CASE STUDY CS-(AR) 181

HYDROMETEOROLOGICAL ASPECTS OF DUDHNAI BASIN (ASSAM / MEGHALAYA)

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PREFACE

Watershed hydrology deals with occurrences, distribution, movement and properties of waters of the earth and their environmental relations. The complexity of today`s environment suggests the need to understand thoroughly the hydrological regime of watersheds since our ability to manage it is wholly influenced by our ability to understand the hydrologic systems. Knowledge of basin hydrology essentially precedes for planning and operation of any water resources development and watershed management program in the basin. Depending upon the conditions of climate, physiography, geology, vegetation-soil-complex, drainability, natural environment, man`s influence etc, hydrologic problems are different for different regions requiring studies specific to the areas. To develop correlations between the interactive parameters of hydrologic cycle, it is humanly not possible to carry out hydrologic investigations separately for each areas in larger scales. Therefore, during International Hydrological Decade , 1965-75, the concept of undertaking detailed hydrological studies, after instrumentation and long term observations at smaller representative basins, regarded as models of larger hydrologically similar basins, was introduced. Since then, many studies have been undertaken throughout the world, basins have been modelled and results successfully extrapolated to ungauged watersheds.

Besides some specific studies in few experimental plots with limited scope carried out by many academic & research organizations, there is no systematic representative basin studies in the country as yet. Oflate, National Institute of Hydrology, through its regional centres, has initiated these studies in some regions. One of such studies has been taken up by the North Eastern Regional Centre, Guwahati during 1994-95 at Dudhnai sub-catchment in the western part of Assam & Meghalaya on the south bank of the river Brahmaputra in consultation with the local water resources organizations of the states. This study was also recommended by the Regional Co-ordination Committee of the centre. This report on the work reviews methodology of the studies, brings about the existing hydrologic scenario in the area, presents the proposed studies/activities and discusses the results of some studies already carried out in the sub-basin.

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ABSTRACT

Understanding hydrological regime of watersheds under the circumstances of widespread man's influence on environment and ecosystem has now engaged serious attention of scientists and engineers throughout the globe for efficient management and conservation of scarce water resources. It involves dealing with a complex of interactive natural processes which cannot be described in conventional mathematical terms. Hydrologic scenario and its resultant impact on water yield being different at different place, representative and experimental basin studies are being undertaken in several countries to have in-depth knowledge of hydrologic phenomena specific to the areas.

North eastern region in India has the herculean task to efficiently plan for development or management of its huge water resources constituting about one third of the total potential of the country for want of sufficient data/information of the basins & sub-basins which are mostly ungauged as yet. This calls for establishing a network of representative basins for intensive instrumentation and long term monitoring so that results could be effectively extrapolated to larger areas and regional correlations could be developed. Dudhnai sub-basin of about 500 sq km in Assam & Meghalaya was selected for the purpose and investigations initiated. In this component part of the study 'Representative Basin Studies at Dudhnai', some basic concepts about these studies, prevailing hydrometeorological factors of the sub-basin and some investigation results have been discussed so as to provide for a reference base for other studies to continue.

1.0 INTRODUCTION :

Since the inception of IHD, during 1965-75, hydrological research through representative and experimental basin studies have been widely undertaken by several countries. Initially such studies had suffered not only from lack of basic data and standardization of observation procedures & monitoring techniques, but also from research methods, thus giving only a limited understanding of the physical processes occurring in the basins. Now, representative basin studies have come a long way and many sub-watershed systems have been modelled successfully.There is a large hydrologic variability in all basins, which needs to be taken into account to evolve an individual approach before any methodology is contemplated. The principal objectives in representative and experimental basin studies include prediction and quantitative estimation of hydrologic parameters through mathematical and physical relationships. Hence the aim of these studies is not only to collect data but also to interpret it, develop correlations, extrapolate the results to other basins and regionalise the relationships.

Representative basins, usually a small sub-system of about 250 to 1000 sq km, have been defined (Toebes et.al, 1970) as basins which are selected as representative of a hydrological region i.e a region within which hydrologic similarity is presumed. Observations on representative basins are taken for a long time and are generally combined with study of climatic, pedological, geological and hydrogeological characteristics. Thus a sparse network of representative basins with minimal natural and cultural changes may reflect general hydrological diversity of region. Representative basins are generally being used for hydrological prediction, extension of records, evaluation of natural changes and for fundamental research. **Benchmark basins** are also representative basins which are still in their natural state (undisturbed) and which have soil and vegetation conditions that are not expected to change for a long time. The benchmark basin is selected to be free from manmade change, both in the past and in the future so that long term shifts and trends in the hydrological regime can be observed. The factors causing these changes may be natural or may be induced by some activity of man exogenous to the basin, such as induced climatic change (Linsley, 1976). Hydrologic benchmark can also resolve the interactions between climatic and hydrologic variables with confidence that the results are not clouded by the effects of the works of man. The interrelationship thus demonstrated at proven hydrologic benchmarks (BM) can provide the base or datum for artificial effects (Leopold, 1962). Special types of representative basins called **vigil basins** are also used in some countries to study the time trends (Heindl, 1967). Similar to representative basins **experimental basins** are those which are intensively instrumented, usually small and used for in depth study ~~of~~ some portion of hydrological cycle (Linsley, 1976). On such basins one or more conditions are deliberately modified such as land use and the effects of these modifications on hydrological characteristics are studied. This general objective makes it imperative that the research organizations has the right to manipulate the land use at will and therefore owning or leasing of watershed for such studies is inevitable (Befany, 1959).

Under the IHD programme and in early sixties, several countries including USA, Australia, UK and other European countries initiated representative and experimental basin studies. The study programs in Australia and Newzealand have a rational planning (Fleming, 1974) of data collection techniques compatible with data analysis based on a conceptual model. The USGS in USA has network of benchmark stations (NASQUAN & BENCHMARK - National Stream Water Quality Network and National Hydrologic Benchmark Network).

Systematic representative basin studies in large scale have not yet been taken up in the country. However, some research organizations like CSWCRTI, CWPRS, DVC etc have carried out many useful studies on small plots/ watersheds to experiment few specific objectives relevant to hydrology. National Institute of Hydrology (Govt of India), through its regional centres at Belgam and Jammu has established representative basins in the Deccan Hard Rock Region and Western Himalayan Region respectively. Within this program, the North Eastern Regional Centre of NIH, Guwahati selected Dudhnai sub-basin above AT Road Crossing in Assam & Meghalaya for representative basin studies. The basin covers an area of about 500 sq. km and has mixed land use with forest, agriculture, homeland, fallow and barren land. The area is free from snowfall but experiences heavy snow fall. Meanwhile, a site for setting up of a meteorological observatory has been finalized with permission from deptt of Agriculture, Meghalaya. For instrumentation of the basin an **Automated Weather** Station [illegible] already been procured and equipments like S.R.R.G, O.R.G, wind-vane, anemometer, evaporimeter, sunshine recorder and set of thermometers to be housed in stevevenson screen are being procured. Field investigations for water quality, soil properties, infiltration characteristics etc are continuing since August,1994. This component part of the report on the representative basin studies at Dudhnai sub-basin brings about the first hand experience, existing hydrologic scenario, broad objectives of studies, and presents the results of the field investigations already completed.

2.0 METHODOLOGY:

Representative basins are effective means to generalize research results and extend their validity and applicability limits both in space and time. The main aspects and principles of how these areas should be selected can be learnt by surveying the objectives and most essential groups of tasks. These are broadly summarized in the UNESCO publication (1970) -" An International Guide for Research & Practice" edited by C. Tobes and V. Ouryvaev as contribution to International Hydrological Decade as follows:

2.1 Tasks & Objectives:

In order to recognize the casual and statistical relationships between subsequent hydrological events, the temporal development of phenomena must often be followed continuously in a large area. This group of tasks includes first of all the selection of so called indicator areas. If in the upper region of some larger water system, a few smaller streams characterizing well the regime of their wider surroundings are selected from the flood waves observed here, conclusions can be drawn as regards peak river stages to be expected later in the lower section of the water system.

In assessing water resources, as well as in solving flood prediction and other hydrological tasks there is need for maps showing the areal distribution of basic data and computation factors respectively. For high lands it is generally more expedient to use aids and diagrams expressing the variations according to elevation above sea level. The preparation of these aids again calls for representative areas, the size and locations of which may change in each case according to scale of the map and objectives of elaboration respectively.

Representative areas are needed in order to find the relationships that express the internal laws of hydrologic phenomena, if the validity of these is geographically restricted within regions or climatic zones. As characteristics example, the relationship between annual precipitation and run - off, the relation of the parameters of unit hydrograph to the physical geographical indices of the drainage area, the interrelations of stream flow and water quality indices according to regions etc may be mentioned.

To be more specific representative basins are set up to suit the purposes outlined below. However, it is not always possible to utilize the basin for all purposes and it is desirable that the primary purposes is specified for each basin.

(i) 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 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; usually suited for the training of staff. It can be carried out on individual basin or on net work of basins.

(ii) Effects of natural changes:

Some representative basins, specially benchmark and vigil basins may be used to study the effects on the hydrological regimen of a natural change. Natural changes, for instance, may be changes in climate, in vegetation, in pedological characteristics such as erosion, podzolization etc.

(iii) Hydrological prediction:

Most representative basins will be used for the development and improvements of methods of hydrological calculations and prediction for assessment of water resources in a region or area. This will involve a detailed analysis of hydrological phenomena and orient the direction of research towards solving methodological problems in hydrology.

(iv) Extension of records:

Ideally representative basins can serve as a basic network of hydrological stations in areas where river basins are generally small (say <3000 sq. km). In some countries the representative network does serve as the network of hydrological stations.

One main purpose of this network is to provide a long term record of basic data to which short term records observed on roving or investigation station may be correlated.

2.2 Requirements of Representative Basin:

To satisfy the short term and long term requirements for the evaluation of present and future land use / management changes for the solution of problems caused by past changes and to provide a medium giving fundamental data for other hydrological problems, it appears essential that basic networks of representative basins should be operated covering the important aspects of the study areas. The necessity of designating representative areas may arise in two aspects: in the case of a defined task or in general (the object of the latter is to achieve that data obtained through the selected areas could be utilized in solving as many as possible of the future tasks). Actually both types of selections are needed. Be the co - ordination and fulfillment of the aspects of presumable tasks ever so good and circumspect, it is always desirable to complete the previously designated basic network of representative areas with additional ones, according to the demands of certain concrete tasks and within the limits of possibilities permitted by the observation network. Representative basin has to satisfy basic requirements as

- They should cover typical catchments over the entire country as regard size as well as other physical characteristics.

- The number should be sufficient to represent important region and they should be operated on a long term basis.

- They should be capable of being instrumented for accurate long term measurement of atleast flow and precipitation.

- They should have reasonably uniform physical condition for quantitative determination of catchment characteristics and subsequent interpretation of data.

- They should have minimal changes in catchment characteristics during the period of observation or where they occur these should be carefully recorded.

- Number of representative basins which have a land use pattern that is not likely to be modified by the influence of man for a long time should be established and termed as benchmark basins.

- The loss of subsurface flow by deep percolation or the gain of this flow from neighboring basin should be negligible.

- The basin should be easily accessible for the purposes of instrumentation and continuous long term observation.

- Over and above, the representative basins should be selected and operated for each hydrological region discussed below.

2.3 Selection of Areas:

Selection of basin is the first and most important stage of the organization of observation and research on representative and experimental basins. An incorrect selection of basins may reduce the value of long term observations and expensive instrumentation and throw doubts on the results of scientific research. It is very difficult to select a basin which is representative of all hydrological features and to satisfy simultaneously all other requirements. Before selection of the basin, hydrological region to be represented has to be delineated.

2.3.1 Delineation of Hydrological Region:

Hydrological regions are relatively homogeneous sub division of an area of a country and in each such region hydrological similarity is assumed. Accurate classification of hydrological region is complex, since hydrological classification of an area with regard to one purpose or in respect of one phase or aspect of the hydrological cycle may be quite different from the classification for another purpose or aspect. Classification of erosional characteristics will be for instance, involve factors such as rainfall intensity and duration, infiltration capacity, vegetative cover, erosional resistivity of the sediment rating. Provided the soils are not impermeable, a low flow classification is governed mainly by the characteristics of geological strata and rainfall. Moreover, even within a small basin smaller areas with different hydrological characteristics may be found. For, this reason hydrological division is approximate only and is based on the most important factors.

A classification is however, essential so that representative basin may be selected and whether or not the regional boundaries are accurately drawn, is not of great importance except when representative basins are established with the limited purpose of hydrological prediction of one hydrological variable for the region as a whole.

For initial selection of hydrological region which is used for the establishment of representative basin, natural physiographical regions should be used . As a rule natural physiographical regions are sufficiently characteristic in many hydrological aspects. It should be noted however, that principles of selection of physiographical region may vary from country to country.

The size of region depends somewhat on the purpose for which representative basin is to be established and on the physiographical conditions of the country. Large area with similar physiography, for instance, could be subdivided into region as large as upto 20,000 Sq km. Small mountainous countries, especially those with more time influences should consider some regions as small as 1,000 sq km.

Where detailed hydrological data for the selection of hydrological regions are not available, selection must be on climatic, vegetational, geomorphological, topographical and geological characteristics. Regions are basically delineated by marking maps of characteristics such as mean annual rainfall, potential evapotranspiration, rock permeability, landslope etc and placing these on top of one another to define common boundaries.

This is not always feasible since coincidence of boundaries is highly dependent on the relative classification of the characteristics used. For instance, annual rainfall could be classified into groups of say perhaps < 1,000 mm, 1000 - 1,500, 1500- 2000 mm etc., but no guarantee could be given that such classes form common boundaries with say selected rock permeability classes. It may be that rainfall classes of say < 800-1,200 mm, 1200-1,600 mm etc give better results but the solution is normally some what more complex and an approach to find the classification of all characteristics selected which will lead to maximum coincidence of boundaries would be major task. There is, in addition, the problem of obtaining quantitative estimates of all the characteristics selected.

The simpler solution is to use one or more characteristics as a base and to adjust boundaries or draw sub - boundaries if other characteristics have locally dominant influence. The most important characteristics to use are climate and / or geological - pedological ones. Geomorphological features correlate reasonably with geology, but the soil and vegetational characteristics are too difficult to handle unless the natural vegetation is considered.

If climate is used as the base, average annual rainfall intensity-frequency-duration relations, average annual temperature, precipitation-potential evapotranspiration relationships or conventional indices are generally satisfactory.

Having drawn a base map of either climatic or geological -pedological features, other characteristics may be introduced and sub-boundaries drawn.

Selection of hydrological region offers greater opportunity in an area where existing hydrological network is already in operation. A statistical treatment of stream flow and precipitation data in the selection of hydrological regions could be carried out to fix the precision required for observations on representative basins and to lay down approximate periods for which representative basins should be operated.

2.3.2 Delineation of Soil-Vegetation Complexes:

Soil and vegetations are so closely interlinked that they form a complex. On the one hand soil influences the vegetation through site characteristics of mineral materials, climate and drainage (the inorganic cycle); on the other, vegetation influences soil by the action of plants and associated organisms in controlling the rate of uptake and return of elements to the soil through the organic cycle. When the correlations between soil and vegetation are established and understood, field observations on one factor can be used to indicate conditions in the other. There are many intermediate patterns which require examination of the geological and vegetational history before correlations can be relied upon to extend site observation to large area. Nevertheless, the widespread value to be obtained from the use of soil vegetation complex as indices of site conditions makes such correlations highly desirable.

For an approximate delineation of soil vegetation-complexes for use in representative and experimental basin research, delineation should be differentiated according to whether sites or basins are being selected. The basic unit of classification is the soil type, which has a narrow range of properties. The vegetation can be similarly grouped in small units on the basis of phytomorphological characteristics. These combination of soil type and vegetation units are the best criteria for the selection of sites within basins.

2.3.3 Selection of Representative Basin:

Having delineated hydrological regions it is necessary to select a representative basin for each region. Countries which have great pyhsiographical variation 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 area will therefore be non - homogeneous in space.

The selection of representative basin is governed to a certain extent by their purposes and a compromise must be made in the selection. Or representative basin must be selected for one or two specific purposes only. In some countries the representative basin network can serve partly or wholly as the basic network of gauging stations. The selection of representative basin is governed mostly by the following factors:

(a) **Representativeness :-** It is most important to consider whether the basin selected represents the hydrological region.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: for instance, if a hydrological region has been defined as P2 K2 S4, where P2 represent a class of mean of annual rainfall, K2 a rock permeability class and S4 a relief class then a basin with the same classification should be selected for its representativeness.

(b) Basin Divide:- The basin divide should be as distinct as possible. 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 sub - surface basin divide. Where possible, stream piracy should be prevented by artificial means. It is to be noted that with a decrease of the basin area, the relative influence of noncoincidance of surface and sub - surface basin area will increase.

(c) Constancy of Condition:- The cultural changes in land use and management, stream flow utilization etc, should be minimal during the period of study and where they are inevitable, should be carefully recorded. Where representative basins are designated as bench mark basins, it is imperative that cultural changes be prevented entirely and that natural changes be minimal.

(d) Deep percolation and Channel Infiltration:- The loss of sub - surface flow by deep percolation, or the gain of this flow from neighboring basins must be as small as possible unless the study of representative basin is for the study of such leakages.

(e) Quality of Flow - Measuring Station:- It is essential that 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. It is important that flow characteristics as they relate to channel features are typical of the region except in arid or semi - arid zones where it may be advantageous to select, if possible, a basin that has a permanent or intermittent flow or at least has some sub - surfaces flow during and shortly after storms.

(f) 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 or to the use of helicopters.

(g) Size:- The size of a representative basin depends on the natural condition and the objectives of the study. It has been suggested (37) that the size ordinarily lies between 1 and 250 sq. km and rarely exceeds 1000 sq. km. If the size of the representative basin is larger it may cause difficulty in the homogeneity of certain basin characteristics and in the organization of instrumentation and observations.

2.4 Observation Programs for Representative Basin:

Representative basin should, as far as possible, have identical programmes and method of observations to facilitate a comparison of research results. Individual programmes must be adjusted, however, to the particular purpose or purposes.

It is necessary to distinguish between minimum and special equipment requirements. These include at least observation on stream flow and precipitation to study basic flow processes. After certain minimum studies, a progressive increase in the observation can be made as indicated by the early research findings. For instance, it may be found that, for a proper rainfall-runoff study, information on soil moisture and infiltration is required .Such special observations can then be added to the initial programme.

Such a progressive development of observations will ensure a better adaptation of measurements of the problem studied in particular conditions of the basin. Moreover, observations on representative basin must be carried out to suit the analysis techniques. If for instance, rainfall - runoff relations are studied on a basin with a relatively short record, storm rainfall should be used rather than annual totals to obtain a statistically valid sample and this aspect must be reflected in the observational technique for instance, rainfall amounts should be measured at the end of each storm.

For any observation which involves an element of sampling in space, a dense sampling programme for limited period can be very useful

For example , to study the representativness of a given basic rainfall network in a basin, a large number of gauges are installed for a limited period. After a short period the data is analyzed by correlation techniques and in many cases, a representative small basic network for the given level of accuracy required can be established.

It is desirable to have a climatological station within the representative basin , but it is possible to use a climatological station located outside the basin , provided its data are representative for the given basin.

2.4.1 Minimum Programme:

For example for the problems of qualitative variation of flow characteristics in forested and unforested catchments it is necessary to organize parallel observations in forested and unforested catchments. The observations should include:

(i) Daily measurement of amount of precipitation on a network of basin.

(ii) stream flow measurements with automatic recording equipments.

When snow occurs in winter it is necessary to carry out snow surveys at the end of the winter to estimate the maximum water equivalent of snow pack before spring snowmelt starts.

2.4.2 Full Programme:

For the problem of determining why variations of flow characteristics occur on forested and unforested basins, a full programme of observation of all water balance components is carried out . The observations include:

1. Measurement of rainfall intensity by recording raingauges

2. Climatological observations

3. Observations of evaporation by evaporation pan.

4. Streamflow measurements with automatic recording instruments.

5. Observations of ground water level.

6. Measurement of soil moisture.

7. Measurement of infiltration capacity.

8. Measurement of interception

9. Snow surveys during the winter.

10. Observations of snowmelt during spring season.

In addition to observations of streamflow and precipitation it is necessary to make a preliminary survey of the basin to consider the physical condition which effects the hydrology of the catchment. The survey should include.

(a) an exact determination of the basin divide and catchment area.

(b) a survey of geological soil and vegetative cover characteristics of the basin.

(c) description of the basin relief.

(d) description of the existing network of hydrological and hydrometeorological stations.

After carrying out minimum observations over a certain period of time, a progressive increase in the observations can be made as guided by the early research finding and as demanded by the research needs.

2.4.3 Frequency of Observations:

The frequency of observations should be such as to obtain both mean variables and an idea of the daily variation of these variables.

2.4.4 Times of Observation:

Times of observations, should if possible, be similar to those observed on the standard climatological network in the country so as to aid in the interpretation and comparison of results.

2.4.5 Period of Observations:

The value of the result and the degree of accuracy obtained depend on the length of the observational period. A problem common to many field experiments concerns the need to operate a measurement programme for a considerable period of time. There are certain studies where a short period of observation can and indeed has generated valuable results. This is a situation with many studies of runoff processes where it is important to identify the mechanisms and where longer period of observation is unlikely to produce any major additional benefits.

Observations in representative basins should include atleast several years (or periods) with high and low flows to establish the natural run-off pattern. In cases such as study of the effects of afforestation on hydrological regimes, the observational period is of longer duration.

A reduction of the observational period may be made in case where correlation can be established between hydrological variables from the research basin and other basins in the same hydrological region. For example correlation of rainfall data from research basin with rainfall data from national network.

With the advent of sophisticated computer models for watershed hydrology, requirement of advanced monitoring techniques and range of data to be observed have increased to a very large extent. A selection of types of hydrological data to be observed is furnished in the Table 2.1.

Table 2.1

A Selection of types of Hydrological Variables

Variable	Parameter	Characteristics
Precipitation		
Rainfall amount	intensity	Basin area
Snow depth, water equivalent	interception	slope
		altitude
snow extent	water equivalent	shape
snow density	melt rate	aspects
glacier extent	movement	etc.
Evaporation		
evaporation amount	potential evapo-	soil type
temperature	heat balance	soil density
vapour pressure		Geology
wind speed		
radiation		
cloud cover		
Water quantity		
water level	discharge	lake area
hydraulic radius	Froude number	reservoir area
cross-sectional	Mannings n	capacity
area		
velocity	discharge of effluents	flood area
ice thickness		
Soil moisture		
weight	density	
tension	measurement by weight	
total count	measurement by volume	
count rate	infiltration	
Ground water	permeability	ground water storage
water level	transmissibility	
well depth	coefficient of storage	
Water quality		
sedimentation	chemical, biological	including erosion & sediment
radioactive parameters		

2.5 **Analysis Techniques & Interpretation of Results:**

One of the primary objectives of studies on representative and experimental basins defined by a set of quantitative parameters, is to translate from it the research results to other basins (normally unguaged). It is also required to define accurately the basin characteristics and hydroclimatological characteristics to formulate a mathematical model representing the hydrological processes or the water balance of the system. While the objectives are ideal and worth aiming, it is very difficult to model the hydrological processes or to derive a satisfactory quantitative index for each element. The variability in space and time and nonlinearity of basin responses associated with uncertainty of inputs make the hydrologic processes difficult to model.

The first step in analyzing the basin, as a hydrologic unit is to quantify basin and climatic characteristics. The basin characteristics include soil & vegetation complex, geomorphological, pedological and geological characteristics which are influenced by hydroclimatic factors (Chapman, 1952), (Strahler, 1957). Vegetation affects the components of hydrological cycle like evaporation, interception, transpiration and infiltration. Measurement of different characteristics characteristics combined with vegetation surveys help quantifying vegetation complexes. Besides investigating soil and geological factors, easily measurable hydrogeomorphological characteristics consisting of linear, areal and relief aspects of the basin & channel network which help in quantifying and synthesizing model parameters (specially for unguaged basins) should also be determined. Generally, it is difficult to specify before hand which climatic characteristics will be predominant to a particular study & successive trials and correlations may be necessary. It is therefore, desirable that initial processing of data such as computation of mean areal precipitation, plots of mass curve, flow duration curves and frequency analysis be carried out with available data to have a reasonable perspective of basin hydrometeorology.

2.5.1 Modelling Representative Basins:

One of the greatest justifications for representative basin studies lies in the use of precisely and reliably collected data for hydrologic modelling. A model is a representation of physical process wherein elements of hydrological cycle and basin characteristics in approximately in stationary conditions are correlated. Initially a conceptual model based on quantitative or semi-quantitative knowledge of the prevailing hydrologic phenomena in a representative or experimental basin is built. This model would contain elements defined by explicit functions, which describe operations effected on various portions of input, output and storage. The recorded input is processed through the model and the resulting output is compared with the recorded output of the natural system. If an acceptable agreement is not found, one or more parameters of the component, subsystem are modified/ adjusted and the process is repeated in a systematic way until there is adequate correspondence between synthetic and observed flow. This is normally achieved through an optimization routine. Most simulation models use unit hydrograph as the central linear element (Crawford & Linsley, 1960).

A number of watershed models have been developed in recent years. Computer simulation models are currently regarded as powerful tool in basin studies and research. Applied to field situations, models can help to determine the basin variables for a given set of conditions and hydroclimatic scenarios.

2.5.2 Linear Model and Graphical Techniques:

Correlation and regression techniques are generally used to explore a combination of variables which affect the hydrologic system. The combination that yields a relationship which closely approximates the recorded output function in terms of the recorded input function and other arbitrary parameters, is adopted as best prediction equation. Correlation techniques are powerful tools when applied to the test of well defined hypothesis in many fields of physical hydrology (Mossiswa, 1962). However, a great deal of subjectivity underlies in such prediction models where judgment and experience should be exercised to avoid physically irrelevant parameters (Wallis, 1965). Graphical techniques generally supplement analytical methods.

3.0 PROBLEM DEFINITION :

The hilly catchments like Dudhnai sub-basin are the sources of water, food, fibre and energy. In order to facilitate a more scientific assessment of water balance of hilly catchments, adequate hydrological and meteorological data base is not yet built up. Special attention needs to be paid for collecting data from higher elevations. The existing network is not adequate and is yet to be strengthened and diversified at selected representative locations. In this context it is an essential pre-requisite to set up representative basins in different hydrological regions of the entire country and standardize instrumentation and monitoring techniques of these model basins. The experiments and fundamental research in the representative basins will go a long way to develop regional rainfall run-off relationships and to transform the results to larger ungauged basins.

With this in view, the Dudhnai sub-catchment, predominantly a rain-fed hilly catchment on south bank of the river Brahmaputra in the states of Assam & Meghalaya, has been taken up for representative basin studies in consultation with the local water resources organizations of the states during 1994-95. The study has also been recommended by the Regional Co-ordination Committee of North Eastern Regional Centre, National Institute of Hydrology, Guwahati.

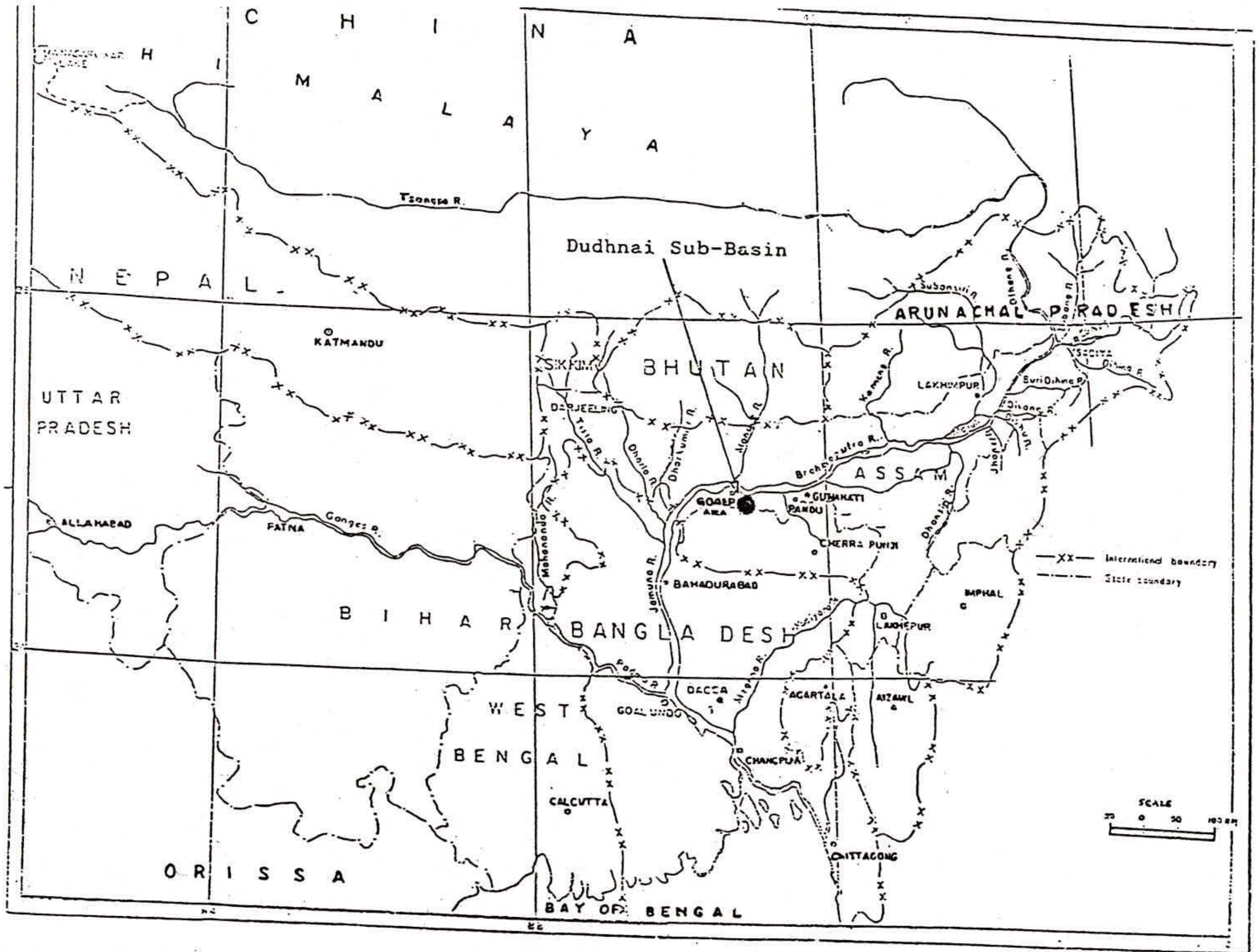
4.0 THE STUDY AREA :

The Dudhnai sub-catchment in the states of Assam and Meghalaya, India selected for long term representative basin studies is situated in between longitude 90Deg-40Min-33Sec E to 90Deg-56Min-1Sec E and latitude 25Deg-36Min-57Sec N to 25Deg- 58Min-45sec N (Fig.1 shows the sub-basin within the North Eastern Region). The basin is bounded by the river Brahmaputra in the North, the hill ranges of the Garo Hills in the South, the Kulsi-Dseosila sub- basin in the East and the Jinary sub-basin in the West.

4.1 North Eastern Region:

The North Eastern Region of India, popularly called as "Seven Sisters" comprises of the states of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Mizoram, Manipur and Tripura. However, the N E Hydrological Region includes hilly parts of West Bengal(Dooaro area) and Sikkim also besides N E States. The entire region is drained by the Brahmaputra River system, the Barak River system, the Tista system and other minor systems like Jaldhaka, Torsa etc. These river systems are briefly as follows:

<u>The Brahmaputra :</u> The Trans-Himalayan River Brahmaputra locally known as Tsangpo originates at an altitude of 5300m at about 63 Km South East of Manas Sarovar Lake in Southern Tibet and flows eastward entering India at Arunachal Pradesh after traversing 1600 Kms length draining an area of 2,93,000 Sq.Kms. Then after flowing in an almost southernly fashion for nearly 225



SOURCE: BRAHMAPUTRA BOARD

FIG.1. THE BRAHMAPUTRA RIVER SYSTEM

Kms through steep hills of Arunachal it enters plains of Assam and is joined thereafter by combined flow of two other Trans-Himalayan rivers named Lohit and Dihang. Then it flows westward under the name of the Brahmaputra for a distance of nearly 700 Kms before entering Bangladesh near Dhubri. During its course through the long and narrow valley of Assam it is joined by about 40 tributaries in North Bank and 20 tributaries in South bank-flowing in from Patkai Hills, Naga Hills, Mikir Hills, Khasi Hills and Garo Hills. The river Brahmaputra drains an additional area of 2,40,000 Sq.Km of India and Bhutan thus making its total catchment area upto Indo-Bangladesh Border 5,33,000 Sq.Km. The river, all along in plains constantly changes its course and thus form large sand bars. During dry season it is found to be flowing in numbers of channels of various magnitude and during monsoon it is found to become a vast sheet of water having width varying from 6 Kms to 15 Kms excepting at Guwahati and Pancharatna where flow remains restricted within 1.5 Kms because of hill outcrops on river banks.

The Barak: The river Barak originating at an altitude of 3000m in southern face of Naga Hills flows southward through Manipur Hills, takes a complete turn at Tipaimukh on Manipur-Mizoram border and debauches in plain a few Kms upstream of Lakhipur traversing a distance of nearly 120 Kms and draining an additional area of 12,000 Sq.Km before bifurcating in two channels and entering in Bangladesh. During its course through plains it is joined by number of tributaries flowing in from Naga Hills, Jayantia Hills and Khasi hills on North bank and from

Mizoram Hills on South bank. The river all along its course in plains flows in a meandering channel of very flat bed slope.

Tista: Originating at an elevation of 7000m from the Northern glaciers of Trans Himalayan ranges in Sikkim, the stream 'Lachung' takes its name as "Tista" after two other streams joining it one after another at elevations of 2400m and 1500m respectively. Traveling southward through hills of Sikkim and Darjeeling district and traversing a distance of nearly 160Km. the river debauches in plains and flows in a south eastern direction for about 90kms. The river enters Bangladesh draining a total area of about 10,500 Sq.Km. During the course in plain of West Bengal, the river flows in a meandering channel shifting its course continuously.

4.1.1 Hydrometeorology:

The presence of the great mountain mass formed by the Himalayas and its spurs on the north along Arunachal Pradesh and of the Ocean on the south are the two major influences operating on the climate of the N-E Region. The climate of N-E Region is different than the rest part of the country due to presence of rich forests and mountain ranges along the three boundary sides of the region. These mountains ranges are Himalayan ranges from north boundary side along Arunachal Pradesh, Patkai ranges from east side running along Indo-Burmese boarder and Garo Khasi-Jayantia ranges from south side along Assam Meghalaya. In the region rainfall activity increases from the month of March and stays up to last week of September or first week of October. Maximum rainfall is observed between the months June and September.

In N-E Region, maximum rainfall is observed due to orographic effect. Convective type of rainfall due to thunder clouds is also observed in the region. Fig.2 & Fig.3 show the seasonal & annual variation of rainfall coefficient in the region. Fig.4 shows the 24-hours heaviest rainfall contours.

The annual average humidity in the plain of the region is 72% ranging from monthly average of 70% in the month of March and 85% in the month of August.

The months of December, January and February constitute the winter season. The season is not homogeneous for all parts of the north-east. During this season the weather is controlled by the sub-tropical jet stream and consequent development of central Asiatic high pressure centers, and the high pressure centers over northern Burma. These high pressure centers extend their outer tongue beyond hills, thereby lowering the diurnal temperature below freezing point over the higher reaches of the mountains. Over the lower slopes fair weather prevails occasionally associated with fogs and haze. In the Brahmaputra plain parts of Meghalaya, Manipur valley, Barak valley and in parts of Tripura, day temperature rises. Occasionally thermal lows are locally developed which disturbs the fair weather. During the winter months, up to a height of 2 to 3 Kms above m.s.l. the surface winds are north easterly; beyond this the westerlies prevail. Due to wind shear at the junction of surface winds and westerlies, and at times when the pulses of western disturbances are carried under the impact of the jet stream, the weather becomes

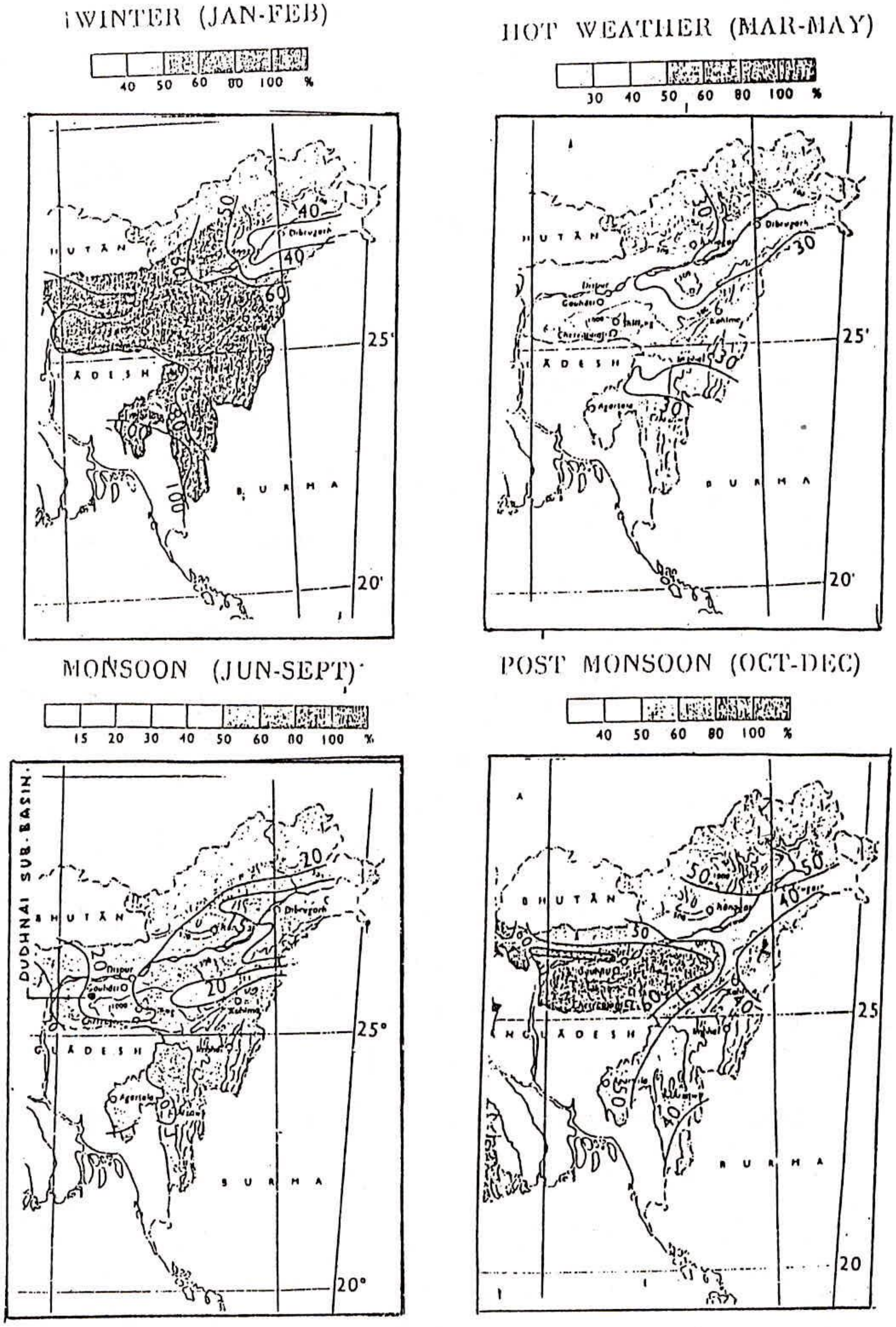


FIG. 2. COEFFICIENT OF RAINFALL VARIATION

SOURCE: IMD

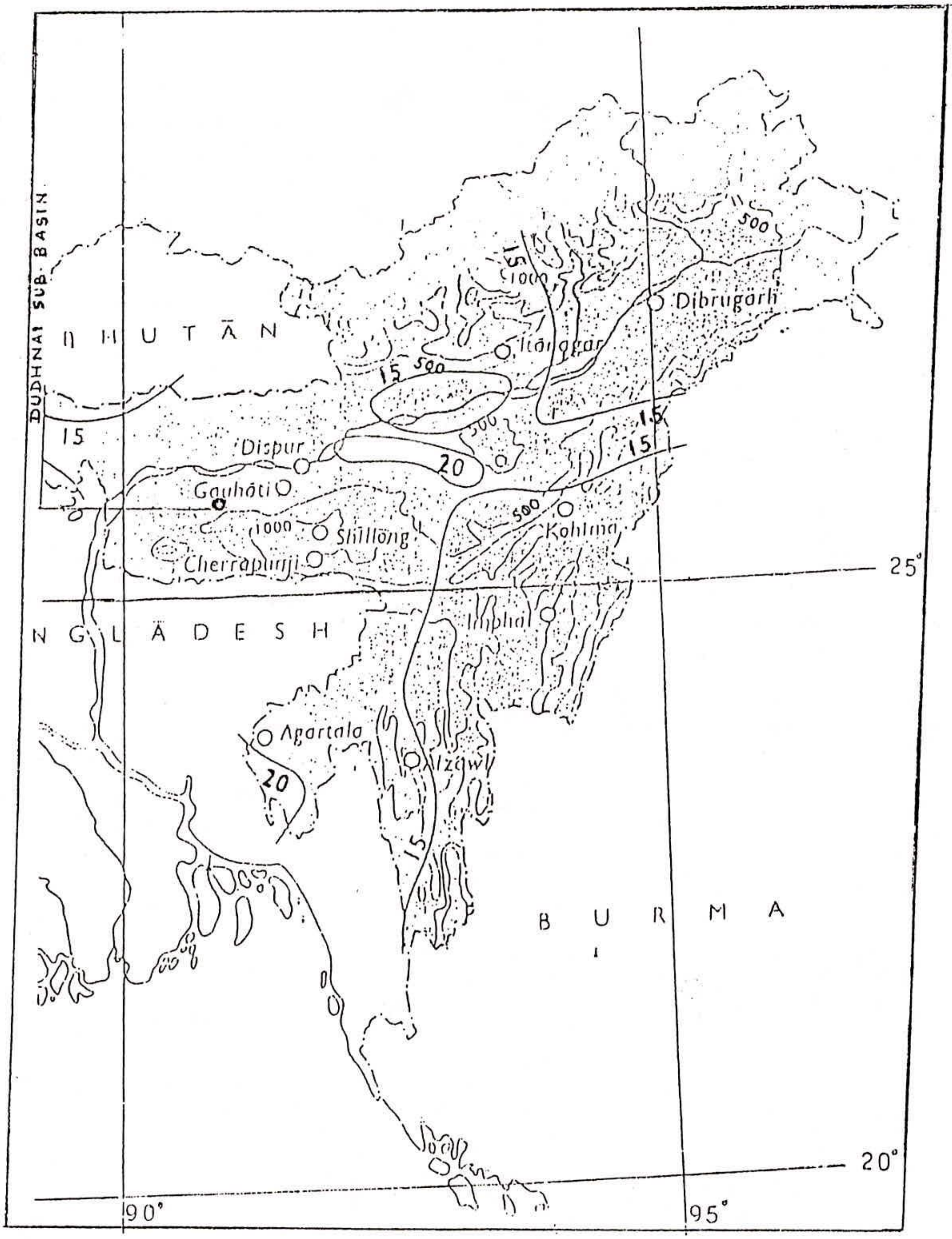


FIG. 3. COEFFICIENT OF RAINFALL VARIATION (ANNUAL)

SOURCE: IMD

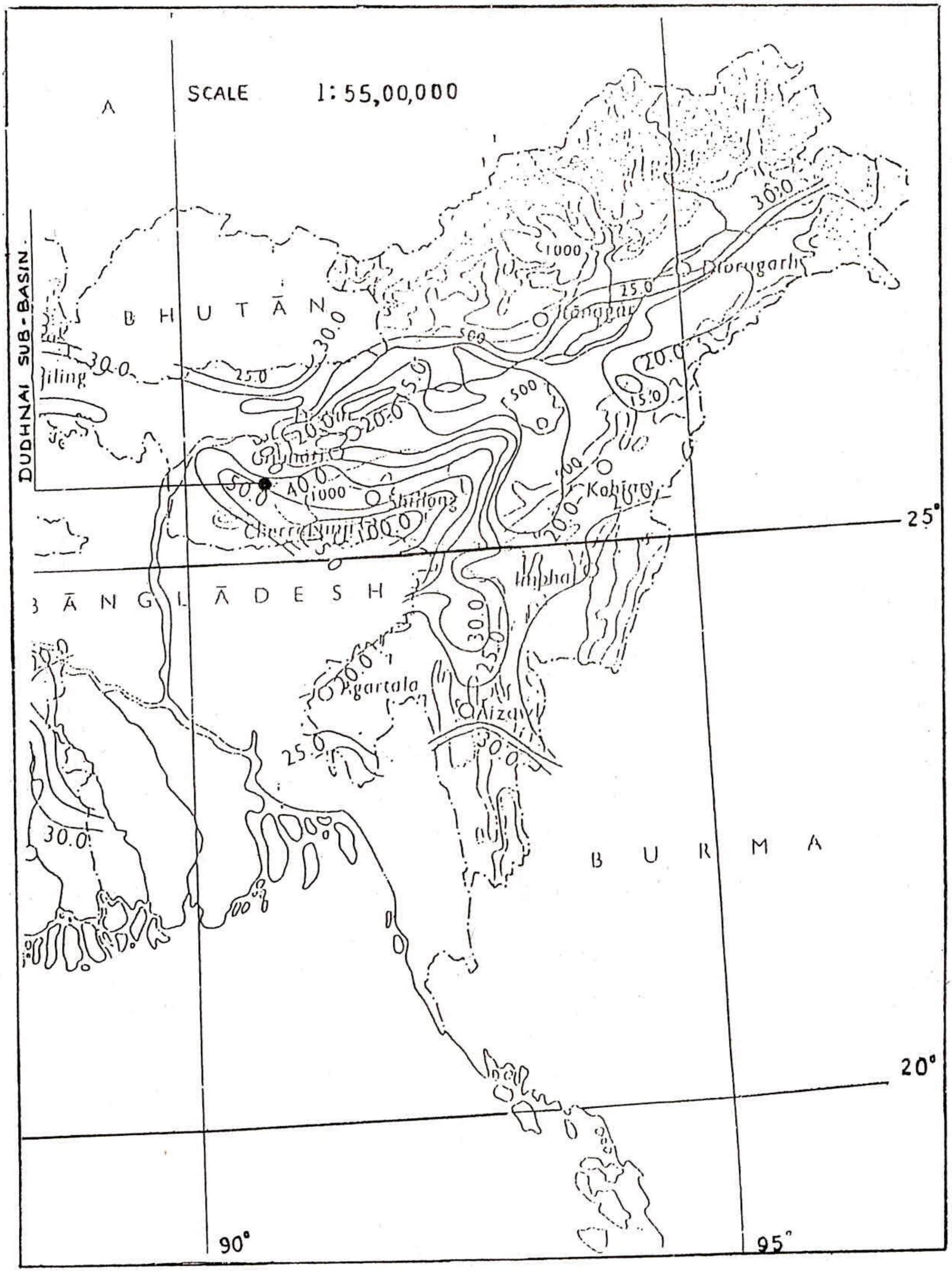


FIG. 4. HEAVIEST RAINFALL IN 24 HOURS

SOURCE: IMD

cloudy and rainy which may continue for a couple of days. Such deterioration increases the severity of cold especially over the high lands. The easterly winds are of local origin and are identified as mountain wind. Fair weather days are marked by mountain and valley winds over the entire north east which reduces the diurnal range of temperature. December and January are the driest months and January is the coldest month for all the states. Normally Manipur remains absolutely dry in winter where as Arunachal Pradesh receives about 50mm of rainfall. Due to low rainfall in winter, floods are not seen in the region. Except ir Mizo hills, other hilly areas having an altitude of more than 1216m, the average temperature for these months remain below freezing point whereas over the rest of the areas the temperature ranges between 8^{o}C to 15^{o}C. One of the notable features of winter weather is the wide spread fogs in the morning hours over the low-lying areas and evening fogs over the hills. Due to mountain winds the fogs are usually brought down to the lower regions in the morning hours. on the south bank of the Brahmaputra, dense. fogs remain for long duration over the low-lying areas, winter season is endurable and pleasant.

The months of March, April and May constitute the <u>pre-monsoon season</u> of N-E India. In this season most of the rainfall over the region is due to thunderstorm activities. From the month of March, the land surface is steadily heated and the temperature rises.

Local depression are found over the Brahmaputra plain where strong convection develops, especially in the afternoon and casually stormy weather follows. In the lower Brahmaputra valley strong north-east wind raises dust from the dry river banks. Besides, the continued influence of the western disturbances not only brings rain but also reduces the shooting temperature. Ice over the lofty northern and eastern hills melts and this melting ice supplies moisture and potential energy for development of thunderstorms. With the migration of the depression over bay of Bengal and incursion of the air masses over the entire region, the frequency of storm increases. The nor'westers locally called 'Bordoichillas' start during this period. The nor'westers move to the north east by the 2nd week of April and by the first week of May it takes western movement. On both the cases thunder showers casually associated with hails, occur over the plains and the foot hills of the entire region. During this period, dry sunny warm days are occasionally interrupted by cloudy and stormy weather. Rainfall ranges between 25cm and 40 cm and the temperature ranges between 19^{o}C to 26^{o}C. In this season rainfall increases the water levels of the rivers. Major floods are not uncommon in this season especially towards the later half of the season.

June to September months constitutes the <u>Monsoon Season</u> for the NE Region. This is the season which is more prone for devastating floods over the region as major rainfall over it takes place. With the onset of monsoon in early June, heavy rainfall occurs and the rising temperature is considerably arrested. Wide spread low clouds and high humidity maintains uniform temperature over uniform terrains. Over the plain average temperature ranges between 20^{o}C and 29^{o}C. Rainfall varies according to the orographic situations. On the windward sides of the hills, the rainfall is heavier than on the leeward slopes. The average rainfall during monsoon season in different states is: Arunachal Pradesh- 185 cm, Assam and Meghalaya- 180 cm, Mizoram and Tripura- 130 cm, Nagaland and Manipur- 170 cm. The most conspicuous characteristics of monsoon weather in N-E India is the association of thunder storm. From June to Sept the frequency of thunder is highest (119 days) over the southern bank of the Brahmaputra and lowest over the Arunachal Pradesh (34 days). Over Nagaland, Manipur and Tripura, the thunder days vary between 40 to 100 days.

Important synoptic features responsible for heavy precipitation during monsoon season are monsoon trough lying close to foot hills of Himalayas, low pressure area or east-west trough at the surface, cyclonic circulation and upper air trough at various levels of atmosphere and approach of monsoon depressions and high or intense system from north bay. Occasionally, the rainfall activity increases due to passage of western disturbances in the north seen as westerly trough in the middle and upper levels of the troposphere. It has been observed that the major floods over the region most commonly occur when (a) the monsoon trough lies close to foot-hills of Himalayas for two to three days or more (this is called as **break monsoon** situation), (b) the depressions and cyclones in north bay move north or north-east and approach the region. Sometimes, low pressure area or east-west trough at the surface with a favourable combination of deep westerly trough in the upper air lying over the region and its neighbourhood produce copious rainfall and floods. However, it has also been observed that the region received less rainfall whenever monsoon depression forms over the north bay as then the moist bay winds do not reach the region.

Months of October and November constitute the post monsoon season. During this season N-E region receives generally light to moderate rains with rainfall decreasing as the monsoon marches. The monsoon withdraws from the N-E India in the last week of September or first week of October. After withdrawal of the monsoon, light unsteady winds are experienced which become north easterly. The cool north easterly winds having origin over the lofty mountains, bring down the temperature. The orographic low pressure gradient is established over the entire region. Rainfall abruptly decreases and it ranges between 20 cm to 25 cm. From the month of October the weather becomes progressively drier. Nagaland, Manipur and Mizoram remain absolutely dry in November. Assam, southern parts of Arunachal and Barak Valley including Tripura experience occasionally thundery weather in the early part of November and due to escalation of the western disturbances and shifting of the easterly jet stream to the south, cloudy weather associated with mid rain prevails for short duration. With the advance of the season, the ground cooling begins and morning fogs appear. Dense haze over the hills is a common phenomenon. The weather progressively clears up and fair sunny days prevail till the end of November. This is the shortest season in the north-east, but most endurable and pleasant period of the year.

Fig.5 shows the average annual rainfall distribution in the

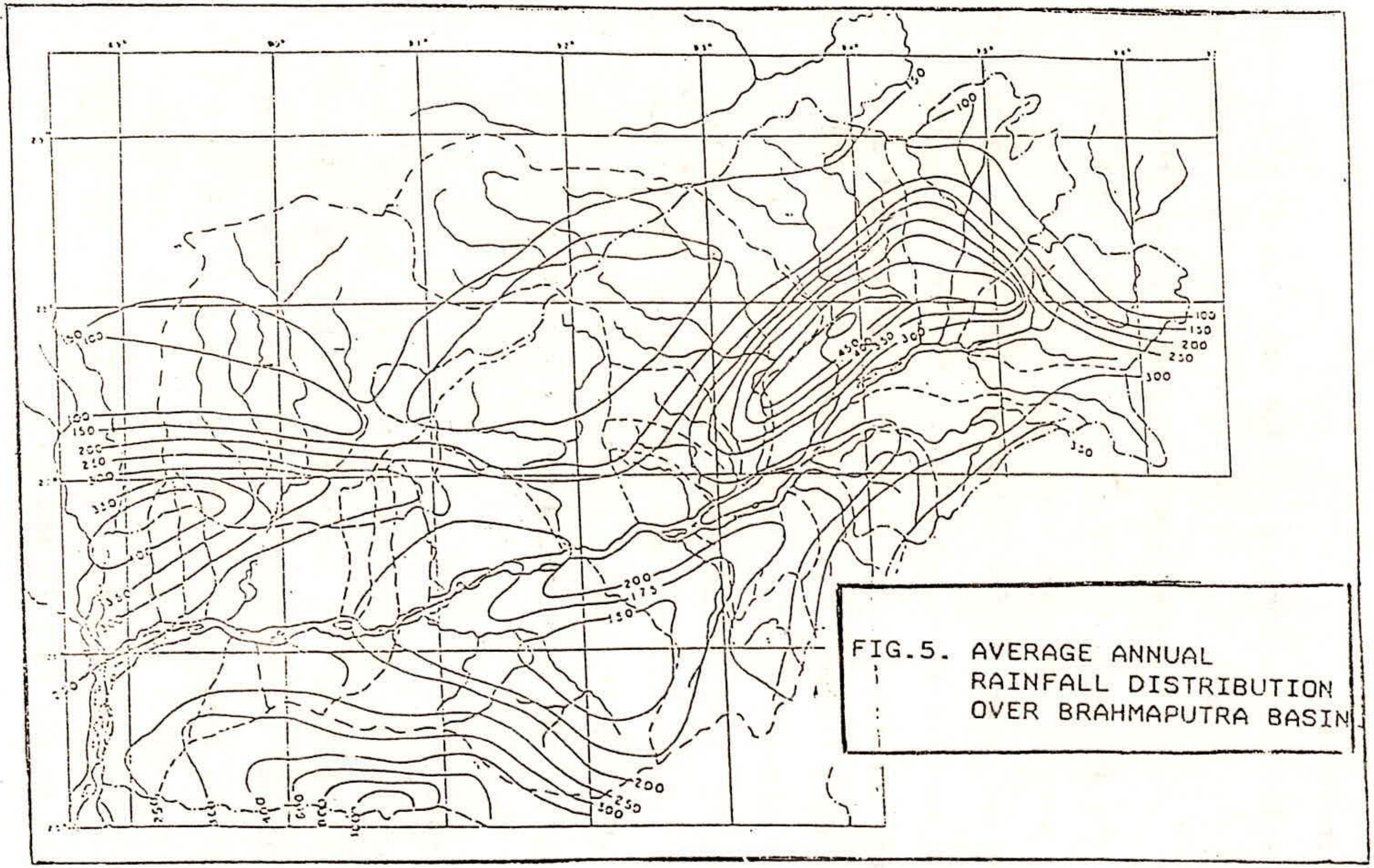


FIG.5. AVERAGE ANNUAL RAINFALL DISTRIBUTION OVER BRAHMAPUTRA BASIN

SOURCE: BRAHMAPUTRA BOARD

North Eastern Region specially on both banks of the Brahmaputra river.

4.1.2 Agriculture

Agriculture and forests are the mainstay of the people in the basin. In Assam, rice is the principal crop. Apart from tea which is grown on comparatively higher land, other important crops grown are jute, mustard, pulses, wheat and sugarcane. In the hilly part of the basin also, agriculture is the main occupation besides forestry. The crops grown are rice, maize, millet, sugarcane, mustard and sweet potato. People are taking to horticulture and the feasibility of growing tea and coffee in the area has been established. Also, experiments on growing cashew-nut and rubber plantation have shown promising results.

Shifting cultivation, known as Jhum cultivation, is being practiced in the hills since long. This pernicious practice denudes the area of vegetal cover and washes down the rich top soil rendering the area progressively infertile.

4.1.3 Forests

According to Summary Report for North Eastern States/Union Territories (December, 1983)published by the National Remote Sensing Agency on the basis of mapping of forest cover in India from Satellite Imagery (1972-75 and 1980-82), the forest cover in the region is about 48.28 per cent. Even on taking the degraded forest into consideration, only Arunachal Pradesh fulfill the norm of the 60 per cent forest cover.

4.2 Dudhnai River Sub-basin:

The Dudhnai basin(Fig.6) lies in the district of East Garo Hills & is bounded on the north by Goalpara district of Assam (The Brahmaputra river plain), on the east by West Khashi hills district of Meghalaya(Deosila sub-basin) and on the west by the east Garo hills region of Meghalaya(Krishnai sub-basin). The catchment area is about **476 sq km** covered under Survey of India maps 78 K/9, 78 K/10, 78 K/13, 78 K/14 of scale 1:50,000 with its elevation varying from 210.0 m. to 2227 m. above m.s.l. and basin slope from south to north. **Fig.7** shows the contour map of the basin. The sub-catchment is within districts of East Garo hills in Meghalaya(83%) and Goalpara district of Assam(17%).

While detailed **soil** investigations in the basin is in progress it has been reported that soil in the lower catchment is predominantly hard reddish clay to light yellowish & light grays felspar & Mica. The basin plains are mostly new alluvium as found in riparian areas. Soil in the upper catchment is sandy loam or silty mainly comprising of quartzite & laterite.

4.2.1 Dudhnai River System

The river Dudhnai is one of the small south bank tributaries of the river Brahmaputra. It originates from the Northern slopes of the Garo Hill ranges of Meghalaya at latitude 25Deg.35Min.N at an elevation of around 400m. From here the river flows in the N.E. direction by the name Manda for a distance of about 26 km till it is joined by the river Rongma -Chichra, a right bank tributary.

Major part of the sub-basin is hilly terrains with a few

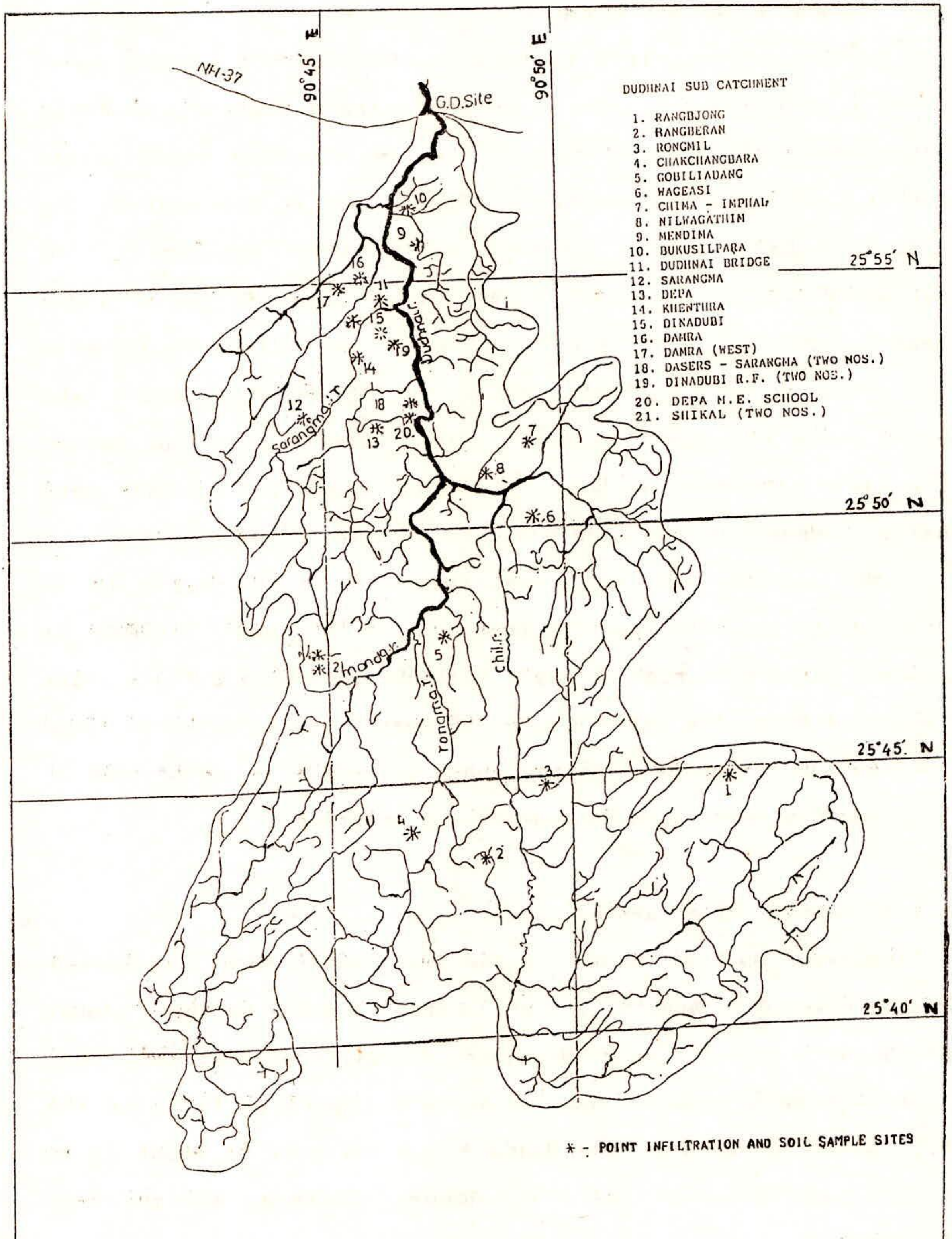


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FIG.6.INDEX MAP OF DUDHNAI SUB-CATCHMENT

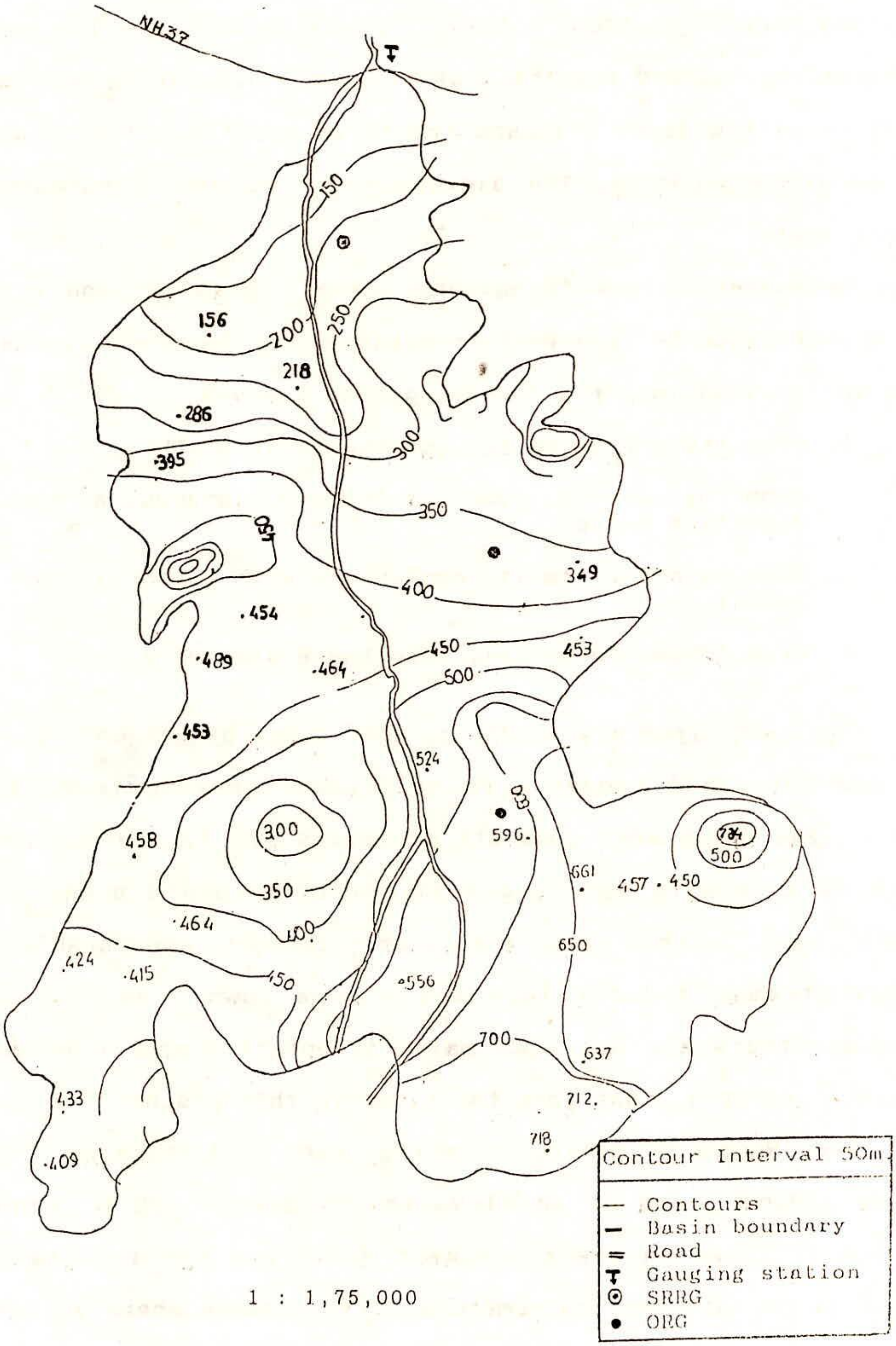


FIG.7. TOPOGRAPHY MAP OF DUDHNAI SUB-CATCHMENT

isolated V shaped valleys developed along the course of river with undulating topography. Geomorphologically the basin can be divided into three broad limits. The first one is hilly gneissic complex, the second one the foot hill zone consisting of unsorted mixture of boulders, clay and the third one i.e. flood plains is of alluvium deposits. The elevation of the basin decreases towards north.

Depending on the topography, river gradient and bifurcation/confluence of important tributaries of the river Dudhnai, it can be divided into the following four reaches:

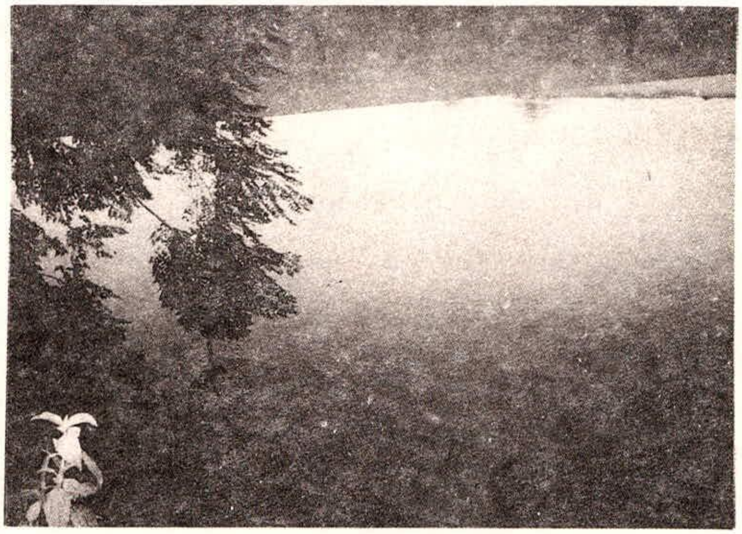
1. From its origin to the joining point of Chil.
2. From the joining point of Chil to Dianadubi at the Assam Meghalaya border.
3. From Dainabubi to its confluence with Krishnai near Domani.
4. From Domani to outfall into the Brahmaputra.

The reach from its origin to confluence of Chilentirely lies in the Garo Hill ranges with altitudes varying from 100m to 400m. The whole area consists of series of hill ranges covered with forests with very small intermittent plain areas in the downstream. In this reach the river intercepts innumerable small hilly streams and rivulets which come down from the hills. However, there are only two major tributaries namely Rongma or Chichra and Chil that join the river in this reach.

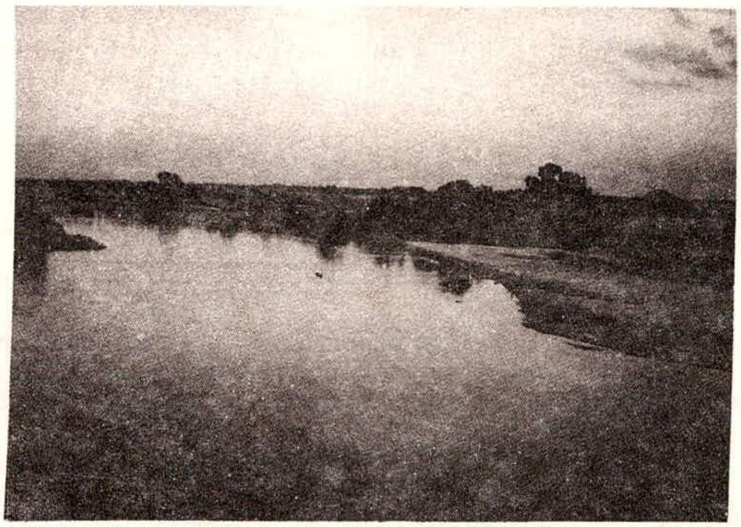
The **Rongma** originates from the Garo Hill range at latitud 25Deg-45Min**N** . and at an elevation of around 600 M. From its origin it flows in the south-west direction for a distance of about 14 Km intercepting numerous hilly streams where it takes a sharp turn and flows towards North after being joined by **Rongit**, a small tributary which also originates from the Garo Hill ranges at latitude 25Deg-40Min N and at an altitude of 600M. Rangit flows for a distance of about 12 Km in a meandering loop (initially S.W. and then towards North). After the confluence with Rongit the river flows straight towards North for a distance of about 8 km intercepting numerous hilly streams and takes a sharp turn and flows for about 12 km before joining Dudhnai in the right bank. The total length of the river from its origin to its confluence with Dudhnai is about 34 km which lies entirely in the hilly region.

The **Chil** is also a right bank tributary of Dudhnai. After originating from the Garo Hills at an altitude of around 400 m (Latitude 25Deg-47Min N & Longitude 90Deg-53Min E), it travels through hilly areas in the North West direction for a distance of about 7 km. After that the river takes a turn towards West and flows for a distance of about 4 km through relatively plain areas before joining Dudhnai. From its origin to its confluence with Dudhnai the river flows for a total distance of about 11 km. The catchment area of this tributary is 66 sq.km.

<u>The reach from the joining point of Chil to Dianadubi</u> of the river is along the middle reserved forest area of the basin. This reach consists of the reserve forests running parallely along the river on the left bank from the confluence point of Chil to Dainadubi. The Eastern Bank is covered with dense mixed jungle. The river in this reach has got a narrow valley which generally widens as the river flows downstream. There is no major



G & D Site at N.H. Crossing on Dudhnai.



Dudhnai River Reach Upstream of G & D Site.

PLATE-I

Dudhnai River Ridge Downstream of G & D Site.

tributary joining the river in the reach.

The reach from Dianadubi to its confluence with Krishnai may be called as the alluvial or flood plain reach of the river which consists of plain area along the South Bank of the Brahmaputra. In this reach the river crosses N.H.37 at Dudhnai town.

The reach from Domani to outfall is of about 7 Km stretch (combined with Krishnai) flowing Northward in meandering loops then turning Westward near Mornai and flowing for about 2 Km before it outfalls into the Brahmaputra near Dakaidal. This reach is the flood plain of the Brahmaputra.

Though the river outfalls into the Brahmaputra near Dakaidal during the lean period, its outfall moves upstream near Mornai during the flood season when the Brahmaputra engulfs the part of Dudhnai river between Mornoi and Dakaidal.

4.2.2 Hydrometeorology of Dudhnai Sub-Basin :

The Dudhnai sub-basin falls within the climatic zone-I which comprises North and North-East India and adjoining parts of Nepal, Bhutan, Bangladesh and North Burma. The sub-basin enjoys an average annual rainfall of 1817.20 mm. In this zone the bulk of the rainfall occurs during the month of May to September. Significant rainfall occurs in May and October too. The months from November to March are generally dry.

Tropical storms and depressions affect the weather in this zone during the months from June and September.

Climatological situation prevailing in Dudhnai sub-basin in different parts of the year is briefly outlined below. It is predominantly characterized by four distinct seasons in a year:(i)Winter, (ii)Pre-Monsoon, (iii)Monsoon and (iv)Post Monsoon seasons.

The Winter Season(Dec-Feb) is the driest season and the rainfall is generally light. The precipitation is in association with the passage of low pressure, originating in the Bay of Bengal and moving in a Westerly and North-Westerly direction. The sub-basin receives significant rain under the influence of Eastern bound tropical disturbances which may appear as low pressure area. However, this season is devoid of flood in the valley due to low rainfall.

The Pre-Monsoon Season(March to May) is the season of thunder storms. The rainfall is in association with thunder storms. The precipitation due to tropical storms developed over the Bay of Bengal sometimes cause extensive rain and floods in the month of May.

The Monsoon Season (June to Sept) is the principal rainy season for the entire region and accounts for 64.54 % of the rainfall. The orographic influence is dominant in the distribution of rainfall during this season as the prevailing winds blow almost at right angles against Khasi-Jayantia hills. The southwest monsoon sets in the first week of June and starts withdrawing by the end of September or beginning of October.

The Post Monsoon Season (Oct. to Nov.) is the season when the catchment receives generally light to moderate rainfall. The rainfall during this season is due to the cyclonic storms which form in the Bay of Bengal. Sometimes, western disturbances appear in the sub-basin mainly in second half of the October and cause light precipitation. However, floods are rare during this season.

The average annual rainfall over the whole catchment is around 1817 mm based on simple arithmetic average of three existing ordinary raingauge stations in the basin. It is seen that maximum rainfall occurs at Damra where the annual average accounts for 2881 mm followed by 1326 mm and 1244 mm at Domoni and Dudhnai respectively. Of the mean annual rainfall of 1817 mm the seasonal distribution is: monsoon (June to Sept.)-1173mm(64.55%), pre-monsoon(March to May)-474.60mm(26.12%), post monsoon (Oct.to Nov.)-140.86mm(07.75%) and winter season(Dec. to Feb.)-28.93mm(01.59%).

From the records of Gauge & Discharge Site at NH crossing at the basin mouth it is seen the maximum H.F.L. observed was 52.15 m on 17.6.84 and the minimum low water level was 46.690 on 1.2.57. The maximum and average flood lifts were 5.460m and 2.960m respectively. The maximum and minimum discharge based on 35 years record were found to be 619.433 cumecs(15.9.60) and 0.19 cumecs(1.4.86) respectively.

4.2.3 Forest:

It is seen from the regional statistics that the forest cover is comparatively more towards upper catchment in East Garo Hills(Meghalaya) which is about 38% and reduces towards the basin mouth in Goalpara district(Assam) which is about 17%. The forest cover areas of Dudhnai under different forest ranges are furnished in **Table-4.1** below which reflects about 16.75% as the forest cover.

TABLE- 4.1
Forest Cover in Dudhnai Sub-basin

Name	Area
1. Upartala R.F.	44.6 Ha.
2. Damra R.F.	336.56 Ha
3. Baghmara R.F.	92.30 Ha
4. Debpara P.R.F.	60.30 Ha.
5. Rong Pathar P.R.F.	58.00 Ha.
6. Chimabangshi R.F.	2331.0 Ha
7. Dhima R.F.	2072 Ha
8. Rangnil USF	200 Ha
9. Wakok U.S.F.	300 Ha.
10. Majolgiri U.S.F.	200 Ha.
11. Chikal	300 H
12. Baringgiri	400 Ha.
13. Wageasi U.S.F.	300 Ha.
14. Imbangiri U.S.F.	100 Ha.
15. Mendima	200 Ha.
16. Bagsi Age U.S.F.	300 Ha.
17. Bangsi U.S.F.	200 Ha
Total	7494.76 Ha(75 sq km)

Note : R.F. = Reserved Fores

P.R.F.= Protected Reserved Forest

U.S.F.= Unclassified Forest

Source Divisional Forest Officer, Goalpara

4.2.4 Ground Water:

Central Ground Water Board and Deptt of Geology & Mining, Govt of Assam have since carried out various investigations on ground water in the area. On the basis of their works the safe yield was of the order of 60 cum/hr at Dudhnai in April,1983 with storage co-efficient of 0.033. Details of these works are discussed in para hereinafter.

4.2.5 Existing Net-work of Observations:

The existing net-work of observation in the basin is not adequate as per IMD norm.However, there are three ordinary RG stations maintained by CWC at Damra, Dudhnai& Domoni.At the basin mouth of the river CWC is maintaining a G&D site at NH crossing. There is no meteorological observations in the basin.

4.2.6 Data Availability:

The details of availability of hydrometeorological data and other information about the basin and sources are furnished in Table-4.2.

4.3 Programme of Studies & Activities:

For in-depth knowledge and fundamental hydrologic studies at Dudhnai sub-basin where existing hydrometeorological data, barring rainfall only at few places, are not available, following studies and activities are proposed initially for further studies to follow.

4.3.1 Short term Program :

1. Hydraulic measurement at river cross-section like measurement of discharge, slope and river profile parameters etc.

2. Setting up observatory and installation of meteorological equipments for continuous long term observation.

3. Design of network of observation and extending existing network to the requirement.

4. Determination of basin characteristics including land use and vegetal cover, water quality, soil, geological, physiographical and geomorphological parameters.

5. Instrumentation, observation and experiments to determine model parameters and other information like precipitation, humidity, dew point, temperature, sunshine hours, solar radiation, wind speed and direction, interception, infiltration and hydraulic conductivity, soil characteristics, soil erosion, stream flow, water quality, ground water data, evaporation and transpiration, soil moisture, and so on.

4.3.2 Long Term Program :

1. Development of rainfall- run off relationships for extension of records.

2. Quantitative analysis to evaluate forest influences on hydrologic regime.

3. Calibrating existing model or developing suitable model capable of describing run-off process of the system and predicting flow expectations under different conditions.

4. Transforming or extrapolating the results to other similar areas of interest.

5. Any other studies that may require in course of time.

4.4 Studies and Works Carried out :

After selecting the Dudhnai sub-catchment for representative basin studies in October, 1994 following studies and works have been carried out till March,1995:

4.4.1 Collection of Data :

Basic catchment area map was prepared after collecting the Survey of India toposheets, of scale 1 : 50000; 78K/9, 10, 13, 14. The basin area was delineated after map study and in consultation with concerned local departments of Govt. of Assam/Meghalaya. Then it was modified after several field visits. For the purpose Landsat imageries (L.S-B234 Dt.11.2.91) were also consulted from Assam Remote Sensing Centre and compared.

Existing hydrogeological, hydrometeorological and other information as available for the area were collected from various departments and their status is given in **Table-4.2.**

For long term daily/hourly rainfall and discharge data (available with CWC), Central Water Commission has been moved to permit local CWC unit for supplying data to NIH for its proposed studies.

4.4.2 Hydrological Observation:

Gauge & Discharge observation :

The gauge site of the river Dudhnai being maintained by CWC is located at the National Highway Bridge and is in the lower reach of the river. The gauge data are available for the period

TABLE-4.2

Data collected for Dudhnai Sub-Basin

S.No.	Particulars	Period	Source
1. Rainfall			
	Average rainfall of Dudhnai catchment (annual) (Daily records are with B.B.)	Aug., 1977 to June, 1987 Dec'89-Feb'91	Brahmaputra Board.
	Daily Rain fall of RG(CWC) Stn, Goalpara . . .	1991-94	CWC
2. Runoff			
	Max. discharge & min. discharge (annual)	1956 to 1990	Brahmaputra Board
	Monthly and annual mean discharge (Dudhnai)	1955 to 1990	- do -
	Monsoon yield (May-Sept)	1955 to 1990	- do -
	Daily Gauge Data(at Depa) 3/8 hourly	1955 to 1957 (May,31) (Dec,31)	FC Deptt
	Daily Gauge & Discharge Data at NH crossing	1955 to 1957 (June,2 Dec,31)	-do-
	Sediment Data(NH Crossing)	1.7.55to31.12.55 1.3.56to31.12.57	-do-
	H.F.L., L.W.L. at GD site (AT Road crossing).	1955 to 1990	CWC
	Sediment data	1963 to 1990	- do -
3. Climatic			
	Temperature, Humidity, (at Borjhar Airport, Guwahati)		I.M.D. (from Brahmaputra Board's literature)
4. Ground water			
	Aquifer performance test date of deep tubewell in Dudhnai (with recuperation & observation well drawdown)	16.5.84	CGWB, Guwahati

Contd.

Contd.

Vertical electrical sounding date of E. Garo Hills.	-do-	- do -
5. <u>Soil</u>		
Soil map & Soil information of Meghalaya	1991	NBSS & LU Jorhat
6. <u>Others</u>		
Annual Flood damage data of Dudhnai-Krishnai sub-basin	1986 to 1990	Brahmaputra Board
Forest Landuse (Dudhnai)	-	DFO, Goalpara Divn., Assam.

1955-90. It is reported the average low water level at this site is 47.06m, the maximum H.F.L. observed so far is 52.150 m on 17.6.84 and the minimum low water level is 46.690m as on 1.2.57. The maximum and average flood lifts have been reported to be 5.460m and 2.960m respectively.

The discharge site of CWC is also located at the National Highway crossing. The discharge data for the period 1955 to 990 are available with CWC and are being collected for analysis. It is reported that maximum discharge recorded is 619.433 cumecs on 15.9.60 followed by 525.871 cumecs on 21.6.74. The minimum discharge reported is 0.19 cumecs on 1.4.86 followed by 0.46 cumec on 26.5.90. The maximum annual mean discharge occurred in the year 1974 which was 51.501 cumecs and the minimum annual mean discharge recorded is 13.590 cumecs in the year 1961.It is seen that monsoon yield accounts for 70.18% of the average annual yield.

4.4.3 Flood Frequency Analysis

The Probable Maximum Floods for the return periods of 5,10,25,50 and 100 years as calculated by log-Pearson type III and Gumbel distribution methods are reported(Brahamputra Board) as: 590.69, 676.75, 783.54, 861.38 and 938.30 cumecs respectively(Log-Pearson) and 623.83, 718.06, 850.53, 948.80 and 1046.33 cumecs respectively(Gumbel).

4.4.4 Soil Test Analysis.

In pursuance of the field study programme soil samples were collected from eighteen different sites of the sub-basin (using ring kit sampler).The samples were analyzed for different soil parameters in the laboratory and the results are shown in **Table 4.3.**

4.4.5 Land Use and Land Cover:

The detailed land utilization statistics of the sub basin is not available. However, land utilization pattern of the surrounding area is furnished in **(Table-4.4):**

From the satellite imagery of February, 1991 land covers were also delineated upto latitude 25Deg-45Min North(about 50% of basin area) and is shown in **Table-4.5.** This will be further studied with imageries of different periods.

4.4.6 Estimation of Geomorphological Parameters

Geomorphological parameters of drainage network provide simple means, specially in mountainous and ungauged catchments to develop empirical precipitation-runoff relationships, synthesize hydrograph parameters and to develop regional Geomorphological Unit Hydrograph. Therefore, on a basin map of 1 : 50,000 scale, the geomorphological parameters consisting linear, areal and relief aspects of drainage network of Dudhnai sub-basin have been worked out and a report on this study has been prepared separately.

Quantitative estimates of drainage net work and geomorphological parameters of Dudhnai River Basin are furnished in **Table-4.6** to **Table-4.9.**

TABLE - 4.3

SOIL PROPERTIES

(ALL SOIL SAMPLES TAKEN DURING NOV-DEC. 1994)

S.No	Name of the Site	Land Use	Soil type	PMC	VR	POR	DGS	SGS	AC	PAV	SAD	SBD
1	Rang Jong	(S) River Bank,	Loamy Sand	24.229	.917	47.822	.576	2.179	.424	20.276	1.615	.615
		(SS) Grassy land	well graded	22.152	.684	40.626	.643	1.985	.357	14.514	1.585	.585
2	Rangberan	(S) Scrub Land	Silty Sand	28.570	.367	26.823	1.241	1.592	-.241	-6.468	1.433	.433
		(SS)	uniformly graded	15.462	1.016	50.397	.305	2.005	.695	35.020	1.498	.498
3	Rongmil	(S) Barren land	Loamy Sand	15.446	1.138	53.220	.351	2.586	.649	34.532	1.742	.742
		(SS)	Medium graded	24.191	.697	41.057	.851	2.450	.149	6.127	1.855	.855
4	Chak Jongdna	(S) Scrub Land	Silty Sand	23.133	.928	48.135	.601	2.410	.399	19.221	1.731	.731
		(SS)	uniformly graded	20.561	.571	36.327	.855	2.373	.145	5.258	1.874	.874
5	Gablianem	(S) Scrub Land	Silty Sand	11.877	1.097	52.321	.239	2.205	.761	39.834	1.574	.574
		(SS)	unifromly graded	24.367	1.138	53.220	.497	2.320	.503	26.780	1.617	.617
6	Gandual	(S) Grassy Land	Loamy Sand	25.168	1.375	57.898	.473	2.585	.527	30.509	1.667	.667
		(SS) River Bank	uniformly graded	20.108	1.066	51.607	.383	2.033	.617	31.826	1.500	.500
7	Chima-Inephal	(S) Barren land	Loamy Sand	28.094	1.138	53.220	.592	2.398	.408	21.707	1.654	.654
		(SS)	well graded	12.814	1.180	54.120	.299	2.750	.701	37.954	1.803	.803
8	Nilagithim	(S) Barren land	Silty Sand	26.406	1.043	51.044	.559	2.208	.441	22.503	1.591	.591
		(SS)	uniformly graded	14.012	.710	41.525	.402	2.037	.598	24.831	1.607	.607
9	Mandima	(S) Forest Cover	Loamy Sand	25.745	.900	47.373	.598	2.090	.402	19.050	1.574	.574
		(SS)	medium graded	10.842	.571	36.327	.403	2.121	.597	21.683	1.714	.714
10	Bukshirparh	(S) Grassy Land	Loamy Sand	21.297	.819	45.034	.465	1.788	.535	24.100	1.433	.433
		(SS)	well graded	10.191	.760	43.196	.323	2.407	.677	29.262	1.799	.799

Contd.

Contd.

11	Dudhnai	(S)	Scrub land	Silty Sand	35.685	1.151	53.513	.716	2.311	.284	15.174	1.610	.610
		(SS)		uniformly graded	19.609	.968	49.187	.429	2.120	.571	28.064	1.569	.569
12	Dianadubi	(S)	Forest Cover	Sandy Loam	28.244	.900	47.373	.606	1.932	.394	18.662	1.490	.490
		(SS)		well graded	13.886	.228	18.553	1.355	2.224	-.355	-6.595	1.997	.997
13	Forest Rest	(S)	Forest Cover	Sandy Loam	16.140	.792	44.183	.438	2.147	.562	24.839	1.640	.640
	House,Dinadubi	(SS)	Forestcover	well graded	18.864	.260	20.641	1.169	1.612	-.169	-3.492	1.486	.486
14	Sarangma Forest	(S)	Forest Cover	Loamy Sand	22.407	.995	49.879	.443	1.969	.557	27.763	1.486	.486
	Site	(SS)		medium grade	9.980	.203	16.904	.755	1.539	.245	4.144	1.448	.448
15	Chikal (Barren)	(S)	Harvested	Sandy Loam	22.133	-.065	-6.925	-3.515	1.029	4.515	-31.268	1.031	.031
		(SS)	Paddy farm	well graded	13.971	.267	21.059	.627	1.196	.373	7.865	1.155	.155
16	Dasera Sarangma	(S)	Harvested	Loamy Sand	11.778	.322	24.373	.595	1.629	.405	9.863	1.476	.476
		(SS)	Paddy farm	medium graded	20.624	.542	35.169	.790	2.078	.210	7.391	1.699	.699
17	Forest Rest	(S)	Barren Land	Sandy Loam	15.589	.929	48.170	.352	2.100	.648	31.202	1.570	.570
	House, Dinadubi	(SS)	Barren land	well graded	21.405	.236	19.110	1.357	1.497	-.357	-6.814	1.402	.402
18	Chikal - Forest	(S)	Grassy Land	Silty Sand	36.869	.394	28.271	1.489	1.591	-.489	-13.815	1.424	.424
		(SS)		medium graded	27.468	.882	46.871	.633	2.032	.367	17.220	1.548	.548

(S) - SURFACE SOIL.

(SS) - SUBSURFACE SOIL AT 50cm BELOW G.L.

CMP - PERCENTAGE MOISTURE CONTENT
VR - VOID RATIO
POR - POROSITY
DGS - DEGREE OF SATURATION
SGS - SPECIFIC GRAVITY OF SOIL
AC - AIR CONTENT
PAV - PERCENTAGE AIR VOID
SAD - SATURATED DENSITY
SBD - SUBMERGED DENSITY

TABLE - 4.4

Land Use of Dudhnai
(Ground Truth from SOI Topo sheet)

Sl. No.	land use	Area in Goalpara Dist	Area in E/Garo Hill	Total
1.	Total area	9988 Ha.	37760Ha.	47748Ha.
2.	Forest	1739 Ha.	13883Ha.	15622Ha.
3.	Barren un- cultivable land	3296 Ha.	5288Ha.	8584Ha.
4.	Cultivable Waste	455 Ha.	10076Ha.	10531Ha.
5.	Fallow Land	210 Ha.	5079Ha.	5289Ha.
6.	Net area sown	4238 Ha.	3434Ha.	7672Ha.

TABLE-4.5

Land Cover Type in Dudhnai (upto 25Deg-45Min North)
(From Imagery, about 50% of the basin)

1.Agricultural Area	2020Ha.
2.Habitable Area	912.5Ha.
3.Degraded Forest	5657.5Ha.
4.Forest Scrubs	970Ha.
5.Jhum Patch	2142Ha.
6.Forest Plantation	840Ha.

TABLE-4.6

Measurement of Drainage Net-work

Stream order	Stream Nos.	Stream length L, Km	Average length L, Km	Area A-Sq. km.	Mean-Area A-sq.Km
1	3036	2569.20	0.846	258.40	0.086
2	0910	0968.55	1.065	115.80	0.127
3	0232	0646.65	2.782	074.08	0.320
4	0072	0296.20	4.130	034.64	0.481
5	0025	0157.05	6.280	026.50	1.060
6	0005	0044.50	8.900	015.90	3.180
7	0001	0019.00	19.000	010.75	10.750
Total	4281	4702.00	43.003	536.00	16.004

Table-4.7

Areal measures of Dudhnai River Basin

1.	Drainage Area, A	536 Sq. Km.
2.	Drainage Density	8.7 Sq. Km.
3.	Constant of channel maintenance, C	0.1149
4.	Channel segment frequency, F	7.98 sq. Km.
5.	Circularity Ratio, RC	0.247
6.	Elongation Ration, RC	0.483
7.	Watershed shape factor, RK	3.13
8.	Unity shape factor, Ru	1.81
9.	Form factor, RF	0.301
10.	Compactness ratio, R	2.009

Table-4.8

Relief Aspects of Dudhnai River Basin

1.	Basin Relief, H	0.562 Km.
2.	Relief Ratio, RH	0.013
3.	Relative relief, RHP	0.003
4.	Ruggedness number, Rn	4.889
5.	Taylor and schawrtg slope	-

Table-4.9

Linear Aspect of Dudhnai Sub-Basin

S.No.	Parameters	Qty/Unit
1.	Length of main channel, 'L'	54 Km.
2.	Length upto centroid, 'Lc'	27 Km.
3.	Total length of channel, 'Lt'	4702 Km.
4.	Length of overland flow 'Lo' (mean)	0.05 Km.
5.	Basin perimeter, 'P'	165 Km.
6.	Watershed eccentricity, 'Ew'	1.49
7.	Length ratio, 'R'	2.01
8.	Wandering ratio, 'Rw'	1.28
9.	Fineness ratio, 'Rf'	28.49
10	Bifurcation ratio, 'Rb'	3.89
11	Drainage density, 'D'	8.7

4.4.7 Infiltration Studies:

The phenomenon of infiltration, that is the process of water entry into the soil deserves a special place in hydrologic cycle. Knowledge of infiltration characteristics of the basin helps in estimating the quantity of rainfall excess resulting from a stream. Infiltration is one of the basic parameters for developing an integrated crop, soil and water management plan and often used in on farm irrigation water management practices. Hydrologic importance of the process is to be seen from the fact that it marks the transition from fast moving surface water to slow moving soil and ground water.

In the infiltration test at Dudhnai sub-basin attempt has been made to develop infiltration curves for the area with the help of point infiltration tests with Double Ring Infiltrometer at selected locations since existing data are not available. Meanwhile, point infiltration tests at 23 locations have been

Guelph Permeameter & Tensiometer Tests at
Observatory Site (Dassera Sarangma)

Infiltrometer Tests at Dianadubi Reserved Forest.

PLATE-II

carried out and of a separate report on this work is prepared The results of the experiments are presented in **Table 4.10**

4.4.8 Ground Water Availability:

In pursuance of the field program, Guelph permeameter tests were conducted at four different sites of the Dudhnai sub-basin where already infiltration and soil tests were carried out. The test results were used to calculate in-situ hydraulic conductivity and flux potential of the soil. All tests were conducted at a depth of 50Cm below ground level. Test data and results are furnished in **Table-4.11.**

Directorate of Geology & Mining, Govt. of Assam had taken up (in 1983-84) construction of deep tube-well at Dudhnai, Goalpara district for first hand approximate resource evaluation of groundwater potential in the surrounding regions of E.Garo Hills/Goalpara Districts. The bore hole site was located in the compound of the Dudhnai College about a kilometer north of NH-37 along Dudhnai-Dolgoma road (Plate-1). The reduced level of the bore hole site is 52.41m. The lithological results are furnished in **Appendix-I.**

An observation well was also drilled by Central Ground Water Board at a distance of 45m west of the main well which tapped the top and the middle aquifer zone of the main well within a depth of 62.80m. The results of this test are reported as below:

1. Transmissivity(T)= 207.65 sq m per day
2. Permeability (K) = 8.20 m/day
3. Specific Capacity= 204.91 Lit/min/m

Table-4.10
Infiltration Results of Dudhnai sub-basin

S. NO.	SITE'S NAME	INFILTRATION RESULTS		
		INITIAL INFIL-TRATION RATE (cm/hr)	FINAL INFIL-TRATION RATE (cm/hr)	TOTAL CUMMU-LATIVE DEPTH (cm)
1	2	3	4	5
1	CHIKAL	0.80 FOR 30 MIN.	0.4 AFTER 240 MIN	1.80
2	CHIKAL	180.0 FOR 1 MIN.	32.0 AFTER 112 MIN.	107.50
3	DASERA SARANGMA	120.0 FOR 1 MIN.	4.60 AFTER 356 MIN.	58.10
4	DASERA SARANGMA (SEEDFARM)	27.60 FOR 5 MIN.	1.40 AFTER 250	11.20
5	DIANADUBI FOREST HOUSE (WEST)	21.60 FOR 5 MIN.	3.80 AFTER 255 MIN.	21.40
6	DIANADUBI FOREST HOUSE (EAST)	43.20 FOR 5 MIN.	5.20 AFTER 195 MIN.	27.90
7	RONG JONG	64.80 FOR 5 MIN.	4.80 AFTER 140 MIN.	32.40
8	RONG BERAM	90.00 FOR 5 MIN.	3.00 AFTER 130 MIN.	29.60

1	2	3	4	5
9	RONG MILE	180.0 FOR 5 MIN.	10.5 AFTER 165 MIN.	84.10
10	CHAKJONGDRA	73.20 FOR 5 MIN.	2.60 AFTER 215 MIN.	42.00
11	GABLIADANG	90.00 FOR 5 MIN.	6.60 AFTER 180 MIN.	52.40
12	GANDUAL	79.20 FOR 5 MIN.	2.00 AFTER 180 MIN.	42.50
13	CHIMA-IMPHAL	97.20 FOR 5 MIN.	4.50 AFTER 145 MIN.	38.00
14	NILWAGITHIM	58.80 FOR 5 MIN.	3.00 AFTER 105 MIN.	19.50
15	MONDIMA	126.0 FOR 5 MIN.	1.60 AFTER 185 MIN.	57.50
16	BUKSILPARA	69.60 FOR 5 MIN.	0.90 AFTER 155 MIN.	27.20
17	DUDHNAI	76.8 FOR 5 MIN.	1.50 AFTER 165 MIN.	40.80
18	SARANGMA	109.2 FOR 5 MIN.	2.10 AFTER 140 MIN.	42.10

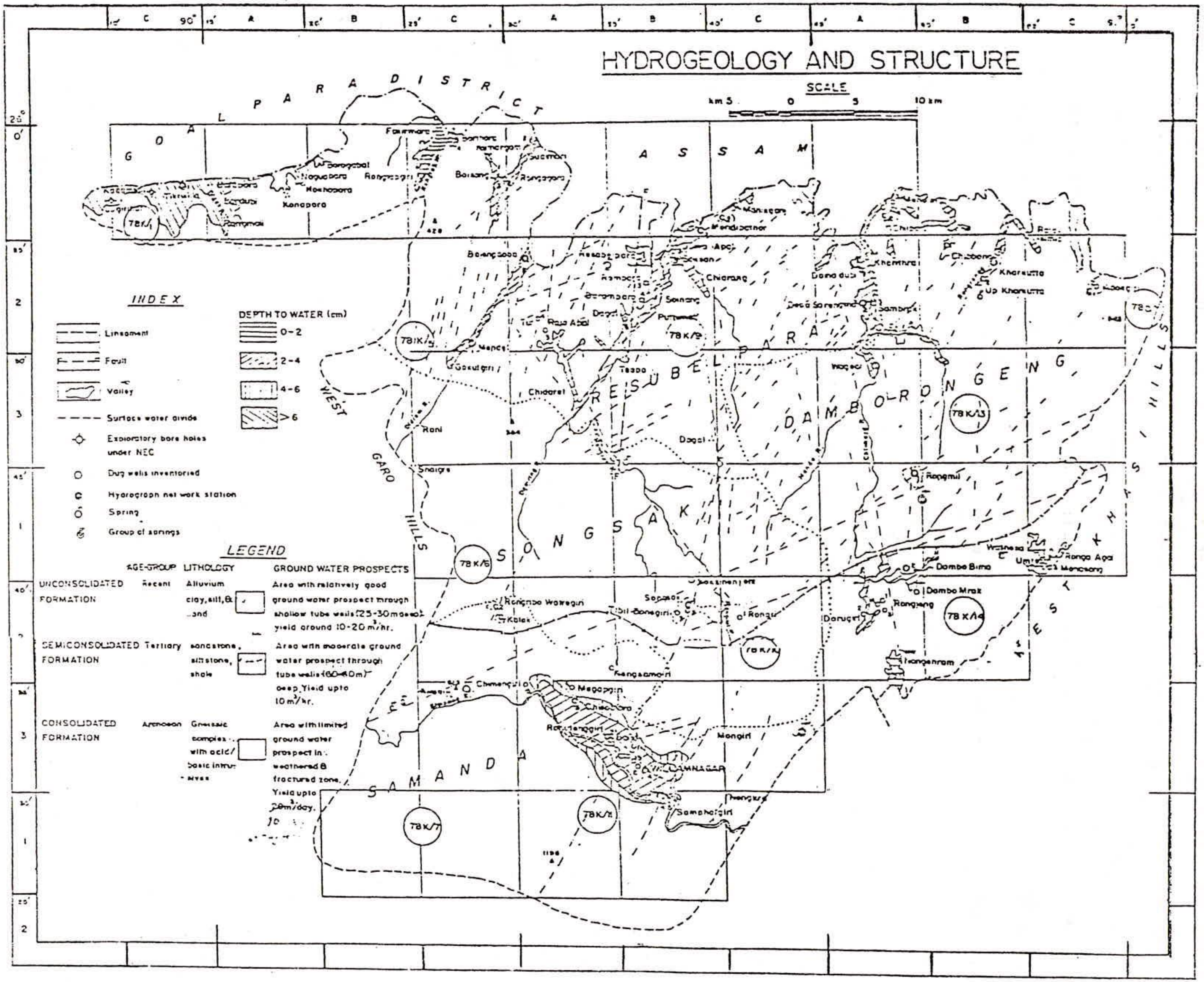
1	2	3	4	5
19	DEPA	87.60 FOR 5 MIN.	1.20 AFTER 140 MIN.	29.40
20	KHENTARA	55.20 FOR 5 MIN.	0.90 AFTER 120 MIN.	16.50
21	DIANADUBI	72.00 FOR 5 MIN.	1.20 AFTER 140 MIN.	20.80
22	DAMARA (EAST)	40.80 FOR 5 MIN.	0.90 AFTER 120 MIN.	14.50
23	DAMARA (WEST)	56.4 FOR 5 MIN.	1.50 AFTER 170 MIN.	29.30

TABLE-4.11

Hydraulic Conductivity and Flux Potential
(At Dudhnai sub-basin)

Sl No.	Name of the site	Date	Soil type	Hydraulic conductivity(k)in cm/hr	Flux potential(o) in sq.cm/hr	Remarks
1.	Chikal Village	27.12.94	Dark gray silty alluvium.	- 0.0078	0.78	a.Tensiometer read 8 centibars in first hour. b.Barren land.
2.	Dasera Sarangma	28.12.94	Light & dark gray silty alluvium.	-0.0615	1.415	a.Harvested paddy field. b.Tank irrigation field
3.	Daserp sarangma (forest site)	28.12.94	Dark gray silty alluvium	0.0053	0.153	a.Forest cover
4.	Dianadubi forest rest house	29.12.94	Light yellowish alluvium	0.017	-0.160	a.Barren land b.Tensiometer read 42 centibar/150min

The Geological & Mining Deptt had carried out some investigations on the geology of the area on the basis of representative Formation Sampling and the lithological log was prepared after carefully studying the drill-cutting and drill time log, which is furnished in the Appendix-II. **Fig.8** shows the hydrogeology and structure map of East Garo Hills district of Meghalaya.



SOURCE: CGWB

FIG. 8. HYDROGEOLOGY AND STRUCTURE MAP OF EAST GARO HILLS DISTRICTS, MEGHALAYA

CONCLUSIONS

Despite constraints and limitations research efforts are improving the state of art. Research in representative and experimental basins involves the formulation of models and its application. Results of hydrologic models developed from representative and experimental basins appear promising towards better understanding of hydrologic processes and predictions for unguaged watersheds.

hydrologic research has come a long way to develop many computer simulation models applicable to various types of watersheds. Though use of these models to mountainous watersheds has been limited in the country, more and more applications have been envisaged in recent years.

In requirement of the sophisticated computer simulation models representative basins can be useful tool for instrumentation and monitoring for long term to ascertain wide range of data and information. For the purpose, important activities to be taken up on priority may be setting up of hydrometeorological observatory, reinforcement of existing net-work of observation as per requirement and so on with a view to carry out initially water balance studies and develop hydrologic regime correlations with water yield specific to the area.

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REFERENCE:

1. Anonymous " Water Resources of India" Central Water Commission,New Delhi - April,1988. pp 5-28

2. Anonymous "Hydrological Influences of Forests" - NIH pamphlet.

3. Anderson W. Henry - Principal Components Analysis of Watershed Variables Affecting Suspended Sediment Discharge After a Major flood" - Pub. NO. 96, AIHS pp. 404 - 405.

4. Anonymous " Influences of Afforestation on Various Hydrological Parameters". - NIH Pamphlet. 1989-90.

5. Anonymous "Hydrological Influences of Land Use changes" - NIH Pamphlet.

6. Anonymous " Training Workshop on Watershed Resources Management and Monitoring". NIH Roorkee, Aug. 24-28, 1992.

7. Brooks Kenneth, N Peter F. Ffolliott et. al. - Hydrology and The Management of Watersheds", Oct. 1988 pp. 131-135.

8. Brown C. Thomas and Martin M. Fogel - "Use of Stream flow Increases from Vegetation Management in the Verde River Basin Water Resources Bulletin, December, 1987.

9. Belt H. George (1992) - " Recommendation for Development of Water Balance Studies in Representative forested Catchments - During visit to Jammu/Tissa under UNDP.

10. Chandra Satish - "President Speaks - Hydrology of Mountainous Regions". - IAH Journal, Vol. XIII No. 1 Jan 1990.

11. Chandra Satish - "Hydrological Response from Different Landuse", in National Seminar on New perspective in Water Management, april 1989.

12. Cobb D. Earnest & J.E. Biesecker - " The National Hydrologic Bench Mark Net Work". - Geological Survey circular, 460-D , Washington, 1971 pp. 1-9.

13. "Economic Review " (1991) - Directorate of Economics and Statistics, Himachal Pradesh.

14. Ferreira V.A. & R.E. Smith - "The Limited Physical Basis of Physically Based Hydrological Models".

15. Ffolliott. F. Peter (1992) - "Report on Consultancy in Forest Hydrology", Vol - I. After visit to Jammu/Chamba.

16. Golding L. Douglas - "Research Results from Marnot Creek

Experimental Watershed, Alberta, Canada" - Pub. No. 96, AIHS pp.397-398.

17. Galgati V.G., V.K. Kulkarni & C.M. Shah - "Control of Sedimentation in Small Reservoirs". - Proc. Vol-II, CBIR, 53 rd R & D session, 8-10 May. 1986, Bhubnshwar, pp. 299-308.

18. James E.J., P.K. Pradeep Kumar - " Studies on The Hydrological Process in the forest Drainage Basins of the Western Ghats in India". - Proc of 167, IAHS, August 1987. pp.223-227.
19. Leopold B.Luna- "The Man and the Hill ". - Geological Survey Circular- Part A, Washington, 1962.

20. Linsley K. Ray - "Representative and Experimental Basins - Where Next?" - Hydrological Science Bulletin. XXI, 4, 12/1976. pp. 217-529.

21. Omakr (1993) - " Snow Cover Mapping of Baira Catchment" (HP), National Institute of Hydrology, Publication (C S - 115)

22. Patwary, B.C.(1993-94) - " Representative Basin Studies at Baira-Nalla Sub-catchment"-NIH Publication No TN-107.

23. Pierce R.S. et al. - "Effect of Estiamtion of Vegetation on Stream Water Quantity and Quality." Publication No. 96 AIHS, pp. 331-327.

24. Raghunath B., D.C. Das & P.K. Thomas- "Some Results of Investigation on Hydrology of the sub Watersheds in the Nilgirils (India)". Pub. - 96, AIHS pp 416-433.

25. Ramasastri K.S. & Avdesh Kumar - "Overland Flow in mountainous Area". NIH Publication (RN-49), 1986-87.

26. Ramasastri K S - "Climatorlogy of India" in course material of NIH's Workshop on "Processing and analysis of Precipitation Data". 1987-1988.

27. Rao D.V.L. Narsimha - " Network Design: Raingauge Ordinary and Self Recording" in manual of Hydrometereology (Part - I), IMD, 1972.

28. Dr Szesztay Techn. K. - "On Principles of Establishing Hydrological Representative and Expeimental Areas.

29. Sastry G., H.N. Mathur, K.G. Tejwani - " Landslide control in North Western Outer Himalayas"s (1981) pp. 1-6.

30. Singh Nater -" Geomorphology of Himalayan rivers" (1990). pp.20-24.

31 "Statistical Outline of Himachal Pradesh" (1989).

32. Sugawara M. - "Difficult Problems About Small Experimental Basins and Necessity of Collecting Informations on Large Basins".

Pub.NO. 96 - AIHS. pp. 393 - 396.

33. Seth S.M. & K.S. Ramasastri - 'Rainfall-Runoff Relationships". NIH'Publicatikon (Rn-20), 1985-86.

34. Seth S.M. & Pratap Singh-"Study of soil Moisture using Neutron Probe". NIH's Publication (TN - 28), 1985-86.

35. Seth S.M. & Rakesh Kumar-" Procedure for Hydrological Network Design". NIH'S publication(RN-42),1986-87.

36. Tobes C. - " The Planning of Representative and Experimental Basin Networks in New Zealand.pp. 147-160.

37. Tobes C and V Ouryraer - Representative and Experimental Basins' - An International Guide for Research and Practice - UNESCO, 1970 pp. 22-74.

38. Varshey R.S. et al - " Variations of Sediment Rates in Himalayan Region With Catchment" - Tech. Session IX, paper No.3 53rd Annual R&D Session, CBIP. Proc. Vol.- II 8-10 May, 1986. PP. 285-297.

39. Wolfe Mary Leigh et al - "Input Data Development for a Distributed Parameter Hydrologic Model."

Appendix-I

LITHOLOGICAL LOG OF THE DUDHNAI BORE-HOLE (MAIN WELL)

Litholögh		Depth range (m)	Thickness (m)
Soil & Clay	- Surface soil and hard reddish clay.	0.00 - 3.00	3.00
Clay	- Light yellowish, hard	3.00 - 12.70	9.70
Sand	- Light grayish, coarse to fine, composed of quartz, feldspar and mica.	12.70 - 15.70	3.00
Sand	- Grayish, very fine to fine, composed of quartz, feldspar and mica.	15.70 - 18.97	3.27
Clay	- Light brown with gravels	18.97 - 28.07	9.10
Sand	- Grayish, very coarse to medium, composed of quartz, feldspar and ocher.	28.07 - 31.07	3.00
Sand	- Light reddish brown, coarse to medium, composed of quartz feldspar.	31.07 - 34.07	3.00
Sand	- Light reddish brown, very coarse to medium, composed of quartz & feldspar.	34.07 - 37.17	3.10
Clay	- Light brown with gravels & hard pieces of ocherous materials.	37.17 - 43.27	6.10
Clay	- Light gray, sticky.	43.27 - 52.37	9.10
Sand & Gravel	- Light grayish, composed mainly of quartz of various shales and feldspar.	52.37 - 61.57	9.20

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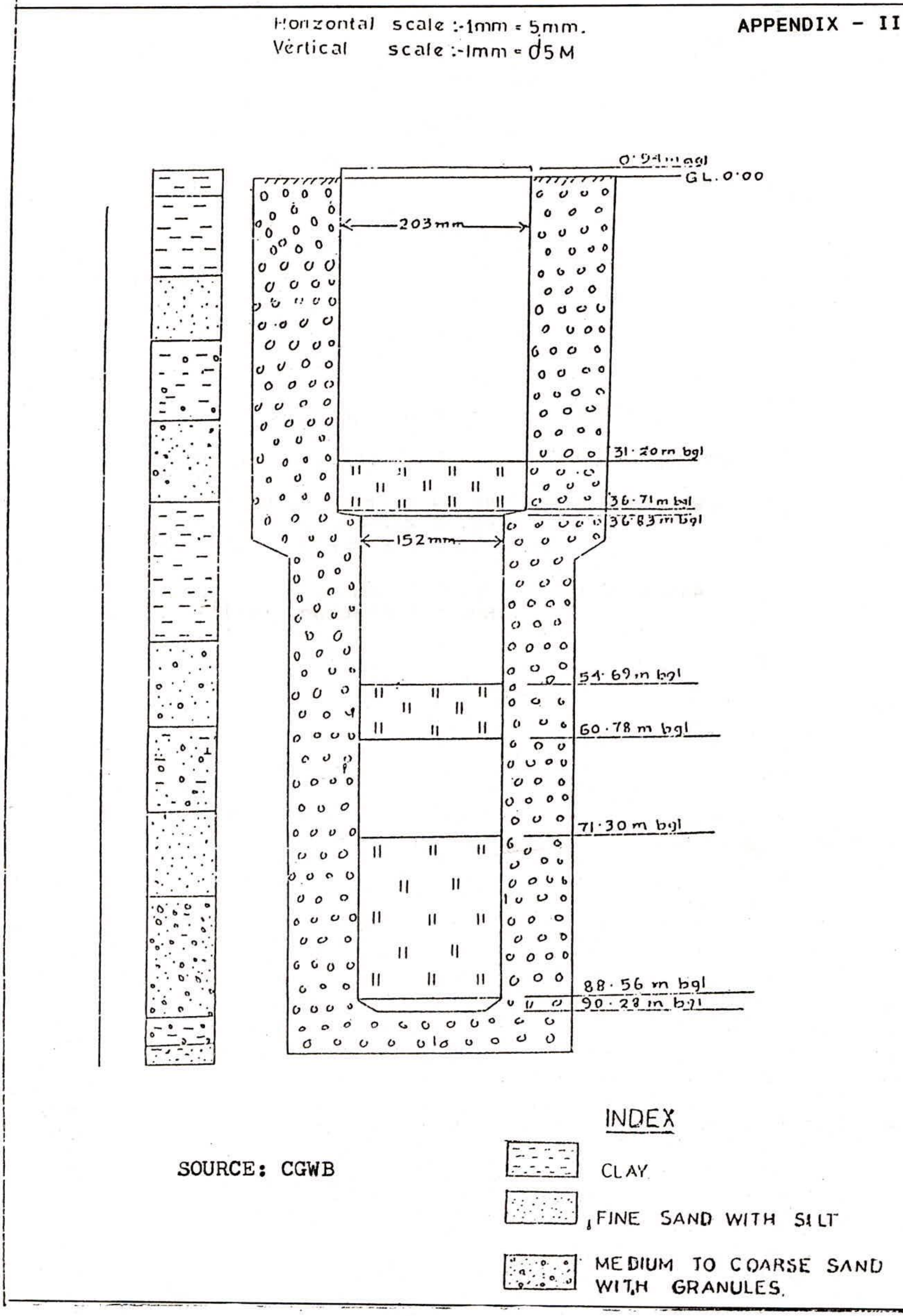
Gravel, Sand & Clay	- Gravel of quartzite & quartz admixed with - coarse sand and clay.	61.57 - 70.67	3.10
Sand	- Light brownish colour, to medium, composed of quartz, feldspar and a few quartzite.	70.67 - 73.77	6.10
Sand	- Light grayish colour, very coarse to coarse, composed of quartz and feldspar.	73.77 - 79.87	6.10
Sand, Gravel & clay	- Grayish, medium to coarse sand with gravel and hard clay.	79.87 - 85.97	6.10
Sand & gravel	- Light brownish-white, composed of quartz, feldspar	85.97 - 92.07	6.10
Clay	- Light brown with gravels.	92.07 - 95.07	3.00
Cuttings of weathered granite, with admixture of sand, fine to coarse and clay.		95.07 - 97.27	2.20



SOURCE: CGWB

Fig. 9. LITHOLOGY AND ASSEMBLY CHART OF DUDHNAI D.T.W.

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