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REPRESENTATIVE BASIN STUDIES IN THE GANGA PLAINS REGION OF INDIA

(PART I)

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE (UP) -247 667

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Preface

Representative basins are basins selected as representative of hydrological region i.e., region within which hydrological similarity is presumed. The studies in representative basin are long term and combined with the study of climatic, geological, geomorphological and hydrological characteristics. They are used for intensive investigations of specific problems of the hydrologic cycle.

The Ganga Plains region is spread over the states of Uttar Pradesh, Bihar, West Bengal and Madhya Pradesh. To have a through study of hydrology problems in this region, the Patna Regional Centre of National Institute of Hydrology Roorkee in consultation with the state government has decided to establish a representative basin for extensive research. The river Punpun is a tributary of the river Ganga. It meets Ganga at Fatwa nearly 25 kms downstream to Patna. It originates at an elevation of 300 m from Chhotnagpur hill of Palamau district in south Bihar. It is located on the right bank of the Ganga and is bounded by the Sone river system in the west and the Kiul-Harohar-Falgu river system on the east.

The catchment lies within the state of Bihar and is spread over the distrits of Patna, Gaya, Aurangabad, Hazaribag and Palamau. The catchment satisfies basic requirements of a representative basin and the centre has already completed studies or Hydrological data year book, land use mapping and precipitation gauge network designs.

The first part of the report consists of general description of the basin with regard to hydrology, hydrometeorology, geography, land use pattern and other necessary informations. Besides it also deals with the concept of representative basin, its kinds, objectives etc.

The GFCC, Patna and Hydrology Cell Govt. of Bihar desire our thanks for their cooperation and guidenance. The report has been prepared by Sri G.Thakur, Sc.'C', Shri R.Jha, Sc.'B' and Shri Manohar Arora, SRA, under the guideance of Dr. K.K.S.Bhatia Head and Sc.'F' Regional Centre Patna. The services of Shri Sivadas A.K. are also acknowledged.

Satish Chandra
(Satish Chandra)
Director

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1.0 INTRODUCTION

Watershed research is one of the important components of the watershed management. Improper management of the watersheds has led to devastation of watersheds. Public awareness of the impending problem concerned with the shortages and the degradation of the quality of the water resources has focused attention on the need for sound overall planning and management based on scientific knowledge. People are becoming increasingly cognizant of the upstream management possibilities for improving water yields. Increased public pressure and demand for scientific watershed management aimed at improving water yield can be expected. Besides this it is also necessary to understand the hydrologic process operating on these basins. Use of representative basins for this purpose is relatively of recent origin, and these are not so much concerned with the identification of changes but are used to identify similarities. These are based on the assumption that the basins can be characterised in terms of similarities in the properties which have a significant effect on the hydrologic cycle.

There is need for research to be carried out on all important soil/ vegetation complexes,to understand hydrological characteristics and their interdependence on multiple complexes, of so called Representative Basins and catchments (typical of large hydrological regions). Such research will be a lengthy process and results will not be available for a considerable time. Since the problems are immediate, it is essential that certain approximating solutions should be provided on a short term basis. Such solutions are not only required to provide a predictor equation of the effect of present changes in land use/ management, but also for flood and erosion problems caused by past land use/ management changes. Such short term solutions can be provided from provisional results obtained on Representative Basin.

There is a need to evolve practical procedures to use the data observed in representative basins to improve the efficiency of hydrologic design for structures of large basins for utilisation of water resources to meet the ever increasing demands (Body 1980)

1.1 Definition of Representative Basin

Linsley (1976) defined the representative basin as " A representative basin is a well instrumented basin which is intended as an index to the behaviour of others for flow forecasting purposes, or as a site for testing hydrological procedures on a set of 'representative date'. Representative Basins are better defined as basins which are selected as representative of a hydrological region, i.e. a region within which hydrological similarity is presumed. They are used for intensive investigation of specific problems of the hydrologic cycle under relatively stable, natural conditions. Thus a sparse network of representative basins may reflect general hydrological features of a given region and their variation over large natural zones. According to the Australian Water Resource Council (1969) a representative basin is one which contains within its boundaries a complex of landforms, geology, landuse and vegetation and which can be recognised in many other catchments of a similar size throughout a particular region. Recently Toebes and Ouryvaeu (1970) have defined the representative basins as " Representative basins are basins which are selected as representative of a hydrological region, i.e., region within which hydrological similarity is presumed.

Riggs (1970) considers a representative basin as "One chosen and instrumented for two purposes : (1) to gain an understanding of the hydrologic process in that hydrologic setting,and (2) to develop procedures by which streamflow characteristics may be transferred to ungauged catchments . In addition a network of Representative Basin can at the same time fulfill the role of a basic network for long term observations to which short term observations can be correlated. The representative basins should have minimal natural or cultural changes during the period of study and in case the changes take place then these should be carefully recorded. The size of representative basin may vary depending upon the conditions and objectives of study. It is better that the area should not exceed more than 1000 km^2 as it may cause certain difficulties in the homogeneity of certain basin characteristics and in the organization of instrumentation and observations.

In the case of representative areas it is the selection of place that is of decisive importance. It follows from the nature of the matter that representative areas are always to be designated networklike,since a certain region or the complex of its subregions,respectively can always be substituted adequately by several sub-regions. As regards instrumentation and schedule of observations, representative areas need not differ essentially from the neighboring areas observed from hydrologic point of view.

Assessment of water resources and impact of landuse changes and vegetal cover requires data collection and research on a geographically well distributed network of representative and experimental basins.

1.2 Scope of Representative Basin Studies

The study in representative basins should be long term and combined with the study of climatic, pedological, geological, geomorphological and hydrogeological characteristics. These studies should be oriented to

- fundamental hydrological research;
- the determination of the effect of natural changes of the hydrological regimen;
- hydrological prediction;
- the formation of a basic network of stations to which short term records from the temporary stations can be correlated, and estimation and prediction can be made for ungauged stations.

1.3 Selection of Representative Basins

In the selection of representative basins following points should be kept in view :

a) It should cover typical catchments over the entire country, as regards size as well as other physical characteristics.

b) The number should be sufficient to represent important regions and they should be operated on a long term basis.

c) It should be capable of being instrumented for accurate long term measurement of atleast flow and precipitation.

d) It should have reasonably uniform physical conditions for quantitative determination of catchment characteristics and subsequent interpretation of data.

e) It should have minimal changes in catchment characteristics, during the period of observation or where they occur these should be carefully recorded; catchment selection may in many cases be done in areas which are beyond possible water resource or control development; more difficulty may be experienced in maintaining a constant land use/management in an eroded country like India which has also extensive agricultural and forest development.

This aspect has been discussed in details in the following chapters.

2.0 OBJECTIVES OF REPRESENTATIVE BASINS STUDIES

To understand the hydrological system and their changes in different hydrological regions representative basin studies are required. The following objectives can be achieved by representative basins :

2.1 Fundamental Research

Representative basins are frequently used for fundamental research. This can take the form of a study of all the physical processes of the hydrological cycle or of any part of it or of any specific hydrological characteristics. It includes research on observational techniques.

The primary motivation of this research is the study of the physical phenomena and, as such is ideally suited for the training of staff. It can be carried out on individual basins or on network of basins.

2.2 Effect of natural changes

Some representative basins, especially benchmark and vigil basins, may be used to study the effects on the hydrological regimen of a natural change. Natural changes may, for instance, be changes in climate, in vegetational characteristics (because of natural growth), in pedological characteristics such as erosion, ponzolization, etc.

2.3 Hydrological prediction

Most representative basins will be used for the development and improvement of methods of hydrological

3.0 SELECTION OF BASIN

The selection of basin is foremost important stage of the organization of observation and research on Representative Basins. Difficulties are caused by the specific requirements and the lack of clear quantitative criteria for proper selection. The principal requirement for Representative Basin is the representativeness (the correspondence of their physiographical characteristics to those of the hydrological region). It is very difficult to select a basin which is representative of all hydrological features and to satisfy simultaneously all other requirements.

3.1 Selection of Hydrological Regions

For the initial selection of hydrological regions which are used for the establishment of representative basin, natural physiographical regions should be used. The natural physiographical regions are sufficient characteristics in many hydrological aspects. The size of a region depends somewhat on the purpose for which a Representative Basin is to be established and on the physiographical conditions of the country. Where detailed hydrological data for the selection of hydrological regions are not available, selection must be on climatic, vegetational, geomorphological, pedological and geological characteristics.

3.2 Selection of Representative Basins

Having delineated hydrological regions, it is necessary to select a Representative Basin for each region. Countries which have great physiographical variations need a dense network of basins, while countries which are rather uniform in character need only a few basins. The distribution of these basins over large areas will therefore be non-homogeneous in space.

The selection of Representative Basins is governed to a certain extent by their purposes and either a compromise must be made in the selection or a Representative Basin must be selected for one or two specific purpose only. In some countries the representative basin network can serve partly or wholly as the basic network of gauging station .

3.2.1 Representativeness

It is most important to consider whether the basin selected represents the hydrological regions. As a guide, the type and range of climatic, vegetational,geomorphological, pedological and geological characteristics of the basin should be compared with those of the hydrological region. A simple way of doing this is to select a basin which has the same classification as the region.

It must be realized, however, that successful basin selection depends, a priori, on the relative success of the definition of hydrological regions.

3.2.2 Basin Divide

The basin divide should be as distinct as possible for the exact determination of the basin areas.

In some cases, if a basin is suitable in all other aspects but the basin divide is not clear, an artificial divide can be constructed by means of small dams, etc.

The 'surface' basin divide should also be coincident with the 'subsurface' basin divide. Where possible, stream piracy should be prevented by artificial means. It should be noted that with a decrease of the basin area, the relative influence of non-coincidence of surface and subsurface basin areas will increase.

Basins with coincident surface and subsurface divides are difficult to find but, if this requirement is not met, at least for the upper aquifers, great problems occur in water-balance calculations.

3.2.3 Consistency of condition

The cultural changes in land use, land management, streamflow utilization, etc. should be minimal during the period of study and, where they are inevitable, should be carefully recorded. Where representative basins are designated benchmark basins, it is imperative that cultural changes be prevented entirely and that natural changes be minimal.

3.2.4 Deep Percolation and Channel Infiltration

The loss of subsurface flow by deep percolation, or the gain of this flow from neighboring basins, must be as small as possible unless the study of the representative basin is, per se, the study of such leakages.

3.2.5 Quality of Flow-Measuring Station

It is essential that the stage-discharge relation is relatively constant. For this purpose, the site for a gauging station should have a natural control or, if this is not available, an artificial control should be constructed. Site selection should be carried out according to standards .It is important that flow characteristics as they relate to channel features are typical of the region expected in arid or semi-arid zones where it may be advantageous to select, if possible, a basin that has perennial or intermittent flow, or at least has some subsurface flow during and shortly after storms.

3.2.6 Access

Access to the gauging station should be available for every streamflow condition. Access in the basin should be such that precipitation and other climatic observations can be carried out. In very difficult terrain, consideration should be given to wholly automated recording of these variables.

3.3 Coincidence of Representative Basin with economic development of basins

Provided that this condition does not clash with the provision of (3.2.3) above, representative basins can be basins which are being investigated for economic development. It is important to consider, however, that measurement and analysis must, in the first instance, be geared entirely to the purpose of

4.0 OBSERVATIONAL PROGRAMME FOR REPRESENTATIVE BASINS

Representative basins should, as far as possible have identical programme and methods of observation to facilitate a comparison of the research result. There are some minimum and special equipment requirement. These include atleast observations on streamflow and precipitation to study basic flow processes. After certain minimum studies, a progressive increase in the observations can be made as dictated by the early research findings. Such a progressive development of observation will ensure a better adaptation of measurements to the problems studied and to the particular condition in the basin. Moreover, observations for representative basins must be carried out to suit the analysis techniques. However the main observational programme will depend upon the use of such studies. Here below, the use-wise observational programme is being discussed.

4.1 For Fundamental Research

Such programmes may need to be fairly complete observational ones but are naturally dictated by the objectives. If, for examples, the hydrological differences between shady and sunny slopes are to be studied, the observational programme must include at least the following for both slopes : flow (frequently with the aid of run-off plots), precipitation, micro-climate, soil moisture, and infiltration.

4.2 For the Study of the Effect, on the Hydrological Regime, of Natural Changes (benchmark and vigil basins)

The study of the effect, on the hydrological regime, of a natural change (for instance, climatic or geomorphological) is extremely difficult. The basin, and consequently the hydrological characteristics, is in a continuous change and this 'non-stationary condition of the basin is difficult to analyse. The observational programme must, therefore, allow for rather precise observations of certain basic elements.

Climatic changes are usually long term and changes over a shorter period within the natural variability of observed phenomena. For this reason, a study of micro-climatic changes may be more productive. As an example of the observational requirements for an expected geomorphological change, the following programme should be regarded as a minimum : flow, precipitation, climate, soil frost, erosion and sedimentation, and geomorphology.

4.3 For Hydrological Prediction

Most representative basins will be used for this purpose and the programme should specify whether long-term or short-term prediction studies are intended so that the observational programme can be adapted accordingly. Moreover, different programmes may be required according to whether or not the prediction requirements will affect the period of observational and processed data, e.g., whether daily or weekly mean discharges are required.

As an example, the minimum observational programme for a representative basin used for long-term prediction of ground water could be as follows (unconfined aquifer): delineation of aquifer ; flow (base-flow studies) especially at spring; infiltration (especially the rate of percolation from the surface to the aquifer).

4.4 For Extension Of Records

This is strictly a special case of hydrological prediction. The important requirement is that observations are made in a similar fashion to that for the short-term station for which extension of records is required. In general, the programme can be restricted to flow and precipitation observations.

4.5 To what use NIH will put it ?

National Institute of Hydrology is to carry out programme which falls in 1st category i.e. fundamental research. The data, thus, collected and consequently analysed may be used for other purposes also with certain modifications if necessary.

5.0 METHODS OF OBSERVATION AND INSTRUMENTATION

Instrumentation and observation of phenomena in Representative Basins is extremely costly and it is very difficult to obtain accurate data on any one characteristic. For this reason it is essential that as many methods as possible are standardized; that instruments are of a similar nature, if possible (to simplify maintenance problems); that observations are made by standard methods; and that instruments are as used by National Hydrological and Meteorological services or as recommended by WMO (249).

General requirements for such instruments are that they should be designed to ensure accurate measurements, they should be reliable in operation, and they should be simple and sturdy and be constructed in such a way that readings are easily made.

Instruments should be supplied with factory certificates and, from time to time, tests should be made on them in special calibration laboratories or else. Their readings should be compared with those of standard instruments (since all hydrological instruments eventually vary from their original calibration).

Special attention should be paid to the method of installation, because the accuracy of almost all instruments depends to a large extent on their proper installation.

In some sparsely populated regions the possibility of damage to instruments by wild animals should be taken into consideration and spares should be available to ensure continuous observations. Recording gauges should be used to make continuous observations where possible. It should be noted that recording gauges, as a rule, do not provide absolute readings and that regular and accurate readings of non-recording gauges are therefore required in addition to obtain absolute values; for example, readings of a staff gauge are associated with those of automatic water-level recorders, etc.

5.1 Precipitation

Precipitation is measured as the vertical depth of water (or water equivalent in the case of snow) that would accumulate on a flat level surface if all the precipitation remained where it had fallen. The measurement of precipitation therefore, presumes that the observations made at a point is representative of certain area around the point to which measurements refer to. There are two types of rain gauges : Nonrecording and Recording.

The raingauge consists essentially of a collector which intercepts the sample of rainfall to be measured and a receiver consisting of a base and a bottle in which the rainfall collected is stored. The collector is exposed above the ground level while the receiver is fixed partially below ground level.

Types : 1S:5225-1969 specifies two collectors 200 cm^2 and 100 cm^2 in area, two bases and three bottles of capacities 2,4 and 10 liters. All components are completely interchangeable and combinations of these provide the raingauge as given below:

Nominal measuring capacity and combinations.

Nominal Measuring capacity, mm rainfall	Collector	Base	Bottle
100	200 cm^2	small	2 litre
200	200 cm^2	small	4 litre
400	100 cm^2	small	9 litre
1000	100 cm^2	large	10 litre

Designation

The raingauge shall be designated by the nominal measuring capacity as shown above.

5.1.1 Rain measures These are nothing but measuring cylinders to measure the rainfall collected for use with raingauges having collector areas of 200 cm^2 and 100 cm^2.

Types

The rain measures shall be of the following types :

(a) Type 1 - 20 mm capacity rain measure suitable for use with precipitation gauges having collectors of 200 cm^2 area.

(b) Type 2- 10 mm capacity rain measure suitable for use with precipitation gauges having collectors of 200 cm^2 area and

(c) Type 3 - 20 mm capacity rain measure suitable for use with precipitation gauges having collectors of 100 cm^2 area.

5.1.2 Recording Gauges

Recording gauges produce a continuous plot of rainfall against time and provide valuable data of intensity and duration of rainfall for hydrological analysis of storm. The following are some of the commonly used recording gauges.

Tipping of Bucket Rain Gauges

It consists of a 300 mm diameter funnel which collects rainwater and conducts it to a pair of small buckets pivoted just below the funnel. The buckets are so designed that when 0.25 mm of rainfall collects in one bucket, it tips and empties its water into the storage tank below and at the same time the other bucket is brought under the funnel. The tipping of the bucket actuates an electric circuit which causes a pen to make a mark on a record sheet on a clock driven revolving drum, since each mark on the record sheet corresponds to 0.25 mm of rainfall, by counting the same, the intensity of rainfall may be determined. The total rainfall as determined from the record at the end of the day may also be checked by measuring the rainwater collected in the storage tank in the same manner as in the case of a non-recording gauge.

Weighing-Bucket Type

In the raingauge, the catch from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket and its contents are recorded on a clock-driven chart. The clockwork mechanism has the capacity to run for as long as one week. This instrument gives a plot of the accumulated rainfall against the elapsed time i.e. the mass curve of rainfall. In some instruments of this type the recording units are so constructed that the pen reverses its direction at every present value so that a continuous plot of storm is obtained.

Natural Siphon Type Recording Raingauge

The recording raingauge consists of a collector and is rainfall recording mechanism mounted on a base. The rainfall measuring unit consists of a float chamber containing a light metal float and a siphon chamber. The rain from the collector is led into the float chamber through an inlet tube and as the float rises, a pen fixed to the float rod draws a line on a chart wound on a rotating drum driven by clockwork. The discharge tube is inside and co-axial with outer tube of the siphon chamber. The top of this outer tube has a polished glass cap and the discharge tube comes to within a very short distance of this. When the level of water in the outer tube rises with that of water in the float chamber and flows over the bend, capillary action causes all the air to be pushed out and down the delivery tube so that a full flow is started at once. Similarly, at the end of the siphoning, once air gets to the top of the tube, the siphoning action is stopped immediately. When siphoning occurs, the pen fixed on the float rod falls to the zero mark on the chart and the gauge is ready to record rainfall again.

Types :

The natural siphon recording raingauge shall be of two types depending on the intensity of the rainfall to be measured :

(a) Recording Raingauge for 10 mm rainfall :

Natural siphon recording raingauge having a collector 325 cm^2 area with a range 0 to 10 mm of rainfall per siphoning used in regions of light or medium rainfall, and

(b) Recording Raingauge for 25 mm Rainfall:

Natural siphon recording raingauge having a collector 130 cm^2 in area with range 0 to 25 mm of rainfall per siphoning for use in regions of heavy rainfall.

Designation

For the purpose of inquiry or order, recording raingauge shall be designated by the maximum of the range of rainfall per siphoning as shown below

Example

A complete recording raingauge with a range 0 to 10 mm rainfall per siphoning, conforming to 1S:5225-1969 small be designated as:

Raingauge, Recording 10 mm Rainfall 1S:5225

Measure Glasses for Recording

The measure glasses shall be of the following two types

(a) 10 mm capacity measure glass for 325 cm^2 recording raingauge.

(b) 25 mm capacity measure glass for 130 cm^2 recording raingauge.

5.2 Interception Losses

5.2.1 Interception of precipitation by vegetation

A large part of the rainfall falling upon forests is evaporated from the aerial parts of trees and from the litter beneath them. Because interception loss may affect total water yield from forest lands, hydrologists need estimates of these losses. For convenience, interception variables are classed as climatic factors or as stand characteristics. Total rainfall and storm frequency are the two most important climatic variables. Analysing gross rainfall and interception factors by covariance techniques usually removes 95 percent or more of the variation between individual measurements. Other climatic variables (i.e., rainfall intensity, wind speed and air temperature are sometimes statistically related to interception factors, but their net effect is small.

5.2.2 Throughfall

Water filtering through the forest canopy varies from point to point by 100 per cent or more. Small cylindrical gauges are favoured because they are easily obtained and positioned in the field. Furthermore, because gross rainfall is sampled with round gauges, the use or round throughfall gauges avoids the problem of comparing data from different types.

5.2.3 Stem flow

Stem flow is usually less than 10 percent of gross rainfall and it is often omitted in interception studies. This omission leads to over estimates of total interception loss and stem flow must therefore be measured in any complete interception study.

Stem flow is sampled by sealing collars or copper or tin sheeting ~~to~~ trees to divert down flowing water into containers for measurement.

5.2.4 Interception of dew and fog

Although different in origin, dew and fog present similar interception problems. Of chief concern is the accurate measurement of the gross precipitation, as the canopy concentrates the moisture which can then be collected by conventional throughfall and stemflow techniques.

Various methods are available for measuring dew. Weighing was the first to be used, but has generally proved cumbersome. The Kessler-Feuss recorder is a refined weighing type. Thermoelectric, absorption and optical method, lack repeat ability, accuracy and sensitivity respectively.

Several of the devices available for dew measurement could be used to record fog. Of these, the most common equipment consists of a series of wire or fiber strands in a frame sited normally to the direction of fog drift.

5.3 Evaporation and Evapotranspiration

Evaporation is the process in which a liquid changes to the gaseous state at the free surface below the boiling point through the transfer of heat energy.

Transpiration is the process by which water leaves the body of a living plant and reaches the atmosphere as water vapours. The water is taken up by the plant-root system and escapes through the leaves.

While transpiration takes place, the land area in which plants stand also loose moisture by the evaporation of water from soil and water bodies. In hydrology and irrigation practice it is found that evaporation and transpiration processes can considered advantageously under one head as evapotranspiration. The term

consumptive use is also used to denote this loss by evapotranspiration. For a given set of atmospheric conditions,evapotranspiration obviously depends on the availability of water. If sufficient moisture is always available to completely meet the needs of vegetation fully covering the area, the resulting evapotranspiration (PET).
Evaporation is estimated by the following methods :

(a) Using evaporimeter data
(b) Empirical evaporation equation
(c) Analytical methods

The following are the evaporimeters generally used in India.

Class A Evaporation Pan

It is a standard pan 1210 mm diameter and 255 depth used by the US Weather Bureau and is known as Class A Land Pan. The depth of water is maintained between 18 cm and 20 cm. The pan is normally made of unpainted galvanized iron sheet. Monel metal is used where corrosion is a problem. The pan is placed on a wooden platform of 15 cm height above the ground to allow free circulation of air below the pan. Evaporation measurements are made by measuring the depth of water with a hook gauge in a stilling well.

ISI Standard Pan

This pan evaporimeter specified by IS:5973-1970, also known as modified class A Pan, consists of a pan 1220 mm in diameter with 255 mm of depth. The pan is made of copper sheet of

0.9 mm thickness, tinned inside and painted white outside. A fixed point gauge indicates the level of water. A calibrated cylindrical measure is used to add or remove water maintaining the water level in the pan to a fixed mark. Top of water maintaining the water level in the pan to a fixed mark. The top of the pan is covered fully with a hexagonal wire netting of galvanized iron to protect the water in the pan from birds. Further, the presence of wire mesh makes the water temperature more uniform during day night. The evaporation from this pan is found to be less by about 14% compared to that unscreened pan. the pan is placed over a square wooden platform of 1225 mm which and 100 mm height to enable circulation of air underneath the pan.

Colorado Sunken Pan

This pan, 920 mm square and 460 mm deep is made up of unpainted galvanised iron sheet and buried into the ground within 100 mm of the top . The chief advantage of the sunken pan is that radiation and aerodynamic characteristics are similar to those of a lake. However, it has the following disadvantages:

(i) difficult to detect leaks,

(ii) extra care is needed to keep the surrounding area free from tall grass, dust etc. and

(iii) expensive to install.

US Geological Survey Floating Pan

With a view to simulate the characteristics of a large body of water, this square pan (900 mm side and 450 mm depth) supported by drum floats in the middle of a raft (4.25 m x 4.87 m) is set afloat in a lake. The water level in the pan is kept at the the same level as the lake leaving a rim of 75 mm. Diagonal baffles provided in the pan reduce the surging in the pan due to wave action. Its high cost of installation and maintenance together with the difficulty involved in performing measurements are its main disadvantages.

Evaporation Stations

It is usual to install evaporation pans in such locations where other meteorological data are also simultaneously collected. The WMO recommends the minimum network of evaporimeter stations as below :

1. Arid Zones - One station for every 30,000 km^2,
2. Humid temperate climates - one station for every 50,000 km^2, and
3. Cold regions - One station for every 100,000 km^2.

Currently India has about 200 pan-evaporimeter stations maintained by the India Meteorological Department.

The measurement of evapotranspiration for a given vegetation type can be carried out in two ways either by using lysimeters or by the use of plots.

Lysimeters

A lysimeter is a special watertight tank containing a block of soil and set in a field or growing plants. The plants grown in the lysimeter are the same as in the surrounding field.

Evapotranspiration is estimated in terms of the amount of water required to maintain constant moisture conditions within the tank measured either volumetrically or gravimetrically through an arrangement made in the lysimeter. Lysimeters should be designed to accurately reproduce the soil conditions, moisture content, type and size of the vegetation of the surrounding area. They should be burried that the soil is at the same level inside and outside the container. Lysimeter studies are time-consuming and expensive.

Field Plots

In special plots all the elements of the water budget in known interval of time are measured and the evapotranspiration determined as

Evapotranspiration = [precipitation + irrigation input - run-off - increase in soil storage - groundwater loss]

Measurements are usually confined to precipitation, irrigation input, surface run-off and soil moisture. Groundwater loss due to deep percolation is difficult to measure and can be minimised by keeping the moisture condition of the plot at the field capacity. This method provides fairly reliable results.

5.4 Wind, Temperature and Humidity

Measurement of wind,temperature and humidity are needed to support many types of hydrologic analyses. Wind is commonly measured using an anemometer, a device that has a wind propelled element such as a cup or propeller whose speed is calibrated to reflect wind velocity. Wind direction is obtained using a vane, which orients itself with the direction of the wind.

Temperature measurements are made using standard thermometers of various types while humidity is measured using a psychrometer. A psychrometer consists of two thermometers one called wet bulb the other a dry bulb. Upon ventilation, the thermometers measure differently and this difference is called the wet-bulb depression. By using appropriate tables, low point, vapour pressure and relative humidity can be determined. Fig (1) shows standard layout of instruments at the meteorological observation site.

5.5 Stream Gauging

Direct collection of stream flow data is called stream gauging and involves measurement of stream discharge and water surface elevation. Stage records are obtained by systematic observations on a manual gauge or from an automatic recorder. Measurements of discharge are made to define the relation between stage and discharge, and this relation is used in computing a continuous record of stream-flow. These records are useful is evaluating the total water supply in forecasting events, in designing hydraulic structures, and in computing the load of streams.

5.5.1 Criteria for site selection

(i) The site should have a stable bank without the river overflowing it. The river should preferably flow in one channel. In case this is not possible, two straight channels are

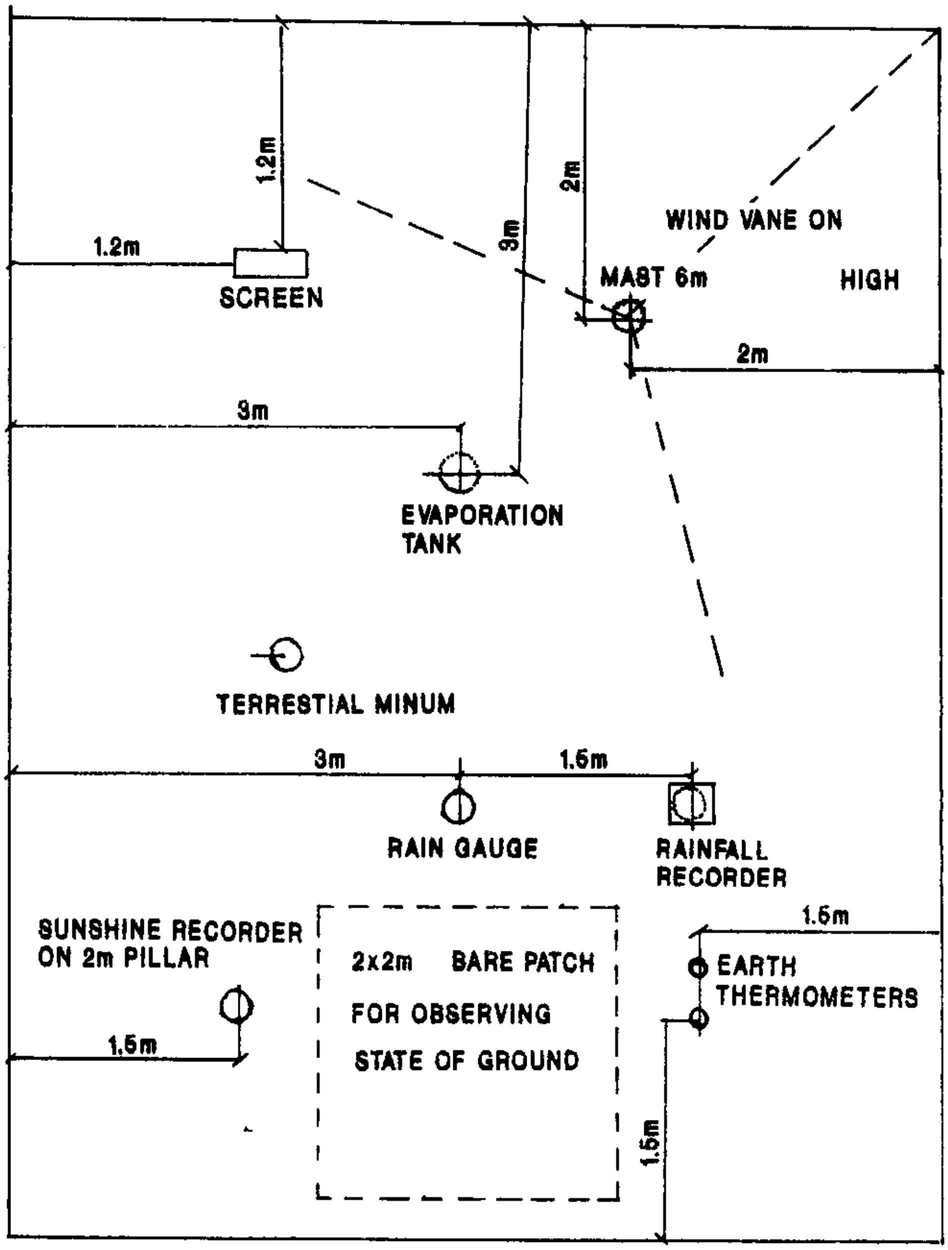


FIG.1 STANDARD LAYOUT OF INSTRUMENTS AT THE METEOROLOGICAL OBSERVATION SITE

preferable to one defective channel.

(2) The site should be in a straight reach of as much length as possible, but not necessarily longer than two kilometers. The length of the run should be 300 to 800 meters depending upon the size of the stream. The stretch to be chosen should be stable and not subject to degradation or aggradation. The bed should drop gradually throughout this reach.

(3) Cross section within the reach should be reasonably uniform at all times of the year.

(4) The direction of the river current should be as divergent as possible from the prevailing wind directions.

(5) The site should be reasonably away from bridges, falls or other structures to avoid their resultant effects on water flow, unless the bridge itself happens to be the discharge observation site.

(6) When near confluences, it should be sufficiently upstream if located on a tributary, and sufficiently downstream if located on the main stream so as to be free from the effects of confluence.

(7) The flow in the reach should be normal to the cross section of the stream.

(8) Where there is a tendency to form a vortex or where there is a backwater flow, the site should be avoided.

(9) The site should be located in the reach where flow is normal, i.e., it should neither be retarded by the formation of site or shingle bars nor accelerated being just below the shingle or silt bars. There should not be any eddies or cross current

formations in the flow.

(10) A normal section should be located in the middle of the selected reach. Subsidiary sections, for fixing slope gauges, should be at the upstream and downstream ends of the straight reach which should be twice the width of the river. When this length is not available, it should be at least half the high supply river width in order to obtain correct measurement of slope.

(11) The site, as far as possible, should be free from trees and obstructions which may interfere with water flow and clear vision during observations.

Station Control

The control is a cross-section or reach of river channel that determines the relationship between stage and discharge at that section for some distance upstream. Controls may either be natural or artificial, depending upon whether they are of natural origins or have been constructed either for specific purpose of stabilising the stage-discharge relation or for some other reasons.

If the stage-discharge relationship of a gauging section is constant and does not change with time the control is said to be permanent. If it changes with time, it is called shifting control.

Water Stage

The stage of a stream or lake is the elevation of the water surface at a specific station above some arbitrary zero datum. the term gauge height is often used interchangeably with the more general term stage. Stage or gauge height is usually expressed in meter divided in hundredths.

Staff gauges

The simplest way to measure river stage is by means of a staff gauge a scale set so that a portion of it is immersed in the water at all times. The gauge may consist of a single vertical scale attached to a bridge pier, piling, wharf, or other structure that extends into the low water channel of the stream. The gauge height records may be obtained by systematic observations hourly or thrice a day.

Recording gauges

Manual gauges are simple and inexpensive but must be read frequently to define the rise and fall of a water surface adequately when the stage is changing rapidly. Water stage recorders overcome this difficulty. It is an instrument for producing a graphic record of the water level fluctuations with respect to time. The line element is controlled by a clock and the gauge-height element is actuated by a float and a counter weight as the water level rises or falls.

5.6 Discharge Measurement

Current meters

River discharge is the volume of water flowing through a cross-section in unit time. Since the control rarely has regular shape for which the discharge can be computed, calibration is accomplished by relating field measurements of discharge with the simultaneous river stage. A current meter is an instrument used to measure the velocity of flowing water.

The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor during a measured time interval, the velocity of water is determined from the rating of the meter. The rating formula may be written as

$$V = an+b \qquad \ldots(1)$$

Where,

v = velocity (m s^{-1})
n = the number of revolutions per second
a & b = constants

Both horizontal axis propeller meters and vertical axis propeller meters are common. Each current meter has its own formula. The rating is done in tanks where the instrument is driven with known velocities through still water. The current meter measures the water velocity at a point. The methods of making discharge measurement at a river cross-section require determination of the mean velocity in a number of selected verticals, sufficient to permit computation of the average velocity in the stream. The cross-sectional area multiplied by the average velocity gives the total discharge.

Vertical-velocity-curve method

This method is considered to be the most accurate one for determination of discharge by using a current meter.

Observation verticals should be located so as to best define the variation in elevation of the stream bed and the horizontal variation in velocity. In general, the the interval between any two verticals should not be greater than 1/20 of the total width, and the discharge between any two verticals should not be more than 10 percent of the total discharge. The velocity is measured at various depths in the verticals. Usually a maximum of five points is sufficient and these should be placed as follows :

1. As near the surface as possible
2. At approx. 2/10 of the total depth.
3. At approx. 5/10 of the total depth.
4. At approx. 8/10 of the total depth.
5. As near the bottom as possible.

Velocity varies approximately as a parabola from zero at the stream bottom to a maximum at (or near) the surface. The particular vertical distribution for each vertical is, however, dependent on the stream bed condition and the rate of turbulence.

Each vertical-velocity-curve is first plotted on an ordinary graph paper and the areas enclosed are computed. These areas represent the product of the mean velocity and the mean depth and are of the dimension $ms^{-1}.m = m^2s^{-1}$. The value of this product at each vertical is then plotted against the width of the river (discharge distribution curve). The area enclosed is of the dimension $m^2s^{-1}.m = m^3s^{-1}$ and represents the discharge of the cross-section.

When computing areas with the dimensions mentioned, the scale factor must be taken into account. By using a planimeter or simply by counting the number of squares, the obtained area is converted into the right dimension by multiplying with the horizontal and also the vertical scale factor.

Computer programs are also available for the computation of discharge.

Two-point method

In this method velocity observations are taken at 0.2 and 0.8 of the total depth. The average of the two values is taken to be the mean velocity in the vertical.

Experience has shown that this method gives more consistent and accurate results than any of the other methods if the number of verticals are sufficiently high. At least 30 verticals should be used.

Six-tenths-depth method

In the 0.6 depth method, velocity observations are taken at 0.6 of the depth, and this value is taken to be the mean velocity in the vertical.

This less-accurate method can be used when the two other methods described are not applicable for instance :

1. When large amounts of slush ice or debris are following, making it impossible to observe the velocity in the upper part of the verticals.
2. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Two-tenths-depth method

In this method, the velocity is observed at 0.2 of the the depth, and then a coefficient is applied to obtain the mean velocity in the vertical. The method should be used only when more accurate methods cannot be used, for instance during periods of high water when the velocities are great and it is impossible to obtain sounding or to place the meter at the 0.8 or the 0.6 depths.

A commonly used coefficient to adjust the 0.2 depth velocity to the mean velocity is 0.88. However, this coefficient should be determined for each measuring section based on measurements where it was possible to measure velocities at greater depths. Experience shows or varies uniformly with stage.

5.6.1 Selection of site

Regardless of the method employed, the accuracy of current meter measurements depends largely upon the characteristics of the metering section. The conditions that favour good results are as follows :

1. The section should be straight and uniform for a distance upstream equal to at least five times the width of the stream.
2. The bed of the stream should be smooth. It should be free from vegetal growth, boulders, or other obstructions.
3. The bed and banks of the stream should be firm and stable.
4. The current should be normal to the metering section.
5. There should be no large overflow section at flood stage.
6. Velocities should be more than 0.15 m s^{-1} and less than 2.5 ms^{-1}.

Measurement of width and depth

The distance to the verticals and the width of the channel are normally measured by a measuring tape or tag line. The measurements in each vertical can be made from bridges, by cableways , by wading or from ice cover. The method chosen is dependent on the conditions at the site.

The measurement of depth requires some further remarks. In many cases the depth is read directly on a graduated rod set on the stream bottom. For measurements in deep water, the meter is often suspended from a cable. Tail vanes to keep the meter facing into the current and a heavy weight to keep the meter cable as nearly vertical as possible are provided. If water velocities are high, the meter and weight will not hang vertically below the point of suspension but will be carried downstream by the current. If the weight on the sounding line is not sufficient to keep the line within 5° of perpendicular to the water surface, the angle between the line and the vertical (0) should be measured to the nearest degree with a protractor. The angle should not exceed 30°.

Figure (2) shows the position assumed by the sounding line as the weight, just off the bed of the stream, is supported entirely by the line. From this figure it is seen that if the weight is slowly lowered to the bottom of the stream, then from the length of cable af must be deducted the distance ae and the difference between the length of ef and bc, in order to determine the depth bc. Both these corrections are functions of the angle 0.

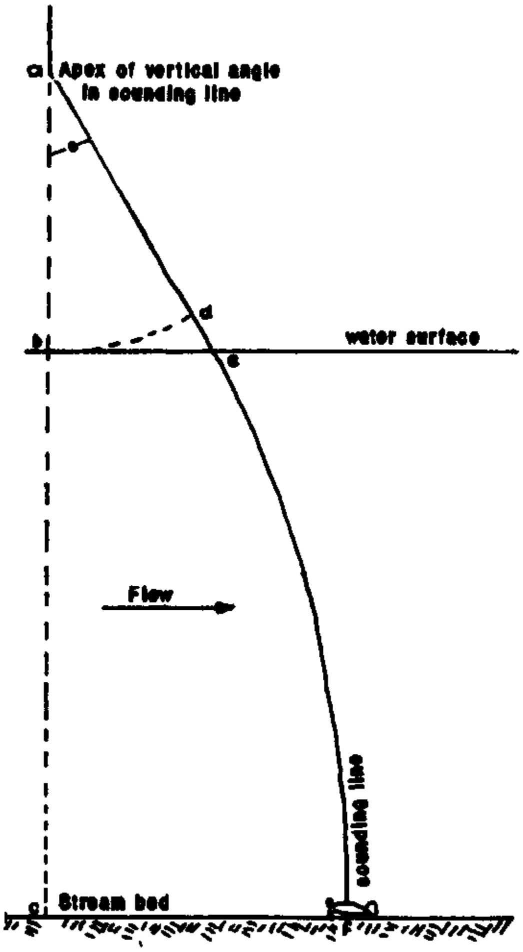


FIG.2 DEPTH CORRECTION

In the figure, ae = ab/cos0. The difference between the length of ef and the depth bc is determined empirically and is equal to k.ef. The following table gives the correction factor k for given values of 0.

0	k	0	k
4°	0.0006	18°	0.0164
6	0.0016	20	0.0204
8	0.0032	22	0.0248
10	0.0050	24	0.0296
12	0.0072	26	0.0350
14	0.0098	28	0.0408
16	0.0128	30	0.0472

Depth correction

If the stream bed is stable, the following method can also be used to make depth corrections. A cross-section survey is made in time of low water. All depths are related to an auxiliary gauge in the measuring section. In this way the correct depth is known at any place in the cross-section and corrections can be made accordingly. Depth corrections for the different points in the vertical are done proportionally accordingly to depth of measurement.

In order to increase the accuracy of the depth measurement, the sounding weight may be equipped with an electrical device which singles the moment the weight makes contact with the stream bed.

Corresponding stage

The stage and the corresponding time should be noted at intervals in such a manner as to identify segments of the total discharge with time and stage. Usually the stage at the mid-time of the measurement can be used as the stage corresponding to the measured discharge. However, if the stage does not change linearly with time, the following weighting procedure should be used, where h is the weighted stage, $Q_1, Q_2, \ldots\ldots$ are segments of discharge corresponding to $h_1, h_2 \ldots$ and A is the total discharge.

$$h = \frac{Q_1 h_1 + Q_2 h_2 + \ldots\ldots + Q_n h_n}{Q} \qquad \ldots(2)$$

Discharge Measurement by dilution methods

Discharge measurements in turbulent rivers can be difficult or impossible to carry out with a current meter. In such cases dilutions methods as described in the following can often be recommended.

The two principal tracer methods used for discharge measurements are the constant-rate injection method and the sudden injection method. The general requirement for both methods are the same.

General requirements

The dilution method is applicable to the measurement of the discharge in channels where the degree of turbulence is sufficiently high to ensure efficient and complete mixing of the injected solution throughout the whole flow. This will normally be the case in hill streams and torrents where the conditions for current meter measurements are unfavourable. The accuracy of the method critically depends on

(a) Complete mixing of the injected solution throughout the stream cross-section before the sampling section is reached.

(b) no absorption or adsorption of the added tracer by bottom material, sediments or organism, and no decomposition of the added tracer in the water of the stream.

Slope-Area Method

A slope-area measurement is the most used form of indirect measurement of discharge. It may be utilized in the determination of mean velocity and total discharge for any stages at which current-meter measurement are not possible or practicable. The greatest value of the method in general stream-gauging lies in the means it affords of ascertaining the magnitude of peak flows, usually after such floods have passed. If correlated with a peak gauge height at the station gauge, such determinations are extremely valuable in helping to define extensions of rating curves above the highest available current-meter discharge measurements.

Basic equations

The slope-area method is based on the use of the Manning's equation, written in terms of discharge

$$Q = 1/n * AR^{2/3}S^{1/2} \text{ (in metric units)} \qquad \ldots(3)$$

Where,

Q = discharge

A = Cross-sectional area

R = hydraulic radius

S = Slope of the energy gradient (or friction slope)

n = roughness coefficient

Flow-Measuring Structures

Use of structures like nothches, weirs, flumes and sluice gates for flow measurement in hydraulic laboratories is well known. These conventional structures are used in field conditions also but their use in limited by the ranges of head, debris or sediment load of the stream and the back-water effects produced by the installations. To overcome many of these limitations a wide variety of flow measuring structures with specific advantages are in use.

The basic principle governing the use of a weir, flume or similar flow measuring structure is that these structures produce a unique control section in the flow. At these structures, the discharge Q is a function of the water-surface elevation measured at a specified upstream location.

$$Q = f(H) \quad \ldots (4)$$

Where,

H = Water surface elevation measured from a specified datum. Thus, for example, for weirs, eq. (4) takes the form

$$Q = KH^n \quad \ldots (5)$$

where,

H = head over the weir and K,

n = system constants.

Equation (4) is applicable so long as the downstream water level is below a certain limiting water level known as the modular limit. Such flows which are independent of the downstream water level are known as free flows. If the tailwater conditions do affect the flow, then the flow is known as drowned or submerged flow. Discharges under drowned condition are obtained by applying a reduction factor to the free flow discharge. For example, the submerged flow over a weir is estimated by the Villemonte formula,

$$Q_s = Q_1 \left[1 - \left(\frac{H_2}{H_1}\right)^n \right]^{0.385} \quad \ldots (6)$$

Where,

Q_s = submerged discharge,

Q_1 = free flow discharge under head

H_1 = upstream water surface elevation measured above the weir crest,

H_2 = downstream water surface elevation measured above the weir crest,

n = exponent of head in the free flow head discharge relationship. For a rectangular weir n = 1.5.

The various flow measuring structures can be broadly considered under three categories :

(1) Thin-plate structures are usually made from a vertically set metal plate. The V-notch, rectangular full width and contracted notches are typical examples under this category.

(2) Long-base weirs, also known as broad-crested weirs are made of concrete of masonry and are used for large discharge values.

(3) Flumes are made of concrete, masonry or metal sheets depending on their use and location. They depend primarily on the width constriction to produce a control section.

5.7 Subsurface water Observation and Measurement

5.7.1 Soil moisture

Soil moisture plays a significant role in the water balance of an area through its influence on the infiltration rate, the run-off, the evapotranspiration rate and the storage available for infiltration water prior to ground-water recharge. Since soils vary significantly, both horizontally and vertically, collection of areal moisture content information is extremely difficult. Methods for predicting soil moisture or soil-moisture change in a basin using other climatic factors have been developed, but these procedures require further assessment before recommendation for general use.

(a) Measurement methods and equipment

Currently, the five most frequently used techniques in the field are; tensiometers for controlled plot studies, electrical resistance units for obtaining a continuous recording of soil moisture in top soil layers or relatively dry soils, thermogravimetric methods (which are simple and economical and form the standards for calibration of other methods), lysimeters for measuring the changes in soil moisture with time, and neutron-scattering methods (which, although involving high capital cost, are the most accurate and should prove time-saving when employed on large projects). The neutron-scattering method is recommended for use on representative and experimental basins.

(b) Water in the saturated zone

All representative and experimental basins should be instrumented to permit definition of the geometry of the ground-water flow systems and to permit quantitative evaluation of their significance in the hydrological balance of the basin.

For water-balance calculations in representative and experimental basins, the study of the upper aquifers (which have a hydraulic relation with streamflow) is particularly important.

(c) Instrumentation

Ground-water equipment is designed to permit location of the ground-water surface (water table) and determination of the ground-water energy potential (measured by pressure) of a series of points. Pits, wells, springs and piezometers are used to observe ground-water conditions.

5.7.2 Infiltration

Lack of reliable data on infiltration has hindered progress for applications in basin hydrology. Methods of obtaining such data are analysis of rainfall and run-off data by infiltrometer; laboratory methods; and analysis of relations between precipitation and ground-water rise. Analysis methods, generally applicable to small basins only because of heterogeneity of large basins, require costly installations and long periods of maintenance between informative events.

Infiltrometer observations may give a fairly good insight into difference in permeability of the soil. They do not, however, give exact values of the hydraulic conductivity. Furthermore, they do not give an evaluation of the infiltration but only an order of magnitude of the infiltration capacity of the soil.

Infiltrometers

Infiltrometers are frequently used to speed up the collection of data. There are two general types of infiltrometer in use : the flood type and the rainfall-simulator type.

5.7.3 Measurement of phytomorphological characteristics

Vegetation measurements and descriptions are essential for the extrapolation of results of hydrological studies. In countries with a seasonal vegetative cover, phytomorphological characteristics bear a direct relation with certain hydrological processes and interrelations between the water-balance components.

Interception and evapotranspiration are the important characteristics that are related to phytomorphological characteristics, but development of foliage, grass cover and agricultural crops also influence the intensity of such processes as erosion, sedimentation, surface flow and infiltration.

5.7.4 Soil physical measurements

Soils differ greatly in their ability to accept, transmit or retain the water that reaches the surface of the ground. There has been considerable progress in the last decade or two in the understanding of the retention and movement of water in soil materials in terms of the interrelation of conductivity, moisture content and potential energy. The number of measurements required to characterize several horizons of each soil type present in a basin requires the use of relatively simple and rapid methods to assess the properties, texture and structure, which govern the interrelation of water content, conductivity and suction in the soil.

5.8 Erosion and Sedimentation

Erosion and sedimentation research projects that are undertaken in representative and experimental basins should be directed to basic processes of hydrology and geomorphology.

5.8.1 Measurement of erosion

The measurement of erosion on hillslopes, channel banks, and channel beds is considered separately from measurement of sediment discharge in streams, primarily because of the difference in the degree of refinement in techniques. Several relatively simple and inexpensive techniques have been developed in recent years for the measurement of changes in channel configuration, channel aggradation and degradation, sheet erosion, and mass movement of soils on hillslopes .

(a) Measurement techniques

A simple way to measure sheet and rill erosion on hillslopes, as it is used in several countries and is here given as an example, is to take a 25 cm nail, slip it through a large washer and drive it flush with the land surface. Subsequent erosion will undermine the washer and let it slide down the nail a distance equal to the increment of erosion . The nails and washers may be installed either in a specified grid pattern on a hillslope or in transects on contour or downslope.

The simplest way to monitor changes in stream- channel morphology is by a surveyed cross-section.

5.8.2 Sedimentation studies

(a) Techniques of sediment measurement

Ordinarily, suspended-sediment concentration are based on laboratory analysis of the water-sediment mixture obtained with a suspended-sediment sampler. Water discharge is computed from velocity measurements taken when the samples are selected. The suspended-sediment discharge per unit area at a point, or per unit width at a vertical, is computed from the sediment concentration and stream discharge.

(b) Sampling equipment

The six general types are : Ordinary vertical pipe; instantaneous vertical pipe ; instantaneous horizontal pipe; bottle type; pumping type; and integrating type.

(c) Sampling procedure

Samples of suspended sediment are collected using two basic methods, depth-integration sampling and point-integration sampling. Depth-integration sampling is used in most routine measurements of sediment discharge. The point-integration method is used on large rivers to define the vertical distribution of sediment.

5.8.3 Measurement of bed load

No reliable devices for sampling bed load exist. All existing devices, when lowered to the river bottom, disturb to some extent the natural regimen of sediment moving near the bottom and do not give accurate results.

For sampling coarse bed load, basket samplers, for sampling sandy and gravel sediments, so-called ribbed samplers are used.

Nuclear techniques for measurement bed-load transport have been most successful.

(a) Gauging methods

Bed load is measured for the purpose of calculating the annual sediment discharge. For this reason, depending on the river regimen, bed load should be measured frequently and preferably not less than ten times a year, including at flood periods.

(b) Bed-material observations

Observations of bed load may include the sampling of bed material at several velocity verticals of the gauging section for a determination of the size composition.

(c) Determination of concentration and particle size distribution

The determination of concentration and particle size distribution from suspended-sediment samples offer numerous problems. Samples may contain only minute quantities of sediment of very small particle size; or the sample may contain such large quantities of sediment that special procedures are necessary . The two most commonly used procedures for determining concentration are the evaporation method and the filtration method.

5.9 Measurement Of Water Quality

The dissolved and suspended material carried by natural waters are characteristic of the soils and rocks making up the basin over which the water flows or through which it percolates.

5.9.1 Location of sampling

The equipment involved in sampling water quality requires that the stations chosen should be reasonably accessible and, in temperate zones, should preferably be serviced with electrical power to facilitate winter heating and operation of electrical water quality equipment. The minimum programme for representative basins should include a quality station near the main gauging station.

For water sampling, thoroughly cleaned glass bottles (1 litre) should be used. The bottle is rinsed several times with water from the stream to be sampled and is then filled with this water, corked and labelled with the name of the stream and the sampling date. As it is important to avoid contamination, all equipment should be clean.

6.0 EXPECTATIONS FROM RESEARCH

Broadly speaking the research in the representative basins is directed mainly with three main expectations. The first is concerned with development of an understanding of the processes of the hydrological cycle and their interaction. These studies will provide the research results and will provide an understanding and insight into the processes. The second will provide the input so that the relationships obtained can be used to extrapolate the results within the region, using regression based or such other techniques. The third expectation that these studies will be able to fulfill the consequences of changes in the basin conditions.

The currently used methods are generally of the regression based approach. These models do consider the important factors in the process, but do not provide a good understanding of the processes involved, as the multiple regression type of models do not account for the complexity of the system. The results obtained may be reasonable for humid or possibly arid regions but have not been found to be successful in semi arid regions due to varying levels of soil moisture in the system at different time periods. These models have been found to give useful indications of the impact of land use changes on the hydrological regime, but have severe limitations for extrapolation of results. These models have also not been found useful for water quality prediction as a result of land use changes.

It is, therefore, apparent that the efforts have to be directed towards the development and application of process based model of the land phase of the hydrologic cycle. This calls for an approach which will define the various parameters representing the processes and also describe the basin characteristics to give the response of basin as a whole to the inputs and changes in the system. It seems that no such model has been successful in providing streamflow, response with any confidence incorporating basin characteristics. The representative and experimental basin studies coupled with the development of model should be continued and initiated in the environment where adequate information is not available. This task is not one for hydrologists alone and would require inputs from a multidisciplinary team of scientists.

7.0 THE GANGA PLAINS REGION AND THE REPRESENTATIVE BASIN

7.1 Ganga Plains Region

The river Ganga is the most important and sacred river in India and reflects the culture of India from ancient times. The river basin bound by the Himalayas in the north and Vindhyas in the south.

7.1.1 Geology

The Ganga basin is a foredeep region of the Himalaya which has develop due to collision of the Indian plate with the Tibetan plate; the former is said to be underthrusting below the latter (Molnar and Tapponnier,1975). The basin in its central part is bounded by two major fault plains, viz., the Faizabad high in the west and Monghyr-Saharsa ridge in he east, running almost parallel to each other trending SW-NE. The northern edge of the basin are demarcated by the Main Boundary Fault, while the Proterozoic rocks of Vindhyan sediments and crystallines of the eastern Indian shield lie to its south.

The basin is essentially filled up with the alluvium deposits of the Quaternary age. The deposit of these alluvium commenced after the final phase of Himalayan uplift which formed the Shiwalik mountain ranges at its foothill, and continued all through the Pleistocene up to the present time (Wadia, 1966). The alluvium represents a wedge which is thick near the Himalayas (1500-2000 m), gradually decreasing southward (Singh, 1987). A general northwardly dip of the Peninsular shield below the

Gangetic alluvium is estimated as 1-3° (Oldham, 1977; Mathur and Kohli, 1964).

7.1.2 Sedimentation Rate

The river Ganga is the largest perennial water body of the country having an average annual discharge which is nearly 25.2 per cent of the total discharge of water from all the river systems of India about 2 per cent of the total flow in all river systems of the world (Rao, 1979). The annual mean discharge of Ganga 468.7 billion m^3 (Das Gupta, 1984) (Table 1), which is numerically equal to 1/10 th of Amazon (Brazil), 1/4th of Congo (Africa), slightly less than Mississippi (U.S.A.), and Brahmaputra (India), more than St. Francisco (Brazil) and Godavari India (Lerman, 1981; Subramanian et al., 1987). Ganga being the largest perennial water system among all the 14 major rivers of India (Table 2).

The sediment load transported by Ganga was compared with other major rivers of the world and found to be the highest ranging from 1085 million tons to 2400 million tons (Holeman, 1968; Coleman, 1969; Curtis et al., 1973; Subramanian, 1979). The geology, topography and climate of the drainage basin are the contributing factors for its high sedimentation load in addition to its drainage and discharge area (Milliman, 1980) and when compared clearly reveals that only one large river in Africa (Orange) had a sediment yield exceeding 100t/km^2, and most north and south American rivers have yield of around 100t/km^2. In contrast, it was found that Asian river basins are having far

Table 1 : Break-up of the Physical and Hydrological Details of River Ganga and its Tributaries in Bihar (After Das Gupta, 1984)

Stream	Catchment		Annual Discharge		Rate of water flow	
	10^3xkm^2	Percent	Billion m^3	Percent	m^3/Sec	10^3xm^3/km^2
Son	71.259	8.3	22.420	4.8	711	314.627
Punpun	8.53	1.0	3.577	0.8	114	419.343
Damodar	25.820	3.0	12.210	2.6	387	472.889
Subarnarekha	19.296	2.0	7.940			411.484
Ghaghara	57.578*	6.7	94.400	20.1	2993	740.392
Gomati	30.437	3.5	7.390	1.6	234	242.797
Gandak	7.620*	0.9	52.200	11.1	1655	1139.738
Kiul	16.580	1.9	5.900	1.3	187	355.075
Karmnasa	11.709	1.4	5.750	1.2	182	491.075
Kosi	11.000*	1.3	61.560	13.1	1982	708.400
Burhi Gandak	10.150	1.2	7.100	1.5	225	699.507
Ajay	6.050	0.7	3.207	0.7	102	530.083
Ganga	861.404	100.0	468.700	100.0	14862	442.170

Table 2 : **Basin Area, Annual Yield and Rate of Water Flow in Riverine System of India (After Das Gupta, 1984)**

River	Catchment area in thousand/Km^2	percent	Annual discharge of water (billion m^3)	percent	Rate of flow (thousand m^3/km^2)
1. **Ganga**	861.40*	26.2	468.70	25.22	442.17
2. **Indus**	321.29*	9.8	79.50	4.28	247.44
3. **Godavari**	312.81	9.5	118.00	6.35	377.22
4. **Krishna**	258.95	7.9	62.80	3.38	243.40
5. **Brahmaputra**	258.01*	7.8	627.00	33.71	1081.03
6. **Mahanandi**	141.59	4.3	66.64	3.58	470.66
7. **Narmada**	98.79	3.0	54.60	2.94	552.66
8. **Cauvery**	87.90	2.7	20.95	1.12	237.77
9. **Tapti**	65.14	2.0	17.98	0.97	276.31
10.**Penner**	55.21	1.7	3.24	0.17	58.65
11.**Brahmani**	39.03	1.2	18.31	0.99	202.70
12.**Mahi**	34.84	1.1	11.80	0.63	338.68
13.**Sabarmati**	21.89	0.7	3.80	0.20	173.55
14.**Subarnarekha**	19.30	0.6	7.94	0.43	411.45
Total of major rivers	2576.15	78.3	1561.26	84.02	5113.69
Medium and minor rivers	711.83	21.7	296.84	15.98	417.01
Grand total of all rivers of India	3287.98	100.0	1858.10	100.00	5530.70

greater sediment yields-the Yellow (China) and Ganga/Brahmaputra both have annual rates in excess of 1000 t/km^2 (Table 3). The fast rate of sedimentation as consequence of high rate of erosion of the Himalaya mountain, and a low rate of subsidence of the basin floor has resulted in the extension of the ganga basin well within the Bay of Bengal as noted by the appearance of New Moore Island off the coast of India.

7.1.3 Hydrology

Hydrologically, the country's river systems fall into two broad groups i.e. the rivers of Himalayan origin and those flowing in Peninsula. The plains adjoining the Himalayan ranges are alluvial type. On account of extensive snow over the Himalayas, the rivers are perennial in nature. The geologically unstable condition of the mountain ranges and the nature of the terrain considerable meandering and uncertainty in the behaviour of these rivers. In sharp contrast, the peninsular rivers, originating at comparatively lower altitudes do not meander so much.

Rising from the snow bound Himalayas, the Ganga is 2525 km long in India and drains out an area 8,61,404 km^2. Its two head streams Alaknanda and Bhagirati meet at Devaprayag. After their confluence the river is known as Ganga. From Devaprayag, the Ganga flows to the west and south-westerly direction through the Himalayas upto Hardwar. The river then enters the plains and passes through the States of Uttar Pradesh, Bihar and West Bengal

Table 3 : Basin Area Discharge, Sediment Load and Sediment Erosion Rate of Some Important River of the World (After Subramanian et al., 1987)

River	Area (10^3 km^2)	Discharge (km^3\yr)	Sediment load (mt)	Sediment erosion rate
Ganga	861.40*	493	729**	1125
Brahmaputra	258.01*	510	558	865
Yellow	770.0	49	1080	1402
Amazon	6150	6300	900	146
Yangtze	1940	900	478	246
Irrawady	430	428	285	662
Magdalena	240	237	220	916
Mississippi	3270	580	210	64
Orinico	990	1100	210	212
Godavari	310	92	170	555
Mekong	800	470	160	200

* Area within the Indian territory

** At Farakka.

by traversing distances of 1450, 550 and 525 km respectively, before meeting the Bay of Bengal. Fig (3) shows location of Ganga Plains region categorised by National Institute of Hydrology for hydrological studies.

The average annual discharge of Ganga and its tributaries at Patna is 3,64,000 m.cu.m. (Rao, 1979) (Table 4) which is more than double of that at Varanasi and greater than half of the total volume of water running in the river at the outfall into the sea (4,93,400 cu.m.). The amount of water Ganga loses through big irrigation channels in the state of Uttar Pradesh up to the lower reaches of Varanasi is more than gained in quantity at Patna, because of the confluence with four tributaries in a very short distance of its run off (Fig(4)). The Son (22.420 b.cu.m.) joins the Ganga from the south at the up stream of Kurji drain, further to the east it receives the Gandak (52.200 b.cu.m.) from the north opposite to Ghagha ghat at Patna. Besides, Gomati (7.390 b.cu.m.) in the up stream and Ghaghara (94.400 b.cu.m.) in the down stream of Chapra, add water almost in 1:1 ratio to Ganga (Table 2). As a result, from Patna downwards, the Ganga flows in wider and deeper channel which continues till Munger keeping the flow of water almost constant.

The river Ganga from Allahabad to Farakka has a flow of water in the range of 4,226 to 10,159 m^3/s (Table 4) which is sufficient enough to disperse the pollutants. However, the flow of water in Ganga both in the up stream of Allahabad and down stream of Farakka is alarming. The pollutional status of Ganga

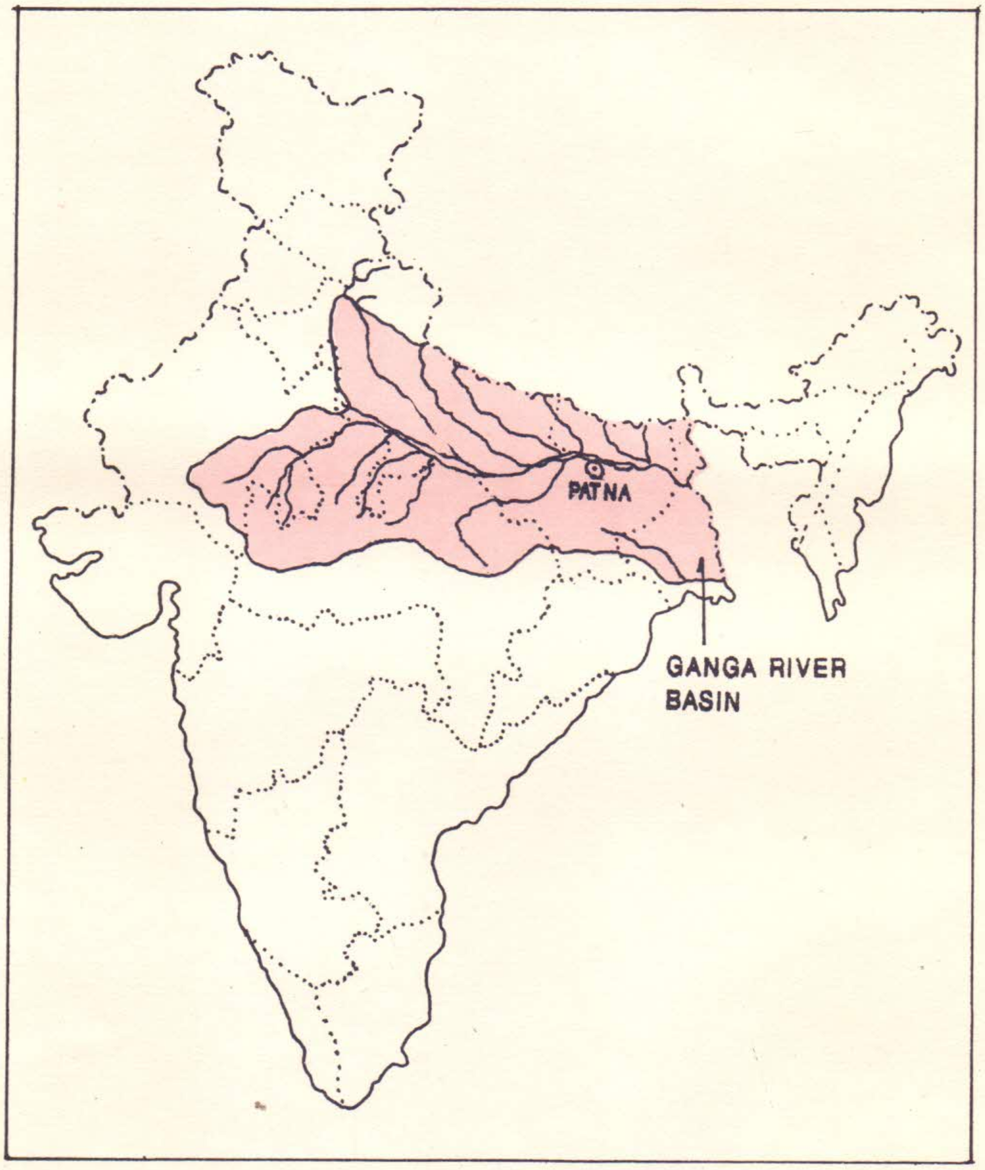


FIG.3 A MAP OF GANGA PLAINS REGION

Table 4 : Hydrological Parameters of River ganga at Various Place From its Source to the Outfall into the Bay of Bengal in India (Rao, 1979; Das Gupta, 1984)

Station	Distance from source (km)	Elevation from mean sea level (m)	Average slope of land	Average mean annual flow (m^3/s)	Range of mean annual flow (m^3/s)	Range of percentile flow of water (m^3/s)
Rishikesh	250	350	1 in 67	856	1305-21631	130-2146
Kanpur	800	138	-	1184	910-30763	45-2310
Allahabad	1050	95	From Rishikesh to Allahabad 1 in 4,100	4226	2987-112206	157-6183
Varanasi	1295	80		4106	2793-112206	177-5777
Buxar	1430	60		4436	3438-113247	
Patna	1600	50		7626	6341-192625	540-13353
Munger						
Bhagalpur						
Rajmahal						
Farraka	2055		From Allahabad in Farraka, 1 in 13500	10159		
Calcutta		19	-	1056		
Nawadwip	2285	12	From	1314	1107-18666	350-1663
Outfall to Bay of Bengal	2525		1 in 24000			

around Kanpur can very well be imagined, particularly in the lean period of summer, when as low as $45 m^3/s$ of water is available, and the volume of municipal and industrial effluent remain the same irrespective of such reduced volume of flow (Table 4).

The river Ganga divides the state of Bihar roughly into two parts, i.e. north and south. North Bihar is predominantly composed of alluvial deposits of Quaternary to Recent Age having an elevation of less than 25 m from the sea level, while south Bihar is covered mostly with crystalline and sedimentary rocks of the Precambrian age . The lithological character of the rocks largely controls the groundwater quality and its resources. The groundwater of north Bihar is rich in iron content, in contrast to hard water of south Bihar (i.e. south of Ganga) . The hydraulic gradient of groundwater in the Patna district shows a gradual decrease north-eastward from Paligang to Fatuwa along the course of Punpun, a tributary of Ganga joining from the south.

The growing load of pollution on river Ganga reflects several undesirable effects in the regions where alluvial type of soil exists. The salinity is rising is Haryana, alkalinity in western U.P., hardness in north Bihar and acidity in West Bengal (Das Gupta, 1984). The greatest demerit of the alluvial soil is its tendency to contaminate the groundwater by leaching the trapped toxic pollutant which are being continuously released into Ganga by several industrial effluents located on its banks. The younger alluvial soils which are present in nearly half of

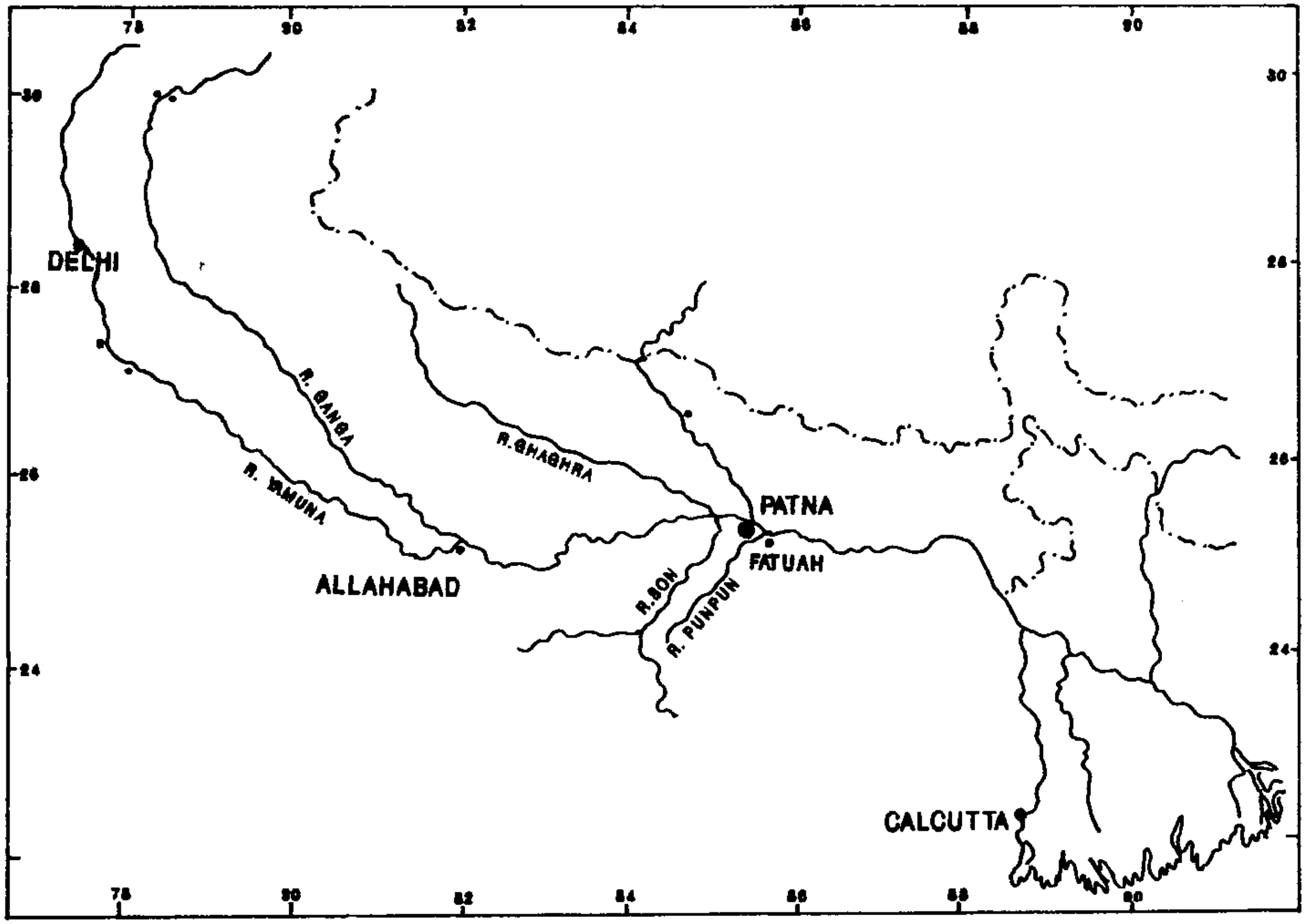


FIG.4 CONFLUENCE OF FOUR TRIBUTARIES IN GANGA RIVER NEAR PATNA

the basin area of Ganga in Bihar and West Bengal have been reported to be moisture laden enough to cause frequent flooding. Some of the tributaries of Ganga, viz., Gandak, Kosi etc. in north Bihar an Sone in south Bihar, have their origin of flow in the limestone-bearing rocks, and dissolve a lot calcareous materials which are brought to the river Ganga resulting in a significant increase in the hardness value of the underground and surface water resources.

The river Ganga running through different different States, like a bond of unity, reaches Bihar after transversing more than half of its total length of 2525 km from its source to the sea. Large industrial complex at Kanpur and Barauni and populous cities like Allahabad, Varanasi, Patna and Calcutta have grown on its bank.

The geographical situation of river Ganga in Bihar is an interesting natural phenomenon because in a very short run off starting from down stream of Varanasi, two big perennial rivers from the north viz. Ghaghara and Gandak, and two from the south - Sone and Punpun-meet the river Ganga near Patna (Fig.(4)) and the water which they bring in a nearly equal to the volume of water flowing in the river at Varanasi.

7.2 Why Punpun is selected ?

As mentioned elsewhere, the river Punpun is a tributary of Ganga meeting Ganga near Fatuwa downstream of Patna. The river lies in south Bihar which is frequently affected by drought. The water resources potential of the basin is yet to be fully harnessed since there is not any conservation scheme operational in the basin till date. It has an added significance of being near Patna the capital of Bihar. Ganga Plains Regional Centre had conducted land use study and prepared water year book earlier. The engineers of Water Resources Dept. Govt. of Bihar were consulted for selection the basin as a representative basin. They also concurred to the proposal and hence river Punpun was selected as representative basin.

7.3 The Representative Basin- Punpun river System

The Punpun, one of the important right bank tributaries of the river Ganga, originates from Chottanagpur hills of Palamau district in Bihar at an elevation of 300 m and at north latitude of 24°11' and east longitude of 84°9' . It flows, for most of its portion, in a north-easterly direction and joins the Ganga near Fatwah, about 25 km. downstream of Patna. The river is rainfed and hence carries very little discharge during non-monsoon period. Its total length is about 232 kms. The river receives most of the discharge from its right bank tributaries. The contribution of left bank tributaries is very small in comparison to right bank tributaries. Like the main river, its tributaries are also rainfed and majority of them originate from the same range of hills in Palamau, Aurangabad and Gaya districts of Bihar. Fig(5) shows location of Punpun river system in Ganga Basin. A list of the tributaries both on left bank as well as right bank is given below :

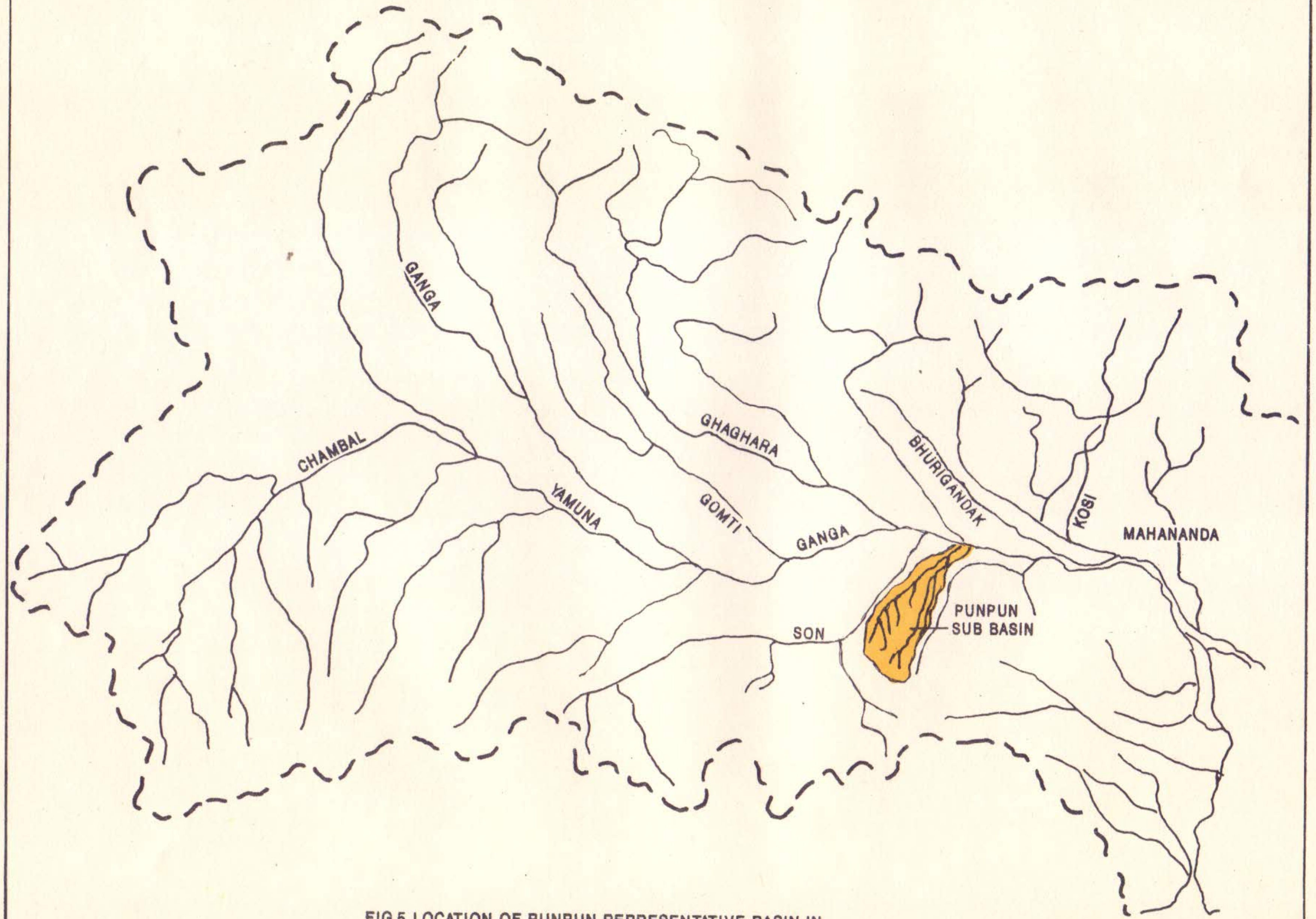


FIG.5 LOCATION OF PUNPUN REPRESENTATIVE BASIN IN

RIGHT BANK TRIBUTARIES

(i) Batane
(ii) Ramrekha
(iii) Barki
(iv) Adri
(v) Madar
(vi) Neera
(vii) Senane
(viii) Morhar, and
(ix) Dardha

LEFT BANK TRIBUTARIES

(i) Begi
(ii) Khudawa
(iii) Mawaria
(iv) Siroka, and
(v) Panchanwa Nalla

The salient features of some of the important tributaries of the Punpun river are as follows :

The Morhar

The Morhar originates in the hills of Palamau district. This river has an elongated catchment. At a place (Lat.24°32' and Long. 84°45') near Roshanganj, the river Morhar bifurcates into two channels. One of the channels is known as Budh River and other is Morhar. These two channels join at a place about 5 kms. north of Sherghati and the combined channel is known as Morhar. Again the river Morhar bifurcates at a place near Koribigha (Lat. 24°45' Long. 84°-51') and the two channels are known as Morhar and Budh respectively. These two channels again join together near village Panchanpur and bifurcate again after about 1.5 kms only. However, the two again meet near village Dhobariya but bifurcate again after about 1.5 kms. The channels Buddh & Morhar again join at a place (Lat. 25°1' and Long. 84°54') near village Men. This time, Morhar bifurcates after about 3.5 kms. and the bifurcating channel on the eastern side is known as Dardha. After this place, Morhar and Dardha flow separately till both of them join Punpun near Ramganj and Jamalpur respectively. Morhar has another channel known as the Ghaghar. The main river, owing to steep gradient and shallow depth keeps changing courses and sometimes along the Ghaghar. According to recent developments, the main Morhar flow is concentrated along the Ghaghar which falls into the Punpun at about 145 kms. upstream of the confluence of Punpun with Ganga. It crosses the the Patna-Gaya railway line between Nadwan and Pothahi Rly. stations. The importance of the river Morhar, along with the Dardha increases mainly as they play significant role in causing flood in the lower reaches of the river system. The catchment area of Morhar-Dardha is 2585 sq. km. and length is 185 kms. There is one possible site of reservoir namely Amakhar dam on river Morhar.

The Dardha

As discussed above, the Morhar bifurcates near village Men (Lat. 25°2', Long. 84°54') and the bifurcating channel is known as the Dardha. Jamuna Nadi which originates from a place south of G.T. Road (NH 2) near Sherghati runs almost parallel to the Morhar and the Dardha and joins the Dardha near Jahanabad. Afterwards, the river flows by the name of the Dardha and outfalls into the Punpun near village Jamalpur. Its outfall in the Punpun is also very near to the confluence of the Punpun with the Ganga.

The Batane

This river also originates from the hills of Palamau district near Dalpatpur village at an elevation at about 225 m. It joins the river Punpun at village Jamadra near crossing of the Punpun with Grand chord Railway line of Eastern Railway. Its catchment area is 634 sq. km. and its length is about 78 Km. There is a reservoir site, namely Batane dam on this river which has already been taken up by the State Government of Bihar.

The Madar

Like the Morhar and the Dardha, this river has also got big catchment. But shape of the catchment is fan shaped and not an elongated one like the Morhar and the Dardha. The river originates from hills of Aurangabad district, near village Barki and joins the Punpun near village Gagarh. Its length is about 56 kms. and catchment are 1255 sq. km. Its tributaries are Tekari Nalla, Jharahi Nalla, Keshar Nalla, Satnadiya Nalla, Dhawa Nalla etc. There is one reservoirs site, namely, Jagnath dam on this river.

7.3.1 The Catchment Area

The Punpun basin lies approximately between longitude 84°10' E- 85° 20'E and latitude 24°11'N - 24°25'N. It is located on the right bank of the Ganga and is bounded by the Sone river system in the west and the Kiul-Harohar-Falgu river system on the east. On its northern side is river Ganga, and on its southern side, it is bounded by Chhotanagpur range of hills

The shape of the Punpun river system is roughly trapezoidal. The length of the catchment is about 180 km. and the average width in upper and lower reaches of the river system is 60 kms. and 25 kms. respectively. The general direction of the drainage is from south-west to north-east. The Grand Trunk Road, divides the catchment into two parts in such a way that almost all the hilly part of the catchment falls on its south and plain area on its north.

The total catchment area of the Punpun river system is about 8,530 sq.kms. which is one percent of total area of the Ganga Sub-basin in the country. The entire catchment lies within the State of Bihar and is spread over the districts of Patna, Gaya, Aurangabad, Hazaribagh and Palamau. The districtwise break-up of the catchment area is given in Table (5) and distribution of of the catchment area in each of the above districts is given in Table (6).

7.3.2 Land Use

The area under agriculture in Punpun river system is about 5,000 sq. kms. and that under forest is about 2,500 sq.kms. The remaining area of 1000 sq.kms. is under miscellaneous use, such as industries, roads, residential buildings etc. It shows that agriculture area, forest area, and area under miscellaneous use constitute 59%, 29% and 12 % of the total area of the river system. The culturable area is mostly concentrated in lower reach of the catchment whereas forest area in the upper reach of the catchment. Besides agriculture, there are large number of small scale industries in the river system mainly concentrated in Fatwah and Gaya towns. A Land Use map showing the area of Punpun

TABLE 5: DISTRICTWISE BREAK UP OF CATCHMENT AREA

Sl. No.	Name of the district	Catchment area in sq. km. lying in the district.	Percentage of total catchment in the district.	Remarks
1.	Patna	960	11.25	
2.	Gaya	3060	35.87	
3.	Aurangabad	2310	27.08	
4.	Hazaribagh	800	9.39	
5.	Palamau	1400	16.41	
	Total :	8530	100.00	

TABLE-(6) DISTRIBUTION OF CATCHMENT AREA IN DIFFERENT DISTRICTS.

Sl.No.	Name of the district.	Total geographical area of the district in sq. km.	catchment area lying in each district in sq. km.	Percentage of distri- in the catchment.
1.	Patna	3202	960	30%
2.	Gaya	6545	3060	47%
3.	Aurangabad	3305	2310	70%
4.	Hazaribagh	11165	800	7%
5.	Palamau	12749	1400	11%
	Total		8530	

basin covered under vegetation, built up area,etc is shown Fig(6) and Fig(7) shows the areas affected by floods.

7.3.3 Agriculture and irrigation

On the basis of data available , some details are given below. The gross cropped area and net area shown in the river system are 527.31 Th.Ha. and 399.28 Th.Ha. respectively. The gross and net irrigated area of the river system are 308.05 Th. Ha. and 264.61 Th.Ha. respectively. Bhadai, Aghani and Rabi are three crop seasons in practice in this river system. The principal crops that are being grown in the river system are Rice, Wheat, Jowar, Bajra, Maize, Barley, Pulses, Oilseeds, Sugarcane etc.

7.3.4 Topography

The upper most catchment which lies in the districts of Palamau and Hazaribagh is hilly and mostly covered under forest. The lower part of the catchment in the district of Aurangabad, Gaya and Patna is mostly plain or having some uniform mild slope and being used for cultivation. The level of the land varies from 300m. (1000 ft.) near origin of the river to about 50 m.(165 ft.)near its out fall into the river Ganga. Details of contours at an interval of 250 ft. are shown in Fig(8) and drainage pattern is shown in Fig(9).

7.3.5 Geology

Broadly, the geology of the area varies from Granite, gneiss, charnockites in the hills to the recent alluvium in the

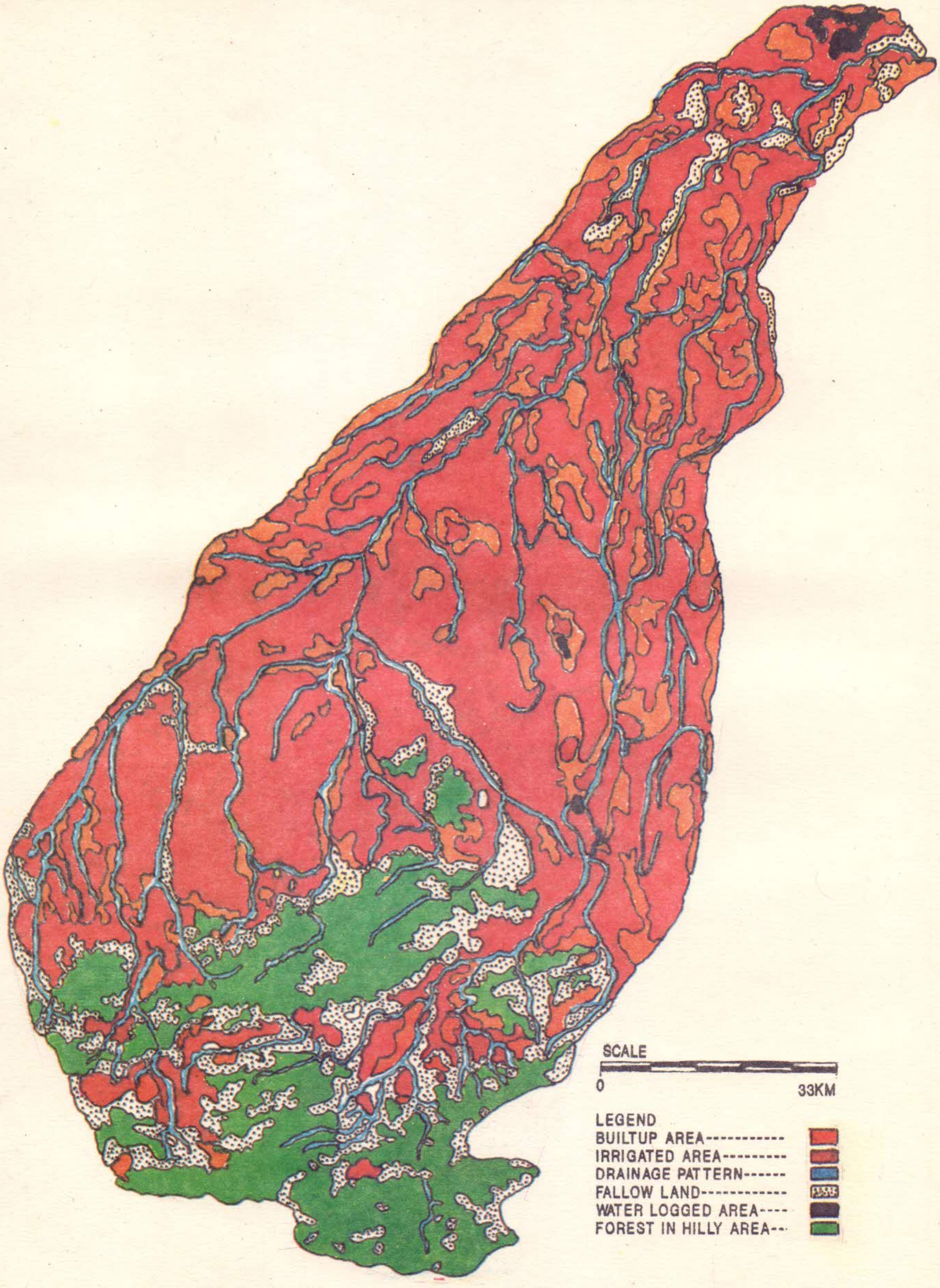
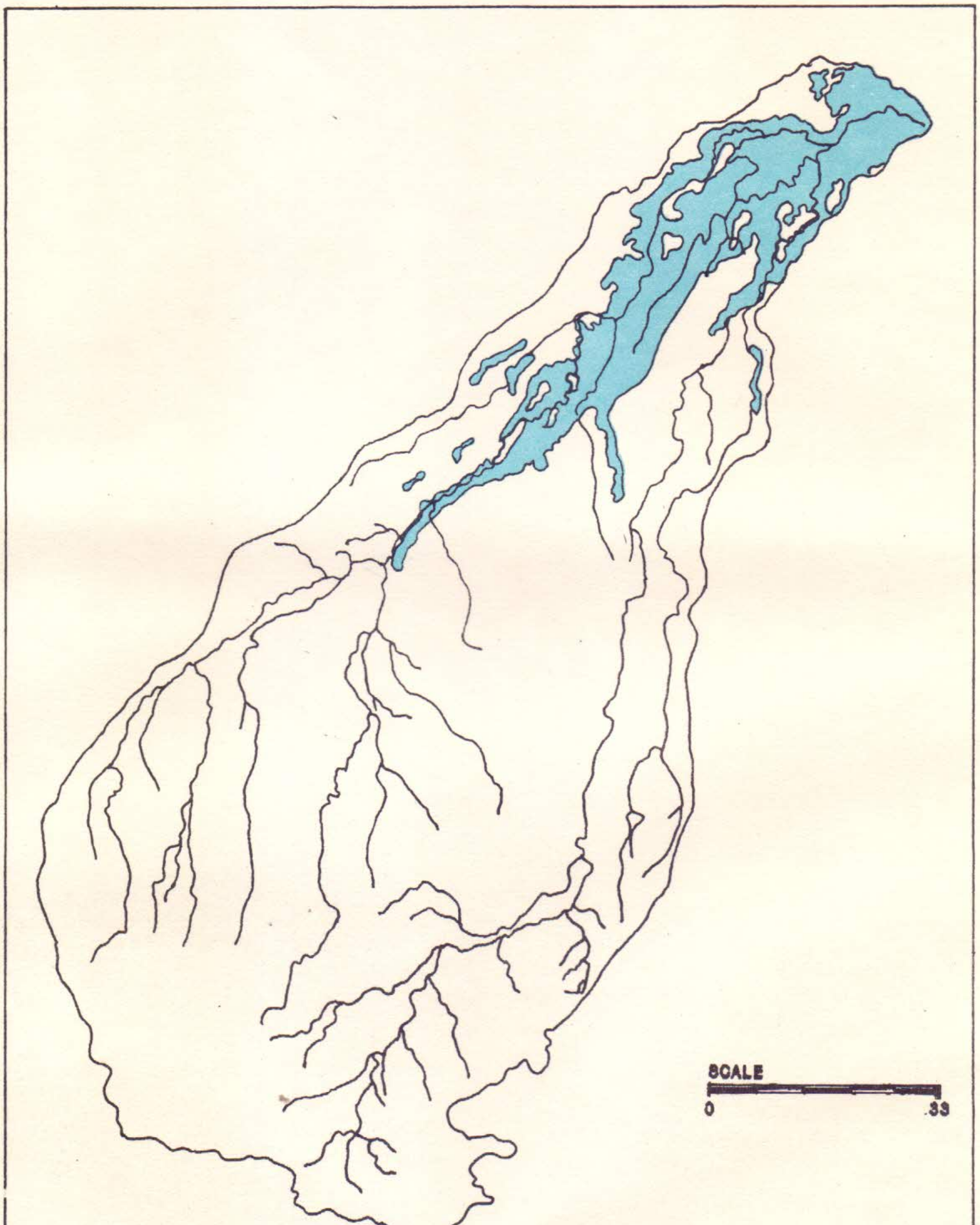
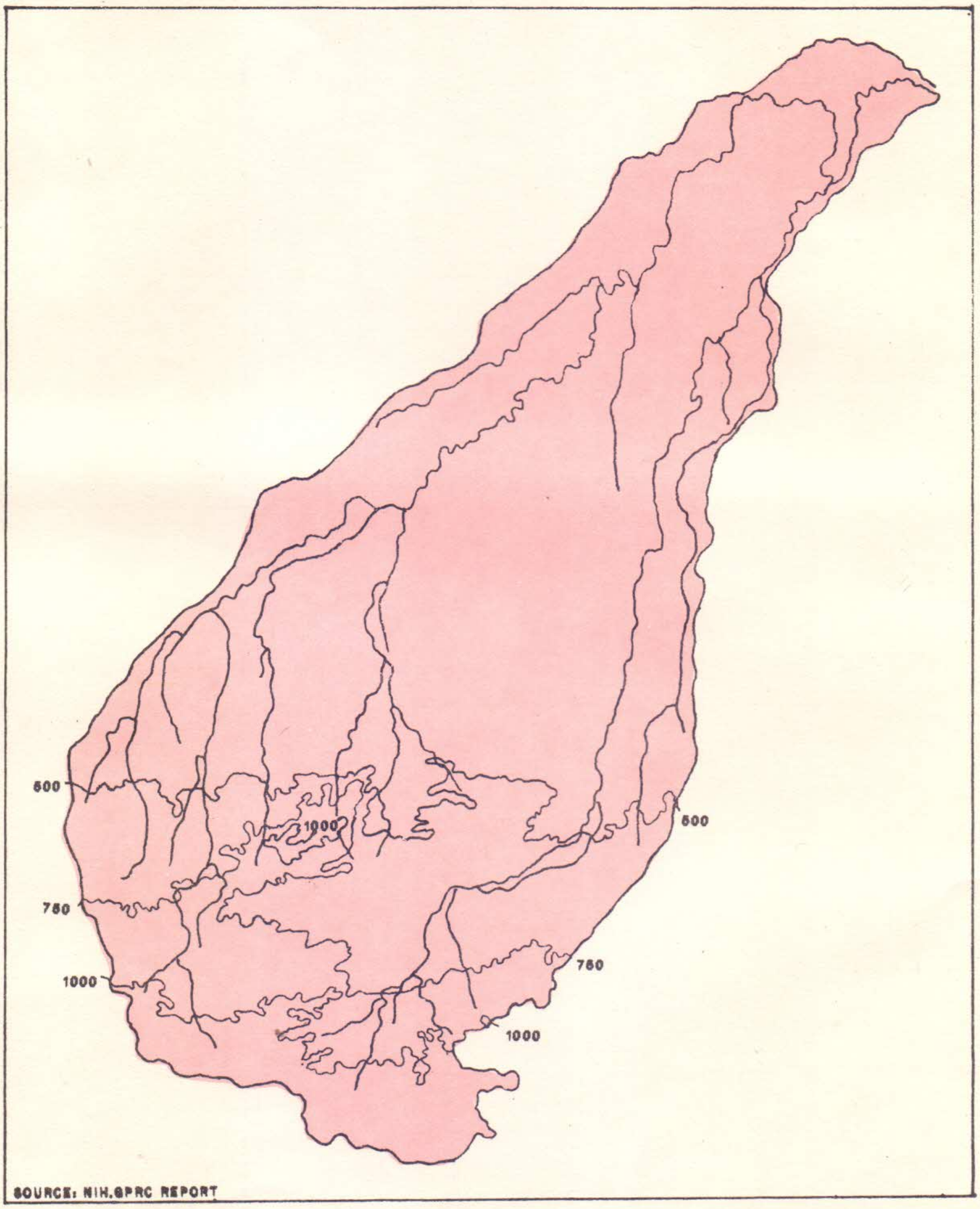


FIG.6 LAND USE MAP OF REPRESENTATIVE BASIN



SOURCE: NIH,GPRC REPORT

FIG.7 COMPUTED FLOOD INUNDATION MAP OF REPRESENTATIVE BASIN



SOURCE: NIH,GPRC REPORT

FIG.8 CONTOUR MAP OF REPRESENTATIVE BASIN

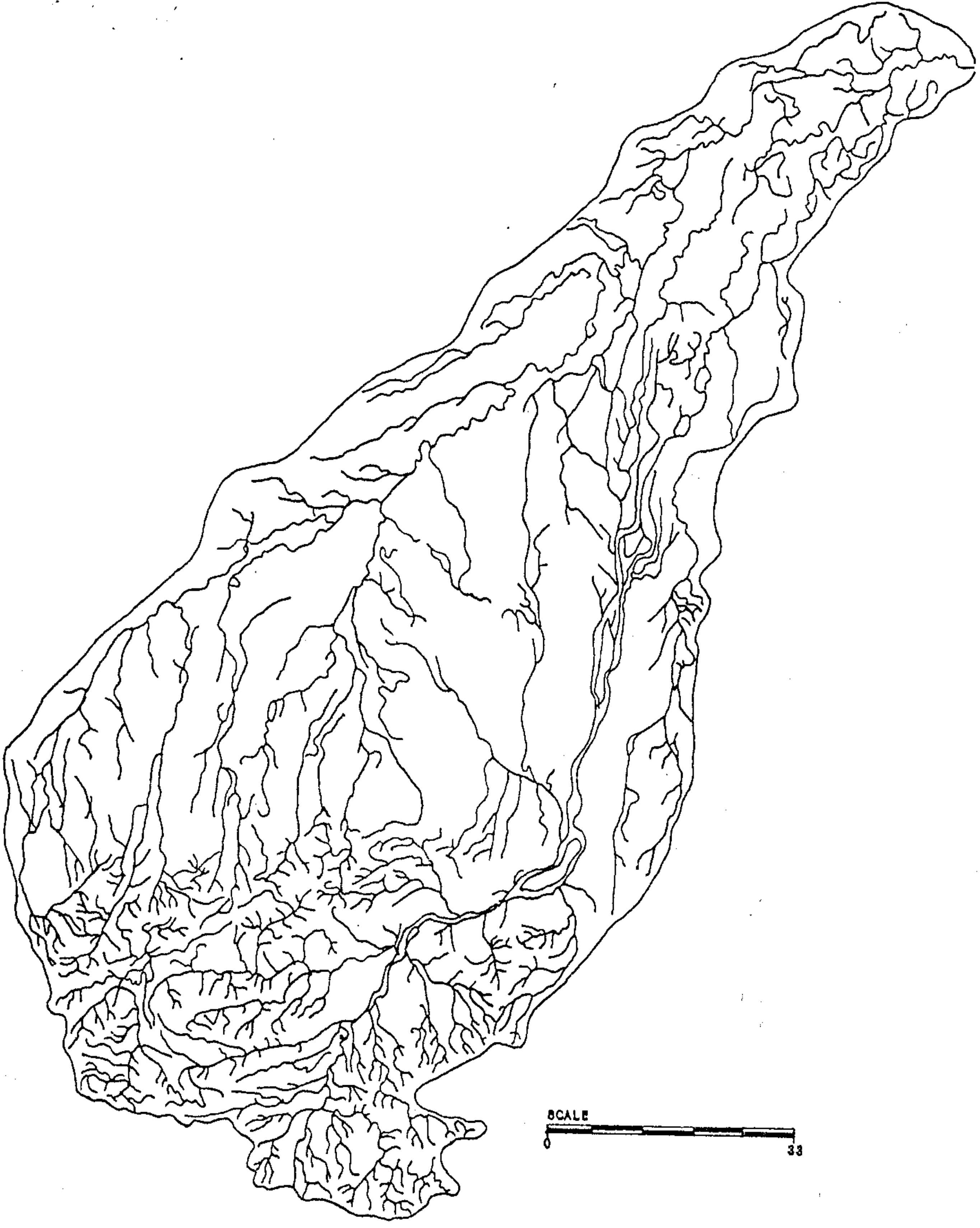


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FIG.8 MAP SHOWING DRAINAGE PATTERN

plains. The broad soil groups are calcium and non-calcium, recent and old alluvial and brown forest soils, red soils podzowe, lateritic soils with cover being very deep in plains and deep to shallow in hills.

7.3.6 Geohydrology

An approximate estimate of total ground water potential has been made by applying Chaturvedi formula with following assumptions :-

(i) The area lying in Palamau and Hazaribagh districts are completely hilly whereas the remaining area in the districts of Patna, Gaya and Aurangabad are completely plain.

(ii) Recharge due to other sources like seepage through irrigated land, canals,ponds, reservoirs etc. has been taken as 10% of total recharge due to rainfall.

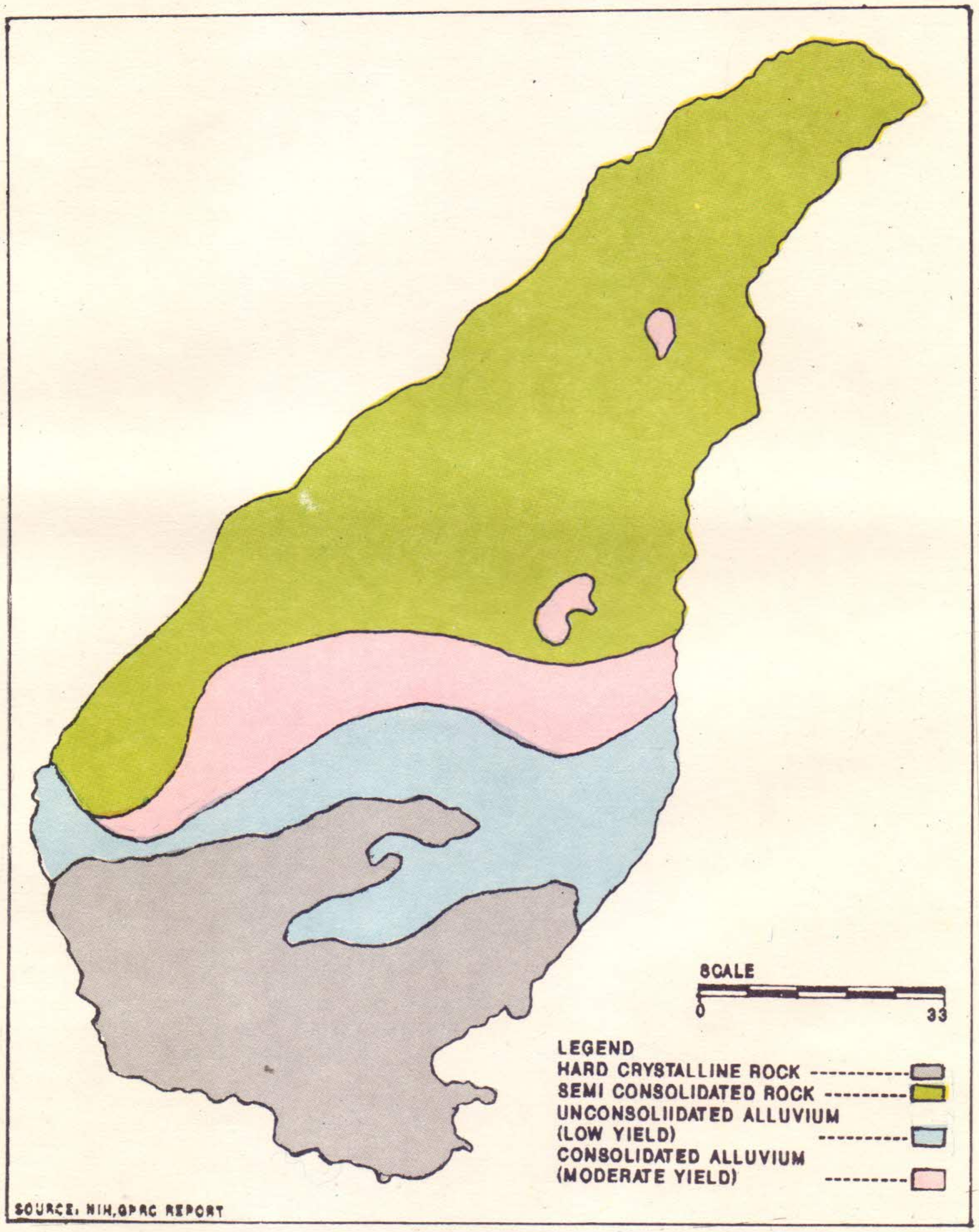
A geohydrological map of representative basin is shown in Fig(10).

On this basis the total gross recharge in the Punpun river system comes out to be 1.618 lakh ha. m. However, only 70% of the total gross recharge can be made available for utilisation because of the occurrence of the following factors which amounts to about 30% as per the report of Central Ground Water Board's Exploitation Committee.

(i) Evapo-transpiration losses from the forest, Water logged and marshy area;

(ii) Inevitable effluent discharge to the river; and

(iii) The maintenance of minimum base flow required in



SOURCE: NIH,GPRC REPORT

FIG.10 GEOHYDROLOGICAL MAP

the river for committee usage on the existing canal system and for ecological reasons.

The Central Ground Water Board, based on field surveys has made a provisional assessment of gross ground water recharge for different States, during the year 1981. As per this assessment, the value of gross recharge for Bihar is 29 lakh ha.m. A comparison of ground water data for the Punpun river system and Bihar (as a whole), shown in table No. (7) and location of groundwater observation wells is shown in Fig(11). Table (7) reveals that its distribution per unit area in the Punpun catchment is comparatively higher than the average distribution per unit area for Bihar.

7.3.7 Hydrometeorology

The river system receives about 85 to 87 percent of its annual rainfall during the south-west monsoon period which occurs from June to September. Average annual rainfall varies from 992 mm. near confluence with the Ganga (Patna district) to 1335 mm. in the upper most reach (Palamau district).

The maximum value of 24 hours rainfall of 50 years frequency is 32 cm. which occurs in the upper catchment of the Morhar river, a tributary of the Punpun. For other portion of the river system, this value remains between 24 to 28 cms.

A list of raingauge stations inside the river system and adjacent to it with their locations, average annual rainfalls, and the period on the basis of which computations were made is given in the Table No. (8) and shown in Fig(12).

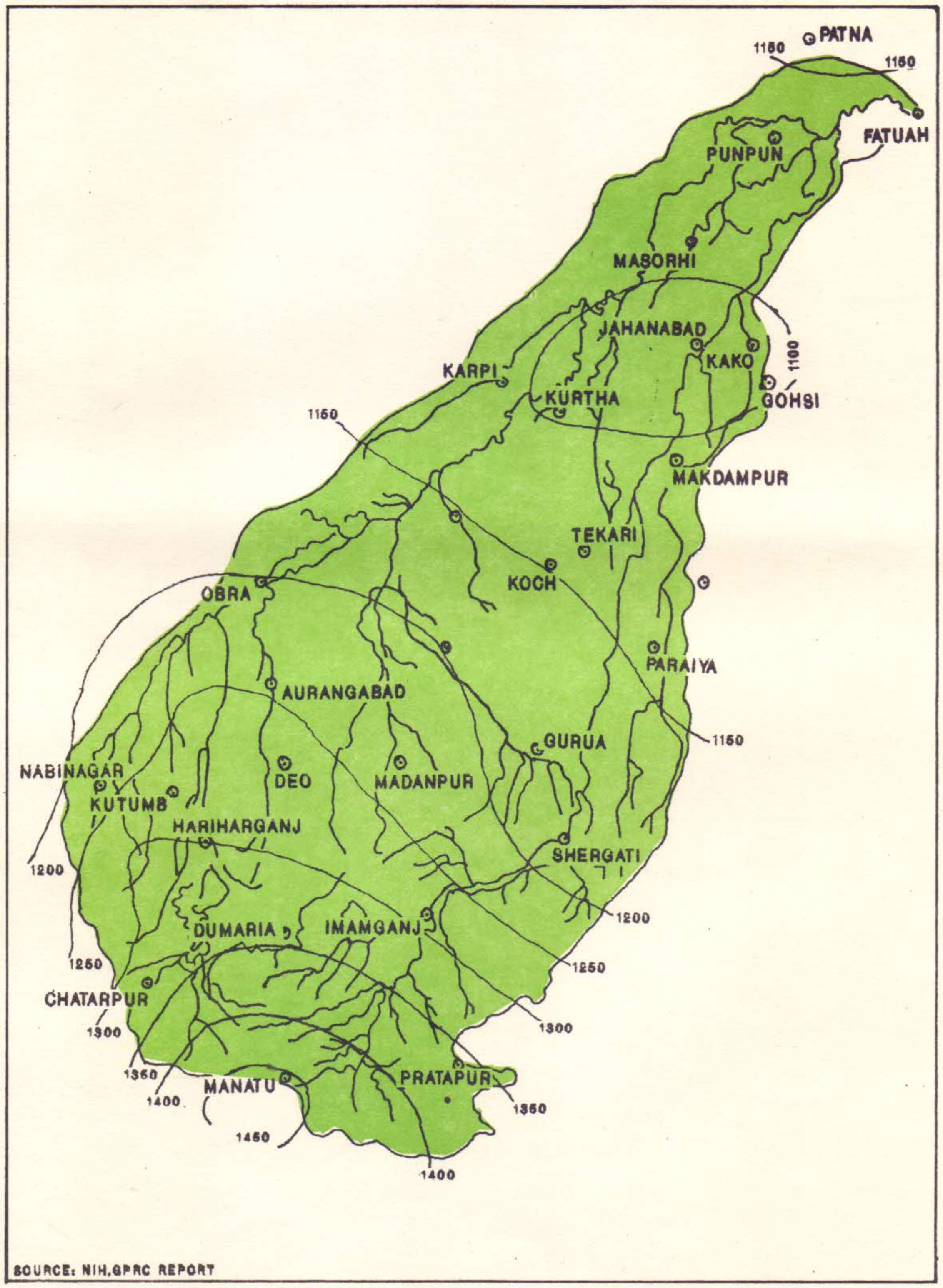
TABLE 7: COMPARISON OF GROUND WATER AVAILABILITY

Sl. no.	River system/ State.	Total ground water availability in lakh ha.m.	Total geographical area of the river system/State in sq.km.	Distribution of ground water availability sq. km.
1.	Punpun river system	1.618	8,530	18.97×10^{-5}
2.	Bihar	29	1,73,876	16.6×10^{-5}

TABLE 8 : LOCATION OF RAINGAUGE STATIONS IN PUNPUN RIVER SYSTEM

Sl. no.	Name of Raingauge Station.	District	Location		Average annual Raingall (1901-50)	Remarks
			Lat.	Long.		
1.	2.	3.	4.	5.	6.	7.
1.	Bikram	Patna	25°-27'	84°-52'	1076.4	(in mm)
2.	Paliganj	Patna	25°-20'	84°-50'	954.0	"
3.	Sanmera	Patna	25°-15'	85°-48'	1107.6	
4.	Arwal	Gaya	25°-14'	84°-41'	1065.9	
5.	Deo	Aurangabad	25°-39'	84°-25'	1260.8	Inside basin
6.	Jahanabad	Gaya	25°-13'	85°-00'	1090.8	
7.	Kurtha	Gaya	25°-08'	84°-48'	1093.5	
8.	Rafiganj	Aurangabad	24°-48'	84°-38'	1215.8	
9.	Nabinagar	Aurangabad	24°-37'	84°-08'	1132.4	
10.	Sherghati	Gaya	24°-33'	84°-48'	1156.9	
11.	Aurangabad	Aurangabad	24°-45'	84°-23'	1263.4	
12.	Ranchi(OBSY)	Ranchi	24°-23'	84°-20'	1512.7	
13.	Gumla	Ranchi	24°-02'	84°-33'	1471.0	Inside basin
14.	Chhatarpur	Palamau	24°-22'	84°-12'	1242.4	
15.	Manatu	Palamau	24°-14'	84°-24'	1490.2	
16.	Patan	Palamau	24°-13'	84°-11'	1279.4	
17.	Latehar	Palamau	23°-45'	84°-13'	1322.7	
18.	Netarhat	Palamau	24°-29'	84°-16'	1817.4	
19.	Hariharganj	Palamau	24°-33'	84°-17'	1311.2	
20.	Patna(OBSY)	Patna	24°-27'	84°-10'	1166.4	
21.	Hariharganj (OBSY)	Hazaribagh	24°-59'	84°-22'	1338.7	
22.	Chatra	Hazaribagh	24°-02'	84°-52'	1344.2	
23.	Hanterganj	Hazaribagh	24°-27'	84°-48'	1315.9	Inside basin
24.	Daltonganj (OBSY)	Daltonganj	24°-03'	84°-04'	1242.1	

FIG.11 GROUND WATER LEVEL OBSERVATION WELLS



SOURCE: NIH,GPRC REPORT

FIG.12 ANNUAL ISOHYTAL AND RAINGAUGE STATIONS

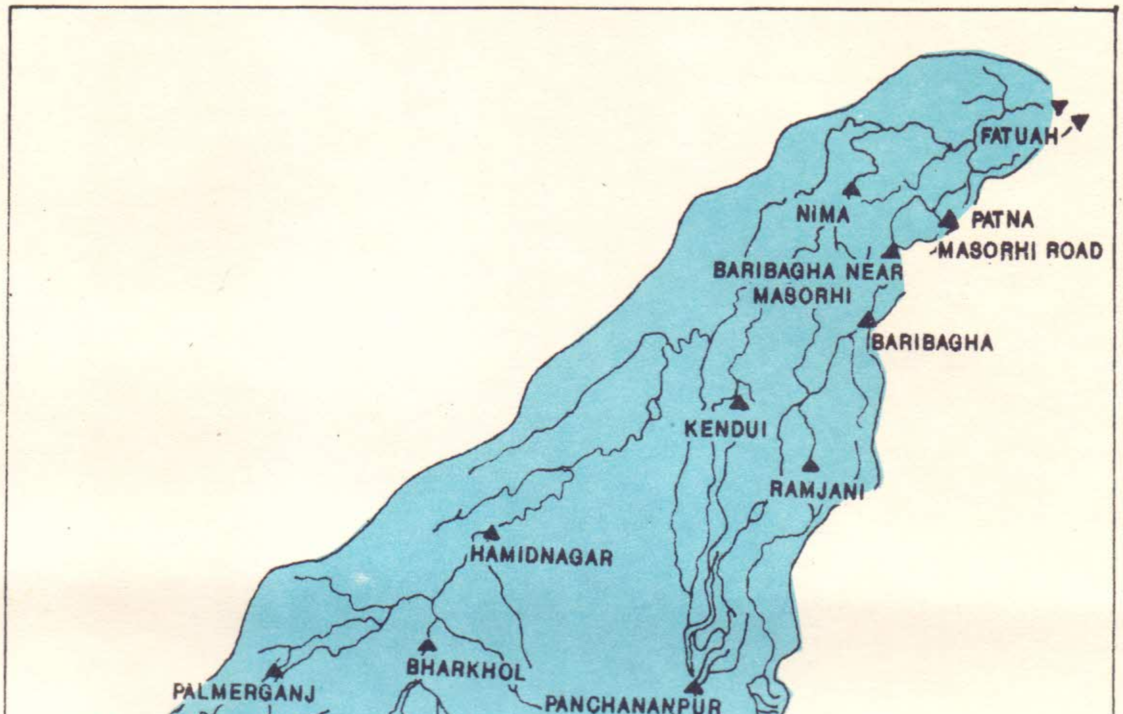
The average annual rainfall over the entire river system works out to 1181.8 mm.

7.4 Raingauge Network Design of Punpun Basin

The precipitation gauge network design of a catchment incorporates knowledge concerning the physical and stochastic nature of the hydrologic processes into a framework that accounts for the effects so that the data will have on future water resources decision. A present network of gauge and discharge sites maintained in the basin is shown in Fig(13). Estimation of number and location of the precipitation gauge stations have been analysed in Punpun catchment of Ganga river system by Jha and Jaiswal (NIH Tech report 1992) using WMO guidelines, Optimal raingauge network, Hall's method (Key station method) and Kagan's method (Spatial Correlation techniques).

From the analysis of Precipitation gauge network design of Punpun catchment, the following points are concluded :

1. The daily rainfall data available only for the years 1974-86 from Hydrology Cell, Water Resources Department, State Government, Bihar were utilised for network design of precipitation gauge stations.
2. The data of Central Water Commission were not utilised because there are only few precipitation gauge stations in the Punpun catchment and available data are not sufficient to fulfill the requirement of network design for the basin.
3. WMO guidelines for the Punpun catchments suggests that according the topography of Punpun basin the required number of



SOURCE: NIH,GPRC REPORT

FIG.13 GAUGE DISCHARGE SITES OF REPRESENTATIVE BASIN raingauges are 20.

4. The Optimal Raingauge Network Design technique results indicated that by considering the catchment as a whole the no. of raingauges required in the catchment, for 10 percent error, are 2 whereas for 5 percent error the no. of raingauges required for the catchment are only 5.

Considering the district wise distribution of precipitation gauge stations, the results obtained by using the above technique indicate that the required no. of precipitation gauge stations are 15 for 5% error and 6 for 10% error.

5. The key station network (Hall's) method indicates that 29 rain gauge stations are required for catchment.

6. The Spatial Inter Station Correlation (Kagan's) method indicates that 25 precipitation gauge stations are required for catchment.

7. The overall results have broadly indicated that the rainfall pattern is almost same in the catchment.

8. It is concluded that there should appropriate criteria for designing the network for hydrological purpose.

9. Due to lack of self recording raingauges in the catchment any modeling for forecasting seems to be difficult. Therefore, a better network of raingauge stations and self recording raingauge stations is necessary.

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DIRECTOR : SATISH CHANDRA

STUDY GROUP : GORAKH THAKUR
RAMAKAR JHA
MANOHAR ARORA

ASSISTANCE : A K SIVADAS