CS (AR) 146

REPRESENTATIVE BASIN STUDIES IN SUDDAGEDDA BASIN NETWORK DESIGN AND INSTALLATION OF EQUIPMENT

आपो हि ष्ठा मयोभुवः

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (U.P.)
INDIA

1993-94

PREFACE

With growing demand on revealing all available water resources to meet the requirement of increasing population a new concept of representative basin studies is in lead all over the world. These representative basins are used for intensive investigations of hydrological cycle under relatively stable natural conditions. Here comes the importance of observations of input parameters. A systematic network of measuring all the inputs is highly recommended to arrive at the acceptable output from the system. To carry out these studies collaborative efforts of all concerned organizations is the need of time.

The Deltaic Regional Centre of National Institute of Hydrology established at Kakinada, A.P. as part of its work programme taken up a representative basin study with the State Groundwater Department, as a collaborative work. The aim of the Collaborative effort is to undertake water balance studies in the representative basin. Suddagedda basin in East Godavari District of Andhra Pradesh is identified as the representative basin of the East Coastal rivers.

The Groundwater Department of Andhra Pradesh, on their part prepared a status report on the data availability of the Suddagedda basin. This report presents the importance of representative basins in conducting hydrological studies, describe the proposed network design, the procedure for installation of equipment,the methods of observations and the recording of different hydrological parameters.

This study conducted by the DRC of NIH, Kakinada is carried out by Shri S.V.Vijayakumar, Sc 'B' and Shri T.Vijay, Sr.R.A. under the guidance of Shri K.S.Rama Sastri, Sc 'F' Dr.P.V.Seethapathi, Sc 'F', supervised the above study as Head and Co-ordinator of the DRC.

(S.M.SETH)
DIRECTOR

Sl.No.	CONTENTS	PAGE NO.

ABSTRACT

A collaborative project between Groundwater Department of Andhra Pradesh and Deltaic Regional Centre of National Institute of Hydrology. is taken up to study the Groundwater balance of a representative basin. The State groundwater department prepared a status report on the availability of data in the Suddagedda basin which is identified as a representative basin of the East Coastal river basins. The total catchment area of the basin is 658 Sq.Km and is bounded on the North by Pampa and in the South by Yeleru river. This report presents the importance of representative basins in undertaking various hydrological studies, while describing the network design for the Suddagedda basin.

At present there are two raingauge stations existing at Prathipadu and Gollaprolu in the Suddagedda basin. A network of three raingauge stations at Sri Santhi Ashram (Sarabhavaram), Ommangi and Subbareddy sagar and a meteorological observatory at Kathipudi are proposed. It is also proposed to establish a gauge discharge site at road bridge near Gollaprolu. The existing groundwater observation well network of two observatory wells at Gollaprolu and Prathipadu, under the control of State Groundwater Department is sufficient for conducting the water balance studies. Evaporation data is to be observed at the Kathipudi observatory and the Subbareddy Sagar reservoir.

Also presented in the report is a detailed resume on installation of various meteorological equipment and the systematic method of observation and recording different hydrological parameters.

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The understanding of the sources of water at or under the earth's surface and its consequence movement back to principal storage in the oceans through various pathways is very important for a Engineering hydrologist. The basis for this is the concept of hydrological cycle. Two of the greatest problems for the hydrologist are quantifying the amount of water in different phases in the cycle and evaluating the rate of transfer of water from one phase to another. Here comes the importance of measurement of these components. This job has not been subjected to co-ordinated planning until recent times.

Authorities put coordinated efforts only during catastrophies i.e. during heavy floods or severe drought. The installation of gauges for rainfall or streamflow has been directed to asses flows for single, simple and immediate purpose. Nowadays with tremendous increase in population and greater demand of water ,schemes for measuring hydrological variables are considered essential for the development and management of water resources at national level.

As part of a collaborative project between Andhra Pradesh State Groundwater Dept and Deltaic Regional Centre of NIH, it is decided to conduct water balance studies in Suddagedda basin lying on the East coast, as part of representative basin studies. In this direction a report on the 'Data availability and status of network' is prepared by A.P.State Groundwater Dept. Now, as part of NIH's responsibility a report on '*Network design and installation of equipment* 'to augment the existing network is prepared.

Suddagedda basin is lying on the Eastcoast of India and is representative of the East flowing rivers lying between Godavari and Mahanadi and originating in Eastern Ghats of India. This report presents the aim of representative basins, brief description of the Suddagedda representative basin, review and design of hydrological network for the basin and a note on installation of meteorological equipment and taking observations of different parameters in detail.

2.0 Representative Basin Studies :

As defined by Toebes and Ouryvaeu (1970) representative basins are basins which are selected as representative of a hydrological region i.e., a region within which hydrological similarity is presumed. They are used for intensive investigations of specific problems of the hydrological cycle (or part there of) under relatively stable natural conditions. Thus a sparse network of representative basins may reflect general hydrological features of a given region and their variations over large natural zones.

With the growing demand on revealing all available water resources and analysis of hydrological conditions in a comprehensive way, a landmark appears in the science of hydrology, that is the contents and interrelation of hydrological activities undergo a radical change. A new means of research is being established in a growing number and within the scope of comprehensive investigations extending to large regions the network of representative areas is formed (Szesztay, 1965). Thus, the aim of hydrological research is not only the collection of data, but rather than an interpretation of these data for use in solution of various management problems such as :

* Flood forecasting and management of floods;
* prediction and estimation of groundwater;
* prediction and estimation of surface water;
* understanding the system of hydrological cycle and the water balance nature under different regions;
* how does the variability of topography, soil, vegetation, geology and climate etc. influence the hydrological cycle within different region ? and
* how a small change within a system can effect the entire hydrological system of a region? etc.

The newly emerged concept of representative basin study is being widely recognised to solve various management problems because :

* principal objectives of hydrological research in representative basin are the prediction and quantitative estimation of various components of the hydrological cycle;

*representative basin studies are used for detailed studies of the hydrological cycle and provide an insight into the characteristics of the area which they represent

* a representative basin takes the more specific role of representing a broad area to which the data can be transformed;

* it is the representative basin study by which a holistic model of hydrological system could be developed which defines that how a small change in one hydrological parameter can effect the other parameters of the system individually and the entire hydrological system as a whole ;

* a holistic model derived from a representative basin study helps in the prediction of various hydrological parameters such as overland flow, sub-surface flow, channel run-off, evaporation, infiltration, groundwater storage, flooding, sheetwash erosion, channel erosion and sedimentation etc.

* prediction of estimation of various hydrological parameters based on a representative studies help planners, decision makers, farmers and engineers to formulate their plans and to execute their plans for different purposes;

* last but not least the representative basin study is the most useful in reducing time and effort required for studies of large areas, and it permits the formulation of rapid approximations and because time is saved it enables more detailed observation to be made and a greater number of variable to be considered.

2.1 Perception of Basin System:

For conducting representative basin studies the basic perception of the drainage basin system is necessary. A basin is an open system. Closed systems are those which possess clearly defined boundaries, across which no import or export of materials or energy takes place. The open system requires a continuing energy supply and removal of energy. Therefore, a basin can be envisaged as receiving energy or inputs from the climate and its losing energy through the water and sediment lost to the basin, largely through the basin mouth. The advantage of the open system approach arise from the facts that it places emphasis upon adjustment and upon relationship between basin characteristics (morphology, geology, soil, vegetation etc.) and hydrological parameters, upon the multivariate character of the many hydrological phenomena, and upon the total hydrological environment. A basin has energy inputs provided by climate, it has different hydrological responses (or outputs) depending upon the characteristics of the basin (Fig. 1). Thus, the representative basin study could be systematically divided into three different components. These are (Table-1) :

* observations of basin input parameters;
* observations of basin output parameters;
* study of basin characteristics

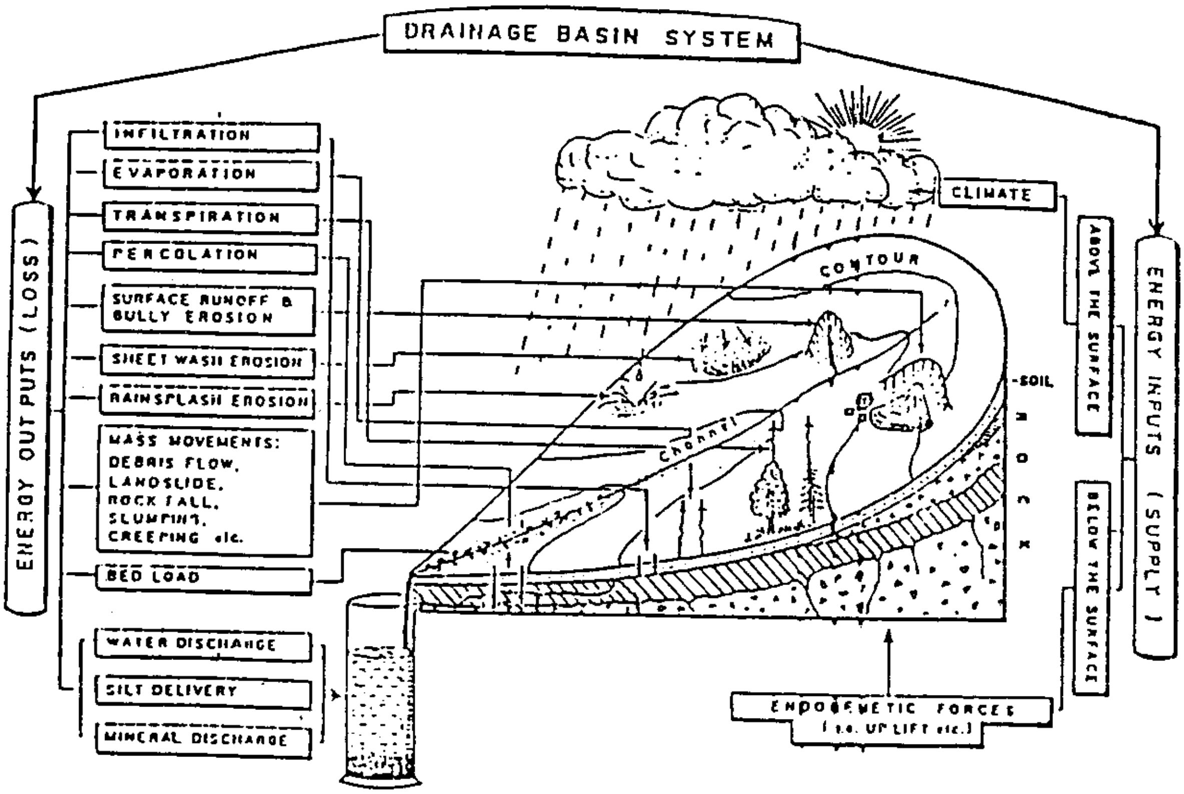


Fig.1 A Model of Basin system showing the Energy inputs and outputs or Basin Responses (after Rawat, 1985)

Table 1: Synoptic outline of representative basin study

Basin energy input parameters	Basin characteristics	Basin responses or outputs
Climate	Geology	At basin mouth
1. Precipitation	1.Rock types	1.water discharge
2. Temperature	2. Structure	2.Sediment and mineral discharge
3.Humidity etc	Vegetation	From basin surface
	2.Types	3.interception loss
	3. Density	
	Geomorphology	4.Evapotranspiration
		5. Infiltration
	4. Morphometry	6.Soil moisture storage
	5.Morphology	
	Soils	7. Overland flow
		8.subsurface flow
	6 Types	9. Groundwater
	7.Characteristics	10.Erosion and sedimentation
	Land use	
	8. Forest	
	9. Agriculture	
	10. Barren etc.	

2.2 Observations of Basin Input Parameters:

In view of the representative basin studies, precipitation is one of the most important basin energy inputs. Following observations are essentially related to the precipitation in the representative basin.

Determination of precipitation gauge network required for the basin

Determination of the type of precipitation , i.e. hail, snow, rainfall, dew etc.

Determination of the amount of precipitation by continuous recording

Determination of spatial variability in precipitation

Determination of temporal variability in precipitation

Determination of intensity-duration relations

Determination of mean basin precipitation for periods of less than one day.

2.3 Observations of Basin Responses (or Outputs):

As soon as the basin receives energy in the form of precipitation, it is regularised through various pathways of the hydrological system within the basin and results in number of hydrological responses. Some of the important hydrological responses in view of the representative basin studies are listed in Table 1 which reveals that these responses are divisible into two main groups (Fig.1).

Hydrological responses from basin mouth

Hydrological responses from basin surface

Thus to define the hydrological response systems of a representative basin, observations of the following parameters are necessary.

Interception

Evapotranspiration

Infiltration

Overland flow

Sub surface flow

Soil moisture storage

Groundwater storage

Channel runoff

Erosion

Sedimentation

However, the number of the parameters for observations may increase as per need of the representative basin or purpose of the study. For example, in the high mountainous terrain observation of snowmelt becomes necessary. Details of observations of these parameters are described by Toebes and Ouryvoev (1970) and are also discussed in sections that follow.

2.4 Mapping of Basin characteristics :

The regularisation of the energy input (precipitation) within the basin largely depends upon the characteristics of the basins. Under identical precipitation, the flow system within the basin may vary from one area to another having different geological, vegetational, pedological and landuse pattern. Hence, it is necessary to define the basin characteristics by preparing the topographic map, morphometric map, geological map , soil map, hydrological map , landuse map, etc.

3.0 DESCRIPTION OF THE BASIN :

Suddagedda is a typical East flowing river and representative of the East flowing rivers that are lying between rivers Godavari and Mahanadi and having their origins in Eastern Ghats and joining Bay of Bengal without forming any deltas. The Suddagedda basin lies between North latitudes 17°09'10" and 17°30' 45" and East longitudes 82°08' 30" and 82 °19'15" occupying an area of 658.3 sq.km. Survey of India toposheets 65 K3, K4, K7, K8 and K12 describe the topography of the basin. The study area is demarkated by the 700m and 20 m contours, sloping towards South-Southeast. Eastern ghats are lying on the northern side of the basin in the form of a series of hill ranges that trend from northeast to southwest. The location map of the basin is shown in Fig. 2.

3.1 Drainage :

The stream rises in Vetangi reserved forest area in Rajavommangi mandal of East Godavari District in Andhra Pradesh at an elevation of about 700m and flows southward as 'Kuntidevi Vagu'. It is joined by many rivulets on its way and is called 'Yeti Kaluva' near Gokavaram village where a reservoir called Subbareddy Sagar is formed. Further travelling southwards it is joined on its left bank by Konda Kaluva near a village Tatiparthi and is called 'Suddagedda River'. At Gollaprolu its catchment area is 526 sq.km. The drainage pattern in the basin is dendritic to sub dendritic. The basin has a drainage density of 1.13 km/sq.km (Fig. 3).

3.2 Hydrogeology:

A major portion of the Suddagedda basin is underlain by Khondalites, granites and charnockites. The central and western parts of the basin is underlain by alluvium. The southern part of the basin is underlain by Khondalite suite of rocks, basaltic formation and Tirupati sandstones.

Fig 2. LOCATION MAP OF SUDDAGEDDA BASIN

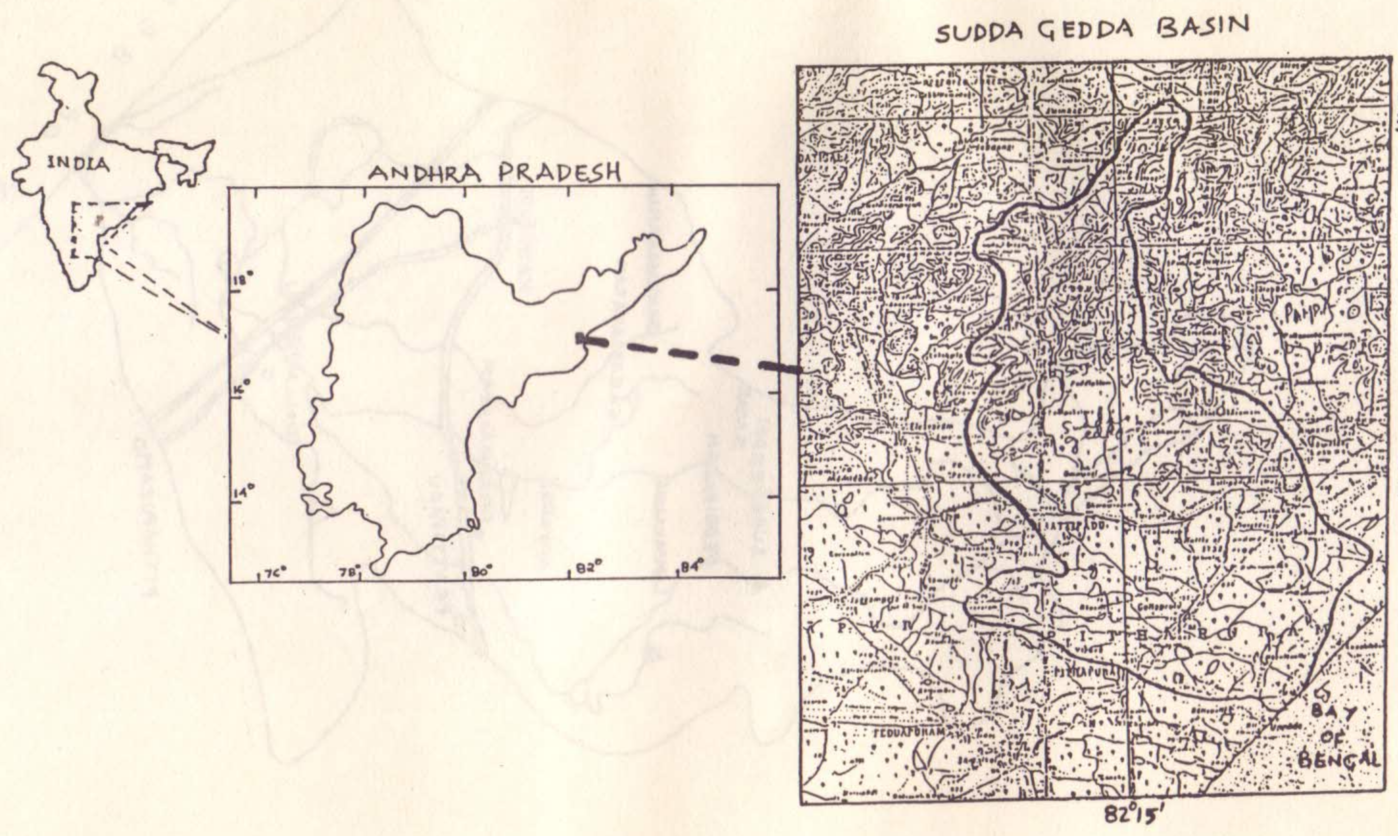
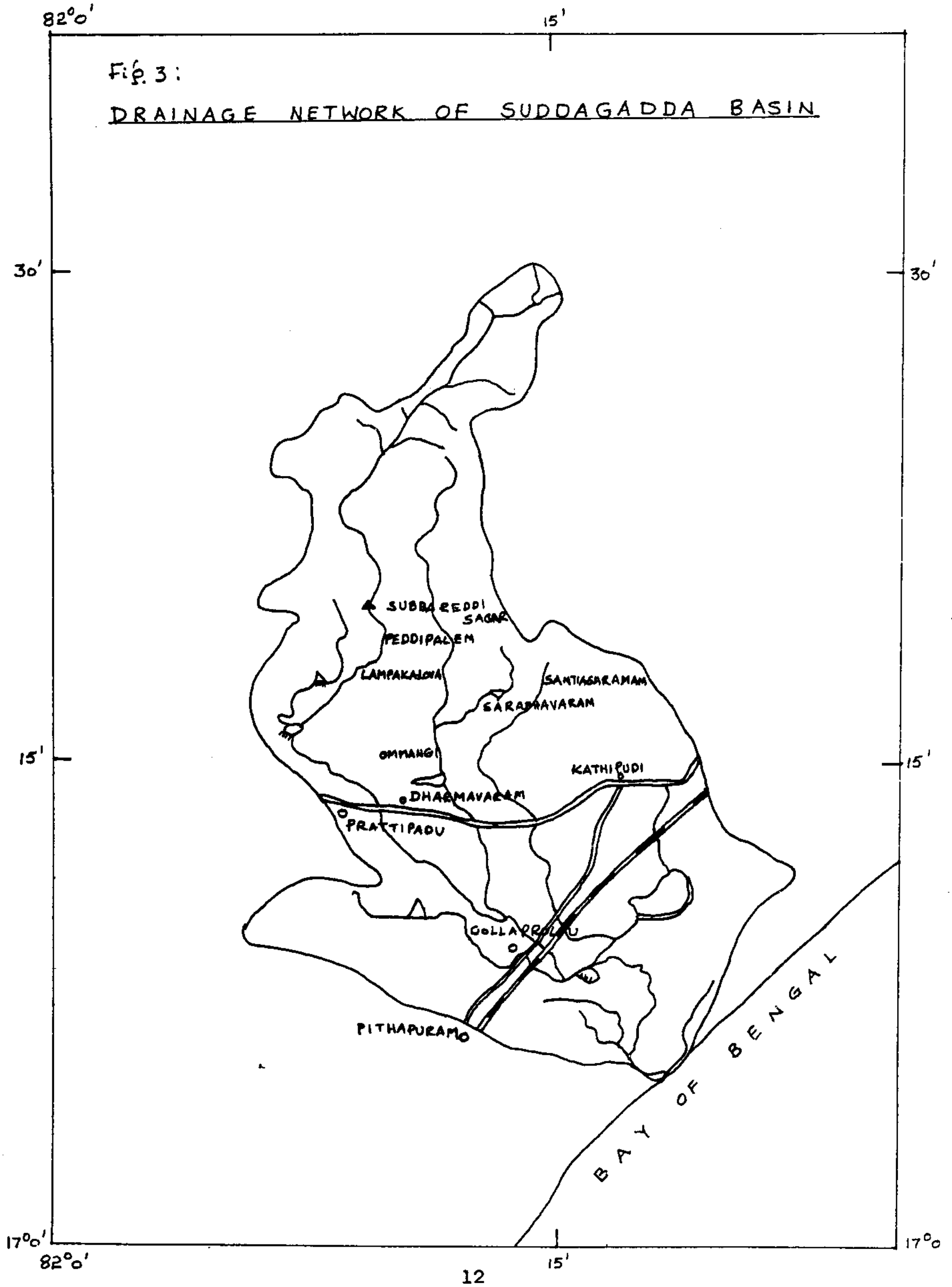


Fig. 3:

DRAINAGE NETWORK OF SUDDAGADDA BASIN



Groundwater in the crystalline rock is restricted to weathered and fractured zones and is being exploited mostly by dug wells, dug-cum-borewells and bore wells at places. Depth of the dug wells ranges between 8m and 12m with an average yield of 30,000 lpd. to 50,000 lpd. Filter point wells/shallow tube wells in the central and western part of the basin are constructed down to 30m to 50m. These wells yielding about 15,000 lph to 30,000 lph. Groundwater is exploited in Tirupati sandstone formation by means of tube wells. The depth of tube wells is in the range of 80m to 130 m.yielding between 30,000 lph to 50,000 lph (GWD, 1993). For the proposed water balance studies to be taken up along with State Ground Water Dept. of Andhra Pradesh a catchment area of 526 sq.km upto Rly. culvert near Gollaprolu Railway station is considered as study area.

3.3 Land Use :

The predominant soils in the basin are black clay, red and light brown sandy soils. Towards the northern part of the basin, red soils are predominant in the hilly tracts and valley portions while in the middle part of the basin light brown soils and towards the southern part black soils are predominant. The main crops are paddy, banana, sugarcane, chillies and cotton. The total area irrigated under surface water sources is 6981 hectares, out of which an extent of 1758 hectares is under Subbareddysagar and 5223 hectares is under Minor Irrigation tanks (GWD, 1993).

3.4 Climate :

The basin area enjoys tropical climate with hot summers and cold winters. The basin receives about 80% of the annual rainfall during the monsoon season of June to November. The region experiences four distinct seasons of climate viz. winter season

(December to February), hot weather or summer season (March to May) southwest monsoon season (June to September) and post monsoon season (October and November). May is the hottest month with maximum daily temperatures touching 40^{0} C. December is coldest month with minimum temperature falling to 15^{0}C. The monthly pan evaporation values in mm in the region from January to December are 120.4, 111.0, 124.5, 124.2, 144.0, 151.6, 112.5, 88.1, 88.9, 128.3, 153.2, and 128.5 as specified in the Master Plan Report of the Yeleru River, which is neighbouring this basin.

4.0 Network Design :

The understanding of the sources of water at or under the earth's surface and its consequence movement back to principal storage in the oceans through various pathways is very important for a Engineering hydrologist. The basis for this is the concept of hydrological cycle. Two of the greatest problems for the hydrologist are quantifying the amount of water in different phases in the cycle and evaluating the rate of transfer of water from one phase to another. Here comes the importance of measurement of these components. This job has not been subjected to co-ordinated planning until recent times.

Rainfall, streamflow or groundwater have been measured for many years by seperate official bodies, private organisations or even individual amatuers. There has been very little logical design in the pattern of measurement (Shaw ,1983). Authorities put coordinated efforts only during catastrophies i.e. during heavy floods or severe drought. The installation of gauges for rainfall or streamflow has been directed to asses flows for single, simple and immediate purpose. Nowadays with tremendous increase in population and greater demand of water ,schemes for measuring hydrological variables are considered essential for the development and management of water resources at national level. The improvement in communication system to serve modern needs has made this job quite practical. Cost-benefit assessments are also being made on the effectiveness of data gathering and hence scientific planning is being recommended to ensure optimum networks to provide the required information (WMO, 1972).

According to Langbein (1965) a network is a organised system for the collection of information of a specific kind : that is, each station, point or region of observation must fill one or more definite niches in either space or time'. In a more simple way Kohler (1958) infers that a hydrological network is one that provides data commonly used by hydrologist. The following sections will present a review on the network design of hydrological aspects.

4.1 Rainguage Network:

Design of network for raingauge stations is of major importance to the hydrologist since it is to provide a measure of the input to the river catchment. The rainfall input is irregularly distributed both over the catchment area and in time. Another consideration in precipitation network design must be rainfall type.

World Meteorological Organization (WMO, 1969) has recommended the minimum precipitation network densities for general hydrometeorological purpose as follows:

1. One station per 600-900 sq.km of area in flat regions of temperate mediterranean and tropical zones

2. One station per 100-250 sq.km of area in mountainous region of temperate, mediterranean and tropical zones

3. One station per 25 sq.km of area in small mountainous islands (<20,000 sq.km).

4. One station per 1500 to 10000 sq.km of area in arid and polar zones.

If the objective is to estimate streamflow (hydrograph, volume, peak etc) then the precipitation network density might be different (Johanson, 1971). Simple guidelines for specific hydrologic purposes have not yet been developed according to Singh (1992). As per the ISI 4987-1988 Standards prescribed in India one station per 518 sq.km is recommended. However, if the catchment lies in the path of the low pressure systems, which causes precipitation in the area during their movement their network should be denser particularly in the upstream of the catchment. In not too elevated regions with an average elevation of one kilometer (1000 mts) above msl the network density shall be one raingauge in 200 sq.km. to 390 sq.km. If the catchment is predominently hilly the density should be one raingauge per every 130 sq.km. Also, ISI recommends that at least 10% of the rainguage station should be equipped with self recording raingauges.

Interesting and valuable studies using very dense raingauge networks have been conducted to determine the standard error of average precipitation estimates over various size drainage areas with various raingauge network densities. Linsley et al(1947) had presented a U.S.Weather Bureau graph which suggested that the standard error of estimate of storm rainfall over Muskingum basin in Chicago, U.S.A (CA = 8000 sq.miles) was about 6 percent for a density of one raingauge per 100 sq.miles (About 250 km^2) and about 14 % for a density of one gauge per 500 sq.miles (about 1250 km^2).

Some of the earliest efforts in the area of data network design were reported by Langbein (1960) essentially consisting of guidelines to estimate the optimum number of base stations and operational time frames for secondary stations relative to precipitation data acquisition in a region. The criteria was to maximize the number of gauged stream years in a hydrologic basin. Langebin further detailed a number of correlation techniques and their utilization for extrapolation of streamflow data.

Huff and Neill (1957) carried out a study of aerial variability of rainfall in a region characterized by thunderstorm activity in Illinois State, USA.

Rainbird (1965) had discussed the problem of network design of precipitation stations and suggested an overview of the problem by assessing the accuracy of data required, the relative importance of precipitation data for the project and the time intervals for which such records need be maintained for a given region.

Hershfield (1965) analyzed rainfall data for 15 storms for each of 15 water sheds with a total of 400 raingauges and found that plots of correlation around key gauges showed evidence of anisotropy.

Caffey (1965) analysed the spatial correlation structure of annual rainfall from 1141 stations from the Western U.S and south-western Canada with an average length of record of 54 years.

The work of Guscina et al (1967) exemplifies some of earliest applications of spatial correlation analysis of rainfall; they presented plots of correlations as a function of distance from a central station for 12 hour, 24 hour, 10 day, monthly and seasonal rainfall for locations in the Valdai area of Russia; the rate of decay was observed to increase with decreasing duration and was assumed to conform to

$$\rho(d) = \rho(0) \exp(-bd)$$

where $b^{-1} = d_0$ is defined as the correlation radius or the distance at which the correlation decays by a factor of e , and $\rho(0)$ is the value of the correlation function when extrapolated to zero distance.

The technique of harmonic analysis and the concepts of distributed linear systems had been applied by Eagleson (1967) to the problem of optimum density of rainfall networks for flood forecasting purposes. Specifications of network density for the study of long term catchment average rainfall was accomplished by considering the long term point rainfall as a homogeneous random variable to be sampled spatially. The author concluded that the incorporation of catchment dynamics into the design of flood forecasting networks reduces the number of gauges needed when compared with those obtained by mere consideration of precipitation variability.

Huff and Shipp (1969) carried out an extensive spatial analysis of rainfall from three dense raingauge networks in Illinois; data ranging from one minute rates to total storm, monthly and seasonal amounts were analysed. The effects of rain type, synoptic storm type and other factors on spatial correlations were studied. Hutchinson (1969) analysed monthly and annual rainfall data from two areas in New Zealand, one relatively flat and the other with variable topography. Plots of correlation around key gauges showed distinct anisotropy for both areas as well as dependence of the rate of decay on topography.

Hendrick and Comer (1970) analysed the spatial structure of daily rainfall data from the Sleepers River Watershed in Northern Vermont. Data for days on which the rainfall at one or more gauges was ≥ 0.10, ≥ 0.50, ≥ 1.0 inches were selected for a winter season and a summer season.

The ISI standard and India Meteorological Dept (1972) had recommended a simple formula based on Rycroft (1949) details of which are given below :

Optimum Number of Raingauges:

Statistical methods are used in determining the optimum number of rain gauges required to be installed in a given catchment. The basis for this is that a certain number of raingauges are necessary to give mean rainfall over the basin with a certain percentage of error. The optimum number of rainguages corresponding to an assigned percentage of error in estimation of mean areal rainfall can be obtained as

$$N = \left(\frac{C_v}{\varepsilon} \right)^2$$

where Cv is the coefficient of variation of the rainfall values of the gauges and ε is the assigned percentage of error in estimation of average areal rainfall. If there are m raingauges in the catchment recording P1, P2, ... Pm values of rainfall for a fixed time interval, then

$$C_v = \frac{100\,S}{\bar{P}} \quad \text{where}$$

$$\bar{P} = \frac{1}{m} \sum_{i=1}^{m} P_i$$

$$S = \left[\frac{1}{m-1} \left[\sum_{i=1}^{m} P_i^2 - \frac{\left(\sum_{i=1}^{m} P_i \right)^2}{m} \right] \right]^{0.5}$$

Usually the values of ε is taken as 10 % (Singh,1992).

Stol (1972) analysed daily rainfall data from 3 groups of stations aligned along different directions for an area in the Netherlands with no relief. Data for days with rainfall > 0.5mm. at all sites were analysed on a month by month basis; no evidence of anisotropy was found. The function

$$\rho(d) = \rho(0) \exp(-bd)$$

was fitted for each month, apparently by least squares regression.

Sharon (1974) discussed some of the limitations of correlation analysis as a basis for network design, particularly in relation to localized storm rainfall.

O'Connell et al (1977) analysed an extensive volume of daily, monthly and annual rainfall data for two regions, one in the east and one in the north of England. Data for a number of categories of daily rainfall were analysed; days on which daily rainfall at a selected number of gauges within each region exceeded 2mm, 5mm and 10mm represented three categories, while a fourth category consisted of data for every 20 th day. Plots of the correlation fields around a number of key stations showed evidence of anisotropy, and an increase in the rate of decay with decreasing threshold; the data for every 20 th day showed the most rapid rate of decrease.

Jones et al (1979) used the optimal estimation procedure for preparation of maps of root mean square error of point interpolation for suggesting procedures for determining the accuracy of estimation of aerial rainfall for any shape of area and any configuration of gauges.

Based on optimal estimation procedures, O'Connell et al (1979) had assessed the accuracy requirements for point and aerial rainfall estimates using the data from existing network in the Wessex Water Authority of Southwest England. Root mean square errors of interpolation were calculated using the estimates of spatial auto-correlation of daily and monthly rainfall. Mooley and Mohammed Ismail (1981) determined the network for estimation of aerial rainfall. They used the method of optimum estimation to determine the network density required for various limits of tolerable error in the aerial estimates of monthly, seasonal and annual rainfall for different size areas in Vidarbha.

Sreedharan and James (1983) used the spatial correlation technique proposed by Kagan for design of raingauge network in the Chaliyar basin in Kerala. Using monthly data of 31 raingauge stations for seven years, the number of raingauge stations required for estimating the aerial rainfall with a given accuracy were derived by stipulating two criteria.

(i) the accuracy with which the average rainfall may be obtained over a given area and
(ii) the accuracy of spatial interpolation

Bastin et al. (1984) used a similar approach of optimal estimation for real time estimation of the aerial average rainfall. For this purpose, the rainfall has been modelled as a two dimensional random variable. The variance was minimized by using the Kriging technique. It was shown that the method could be used for the optimal selection of the raingauge locations in a basin.

Mehra (1986) had also used the Kagan's technique for determining the raingauge network using the accuracy criteria as above.

4.2 Evaporation Network:

Evaporation and transpiration over an area are relatively conservative quantities in the hydrological cycle. Hence fewer gauging stations are required to measure areal evaporation than for areal rainfall. Since evaporation and transpiration are dependent on altitude a network of measuring stations should sample different elevation zones in larger catchments. A reliable single station would provide adequate information over a flat plain (Shaw, 1983).

4.3 Streamgauging Network:

Establishment of a stream gauging site is the most costly item in a hydrometric scheme. The density of the gauging stations depends on the nature of the terrain. The mode of stream gauging depends upon the purpose of the study to be undertaken. The ultimate design and establishment of stream gauging network depends on the data requirement. hydrologic characteristics of the area and achievement of an acceptable cost benefit ratio for the scheme.

4.4 Ground water Network:

Ground water investigation should be aimed to identify productive aquifers, to determine their hydraulic properties and to make arrangements for monitoring water levels within the aquifers. while selecting location of observation wells one should take into account differences in aquifer characteristics within an aquifer in addition to variations between aquifers. In planning a network of observation wells, the sites of existing wells must be noted as these may have reliable consistant water level records which give the long term fluctuation of the water table (Shaw.1983).

5.0 Network for Suddagedda Basin:

Suddagedda basin is typical east coastal river basin. Northern most part of the basin is located in Eastern Ghats ranging to a height of less than 1000m and is covered mostly by deciduous forests. Communication and transportation is a big problem in this area and human settlements are scarcely present. Southern part of the basin is rather plain and is knitted with villages and small towns. National Highway (NH5) passes through the basin from East to West for about 15 kms in the southern part connecting Kathipudi and Prathipadu. Railway line connecting Howrah and Madras passes through the southern most part of the basin. There are good number of tanks (small surface reservoir) in the basin under the control of Minor Irrigation Department of Govt. of Andhra Pradesh. Subbareddy Sagar project is a minor irrigation project with wier type structure across the stream in the upper reaches of the basin with a catchment area of 104 sq.km. where Estern Ghats slopes meet the plains near village called Gokavaram in Prattipadu mandal.

5.1 Existing Network :

The exisiting network of raingauge station are shown in Fig.4. There are three non-recording raingauge stations under the Revenue authorities at Prathipadu, Gollaprolu and Pithapuram. Out of these Pithapuram lies just outside the basin. Existing ground water observation wells are shown in Fig.5. These wells at Prathipadu and Gollaprolu are under the close monitoring of State Groundwater Dept. There are no stream gauging sites for the regular measurement of flow on the stream. There is a culvert on the Railway line to the north of Gollaprolu Railway Station (Culvert No. 455) on the SCR, where water levels of peak floods are being observed.

Fig.4. RAINGAUGE NETWORK IN SUDDAGADDA BASIN (EXISTING)

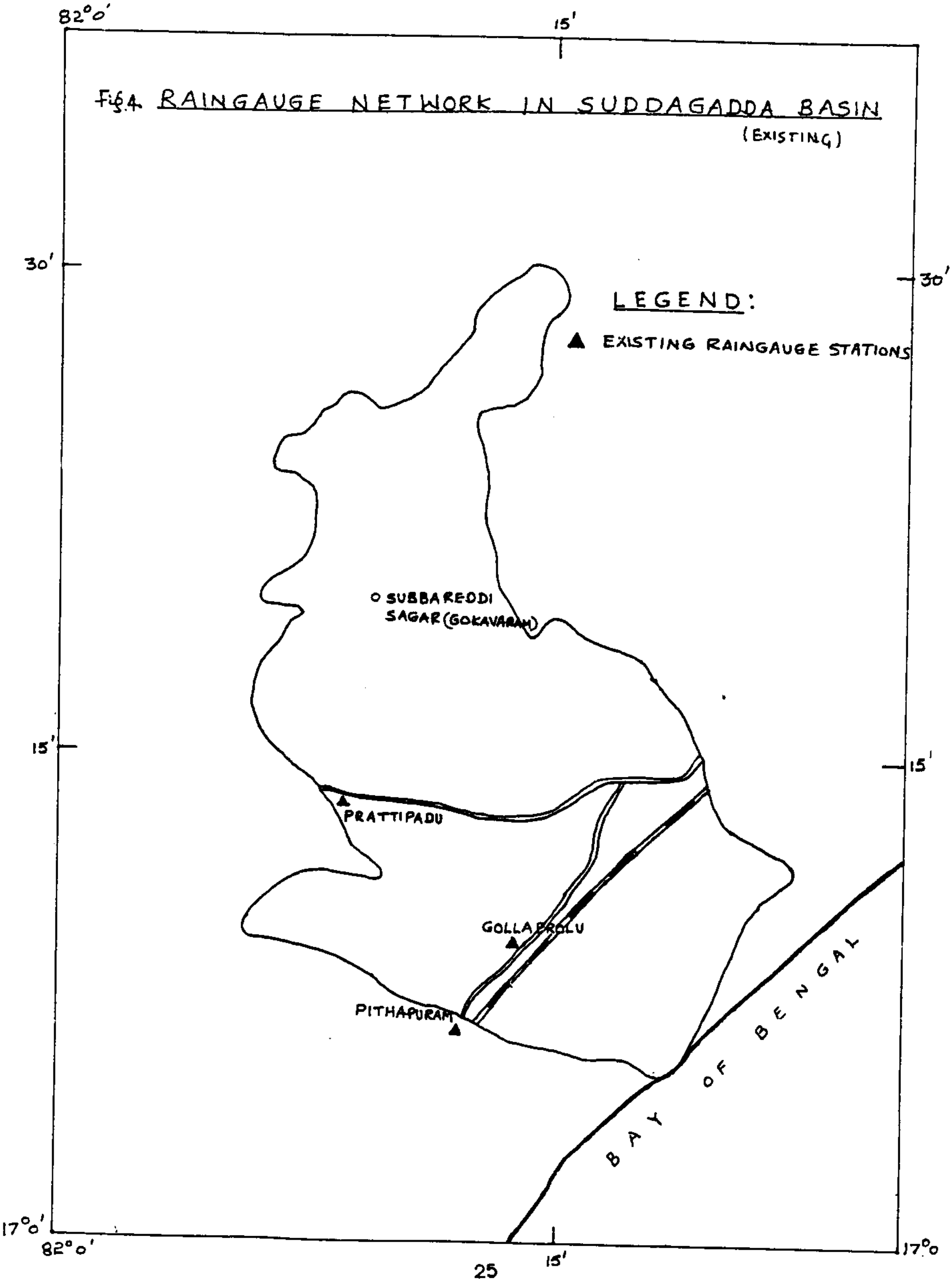
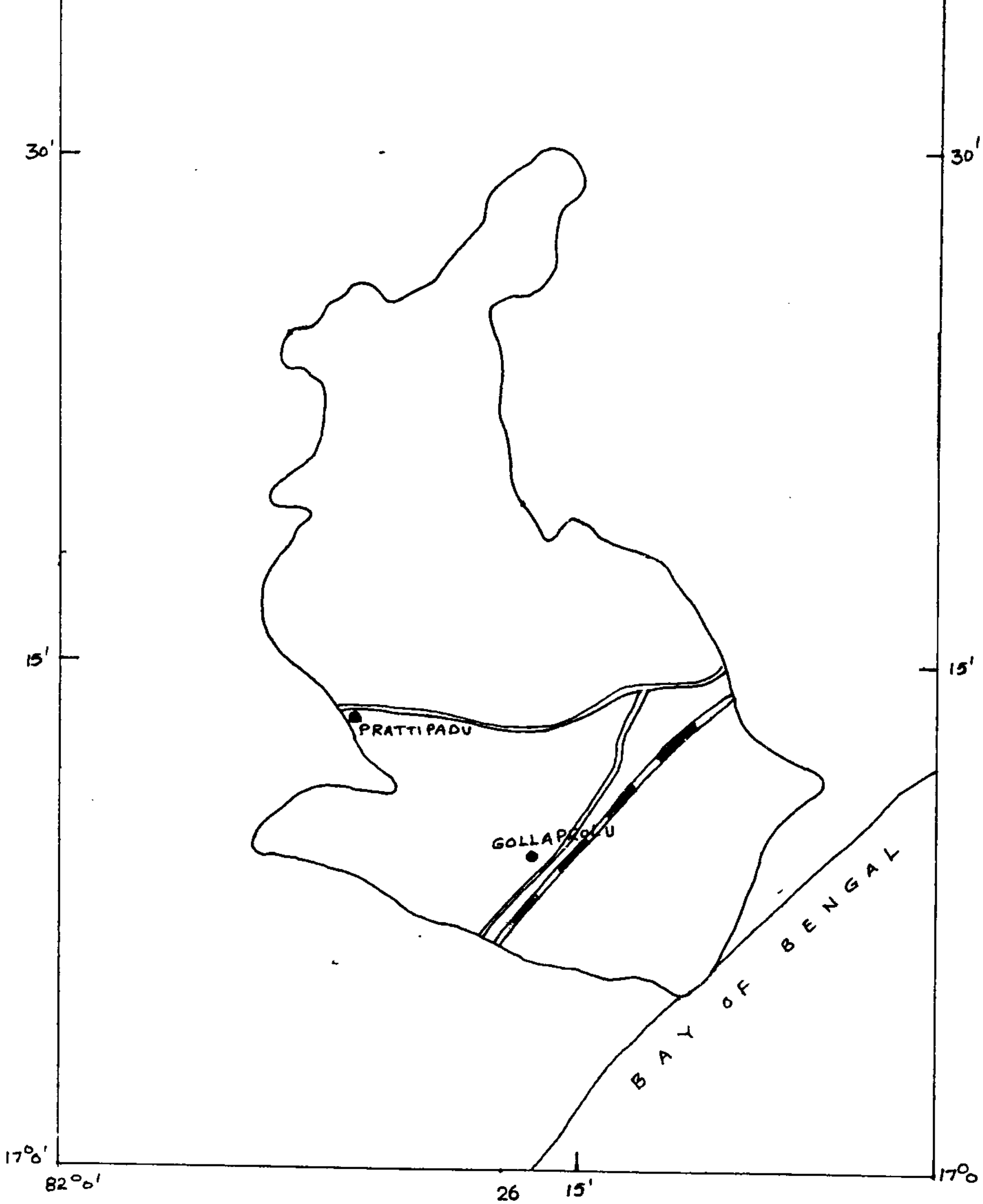


Fig 5 NETWORK OF OBSERVATION WELLS



5.2 Proposed Network:

It is proposed to have one Meteorological Observatory at Kathipudi consisting of the following equipment.

- Non recording raingauge } to measure rainfall
- Recoridng rainguage }

- Steevenson's Screen -- to protect the thermometers from direct heat and wind

- Maximum and Minimum Thermometer set-- to measure temp.

- Dry bulb -Wet bulb Thermometer set -- to measure relative humidity

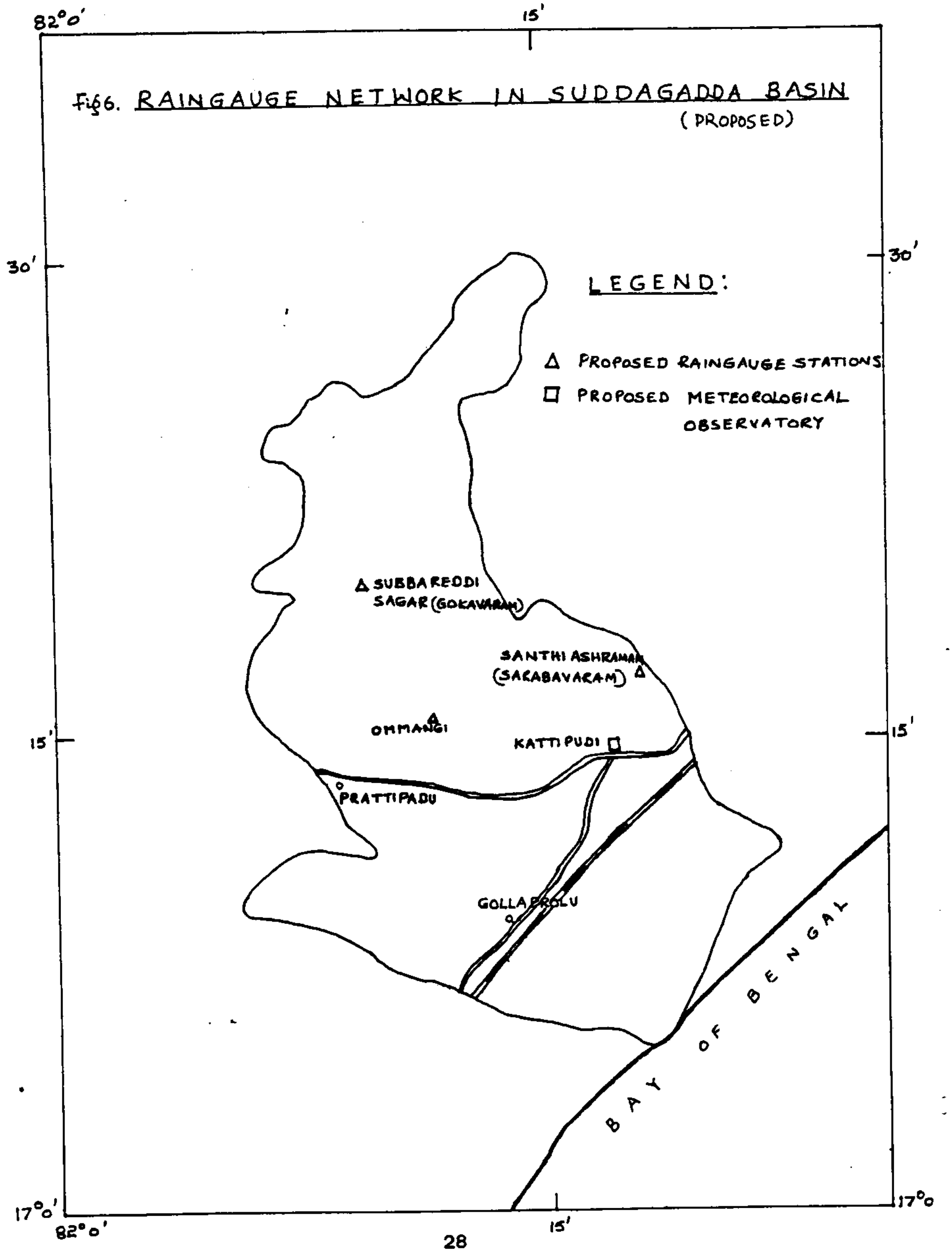
- Anemometer & wind vane -- to measure wind speed and direction

- Pan evaporimeter -- to measure evaporation

Also it is proposed that Ommangi, Sri Shanti Ashram (Sarabhavaram) and Subba Reddy Sagar (near Gokavaram village of Prathipadu mandal) be provided with raingauges of both recording and non recording type. The proposed network of raingauge stations are presented in Fig. 6.

Stream gauging site is proposed at a road culvert near Gollaprolu on the State highway connecting Kakinada and Kathipudi. Discharge measurement may be made through float technique and stream gauging may be done through the scale painted on the abutments of the culvert. Current meter technique may also be followed for flow measurement.

Total number of raingauges in the basin will become Six with the proposed sites at these places. This will satisfy the requirement of 5 stations found as the optimum number of stations through statistical method, calculations of which are presented below. Statistical analysis for the annual rainfall of 1990 at


82°0'
15'
Fig6. RAINGAUGE NETWORK IN SUDDAGADDA BASIN
(PROPOSED)
30'
30'
LEGEND:
△ PROPOSED RAINGAUGE STATIONS
□ PROPOSED METEOROLOGICAL OBSERVATORY
SUBBAREDDI SAGAR (GOKAVARAM)
SANTHI ASHRAMAM (SARABAVARAM)
OMMANGI
KATTIPUDI
15'
15'
PRATTIPADU
GOLLAPROLU
BAY OF BENGAL
17°0'
17°0
82°0'
15'

three existing rain gauge sites is presented at Annex. I. The total network of 5 raingauge stations will also satisfy the WMO requirement.

Optimum Number of Stations through Statistical Method :

$$N = \left(\frac{C_v}{\varepsilon}\right)^2$$

$$C_v = \frac{100\ S}{P} = \frac{100 * 370}{1708} = 21.7$$

with an allowing error ε of 10%

$$N = \left(\frac{21.7}{10}\right)^2 = 4.7 = 5\ \text{(Say)}$$

No Groundwater observation wells are proposed for the time being, as the existing groundwater observation wells under State Groundwater Dept are satisfying the requirement. In the following section procedure for establishing a meteorological observatory, installation of equipment and taking observations of various parameters are presented. To measure the evaporation a Pan Evaporimeter is also proposed at the Subbareddy Sagar, where a raingauge station is proposed.

6.0 INSTALLATION AND OBSERVATION :

Almost all hydrological studies require measurements of precipitation amounts. The amount, intensity and areal distribution of precipitation are essential in any hydrological study more so for design purposes. Observations of other meteorological parameters such as temperature, humidity, wind speed and direction, evaporation, sunshine are also essnetial. for studies relating to water balance studies leading to water management and watershed development.

For systematic collection of this scientific data, the observatories have to be established to confirm to international standards. Observation of parameters should be accurate and scientific. Even the compilation of the data has to be systematic.

6.1 Layout of the Observatory :

The hydrometeorological observatory proposed at Kathipudi in the study area consists of the following instruments.

1. raingague (non-recording)
2. raingauge (Self recording)
3. Steevensen screen in which maximum and minimum, wet and dry bulb thermometers are kept
5. Anemometer
6. Wind vane
7. U S Class A pan evaporimeter

The minimum dimensions for the observatory site should be atleast 15m X 15 m and preferably 20m X 20 m. The general layout plan showing location and orientation of various meteorological instruments is shown in Fig.7.

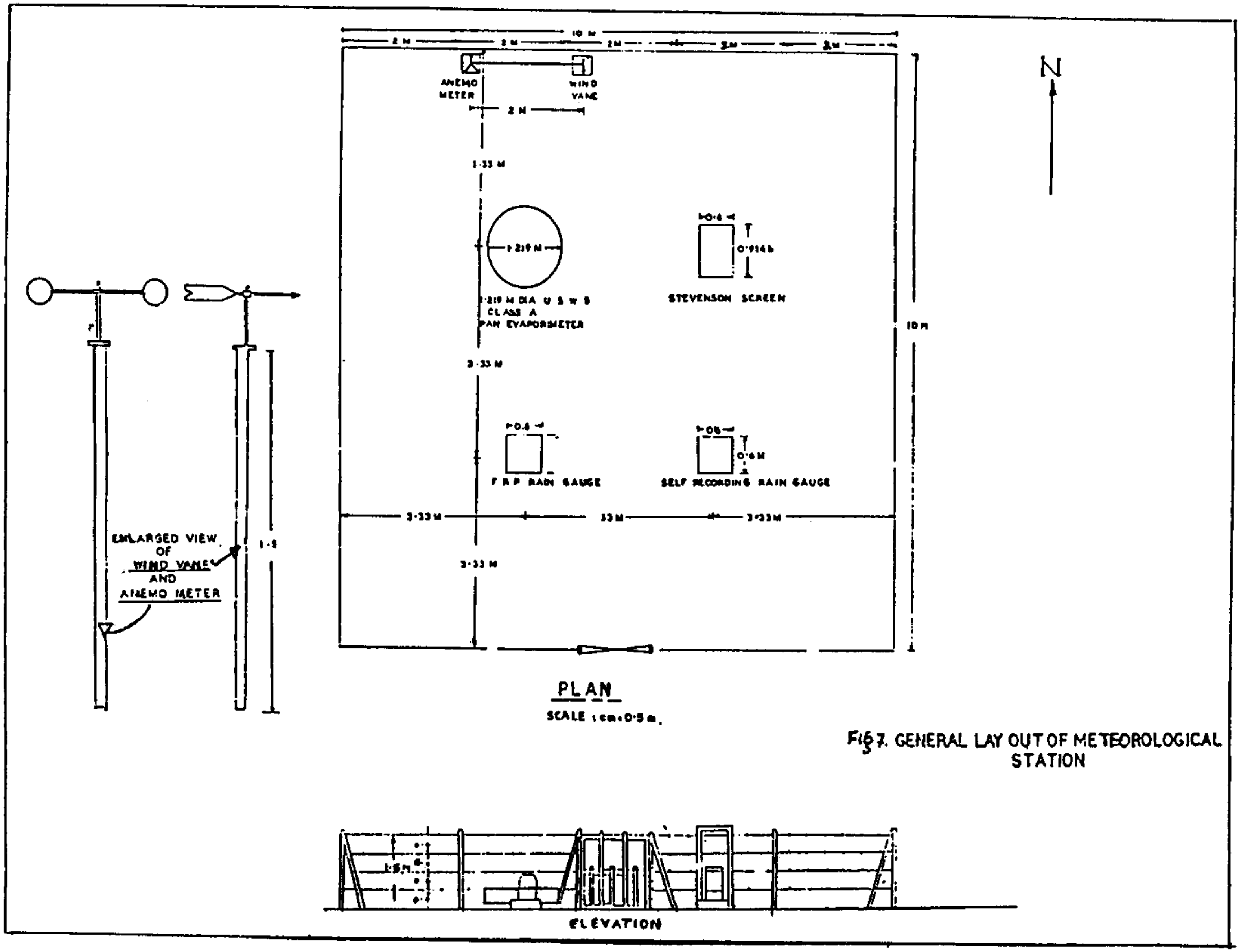


Fig 7. GENERAL LAY OUT OF METEOROLOGICAL STATION

As a general principle the site chosen for a meteorological observatory should be an open one so that there is free flow of air over the plot of ground on which the out door instruments are installed. The site needs to be fenced to keep out animals and unauthorised persons. The fencing should be of angle iron and barbed wire.

The ground should be level and may be provided with turf. It should not be located on mound with steeply sloping ground. While installing the instruments, care should be taken to see that none of the instruments vitiates the data of the other. The main criteria is that the spacing between instruments should be such that they are located at a distance of atleast twice the height of the neighbouring instrument. For example, if the height of the Steevenson screen is 1.5 m the other instruments like raingauge or evaporimeter should be located at a distance of 3m from the Steevenson screen.

6.2 Measurement of Rainfall :

The total amount of rainfall which reaches the ground in a stated period is expressed as the depth to which it would cover in liquid form a horizontal projection of the earth's surface. The units of precipitation are linear and daily amounts of precipitation should be read to the nearest 0.1mm. Weekly, fortnightly and monthly amounts should, however, be read to the nearest 1mm at least. WMO also recommends that daily observations of precipitation are made at 0830 hrs.

Different types of raingauges have been designed and used. These consisted of a collector for delineating the area of the sample and a funnel leading to a storage device. The precipitation thus collected was measured by transferring the contents to a graduated measuring jar which goes along with the particular raingauges. The area of the collector and size of the gauges vary according to the depth of the precipitation normally received in the region where the precipitation gauges is located and also depends on whetehr the measurements are made daily, weekly or at fortnightly intervals.

Since the size, shape and exposure affect the precipitation caught by a gauge it is desirable to use a standard gauge so that observations from different gauges could be comparable. In India the Symon's raingauge has been adopted as the standard rain measure since the British days.

6.3 Non recording Raingauge:

The Symon's raingauge consists of a funnel which has accurately turned and bevelled gunmetal rim 127 mm in diameter cylindrical body, a receiver with a narrow neck and a splayed base which is fixed in the ground.

These gauges are now being replaced by Fibre Glass Reinforced Plastic (FRP) raingauges having same dimensions. The collector area of the FRP gauge is 200 sq.cm. In heavy rainfall areas a gauge with a smaller orifice (usually 100 sq.cm) area is preferred to allow collection of less volume (more depth) of rain water.

Installation of raingauge:

The raingauge shall be fixed on a masonary concrete foundation 60 X 60 X 60 cub.cm sunk into the ground. The gauge should be cemented into the platform in such a way that the rim of the gauge is approximately 30 cm above ground level. This height is necessary to prevent the splashing of water into the gauge A height of more than 30 cm would result in wind eddies created by the gauge which may result in loss of catch. Where the gauge is likely to be flooded the raingauge is to be installed in such a way that the rim of the raingauge is 30 cm above the maximum expected flood level. It should be ensured that the rim of the gauge is perfectly level.

Exposure of raingauge:

The precipitation collected depends on the exposure of raingauge. The following points, therefore, need special attention while installing the gauge as per ISI 4986 (1983).

i) The gauge shall be placed on level ground and not upon slope or terrace and never on a wall or roof.

ii) On no account the raingauge shall be placed on a slope such that the ground falls away steeeply on the side of the prevailing ground.

iii) The distance between the raingauge and the nearest object should be generally four times the height of the nearest object/obstruction but in no case the distance shall be less than twice the height of the object/obstruction.

iv) Great care shall be taken at mountain and coastal stations such that the gauges are not unduly exposed to the sweep of the wind. A belt of trees or a wall on the side of the prevailing wind at a distance as mentioned in (iii) above is recommended as an efficient wind shelter.

v) In the hills where it is difficult to find a level space, the site for the gauge shall be chosen with a minimum level area of 6m x 6m where it is best shielded from high winds and where the wind does not cause eddies.

Measurement of rainfall:

To measure the rainfall, the water in the bottle should be poured into the measuring glass cylinder which should be placed on a level surface. The glass cylinder is graduated to 0.2mm accuracy. It could, however be read upto 0.1mm accuracy if the water miniscus rests between two divisions. Care should be taken to avoid spilling and paralax error while reading.

If there is more water in the bottle than the measure glass could hold, the glass is filled upto the 20mm mark and the water is thrown away after noting. The procedure is repeated until all the water in the bottle is measured. The total rainfall will be the sum of all the readings noted.

If at the time of observation rainfall happens to occur, a spare bottle could be placed beneath the funnel to avoid loss of catch. The contents of the spare bottle are subsequently transferred to the original bottle.

All observations of rain are taken in India at 0830 IST to ensure standardization and intercomparison of rainfall from different rainguage stations. The rainfall measured at 0830 hrs on any particular date is entered against the date and it is understood that the rainfall so registered has been received in 24hrs preceding 0830hrs of that day (Table 2)..

6.4 Recording Raingauges :

Three types of recording precipitation gauges are in general use. They are the float type, the tilting or tipping type and the weighing type. In India, the float and syphon type recording rainguage usually referred to as self recording rain gauge (SRRG) is most commonly used as part of an operation network.

The float and siphon recording gauge is an instrument designed to give a continuous record of rainfall. The instrument can record

i) The total amount of rainfall which has fallen since the record was started.

ii) The times of start and cessation of rain and, therefore, the duration of rain

TABLE 2

Station : National Institute of Hydrology   Lat: 29° 51' Long: 77° 53'
District : Hardwar State : Uttar Pradesh   Elev : 274 m Year :

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Total Rainfall												
Total Rainy Days												

From the record the rate of rainfall could be estimated. The recording raingauge is generally used in conjunction with a non-recording raingauge installed closeby for use as standard by means of which the readings of the recording raingauge could be checked and if necessary adjusted.

The float and siphon recording raingauge consists of a collector and rainfall recording mechanism mounted on a base. The recording mechanism consists of a float chamber containing a light metal (brass) and a siphon. The siphon is fixed to the float chamber by means of four screws with provision for adjusting to enable correct siphoning. The lower end of the float chamber is provided with a hexagonal cap which can be removed for cleaning the float chamber. A wire gauge filter is provided which fits into the inlet tube. The recording pen is mounted on the stem of the float. The time is marked by a horizontally rotating drum driven by a clock. The clockwork mechanism could be mechanical or quartz type.

As rain falls in the funnel the rain water is led into the float chamber through the inlet pipe and the water level in the float chamber rises and the pen records the cumulative rain on the chart wound on the clock drum. The float rises until a specified amount of rain (usually 10mm or 25mm) is received. After the specified amount of rain is received the rain water is automatically siphoned out and the float comes down. The float rises again when more rainwater enters the float chamber and the pen attached to the float rises again from the zero line on the chart. If there is no rain, the pen traces a horizontal line from where it stops rising indicating cessation of rain.

The gauge generally has a capacity of 10mm of rainfall for each siphoning and has a collector having a rim area of 325 sq.cm

(203.4mm diameter). To record the precipitation at stations where heavy rainfall with high intensity is experienced, it is preferable to have a rainguage with a collector having a rim of 130 sq.cm (128.6 mm diameter). With this collector, the rainguage would have a capacity of 25mm of rainfall for each siphoning.A typical chart from a recording raingauge is shown in Fig 8.

Installation of recording raingauge :

The exposure conditions for the recording raingauge are the same as those for the non recording raingauge. The recording raingauge is installed on a concrete platform 60 cub.cm. The gauge is fixed to the concrete platform by a 15cm bolt fixed in the centre of the platform. The gauge shall be so installed that the rim of the funnel is level and at a height of exactly 750mm above the ground level. The recording raingauge should be at a distance of atleast 2m from the non recording raingauge and preferably 3m away.

Use of recording raingauge:

An appropriate chart is wrapped on the clock drum while taking care to see that corresponding horizontal lines on the overlapping portions are coincident and that the bottom of the chart is as near to the flange at the bottom as possible.

The clock is wound and the pen is set after putting enough ink in the pen. Water is poured gradually into the inlet tube until the water begins to siphon. After siphoning is complete the pen should rest against the zero line on the chart. If it does not, the screw is loosened and the pen is fixed on the float rod and moved until it rests exactly on zero line and the screw tightened. The chart is changed at the same time every day, usally between 0800 and 0900 IST.

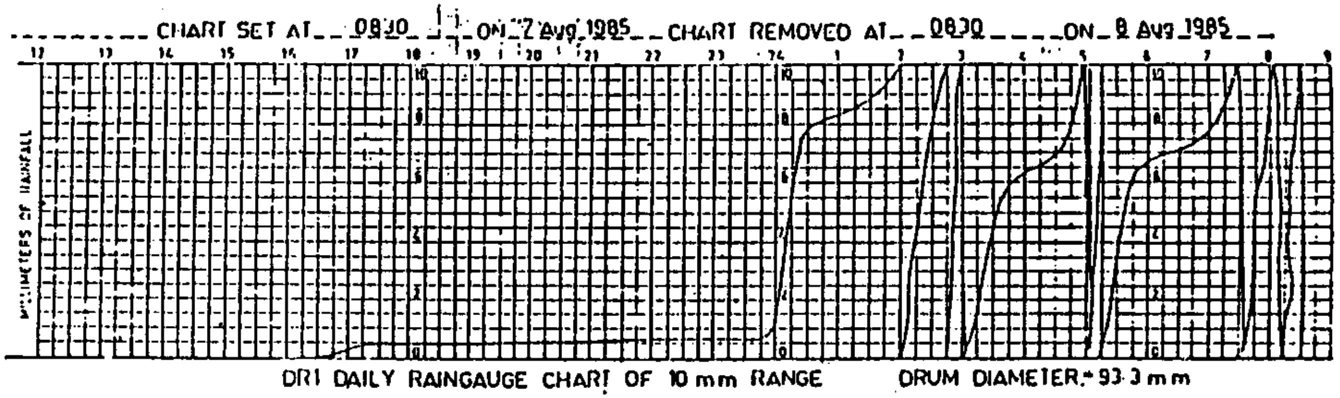


Fig. 8 Recording raingauge chart

Tabulation of hourly values:

The charts removed from the instrument every day are analysed and hourly rainfall is tabulated (Table 3).

The sum of the 24 hourly values for the hours 1 to 24 should be entered in the column 'Raw Total (S)'. The entry in the column divided by 24 gives the daily mean and should be entered in column 'Mean (S/24)'. The maximum rainfall among all the hours of a day together with the hour in which it has occured should be entered in columns 'Max. rainfall' and 'Hour and Time' respectively. The next column is meant for the total duration of rainfall in hours and minutes. For example if the total duration of rainfall during a 24 hr period is 5hr and 25 minutes it is entered as such in Hours and minutes columns respectively.

6.5 Steevenson Screen:

The Steevenson screen is a louvered wooden box through which air can pass freely. It has double roof and a bottom. It is mounted on legs sunk into ground which are fixed in concrete firmly such that the bulbs of the two vertically hung thermometers (Dry bulb and Wet bulb) are at a height of 1.3m (4feet) above ground level. In double Steevenson screen both recording and non recording type of instruments can be housed whereas in a single Steevenson screen only maximum and minimum thermometers, Dry bulb and Wet bulb thermometers are kept.

While installing, the screen is oriented in such a way that the door opens towards the north in the northern hemisphere and towards south in southern hemisphere. This is meant to minimise the risk of direct exposure of the thermometers to sun rays when the door is opened for observations.

6.6 Temperature:

For estimating evaporation and evapotranspiration the daily mean or monthly mean temperature data are needed. This data is obtained with the help of maximum and minimum thermometers. The

TABLE 3
PROFORMA FOR RECORDING HOURLY RAINFALL

Station : District : State:

Lat : Long: Elev: Year : Month: Units :

Date	Hours																								Raw total	Mean	Maximum Rain		Duration of Rain	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	S	S/24	Amount	Time	Hours	Minutes
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														
12																														
13																														
14																														
15																														
16																														
17																														
18																														
19																														
20																														
21																														
22																														
23																														
24																														
25																														
26																														
27																														
28																														
29																														
30																														
31																														

average of daily maximum and daily minimum gives the daily mean temperature.

The maximum and minimum thermometers are mounted on a single board. The maximum thermometer is mercury filled and minimum thermometer is alcohal filled. The maximum temperature of the day is measured through the rise of mercury column. An index provided in the thermometer is pushed by the rising mercury column and stays at the maximum even after the temperature decreases and the mercury column recedes. The lower end of the index is the maximum temperature. After noting the maximum temperature, the index is brought to the prevailing temperature by vigorously jerking.

The minimum temperature is measured by the recession of the alcohal. The receding alcohal pulls the index along with it and leaves it at the minimum temperature even after temperature rises after sun rise. The upper end of the index gives the minimum temperature. The index is brought to the prevailing temperature by slightly tilting the thermometer.

6.7 Humidity :

The humidity is observed with the help of Dry and Wet bulb thermometers. Both the dry and wet bulb are mercury filled thermometers. While the bulb of the dry bulb thermometer is not covered, the bulb of the wet bulb thermometer is covered by muslin cloth which is kept wet continuously with water drawn by capillary action through a wick dipped in a bottle of distilled water. The dry bulb and wet bulb thermometers are placed in the Steevenson screen along with the maximum and minimum thermometers.

The dry bulb gives the air temperature prevailing at any given time. In the case of wet bulb thermometer the water from the moist bulb evaporates and in the process cools the bulb with the result the wet bulb always indicates a temperature less than that indicated by the dry bulb. The temperature of the wet bulb and dry bulb would be equal only when the air is super saturated with water vapour. The cooling of the bulb is thus dependent on the humidity of the air and the difference between the dry bulb and wet bulb temperature known as wet bulb depression is used as a measure of the level of moisture content (humidity) in the air.

Table.4 give values of relative humidity at 900mb for different values of dry bulb and wet bulb temperature.

6.8 Wind Speed:

Information on wind speed is required for estimating the wave height in reservoirs and for estimation of evaporation and crop water requirements from meteorological parameters. The wind speed is measured with the help of anemometer. In India cup type anemometer approved by the IMD is used. For hydrological purposes, the wind speed would be required at the reservoir level or at the crop level. The suitable height for the anemometer would be 1to 5ft (0.3m to 2m) above ground level.

Installation of anemometer:

The anemometer should be fixed in the corner of the observatory. It is fixed to a 20mm G.I.Pipe embedded in a concrete block of suitable height as may be required. It should be located in such a way to ensure that it is free from any obstruction for free flow of wind.

Measurement of wind speed:

The wind speed is measured twice daily at 0830 and 1730hrs. The anemometer is provided with a digital indicator which is calibrated to give wind speed in Km. The difference between two readings divided by the time interval would give the speed in km/hr. For hydrological purposes the 24hr average wind speed is recorded.

TABLE 4: Hygrometric table for computing relative humidity in %(900 mb)

Dry bulb °C	wet bulb °C																								
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
10	42	53	64	76	88	100																			
11	34	44	55	65	77	88	100																		
12	27	36	46	56	66	77	68	100																	
13	20	29	38	48	57	68	78	89	100																
14	14	23	31	40	49	59	69	79	89	100															
15	9	17	25	33	42	51	60	70	79	89	100														
16	5	12	20	27	35	44	52	61	70	80	90	100													
17	1	8	15	22	30	37	45	54	62	71	80	90	100												
18		4	10	17	24	32	39	47	55	63	72	81	90	100											
19			6	13	20	26	33	41	48	56	64	73	82	91	100										
20			3	9	15	22	28	35	42	50	57	65	73	82	91	100									
21				6	11	17	24	30	37	44	51	58	66	74	82	91	100								
22				3	8	14	20	26	32	39	45	52	59	67	75	93	91	100							
23					5	10	16	22	28	34	40	47	53	60	68	75	83	91	100						
24					2	7	13	18	23	29	35	41	48	54	61	69	76	84	92	100					
25						5	10	15	20	25	31	37	43	49	56	62	69	76	84	92	100				
26						2	7	12	17	22	27	32	38	44	50	56	63	70	77	84	92	100			
27							4	9	14	18	23	29	34	39	45	51	57	64	71	77	85	92	100		
28							2	7	11	15	20	25	30	35	41	46	52	58	65	71	78	85	92	100	
29								4	8	13	17	22	27	31	37	42	47	53	59	65	72	78	85	93	100
30								2	6	10	14	19	23	28	33	38	43	48	54	60	66	72	79	66	93
31								1	4	8	12	16	20	25	29	34	39	44	49	55	61	67	73	79	86
32									3	6	10	14	18	22	26	31	35	40	45	50	56	61	67	73	80
33									1	4	8	12	15	19	23	28	32	36	41	46	51	57	62	68	74
34										3	6	10	13	17	21	25	29	33	38	42	47	52	57	63	68
35										1	4	8	11	15	18	22	26	30	34	39	43	48	53	58	63
36											3	6	9	13	16	20	23	27	31	35	40	44	49	54	59
37											2	5	8	11	14	17	21	25	28	32	36	41	45	50	54
38											1	3	6	9	12	15	19	22	26	29	33	37	41	46	50
39												2	5	8	10	14	17	20	23	27	31	34	38	42	47
40												1	4	6	9	12	15	18	21	24	28	32	35	39	43
41													2	5	8	10	13	16	19	22	26	29	32	36	40
42													1	4	6	9	12	14	17	20	23	27	30	33	37
43														3	5	8	10	13	15	18	21	24	28	31	34
44														2	4	6	9	11	14	17	19	22	25	28	32
45														1	3	5	8	10	12	15	16	20	23	26	29

Extract from IMD Hygrometric Tables (900 mb), Rota Print, Poona-5, December 1975.

6.9 Wind Direction:

The wind direction is of importance in meteorology, aviation, shipping, transport, construction engineering and many other areas of application. The wind direction is referred to that direction from which the wind is blowing and is specified relative to the true north at the place of observation.

The wind direction is determined with the help of a wind vane. It consists of a horizontal arm which carries a flat rail at one end and a counter weight at the other end. The horizontal arm is mounted on a vertical spindle mounted on bearings. A capnut is provided on the top end of the spindel to hold the horizontal arm. The support table has at the bottom a mounting ring for fixing the direction arms. Four direction arms are provided which carry the letters N,E,S and W indicating the four directions North, East, South and West. Lock nuts are provided for tightening the direction arms to the mounting ring. The position of the counter weight with respect to the direction arms indicates the wind direction and may be determined by observing the prevailing direction for a few minutes. Where necessary, the direction can be interpolated between N and E to give Northeast, E and S to give Southeast and so on.

Installation of wind vane:

The wind vane shall be mounted on a main mast with the direction arms indicating the true direction, which shall be set with a magnetic compass. The wind vane shall be located in such a way that it is not shielded to wind flow by tall buildings or trees. The bearing assembly shall be oiled at regular intervals for facilitating smooth movement of horizontal arm.

6.10 Evaporation:

The evaporation from large water bodies like reservoirs and lakes is estimated by measuring evaporation from a small evaporation pan called the Pan Evaporimeter. In India, the US class A Pan is recommended by IMD and is widely used. The pan is covered with a hexagonal wire mesh (0.70mm) to avoid drinking of water from the pan by animals and birds.

The pan evaporimeter is made of 1mm thick copper sheet tinned inside or of galvanised iron painted white inside and outside. It is 122.5cm in diameter and 25.5 cm high. A measuring cylinder is used 1/10th of the pan such that the area of the cylinder is 1/100 th of the pan. The cylinder is graduated from 0 to 200mm and a cylinder full of water corresponds to 2mm depth of evaporation from the pan.

Installation of Evaporimeter:

The pan is mounted on a wooden platform, 10cm high to allow for air circulation below the pan. No concrete or masonary platform should be made as they will cause radiation of heat to the pan. The fixed point in the pan should be at a height of 30cm above ground level. It is also customary to measure the temperature of the water and wind speed at the pan level. A anemometer is installed by the side of the pan at the pan level. Temperature is measured with the help of mercury thermometer.

To maintain accuracy in the measurements it is advisable to change the water atleast once in 15 days and periodically paint the evaporimeter to avoid rusting and leakages.

Measurement of Evaporation:

To measure evaporation from the pan the level of water in the pan is brought to the tip of the fixed point in the pan by adding water with the help of the measuring cylinder. The amount of water added to bring the water level to the tip of the point divided by 100 is the evaporation. In case of rainfall, however, the following method is adopted.

i) if the rainfall is light, the water level is brought to the tip as explained above. The rainfall depth observed by the nearby raingauge is added to the evaporation measured to get the total evaporation.

ii) if the rainfall is heavy, water is removed from the pan with the help of the cylinder to bring the water level in the pan to the tip of the point. The difference between rainfall depth and the depth corresponding to the amount of water removed from the pan is the evaporation.

iii) if the rainfall is very heavy and the pan overflows with water, a remark is written in the record that the pan overflowed. Evaporation during heavy rain spells will be any way negligible.

7.0 CONCLUSIONS :

The previous sections discussed present the hydrological network design for Suddagedda basin, along with the necessary procedures for installation of different meteorological equipment. Notes of taking meteorological observation is also dealt at length.

At present, there are raingauges recording daily precipitation at Prathipadu, Pithapuram, Gollaprolu. A Meteorological Observatory at Kathipudi along with recording and non-recording raingauges at Sri Santhi Ashram (Sarabhavaram), Ommangi and Subbareddy Sagar (near Gokavaram village of Prathipadu Mandal) are proposed.

As far as groundwater network, it is felt that the existing observation wells at Prathipadu and Gollaprolu are sufficient. Since no stream gauging site is existing at present, it is proposed to establish a gauge discharge site at road bridge near Gollaprolu, using float method or if feasible using current meter technique. It is concluded that the proposed network will suffice the data needs required for conducting water balance studies in the basin. Evaporation data is to be observed at two places i.e., the Kathipudi Observatory and the Subbareddy Sagar raingauge site.

8.0 REFERENCES

1. Bastin, G., B. Lorent, C.Duque and M.Gevers. 1984. Optimal estimation of the average aerial rainfall and optimal selection of raingauge locations. Wat. Res. Res. Vol. 20. No.4. pp.463-470.470.

2. Caffey, J.E. 1965. Inter-station correlations in annual precipitation and in annual effective precipitation. Hydrology Papers, No.66.447 pp Colorado State University, Fort Collins, Colarado.

3. Eagleson, P.S. 1967. Optimum density of rainfall networks. Wat. Res. Res. Vol.3. no.4, pp 1021-1023.

4. Guscina, M.V., Kagan, R.L. and polishchuck, A.I. 1967, accuracy in determining the mean precipitation depth over an area, Soviet Hydrology selected paper No. 6. pp : 585-596.

5. GWD (1993) : A status report on the 'Suddagedda Basin' Groundwater Dept, Govt. of A.P., Hyderabad.

6. Hendrick, R.I. and Comer, G.H. 1970. Space variations of precipitation and implications for raingauge network design. Journal of hydrology, Vol.10, pp 151-163.

7. Hershfield, D.M. 1965. On the spacing of raingauge. Symposium on Design of Hydrological Networks, I, Quebec, W.M.O.-I.A.S.H. publication No. 67, pp 72-81.

8. Huff, F.A. and J.C.Neill. 1957, Rainfall relations in a urban catchment. Bull. Illinois State Water Survey No. 44.

9. Hutchinson. P. 1969. Estimation of rainfall in sparsely gauged areas. Bulletin International Association of Scientific Hydrology, Vol. 14, No. 1, pp 101-119.

10. India Meteorological Department. 1972. Manual on hydrometeorology, Chapter III, pp 13-18.

11. Johanson, R.C. (1971) 'Precipitation Network Requirements for Streamflow Estimation' Tech. Rep. No :147, Stanford, CA: Dept. of Civil Engineering, USA.

12. Jones, D.A., R.J.Gurney and P.E.O'Connell. 1979. Network design using optimal estimation procedures. Wat. Res. Res. Vol 15. No 6. pp: 1801-1812.812.

13. Kohler,M.(1958), 'Design of Hydrological Networks' WMO Tech Note No: 25, 16pp.

14. Langbein, W.B. 1960. 'Hydrologic data Networks and Methods of Extrapolating or Extending Available Hydrologic Data'. Hydrologic Networks and Methods, United Nations - Flood Control Series. No. 15, pp 13-41, WMO, Bangkok.

15. Langbein, W.B. (1965):'National Networks of Hydrological data' IASH Pub. No: 67, pp. 5-11.

16. Mehra, H.C. 1986. On certain aspects of estimation of areal rainfall. Mausam. Vol. 37, No.1, pp 97-102.

17. Mooley, D.A. and P.M. Mohammad Ismail, 1981. Network density for the estimation of areal rainfall. Hydro. Sci. Bull Vol. 26 No. 4. pp 369-378.

18. O'Connell. P.E., Neran, M.A., Gurney, R.J., Jones, D.A. and Moore, R.J. 1977. Methods for evaluation the U.K. raingauge network. Institute of Hydrology, report No, 40, pp 262, Wallingford, Oxfordshire.

19. O'Connell, P.E., R.J.Gurney, D.A.Jones, J.B.Miller, C.A. Nicholass and M.R.Senior, 1979. A case study of rationalisation of a rain gauge network in south west England. Wat.Res. Res.vol 15, No.6 pp 1813-1822.

20. Rainbird, A.F. 1965, Precipitation basic principles of network design. WMO/IASH symp. on design of hydrological networks. Qubec. Canada, pp 19-30.

21. Rawat, J.S. (1985) : Hydrometric implications of morphology and geology, a study of lower Ramganga Catchment, Jl. G.S.I., 26 (10), 734-743

22. Rycroft, H.B. 1949. Random sampling of rainfall. Journal of South Africa Farmers Assoc. Vol. 18, pp 71-81.

23. Sharon. D. 1974. On the modelling of correlation functions for rainfall studies. Journal of Hydrology, Vol. 22, pp 219-224.

24. Shaw, E.M.(1983):' Hydrometric networks in Hydrology in practice, Van Nostrand Reinhold (UK).

25. Singh,V.P. (1992), ' Measurement of Precipitation and Analysis of Precipitation data' in Elementary hydrology, Prentice

Hall, NJ, USA.

26. Sreedharan, K.E. and E.J.James, 1983. Design of raingauge network for the Chaliyar river basin using spatial correlation techniques. Jour. of Inst. of Eng (Civil). Vol 64, c13. pp 170-184.

27. Stol, Ph.Th. 1972. The relative efficiency of the density of raingauge networks. Journal of Hydrology, Vol. 15, pp 193-208.

28. Szesztay, K., (1965) : On principles of establishing hydrological representative and experimental areas. IASH, Publ.No.66, 1:64-74.

29. Toebes, C. and Ouryvaev, V.(eds), 1970 : Representative and experimental basins. An international guide for research and practice, UNESCO.

30. WMO (1969): 'Guide to Hydrometeorological Practices', 2nd Edition, Tech. Rep. No. 82, WMO No:168, Geneva.

31. WMO (1972):'Casebook on Hydrological Network design' WMO. pub. No : 324, Geneva.

Statistical analysis of sequences

Event : ANNUAL RAINFALL IN SUDDAGEDDA IN 1990

Variables

2076.100
1720.400
1328.700

Number of variables 3

Mean +1708.400

Variance +139759.800

Standard deviation +373.845

95% level of confidence that the mean is within 779.6438 TO 2637.156
99% level of confidence that the mean is within -433.8046 TO 3850.605

No	Variable	Empirical probability M/(N+1)	(M-.3)/(N+.4)	(M-.5)/N
1.000	2076.100	0.250	0.206	0.167
2.000	1720.400	0.500	0.500	0.500
3.000	1328.700	0.750	0.794	0.833

Coef.of variability +0.219
Coef. of assymetry

Probability %		Gauss	Lognormal	Gumbel	Pearson III
99.90	0.10	2863.58	3255.85	3557.38	3076.67
99.00	1.00	2578.34	2760.57	2881.74	2684.13
98.00	2.00	2477.40	2603.99	2677.91	2553.29
95.00	5.00	2323.37	2382.00	2406.14	2362.63
90.00	10.00	2187.67	2202.15	2167.03	2201.87
80.00	20.00	2022.80	2001.82	1977.49	2014.95
50.00	50.00	1708.40	1668.91	1647.11	1705.78
20.00	80.00	1394.00	1391.36	1401.29	1390.63
10.00	90.00	1229.13	1264.79	1296.90	1248.57
5.00	95.00	1093.43	1169.29	1220.21	1140.16
2.00	98.00	939.40	1069.61	1142.35	1011.18
1.00	99.00	838.46	1008.94	1094.82	949.50
0.10	99.90	553.22	855.46	976.43	758.83

DIRECTOR : S. M. SETH

HEAD AND COORDINATOR : P. V. SEETHAPATHI

STUDY GROUP

S. V. VIJAYA KUMAR

K. S. RAMASASTRI

T.VIJAV