 13.12 | 9.84 |
| 27-28 | 51.84 | 38.08 | 34.56 | 36.72 | 22.55 | 17.28 | 12.96 |
| 28-29 | 19.61 | 14.58 | 12.96 | 13.77 | 8.91 | 6.48 | 4.86 |
| 29-30 | 61.68 | 46.26 | 41.12 | 43.69 | 28.29 | 20.56 | 15.42 |
| 30-31 | 32.88 | 24.66 | 21.92 | 23.29 | 15.07 | 10.96 | 8.22 |
| 31-32 | 11.49 | 8.46 | 7.52 | 7.99 | 5.17 | 3.76 | 2.82 |
| 32-33 | 59.04 | 44.28 | 39.36 | 41.82 | 27.06 | 19.68 | 14.76 |
| 33-34 | 25.92 | 19.44 | 17.28 | 18.36 | 11.88 | 8.64 | 6.48 |
| 34-35 | 38.40 | 28.80 | 25.60 | 27.20 | 17.60 | 12.80 | 9.60 |
| 35-36 | 38.64 | 28.98 | 25.76 | 27.37 | 17.71 | 12.88 | 9.66 |
| 36-37 | 64.80 | 48.60 | 43.20 | 45.90 | 29.70 | 21.60 | 16.20 |
| 37-38 | 53.28 | 39.96 | 35.52 | 37.74 | 24.42 | 17.76 | 13.32 |
| 38-39 | 21.84 | 16.38 | 14.56 | 15.47 | 10.01 | 7.28 | 5.46 |
| 39-40 | 51.36 | 38.52 | 34.24 | 36.38 | 23.54 | 17.12 | 12.84 |
| 40-41 | 40.56 | 30.42 | 27.04 | 28.73 | 18.59 | 13.52 | 10.14 |

Contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 1941-42 | 54.72 | 41.04 | 36.48 | 38.76 | 25.08 | 18.24 | 13.68 |
| 42-43 | 37.68 | 28.26 | 25.12 | 26.69 | 17.27 | 12.56 | 9.42 |
| 43-44 | 49.92 | 37.44 | 33.28 | 35.36 | 22.88 | 16.64 | 12.48 |
| 44-45 | 35.28 | 26.46 | 23.52 | 24.99 | 16.17 | 11.76 | 8.82 |
| 45-46 | 46.08 | 34.56 | 30.72 | 32.64 | 21.12 | 15.36 | 11.52 |
| 46-47 | 32.16 | 24.12 | 21.44 | 22.78 | 14.74 | 10.72 | 8.04 |
| 47-48 | 37.20 | 27.90 | 24.80 | 26.35 | 17.05 | 12.40 | 9.30 |
| 48-49 | 43.92 | 32.94 | 29.28 | 31.11 | 20.13 | 14.64 | 10.98 |
| 49-50 | 41.09 | 30.78 | 27.36 | 29.07 | 18.81 | 13.68 | 10.26 |
| 50-51 | 38.16 | 28.62 | 25.44 | 27.03 | 17.49 | 12.72 | 9.54 |
| 51-52 | 53.04 | 39.96 | 35.36 | 37.57 | 24.31 | 17.68 | 13.26 |
| 52-53 | 30.00 | 22.50 | 20.00 | 21.25 | 13.75 | 10.01 | 7.50 |
| 53-54 | 60.04 | 45.03 | 40.03 | 42.50 | 27.50 | 20.02 | 15.03 |
| 54-55 | 35.56 | 25.92 | 23.04 | 24.48 | 15.84 | 11.52 | 8.64 |
| 55-56 | 37.24 | 27.90 | 24.80 | 26.35 | 17.05 | 12.40 | 9.30 |
| 56-57 | 52.56 | 39.42 | 35.04 | 37.23 | 24.09 | 17.52 | 12.54 |
| 57-58 | 33.84 | 25.38 | 22.56 | 23.97 | 15.51 | 11.28 | 8.46 |
| 58-59 | 48.48 | 36.36 | 32.32 | 34.34 | 22.22 | 16.16 | 12.12 |
| 59-60 | 42.00 | 31.52 | 28.02 | 29.75 | 19.25 | 14.00 | 10.50 |
| 60-61 | 42.00 | 31.52 | 28.02 | 29.75 | 19.25 | 14.00 | 10.50 |

TABLE - 4.14 : FOR RUNOFF SERIES COMPUTED USING LINEAR REGRESSION

| Month | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (mm) | 33.82 | 220.54 | 296.54 | 183.66 | 19.14 | 41.69 | 31.26 | 27.79 | 29.53 | 19.11 | 33.89 | 10.42 |
| Standard Deviation (mm) | 20.28 | 47.56 | 70.70 | 84.12 | 9.05 | 16.02 | 12.02 | 10.68 | 11.35 | 7.34 | 5.34 | 4.00 |
| Co-efficient of variation | 0.599 | 0.215 | 0.238 | 0.458 | 0.472 | 0.384 | 0.384 | 0.384 | 0.38 | 0.384 | 0.384 | 0.384 |

TABLE - 4.15 : FOR RUNOFF SERIES COMPUTED USING MULTIPLE LINEAR REGRESSION

| | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (mm) | | 282.96 | 258.41 | 20.13 | 65.52 | | | | | | | |
| Standard Deviation(mm) | | 62.88 | 81.78 | 8.83 | 89.25 | | | | | | | |
| Co-efficient of variation | | 0.22 | 0.316 | 0.438 | 0.136 | | | | | | | |

TABLE - 4.16 : FROM RUNOFF SERIES COMPUTED IN PROJECT REPORT

| | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (mm) | 14.92 | 103.38 | 267.23 | 159.18 | 69.59 | 31.38 | 23.53 | 20.92 | 22.23 | 14.38 | 10.46 | 7.84 |
| Standard deviation(mm) | 8.89 | 31.75 | 84.22 | 70.86 | 96.80 | 10.39 | 7.79 | 6.92 | 7.36 | 4.76 | 3.46 | 2.59 |
| Co-efficient of variation | 0.595 | 0.307 | 0.315 | 0.445 | 1.39 | 0.331 | 0.331 | 0.331 | 0.331 | 0.331 | 0.331 | 0.331 |

TABLE - 4.17

FLOW DURATION ANALYSIS OF ANNUAL SERIES AS PER RUNOFF SERIES COMPUTED IN PROJECT REPORT

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1 | 1100 - 1400 | 3 | 5 | 5 | 95.00 |
| 2 | 1400 - 1700 | 7 | 11.66 | 16.66 | 83.34 |
| 3 | 1700 - 2000 | 10 | 16.66 | 33.33 | 66.64 |
| 4 | 2000 - 2300 | 8 | 13.33 | 46.66 | 53.34 |
| 5 | 2300 - 2600 | 11 | 18.33 | 64.99 | 35.01 |
| 6 | 2600 - 2900 | 12 | 20.00 | 84.99 | 15.01 |
| 7 | 2900 - 3200 | 5 | 8.33 | 93.32 | 6.68 |
| 8 | 3200 - 3500 | 2 | 3.33 | 96.66 | 3.34 |
| 9 | 3500 - 3800 | 1 | 1.67 | 98.33 | 1.67 |
| 10 | 3800 - 4100 | 0 | 0 | 98.33 | 1.67 |
| 11 | 4100 - 4400 | 1 | 1.67 | 100.0 | 0 |

TABLE - 4.18

FLOW DURATION ANALYSIS OF ANNUAL SERIES AS PER PRESENT RUNOFF SERIES COMPUTED BY LINEAR REGRESSION

| Sl. No. | Range in Million Cu. metre | No. of Occurance | % of Occurance | Cumulative % | Percentage exceeded |
|---|---|---|---|---|---|
| 1 | 1700 - 2000 | 1 | 1.67 | 1.67 | 98.33 |
| 2 | 2000 - 2300 | 5 | 8.33 | 10.00 | 90.00 |
| 3 | 2300 - 2600 | 11 | 18.34 | 28.34 | 71.66 |
| 4 | 2600 - 2900 | 14 | 23.33 | 51.67 | 48.33 |
| 5 | 2900 - 3200 | 9 | 15.00 | 66.67 | 33.33 |
| 6 | 3200 - 3500 | 12 | 20.00 | 86.67 | 13.33 |
| 7 | 3500 - 3800 | 6 | 10.00 | 96.67 | 3.33 |
| 8 | 3800 - 4100 | 2 | 3.33 | 100.00 | 0 |
| 9 | 4100 - 4400 | 0 | 0 | 0 | 0 |
| 10 | 4400 - 4700 | 0 | 0 | 0 | 0 |

TABLE - 4.19

FLOW DURATION ANALYSIS OF ANNUAL SERIES AS PER PRESENT RUNOFF SERIES COMPUTED BY MULTIPLE LINEAR REGRESSION

| Sl. No. | Class in Range in Mcum | No. of occur-ance | % of time occurance | Cumulative % of time | % of time exceeded |
|---|---|---|---|---|---|
| 1 | 1500 - 1700 | 1 | 1.67 | 1.67 | 98.33 |
| 2 | 1701 - 1900 | 2 | 3.33 | 5.00 | 95.00 |
| 3 | 1901 - 2100 | 4 | 6.67 | 11.67 | 88.33 |
| 4 | 2101 - 2300 | 11 | 18.33 | 30.0 | 70.00 |
| 5 | 2301 - 2500 | 10 | 16.66 | 46.66 | 53.34 |
| 6 | 2501 - 2700 | 9 | 15.00 | 61.66 | 38.34 |
| 7 | 2701 - 2900 | 11 | 18.33 | 79.99 | 20.01 |
| 8 | 2901 - 3100 | 4 | 6.67 | 86.66 | 13.34 |
| 9 | 3101 - 3300 | 1 | 1.67 | 88.33 | 11.67 |
| 10 | 3301 - 3500 | 4 | 6.67 | 95.00 | 5.00 |
| 11 | 3501 - 3700 | 1 | 1.67 | 96.67 | 3.33 |
| 12 | 3701 - 3900 | - | - | 96.67 | 3.33 |
| 13 | 3901 - 4100 | 1 | 1.67 | 98.34 | 1.66 |
| 14 | 4101 - 4300 | - | - | 98.34 | 1.66 |
| 15 | 4301 - 4500 | 1 | 1.67 | 100.00 | 0 |

# CHAPTER - 5

## CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The study of water availability for Ramganga basin upto Kalagarh has been done by computing 60 years of monthly flow series using available monthly rainfall data of 60 years for five raingauge stations situated out side the catchment. For estimating average basin rainfall relationships have been developed using available 10 years data of monthly rainfall for 12 raingauge station situated inside the catchment. Monthly rainfall runoff relationships have been developed using statistical techniques of linear regression and multiple linear regression. The water availability has been worked out for 60 years monthly flow series obtained by (1) Linear regression relationships (2) Multiple linear regression. The comparision has been done for water availability worked out for these two cases with that for monthly flow series worked out by project people. On the basis of the present study the following conclusion can be drawn :

(1) For developing the relationships between monthly rainfall recorded by external raingauge stations to the average rainfall over its Thiessen Polygon as recorded by internal raingauge station was tried, but suitable relationships could not be established due to lack of suitable data for a longer period.

(2) Reasonably satisfactory relation is established between average monthly basin rainfall obtained by using external raingauge data and corresponding average monthly basin rainfall obtained by data of internal raingauge stations.

(3) The base flow contribution to monthly run-off could not be taken into account satisfactorily, since the base flow is influenced by rainfall in preceding months also. In order to get better relationships between monthly rainfall and monthly runoff, the rainfall of the previous month has to be considered. For this, multiple linear regression analysis should be used to develop relationship between monthly rainfall and monthly runoff for monsoon period by considering the rainfall of previous month also.

(4) The non-monsoon flow could be estimated as total for entire seven months period (November to May) and then can be redistributed in constant proportion to individual months.

(5) The estimation of water availability is affected by the procedure used in computing the monthly flow series and various assumptions made, as is clearly indicated by different magnitudes of water availability obtained for three cases.

(6) An attempt was made to develop a simple stochastic model with the available data of daily flows. But the suitable model could not be established in view of seasonal nature of data with most of runoff occurring during monsoon season. It may be necessary to develop two separate model structures for monsoon and non-monsoon seasons.

SUGGESTIONS:

With the availability of larger period rainfall data of internal raingauge stations, the individual correlation between rainfall data of external raingauge station and corresponding average rainfall over its Thiessen Polygon obtained from internal raingauge stations could developed for better results.

Correction for rainfall of last few days of the month to the runoff of the next month is necessary. This effect could not taken into account in present study as only monthly rainfall data was available.

A suitable simple stochastic model of daily runoff by separately considering the monsoon and non-monsoon flow could be developed with about 15 - 20 years of daily flow data. Then the alternate sequences could be generated for obtaining better estimates of water availability.

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# APPENDIX-I

```
C     C     CORELATUON A WASIF   K
            DIMENSION X(210),Y(210)
            READ1,NS,N
        1   FORMAT(16I5)
            DO 10 IJ=1,NS
            READ 2,(X(I),I=1,N)
            READ2,(Y(I),I=1,N)
     2      FORMAT(8F10.4)
            SUMY=0.0
            SUMX=0.0
            OUMX2=0.0
            SUMY2=0.0
            SUMXY=0.0
            40 20 I=1,N
            CUMX=SUMX+X(I)
            CUMY=SUMY+Y(I)
            SUMX2=SUMX2+X(I)*X(I)
            SUMY2=SUMY2+Y(I)*Y(I)
            SUMXY=SUMXY+X(I)*Y(I)
       20   CONTINUE
            PUNCH 4,SUMX,SUMY,SUMX2,SUMY2,SUMXY
        4   FORMAT(2X,5HSUMX=, E13.5,5HSUMY=,E13.5/2X,6HSUMX2=,E13.5,6HSUMY2=
          1E13.5,6HSUMXY=,F13.5//)
            AN=N
            J=1
       13   B=(SUMXY-SUMX*SUMY/AN)/(SUMX2-SUMX*SUMX/AN)
            A=SUMY/AN-B*SUMX/AN
            R1=SUMXY-SUMX*SUMY/AN
            R2=SQRTF((SUMX2-SUMX*SUMX/AN)*(SUMY2-SUMY*SUMY/AN))
            R=R1/R2
            PUNCH3,IJ,A,B,R
3           FORMAT(5X,10HSERIES.NO=,I2/5X,2HA=,E16.7,15X,2HB=,E16.7,5X,2HR=,
          1E16.7//)
            IF(J-1)12,12,10
       12   A1=SUMX
            A2=SUMY
            A3=SUMX2
            A4=SUMY2
            SUMX=A2
            SUMY=A1
            SUMX2=A4
            SUMY2=A3
            J=J+1
            GO TO 13
       10   CONTINUE
            STOP
            END
```

# APPENDIX-II

```
C  C   MULTIPLE REGRESSION ANALYSIS BY A.WASIF
**
       DIMENSION B(5),SR(5),RM(5),RPAR(5) ,C(5,5),CY(5),CXBAR(5)
       DIMENSION S1(5),S2(5),S3(5),XB(5),BPAR(5),APAR(5),STDX(5),R(5)
       READ 1,NMN
       DO 29 IN=1,NMN
       READ1,NDATA,NPAR,NS,NTRY
  1    FORMAT(5I5)
       NT=NPAR+1
       READ 1,(IP(I),I=1,NT)
       DO 100 I=1,NDATA
 100   READ 2,(Z(I,J),J=1,NS)
    2  FORMAT(10F6.2)
       K=NS-1
       S4=0.
       S5=0.
       DO 700 J=1,K
       S1(J)=0.
       S2(J)=0.
       S3(J)=0.
       DO 700 I=1,NDATA
       S1(J)=S1(J)+Z(I,J)
       S2(J)=S2(J)+Z(I,J)*Z(I,J)
  700  S3(J)=S3(J)+Z(I,J)*Z(I,NS)
       DO 601 I=1,NDATA
       S5=S5+Z(I,NS)*Z(I,NS)
 601   S4=S4+Z(I,NS)
       AN=NDATA
       FN=NDATA-1
       YB=S4/AN
       STDY=SQRTF((S5-AN*YB**2)/FN)
       DO 602 J=1,K
       XB(J)=S1(J)/AN
       BPAR(J)=(S3(J)-AN*XB(J)*YB)/(S2(J)-AN*XB(J)**2)
       APAR(J)=YB-BPAR(J)*XB(J)
       STDX(J)=SQRTF((S2(J)-AN*XB(J)**2)/FN)
 602   R(J)=(S3(J)-AN*XB(J)*YB)/(STDX(J)*STDY*FN)
       7UNCH 2000
 2000  FORMAT(1X,3H*1*)
       DO 603 J=1,K
 603   PUNCH 1000, BPAR(J),APAR(J),R(J)
1000   FORMAT(3F16.7)
       PUNCH 47,(STDX(J),J=1,K),STDY
  47   FORMAT(5E16.7)
       PUNCH 47,(XB(J),J=1,K),YB
       IP1=IP(NT)
       DO 101 I=1,NDATA
  101   X(I,NT)=Z(I,IP1)
       DO 102 J=1,NPAR
       IPJ=IP(J)
```

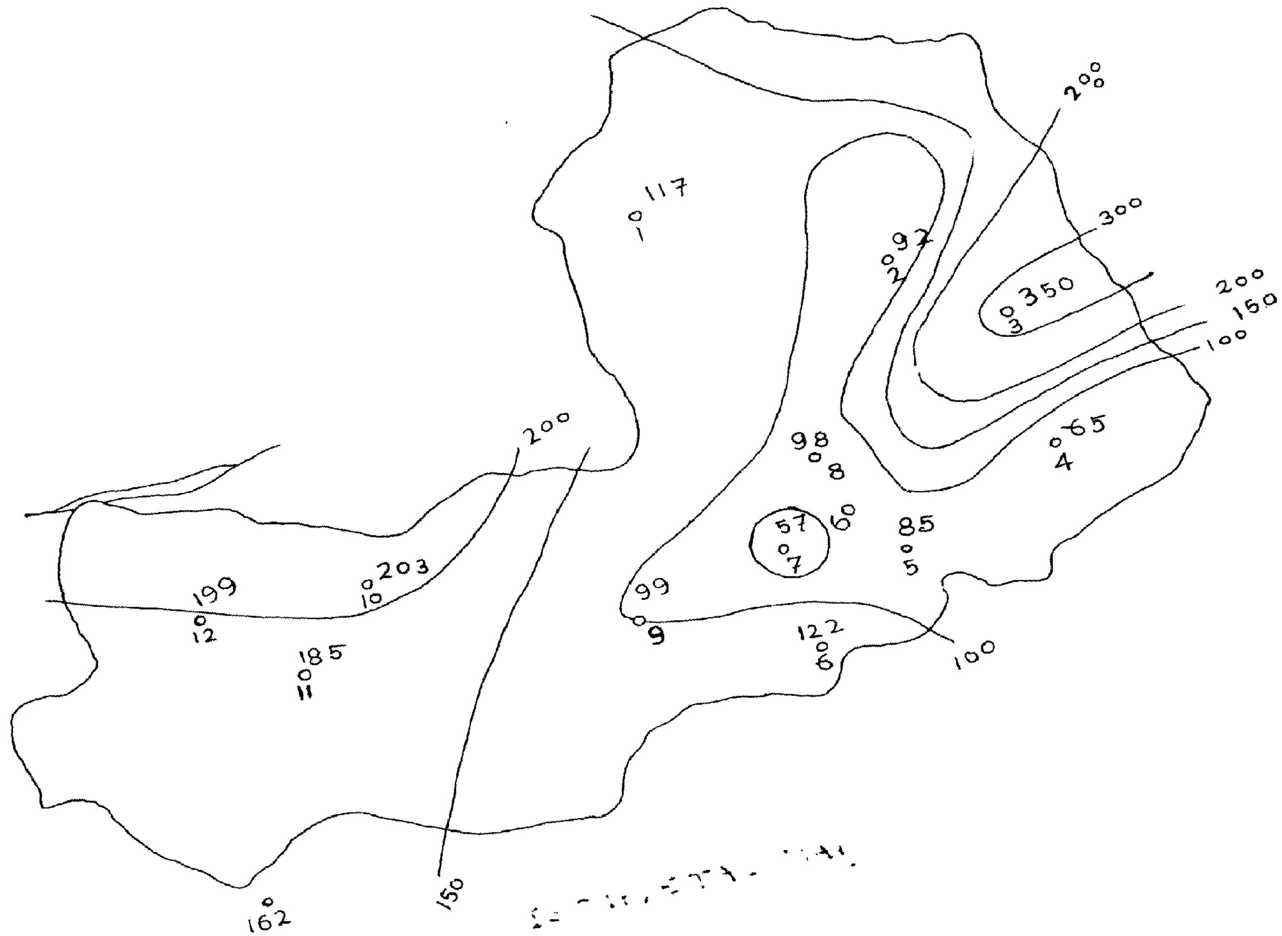
```
      DO 102 I=1,NDATA
  102 X(I,J)=Z(I,IPJ)
      DO 103 J=1,NT
  103 SUM(J)=0.
      DO 104 J=1,NT
      DO 104 I=1,NDATA
  104 SUM(J)=SUM(J)+X(I,J)
      DO 105 J=1,NT
  105 XBAR(J)=SUM(J)/AN
      PUNCH 2001
 2001 FORMAT(1X,3H*2*)
      DO 99 I=1,NDATA
   99 PUNCH 2,(X(I,J),J=1,NT)
      DO 106 J=1,NT
      DO 106 I=1,NDATA
  106 X(I,J)=X(I,J)-XBAR(J)
      DO 107 J=1,NPAR
      DO 107 I=1,NPAR
  107 AM(I,J)=0.
      DO 109 I=1,NPAR
  109 AY(I)=0.
      AY2=0.
      DO 111 K=1,NDATA
      DO 110 I=1,NPAR
      AY(I)=AY(I)+X(K,I)*X(K,NT)
       DO 110 J=1,NPAR
  110 AM(I,J)=AM(I,J)+X(K,I)*X(K,J)
  111 AY2=AY2+X(K,NT)*X(K,NT)
      PUNCH 2002
 2002 FORMAT(1X,3H*3*)
      DO 97 I=1,NPAR
   97 PUNCH 96,((AM(I,J),J=1,NPAR),AY(I),AY2)
   96 FORMAT(5E16.7)
      DO 80 I=1,NPAR
      DO 80 J=1,NPAR
   80 C(I,J)=AM(I,J)
      DO 500 I=1,NPAR
      PIVOT=AM(I,I)
      AM(I,I)=1.0
      DO 590 L=1,NPAR
  590 AM(I,L)=AM(I,L)/PIVOT
      DO 500 L1=1,NPAR
      IF(L1-I) 600,500,600
  600 T=AM(L1,I)
      AM(L1,I)=0.0
      DO 580 L=1,NPAR
  580 AM(L1,L)=AM(L1,L)-AM(I,L)*T
  500 CONTINUE
      DO 540 I=1,NPAR
      B(I)=0.0
      DO 540 J=1,NPAR
      B(I)=B(I)+AM(I,J)*AY(J)
```

```
  540   CONTINUE
        S=0.
        DO 112 I=1,NPAR
  112   S=S+B(I)*XBAR(I)
        B(NT)=XBAR(NT)-S
        PUNCH 2003
 2003   FORMAT(1X,3H*4*)
        PUNCH 3,(B(I),I=1,NT)
    3   FORMAT(5E16.7)
        S=0.
        DO 113 I=1,NPAR
  113   S=S+B(I)*AY(I)
        FN1=NDATA-NPAR
        SDR=SQRTF((AY2-S)/FN1)
        RMULT=SQRTF(S/AY2)
        PUNCH 2004
 2004   FORMAT(1X,3H*5*)
        PUNCH 5,SDR,RMULT
    5   FORMAT(2E16.7)
        DO 81 I=1,NPAR
        DO 81 J=1,NPAR
   81   AM(I,J)=C(I,J)
        IF(NTRY-1) 68,49,68
   49   NK=NPAR-1
        DO 50 K1=1,NPAR
        DO 51 I=1,NK
        DO 52 J=1,NK
        IF(I-K1) 53,54,54
   53   IF(J-K1) 55,56,56
   55   C(I,J)=AM(I,J)
        GO TO 52
   56   C(I,J)=AM(I,J+1)
        GO TO 52
   54   IF(J-K1) 57,58,58
   57   C(I,J)=AM(I+1,J)
        GO TO 52
   58   C(I,J)=AM(I+1,J+1)
   52   CONTINUE
   51   CONTINUE
        PUNCH 2005
 2005   FORMAT(1X,3H*6*)
        DO 59 I=1,NK
   59   PUNCH 96,(C(I,J),J=1,NK)
        DO 60 I=1,NK
        IF(I-K1) 61,62,62
   62   CY(I)=AY(I+1)
        CXBAR(I)=XBAR(I+1)
        GO TO 60
   61   CY(I)=AY(I)
         CXBAR(I)=XBAR(I)
   60   CONTINUE
```

```
      PUNCH 2006
2006  FORMAT(1X,3H*7*)
      PUNCH 96,(CY(I),I=1,NK)
      DO 1500 I=1,NK
      PIVOT=C(I,I)
       C(I,I)=1.0
      DO 1590 L=1,NK
 1590 C(I,L)=C(I,L)/PIVOT
       DO 1500 L1=1,NK
      IF(L1-I) 1600,1500,1600
 1600 T=C(L1,I)
      C(L1,I)=0.0
      DO 1580 L=1,NK
 1580 C(L1,L)=C(L1,L)-C(I,L)*T
 1500 CONTINUE
      DO 63 I=1,NK
      B(I)=0.0
      DO 63 J=1,NK
      B(I)=B(I)+C(I,J)*CY(J)
   63 CONTINUE
      S=0.
      DO 64 I=1,NK
   64 S=S+B(I)*CXBAR(I)
      B(NPAR)=XBAR(NT)-S
      PUNCH 2007
2007  FORMAT(1X,3H*8*)
      PUNCH 3,(B(I),I=1,NPAR)
      S=0.0
      DO 65 I=1,NK
   65 S=S+B(I)*CY(I)
      FN1=NDATA-NK
      SDR=SQRTF((AY2-S)/FN1)
      RM(K1)=SQRTF(S/AY2)
      PUNCH 2008
 2008 FORMAT(1X,3H*9*)
      PUNCH 5,SDR,RM(K1)
   50 CONTINUE
      DO 66  J=1,NPAR
   66 RPAR(J)=1.-(1.-RMULT**2)/(1.-RM(J)**2)
      PUNCH 2009
2009  FORMAT(1X,4H*10*)
      PUNCH 67,(RPAR(J),J=1,NPAR)
   67 FORMAT(5E16.7)
    68 CONTINUE
   29 CONTINUE
      STOP
      END
```

# APPENDIX - III

JUNE '63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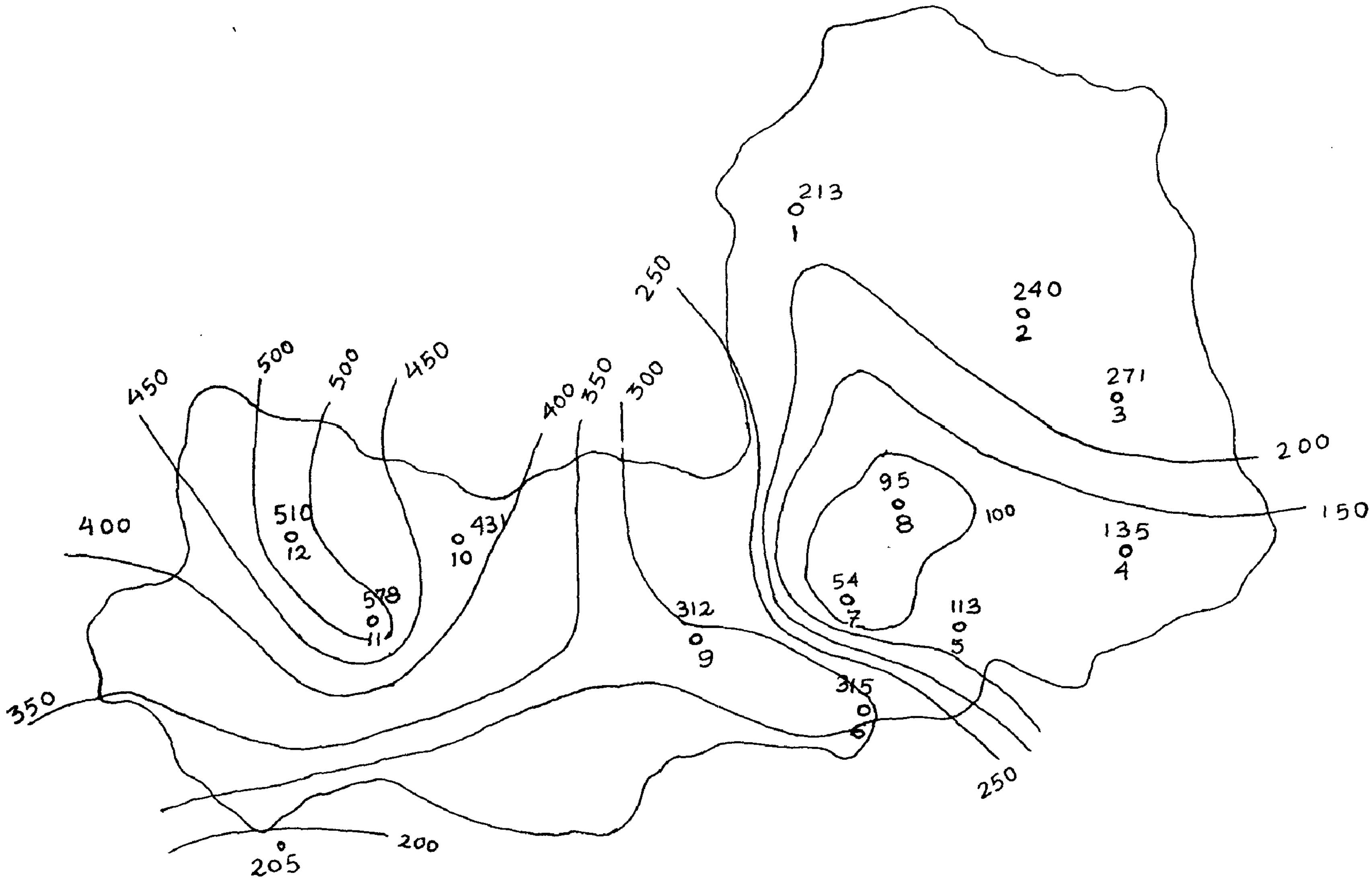
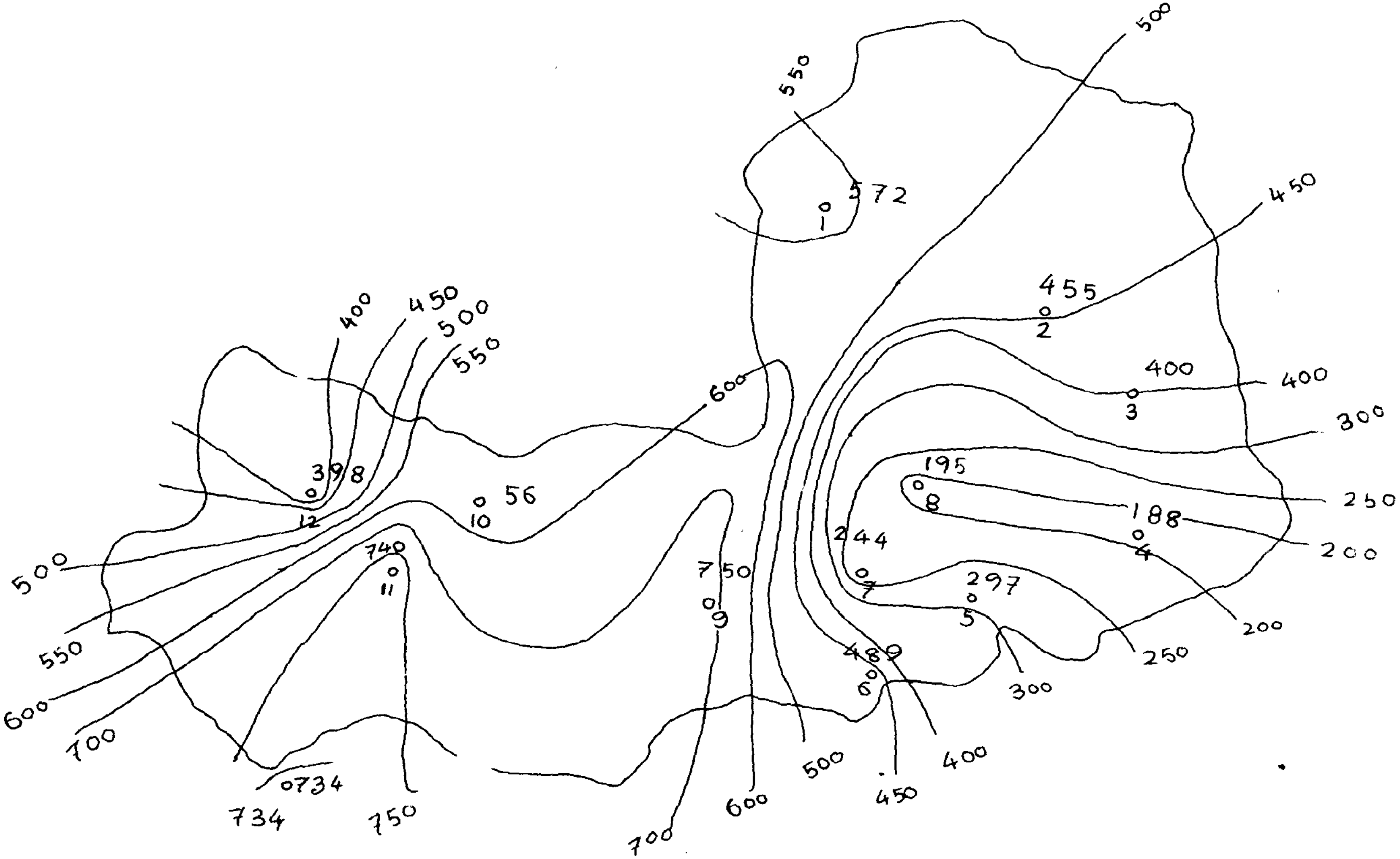
300
350
3
200
150
100
65
4
117
1
92
2
98
8
57
7
60
85
5
99
9
122
6
100
200
203
10
199
12
185
11
150
162




ISOHYETAL MAP

# AUG' 63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455
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3
400
300
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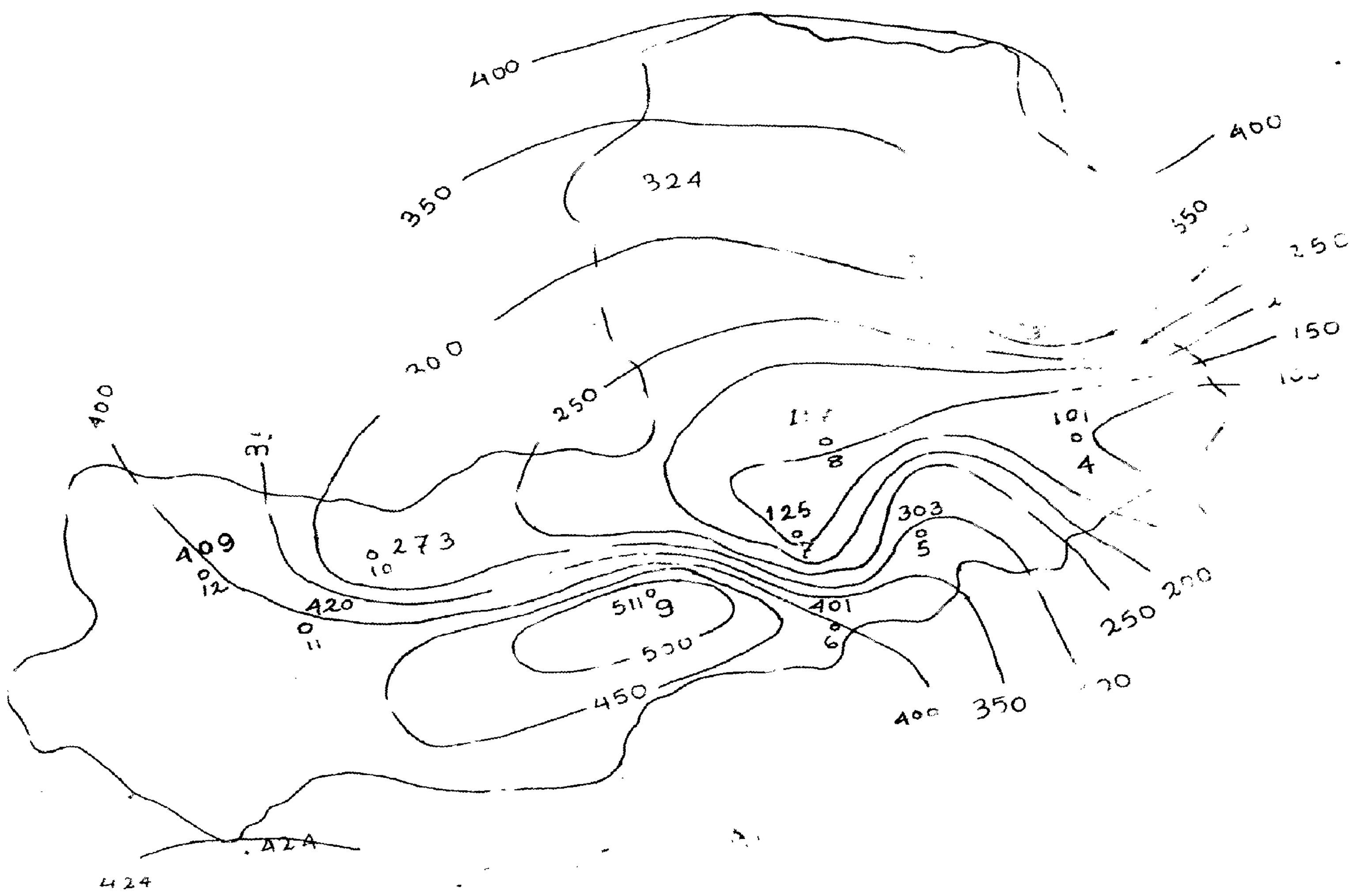
200
195
8
188
4
200
244
7
297
5
250
300
489
6
400
450
500
600
700
600
750
9
56
10
400
450
500
550
398
12
740
11
500
550
600
700
734
0734
750

SEPT' 63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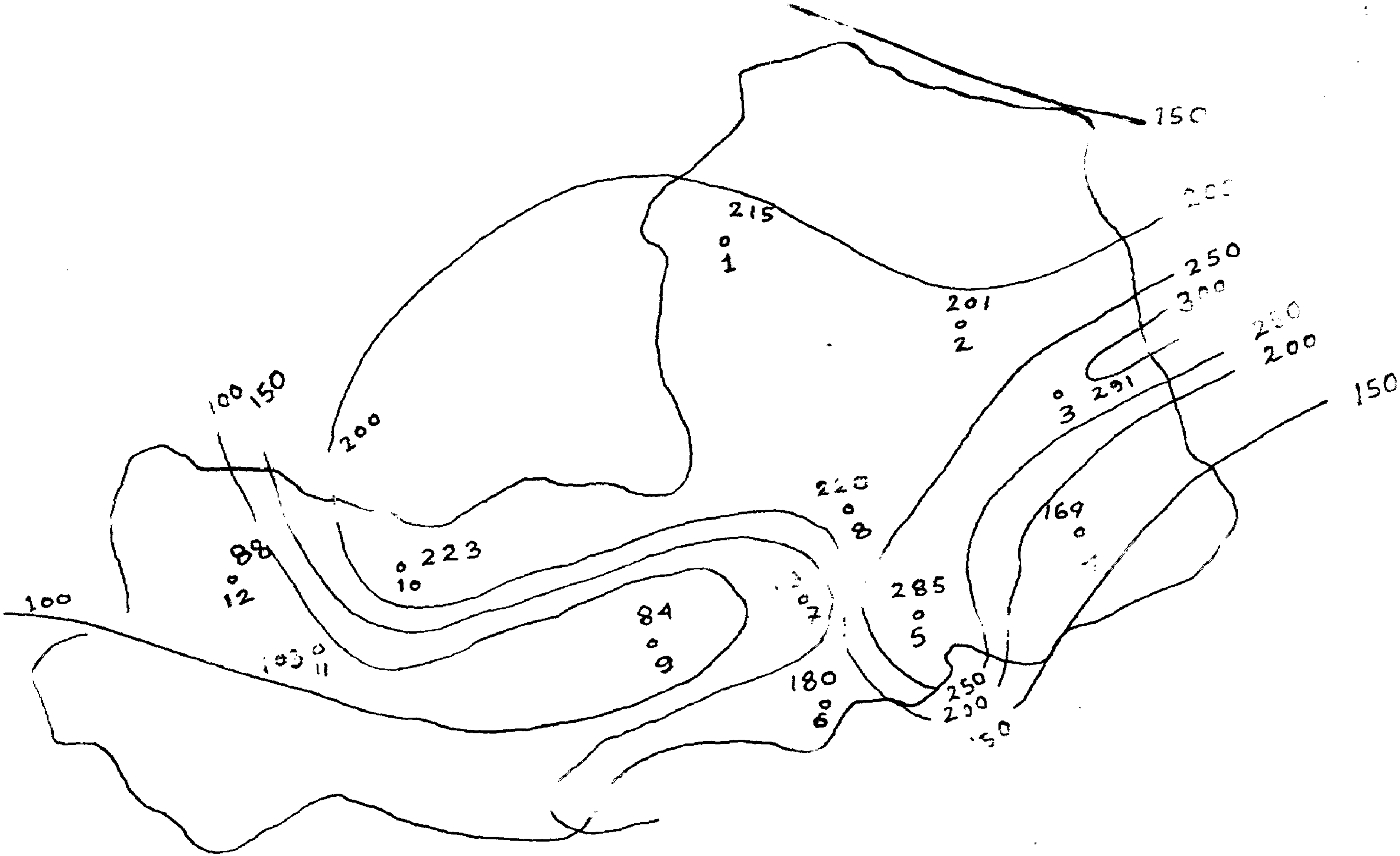
350
324
300
250
400
409
12
273
10
420
11
511
9
500
450
125
7
8
303
5
401
6
101
4
400
350
250
150
250
200
400
350
424
424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200
250
300
250
200
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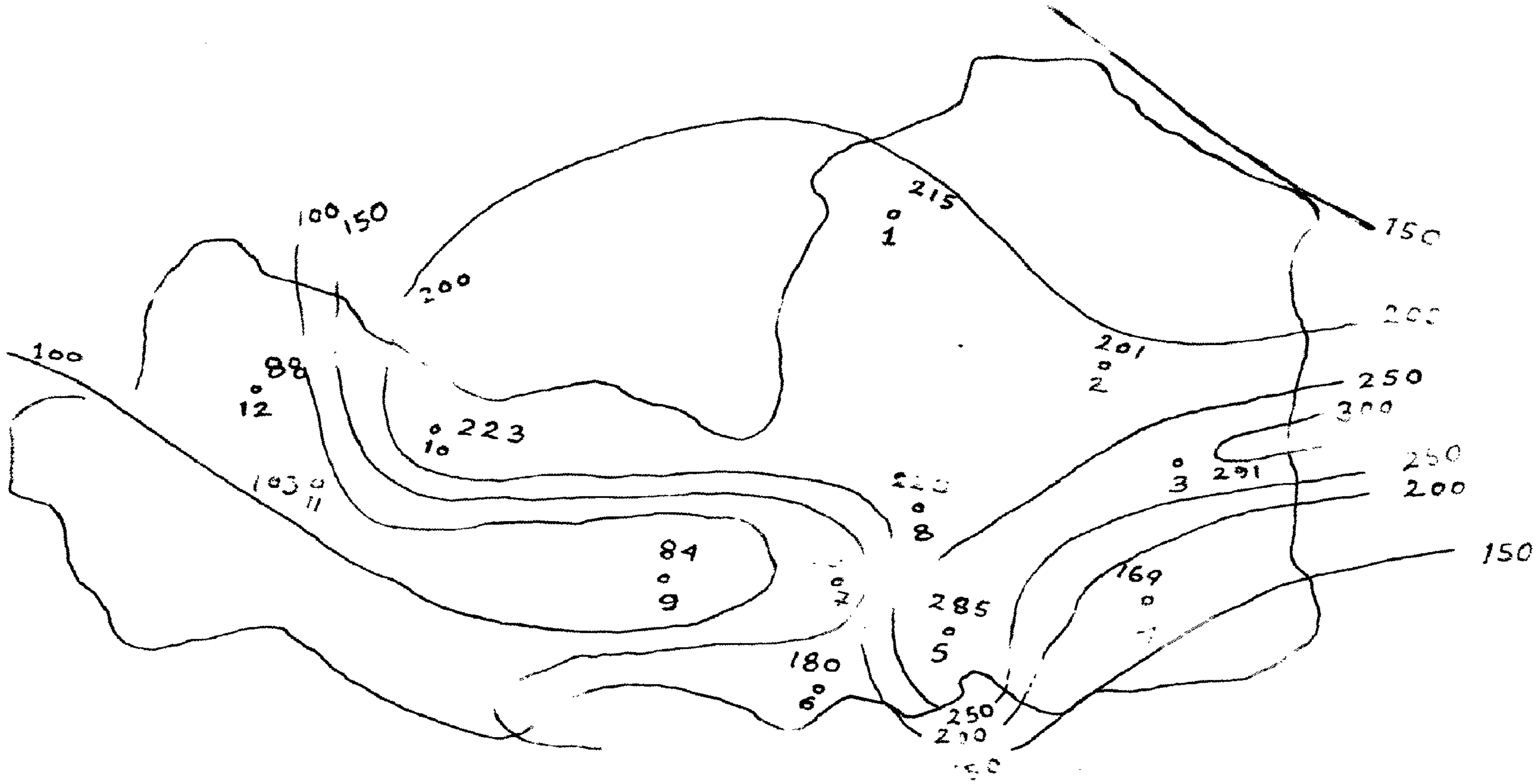
215
1
201
2
291
3
169
220
8
285
5
250
200
150
180
6
84
9
223
10
200
100
150
88
12
100
11


150
200
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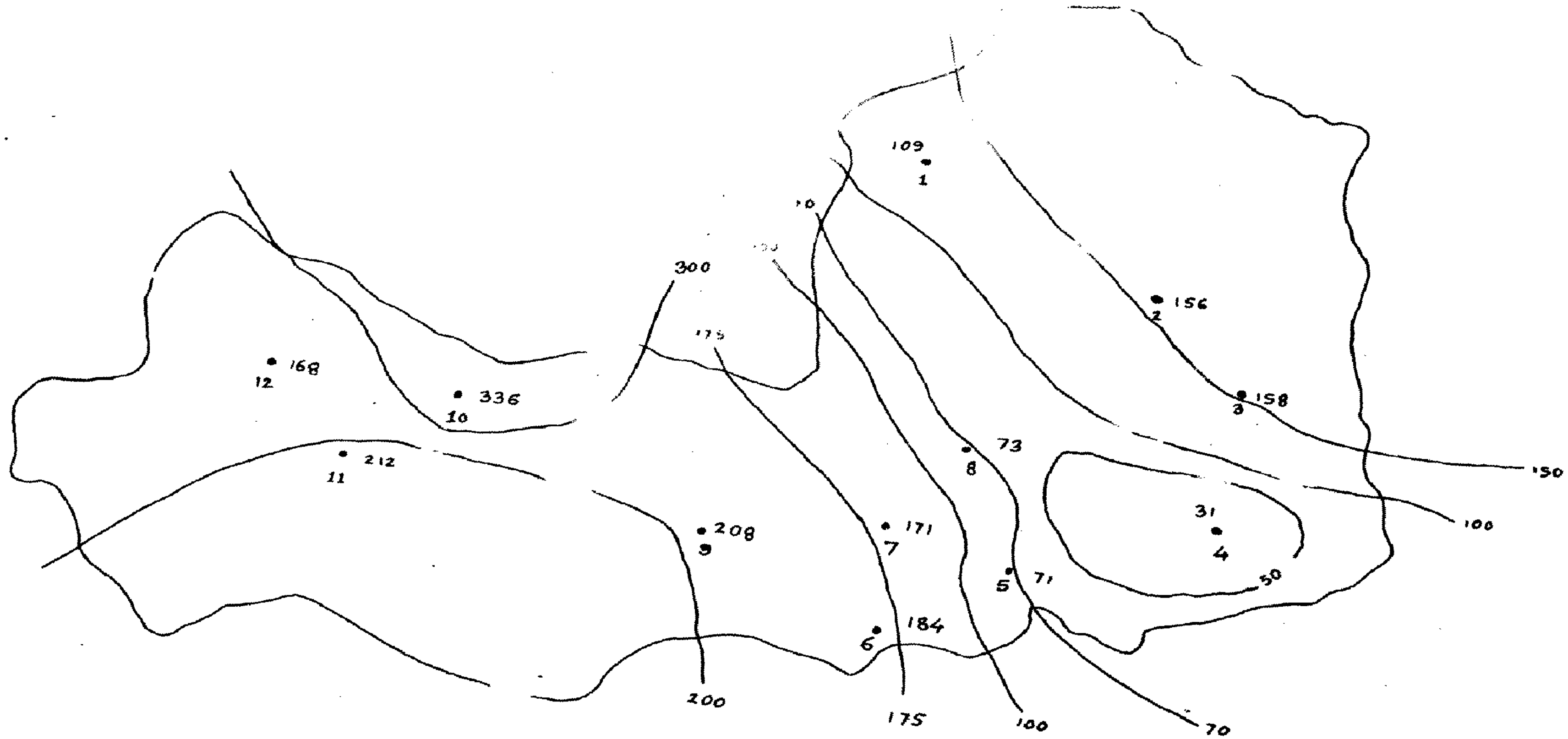
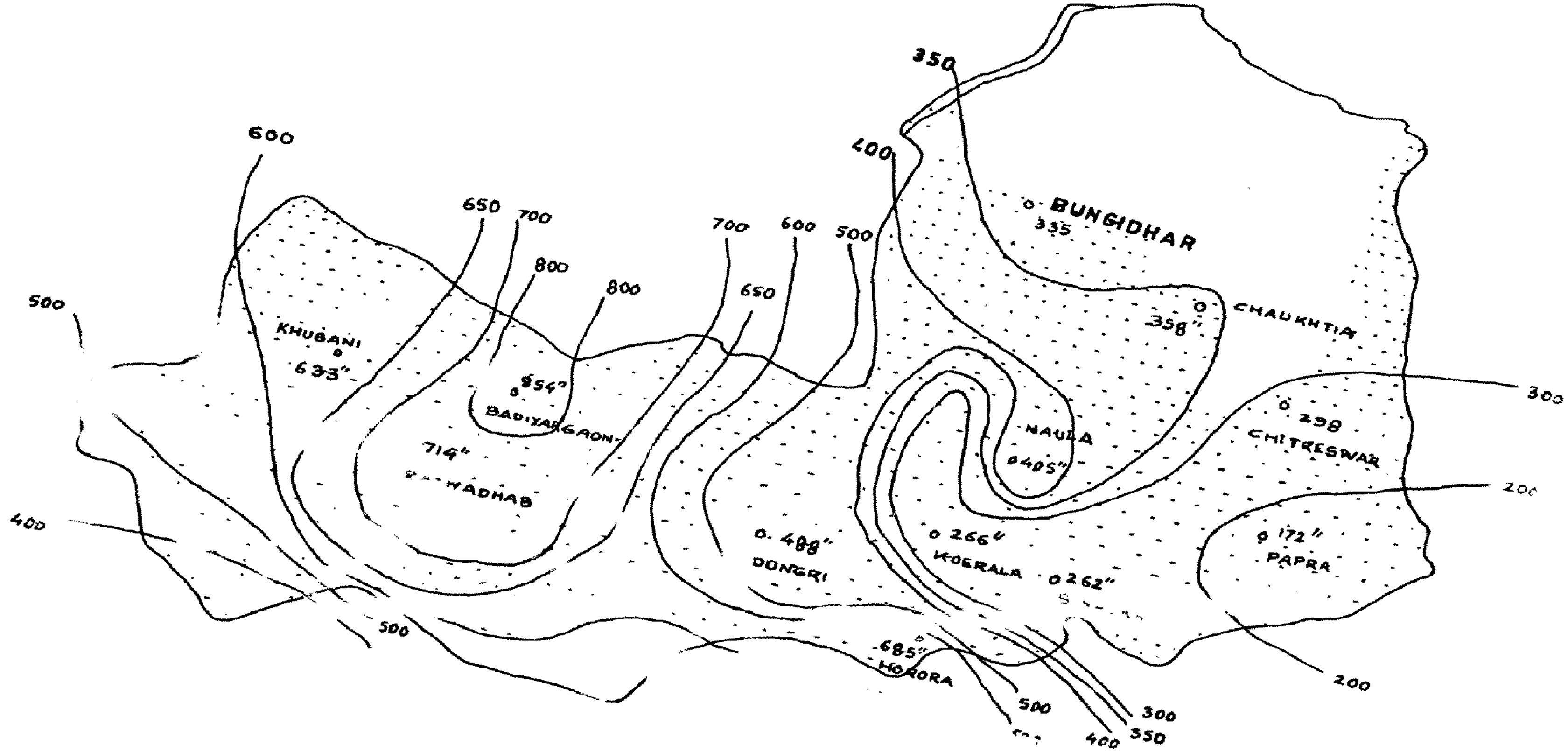
300
250
200
150
215
1
201
2
3
291
169
8
285
5
180
6
250
200
84
9
7
223
10
88
12
103
11
100
150
200
100

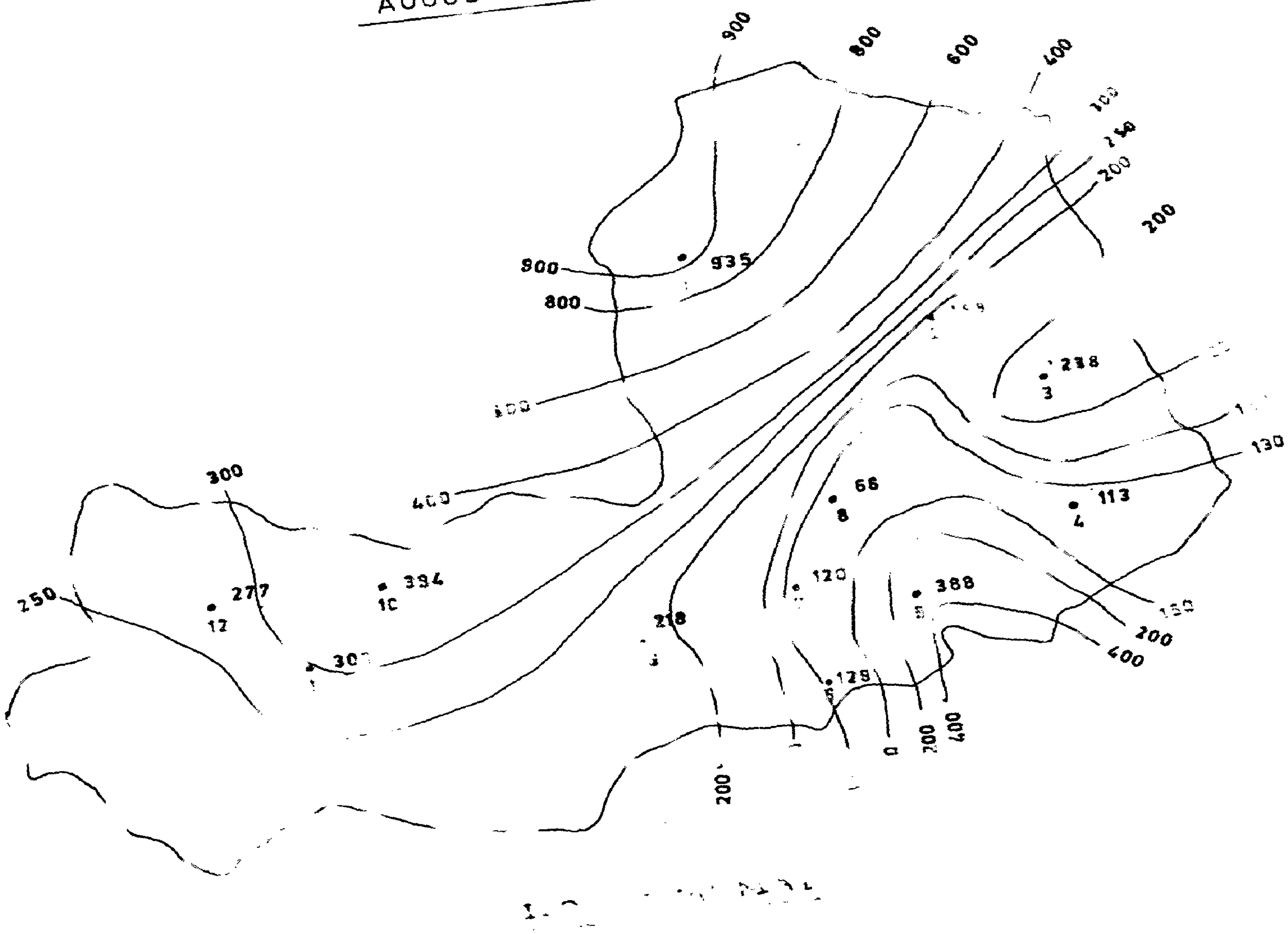
MAI



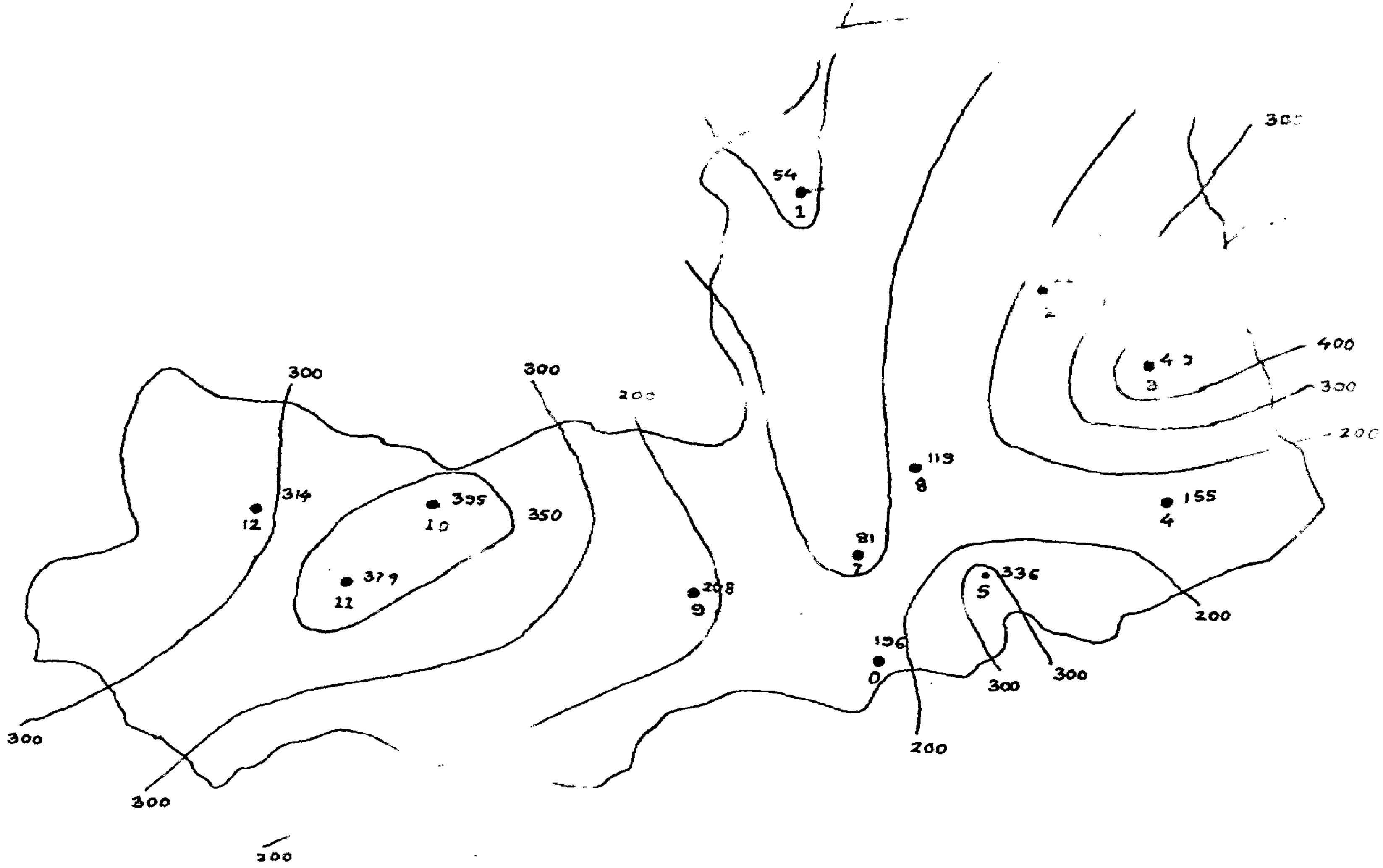
109
1
156
2
158
3
31
4
50
71
5
73
8
171
7
184
6
208
9
336
10
212
11
168
12
150
100
70
100
175
200
300
175


BUNGIDHAR
335
CHAUKHTIA
358"
CHITRESWAR
298
PAPRA
172"
NAULA
405"
KOERALA
266"
262"
DONGRI
488"
HORORA
685"
BADIYARGAON
854"
WADHAB
714"
KHUBANI
633"
350
400
500
600
650
700
800
300
200

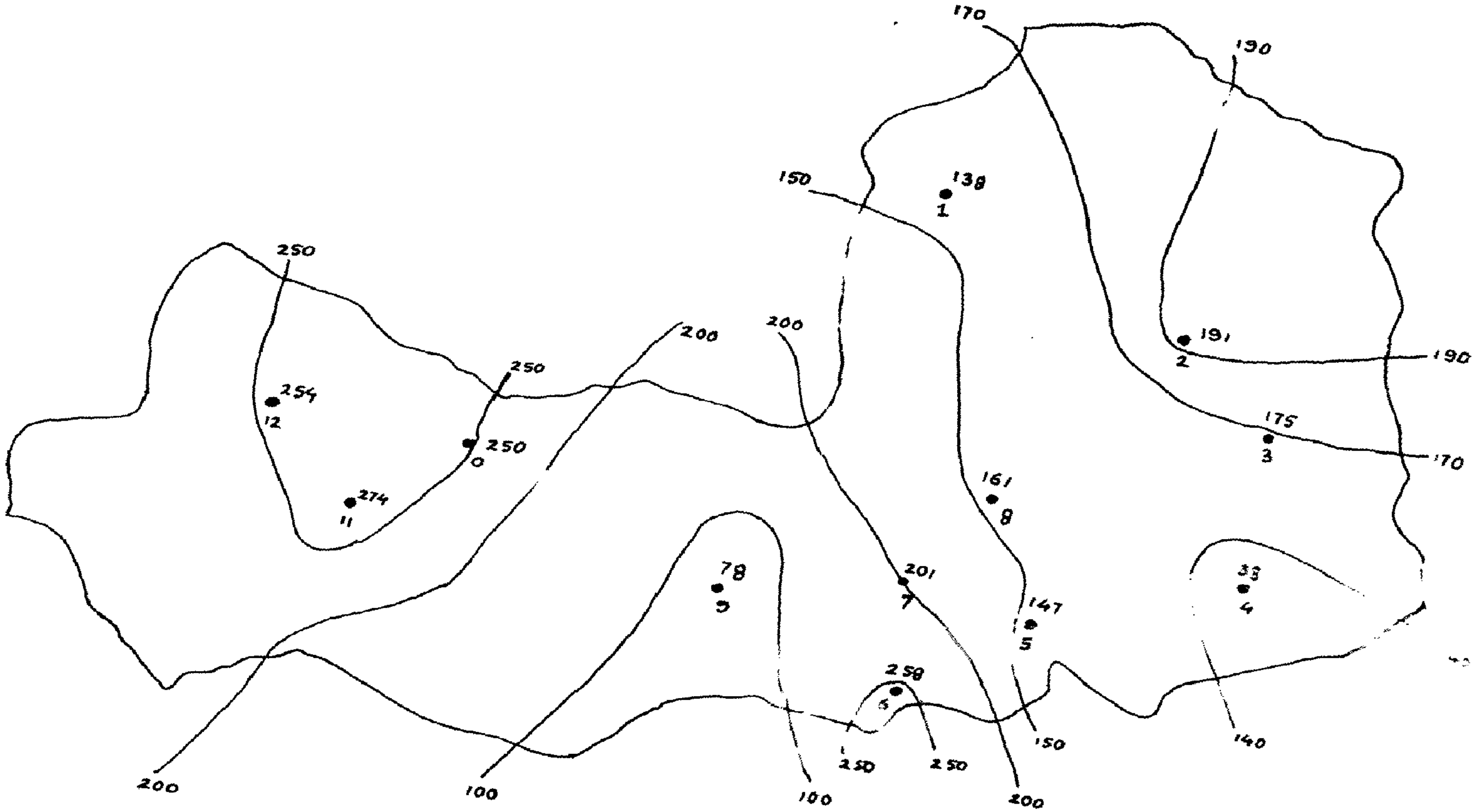
AUGUST. 1962.



900
800
600
400
200
935
238
113
388
66
120
128
218
334
277
300
250
130



54
1
300
300
200
400
300
200
119
8
155
4
314
12
395
10
350
379
11
81
7
208
9
336
5
196
0
200
300
300
300
300
200
200



138
1
191
2
175
3
33
4
147
5
258
6
201
7
161
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9
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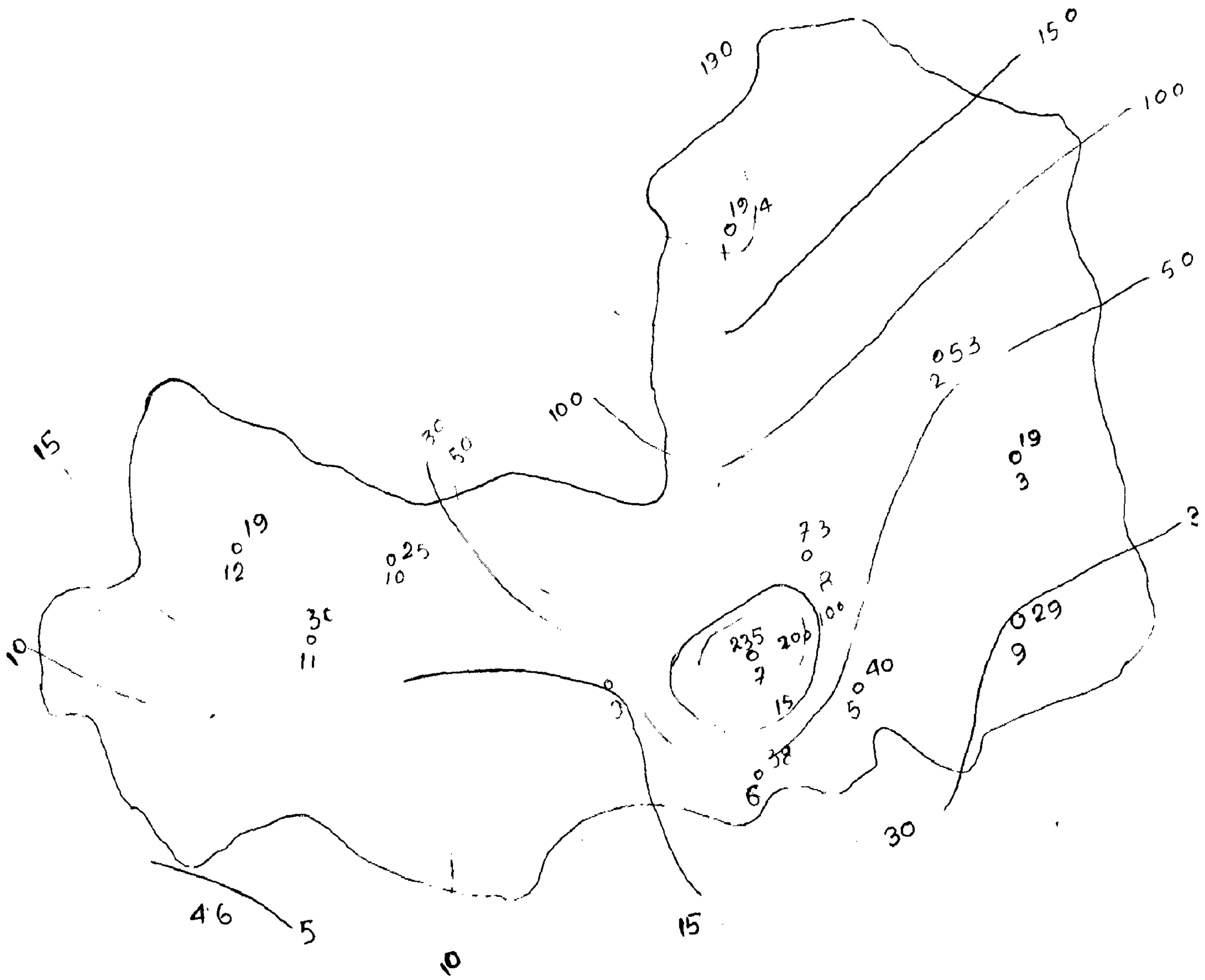
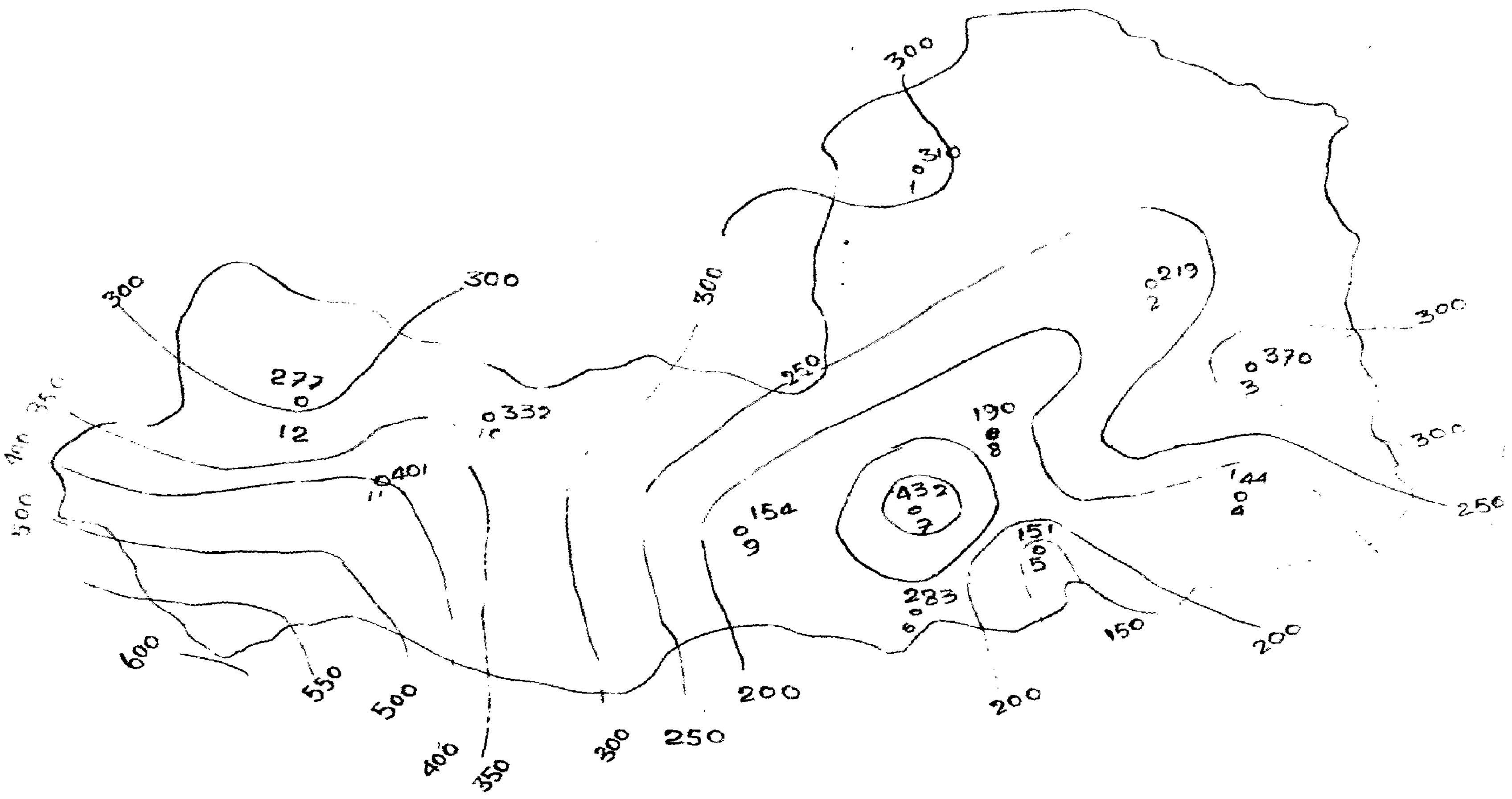
0
274
11
254
12
100
140
150
170
190
200
250

# JUNE '65



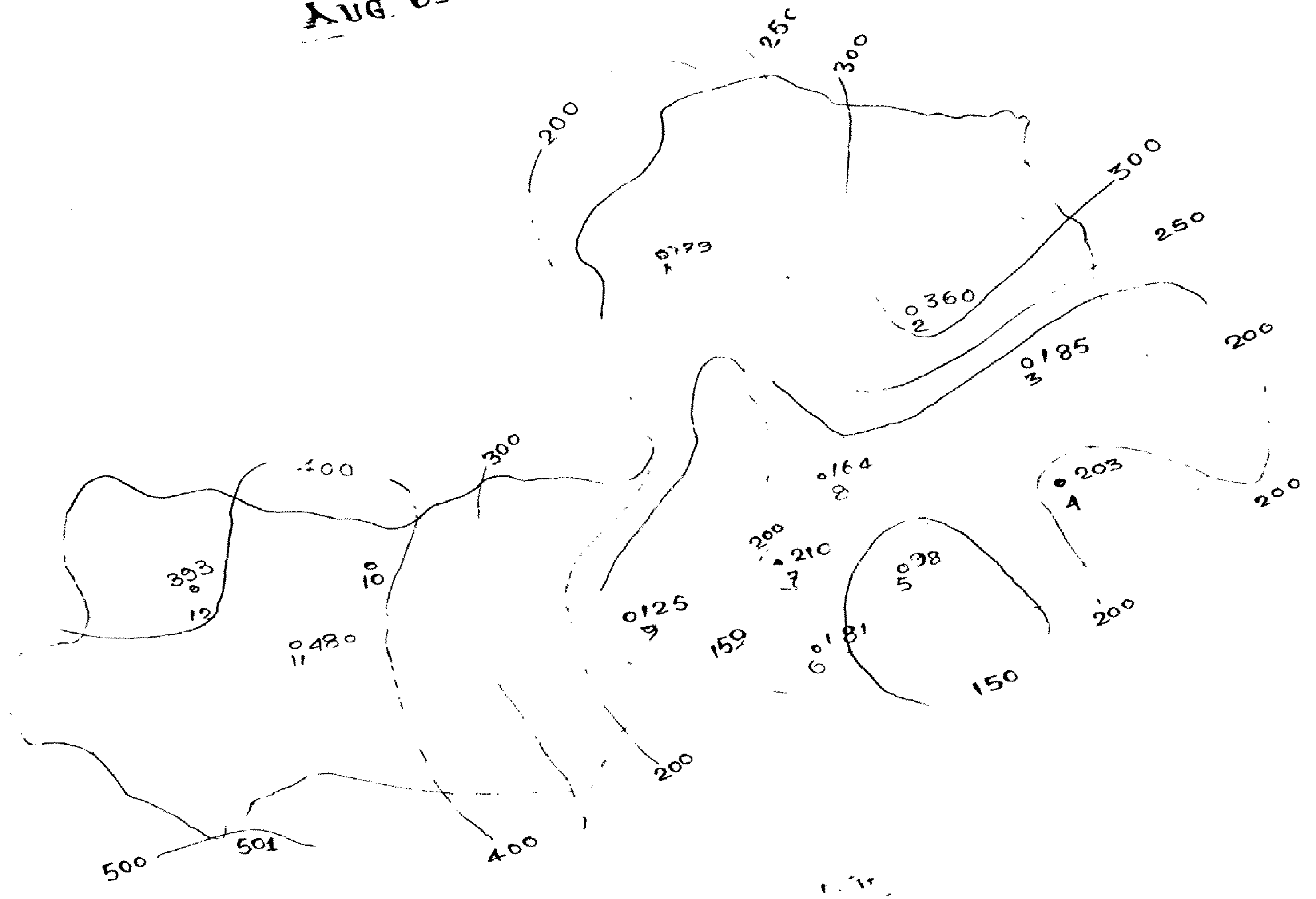

ISOHYETAL MAP

JULY '65



300
310
300
300
277
12
332
401
250
219
370
300
300
190
432
154
283
151
144
250
150
200
200
250
300
350
400
500
550
600

AUG '65



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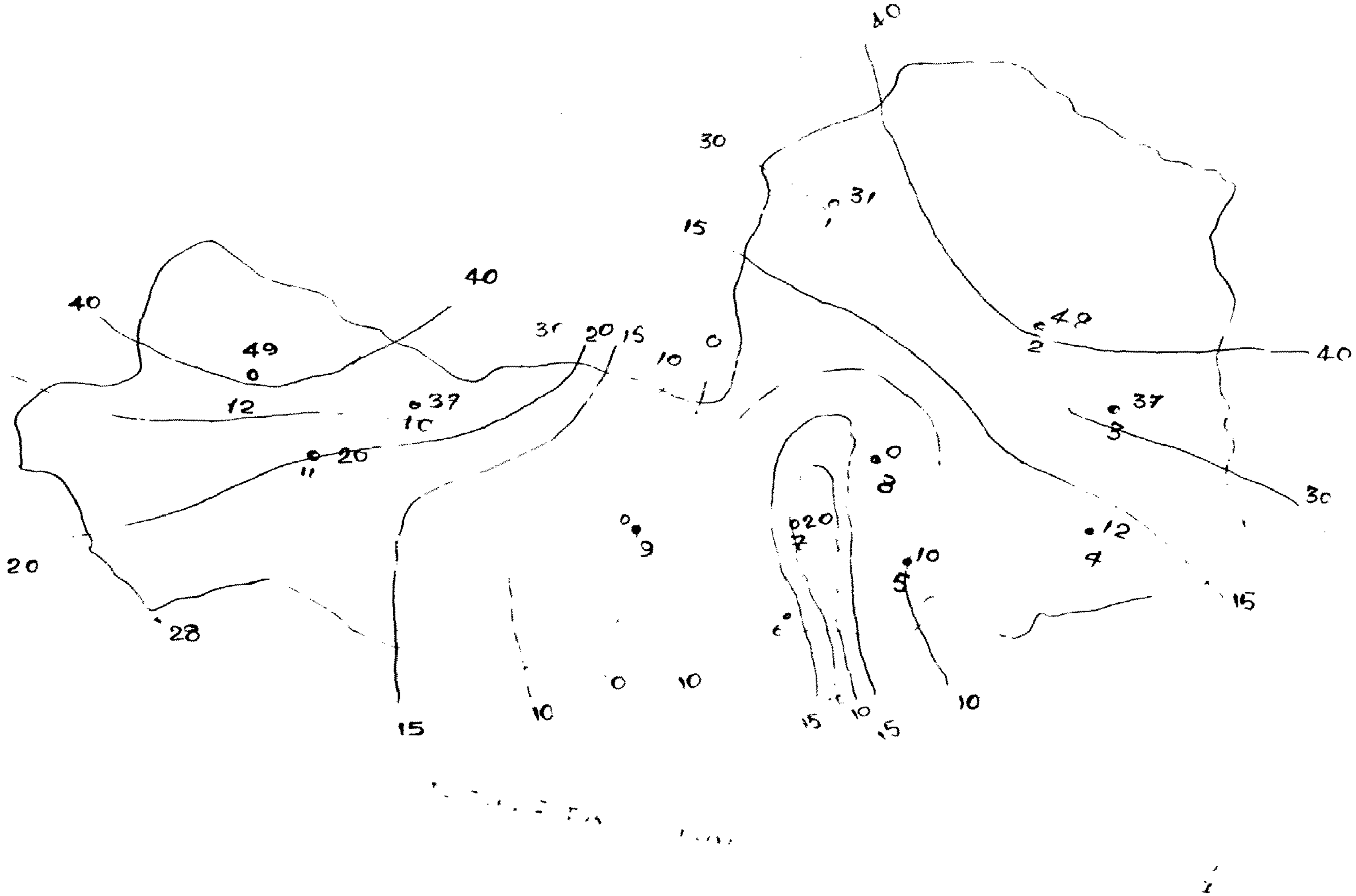
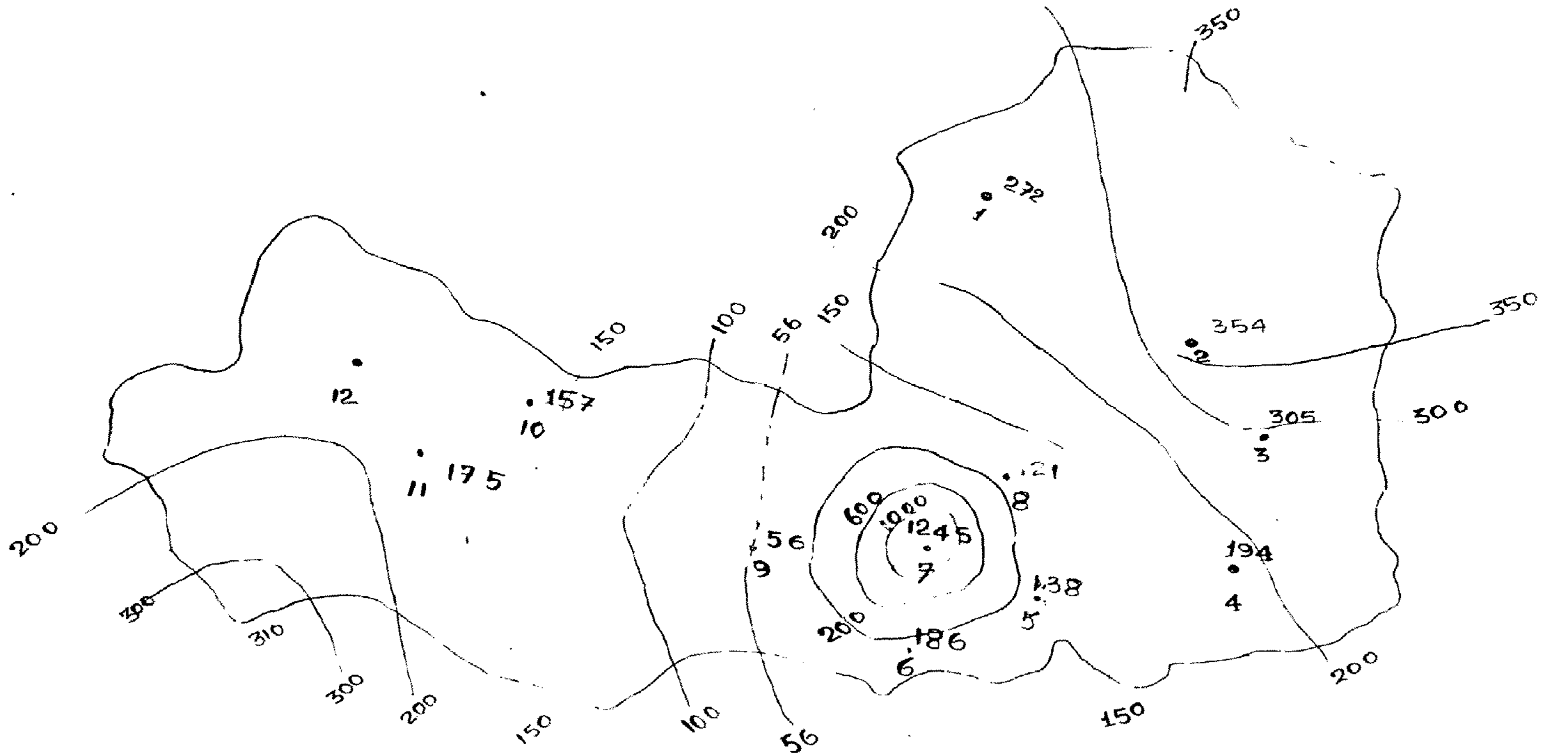
300
200
179
360
2
300
250
185
3
200
164
8
203
A
200
400
300
393
12
10
480
11
125
9
150
181
6
210
7
200
98
5
200
150
200
500
501
400

Oct '65




350
350
300
354
305
272
194
200
150
100
56
600
1000
1245
121
138
186
157
175
300
310
1
2
3
4
5
6
7
8
9
10
11
12