ANALYSIS OF GROUNDWATER FLOW FOR CENTRAL PART OF PALER SUB BASIN, ANDHRA PRADESH

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
HYDROLOGY

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"ANALYSIS OF GROUNDWATER FLOW FOR CENTRAL PART OF PALER SUB BASIN, ANDHRA PRADESH"** in partial fulfilment of the requirement for the award of the degree of Master of Engineering in Hydrology of the University is an authentic record of my own work carried out during the period of 16th July 1999 to 24th Dec 1999, under the supervision of **Dr. D.C. Singhal,** Professor, Department of Hydrology, University of Roorkee and **Dr. K.S. Hari Prasad,** Lecturer, Department of Civil Engineering, University of Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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SYNOPSIS

Groundwater is a vital source of water supply for drinking and agricultural needs, throughout the world. The management of groundwater resources largely depends on their proper assessment and development. Nutankal, a mandal of Nalgonda district of Andhra Pradesh, has been taken up for present study and forms the central part of catchment of Paler sub basin of Krishna river basin. Groundwater is the major source of water supply in the area. The groundwater in the study area is extracted mainly from unconfined aquifer. The natural ground water is derived mainly from direct rainfall percolation.

The area was categorized, 'Dark', based on ground water assessment, for the year 1993. In the present study a an attempt has been made to calibrate a groundwater flow model to analyse the groundwater flow and to study the impact of artificial recharge and reduced pumpage on groundwater regime of the area.

The climate is dry and semi-arid with normal annual rainfall of 830 mm. The major crop in the study area is paddy. Approximately 90% of the irrigation and domestic water supply is derived from groundwater. The geology of the area is weathered and fractured granites underlain by impervious bedrock. The groundwater occurs under water table conditions and the well yields range from 35 to 60 m^3/day.

An initial exercise of water balance is carried out for the study area as a lumped model for ascertaining the different components. A finite difference numerical flow model (MODFLOW) is used for comprehensive analysis of groundwater flow in the study area. A grid of 16*18 cells has been designed for the study. The model is calibrated by simulating the water table elevations close to the observed water table elevations during the monsoon season of 1992. The calibrated model is further validated with the monsoon data of 1998. The value of Root Mean Square error (rms) is found to be 1.02 and 1.16 for calibration and validation respectively. The groundwater balance from the distributed model is verified with the groundwater balance carried out by lumped model (GEC 1997).

The effect of artificial recharge and increased pumpage on the groundwater regime is studied. The future water table trends are predicted with different strategies of artificial recharge and reduction of abstraction rates. The results confirm that study area is overexploited and there is a need for proper groundwater management. It is possible to improve the groundwater balance through artificial recharge from existing irrigation tanks by partially closing the sluices, adopting a specific strategy for period of one or two months after post monsoon period, in consultation with the water users association in the study area. The model can be used as a tool for decision making by administrators for future ground water development.

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CHAPTER 1

INTRODUCTION

Groundwater is a vital source of water supply for drinking and agricultural needs, throughout the world. The management of groundwater resources largely depend on their proper assessment and development. Mathematical modeling is an effective tool for proper assessment of dynamic recharge component on a regional scale in a groundwater basin. Nowadays, mathematical models are used in all branches of science and engineering. In hydrogeology, one deals with natural systems, which may be highly complex in their composition and arrangement of the component materials.

Groundwater flow, in general, is a complex phenomenon and its complexity increases many a time when the flow is in fractured media. Heterogeneity is present on such a large scale that it is hardly possible to define the actual velocity vectors in the study domain. Its spatial and temporal variation has not always been successfully handled by computers owing to the paucity of large memory. The individual pathways are not the main aspect of proposed problem to resolve, but its sole objective may be confined to look into the response of the system modeled, having mathematical resemblance with the overall behavior of the actual physical domain. What one needs is a realistic sense of what a model can do and what it can not.

Many of the river basins and sub-basins of peninsular India have been facing problems in groundwater development, of various nature and degree. Paler sub-basin of Krishna river basin, in Andhra Pradesh, has in recent times witnessed many cases of failure of open dug wells due to depletion of water table, resulting in, abandoning of their lands by farmers. A proper scientific approach is therefore necessary, to find out the factors, responsible for such problems and to arrive at a permanent viable solution. Temporary abatement measures like resorting to drilling of deep borewells (or dug-cum-borewells) do not lead to long term remedies. The remedy should involve consideration of different aspects such as hydrogeology, annual rainfall, net annual draft and other natural factors for proper assessment of the situation.

In the light of problem of depleting groundwater levels in Nutankal mandal of Nalgonda district, Andhra Pradesh, which forms the central part of Paler sub basin, a groundwater flow model has been applied, in the present work. The objective is, to assess the groundwater potential in the study area, with the aim of ascertaining the impact of increased pumpage and also the effect of inducing artificial recharge through existing irrigation tanks, on depleting groundwater resources.

1.1 REVIEW OF LITERATURE

An outline of available literature on groundwater models has been discussed below. The complexity of the problem in assessment of water resources for effective planning has made the experts to resort for modeling techniques to simplify and at the same time to represent the actual field conditions as far as possible for simulating effective use of available water resources.

The typical groundwater flow equation for a two dimensional, anisotropic, nonhomogeneous system is given by

$$\frac{\partial}{\partial x}(Tx\ \partial h/\partial x) + \frac{\partial}{\partial y}(Ty\ \partial h/\partial y) = S_y\ \partial h/\partial t + Q_g - Q_r \qquad (1.1)$$

Where T_x and T_y are the transmissivities in x and y directions, S represents Storage coefficient or Specific yield (S_y) for confined or unconfined conditions respectively, Q_g is the pumping rate per unit area and Q_r is the recharge rate from rainfall per unit area; x, y are the Cartesian co-ordinates and 't' is the time co-ordinate. Q_r may be expressed as linear function of rainfall using a suitable rainfall recharge factor based on geological formation and soils in the basin. A direct problem in groundwater system aims at the determination of

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heads / water levels using equation (1.1), knowing the parameters such as transmissivities, specific yield and rainfall recharge factor, at every node or element in the adopted numerical model.

A solution of the flow equation for regional groundwater flow system involves a two dimensional analysis mainly because vertical variations of head are very small on a regional scale (Mercer and Faust, 1980). The equation (1.1) is of parabolic nature and can be solved by standard numerical techniques. Equation (1.1) needs initial and boundary conditions to get the particular solution. The initial condition refers to the specification of head or water level at the start of simulation period. In general, two types of boundary conditions are used; namely, Dirichlet boundary condition of specified head and Neumann boundary condition of specified flux.

The first application of numerical techniques to groundwater flow problem was made by Fayers et al.(1962). A three-dimensional model was applied to a problem, which evaluated the magnitude and direction of steady state flow in a nonhomogeneous, isotropic multilayer aquifer system. Fiering (1964) solved numerically the finite difference approximations for the response of groundwater basin to pumping stresses, using an implicit iterative technique. Remson and Appel (1965) were the first to succeed in application of a steady state digital model to evaluate the effect of a proposed reservoir on groundwater levels in an underlying aquifer. Pinder and Bredhoeft (1968) used non-iterative Alternating Direction Implicit (ADI) method for solving the system of equations while modeling a groundwater basin. Prickett and Lonnquist (1968) developed a general purpose computer model for a two dimensional groundwater flow analysis which considers different types of classical aquifer systems. Cooley (1974) and Trescott (1975) used strongly Implicit Method (SIP) for solving the system of equations while analysing the regional groundwater flow problem. Trescott and Larson (1977) compared several methods for solving the system of equations and obtained, using a Finite Difference Method (FDM) and concluded that SIP is the most powerful method. Kuiper (1981) made a comparative study of SIP and Conjugate gradient methods and concluded that incomplete Cholesky - Conjugate gradient method is more efficient for the linear isotropic problems.

Sridharan et al. (1986), Reddy and Gurunadha Rao (1991), Ting et al. (1998) and Gore and Gurunadha Rao (1998) are among the others who used FDM for groundwater flow modeling. Sridharan (1992), using trial and error approach, calibrated the regional groundwater simulation model for Chitradurga district comprising an area of 10,000 km^2. It must be noted that such a trial and error approach requires prior knowledge of the range of parameters in the study area..

Mazumdar (1997) used MODFLOW to model the regional groundwater potential in Ghataprabha subbasin of Krishna river basin covering an area of 8829 km^2 falling in Karnataka and Maharashtra states. The aquifer parameters used in his study were obtained from the available pump test data in the region.

1.2 OBJECTIVE AND SCOPE OF STUDY

Nutankal, a mandal in Nalgonda district, of Andhra pradesh, is the present study area. It was categorized as dark (or critical) area, from 1993 onwards, based on groundwater assessment carried out, by Andhra Pradesh Groundwater Department. Subsequently all the financing agencies were advised not to advance loans to the farmers, for further groundwater development. In this study, an attempt has been made to calibrate a groundwater flow model to analyze the flow and study the impact of artificial recharge and reduction of pumpage on the groundwater regime of the area. A two dimensional, one layered, finite difference model (MODFLOW) has been applied to develop different groundwater scenarios for the central part of Paler sub-basin. The model has been calibrated by performing groundwater balance analysis for a particular year (1992). Calibration provided the optimum parameters to be used in the study. Further, the model is validated satisfactorily simulating the groundwater response for another year (1998). Various existing and proposed groundwater development scenarios have been simulated to recommend solution to the existing groundwater problems. The model can be useful to the administrators for decision making to visualize the effect of further groundwater development and impact of artificial recharge on groundwater regime in the region.

1.3 CHAPTER CHARACTERISATION

Chapter1 gives a brief introduction, review of literature and objective and scope of study. In chapter II, a brief description of the Location, Geology, Hydrogeological conditions and Surface water irrigation in the study area have been discussed. Chapter III deals with the conceptual model, model structure, spatial and temporal discretization and model inputs. Chapter IV deals with modeling details like model calibration, Validation, Sensitivity analysis for various parameters and Projections for different strategies. Chapter V outlines the Conclusions and Recommendations for further research.

CHAPTER 2

DETAILS OF STUDY AREA

2.1 LOCATION

The study area is located in South-central part of India, 130 km East of Hyderabad in Andhra Pradesh. The area of present study covers a mandal (a revenue unit) in Nalgonda district of Andhra Pradesh, which forms central part of Paler sub basin of Krishna river basin. It is situated within the North latitudes 17^0 16' 40" to 17^0 24' 45" and East longitudes 79^0 39' 20" to 79^0 49' 20" and falls in Survey of India toposheets No 56 O/11 and 56 O/15. The location map of study area is given in Fig.2.1.

2.2 GENERAL INFORMATION

The study area, viz., Nutankal mandal is bounded towards North by Warangal district whereas river Paler forms its Northeast and Eastern boundaries. Towards South, Tette vagu, an intermittent local stream is present, with Tungaturthy mandal being situated in the West. The areal extent of the study area is 180.32 km^2. The topography of the area varies from normal to undulating, with gentle slope to Southeast. Physiographically, it is characterised by gently undulating topography with rarely seen outcrops. The elevation of land surface of study area varies from 150 to 200m above mean sea level (AMSL). The general slope of the study area varies from 1 in 400 to 1 in 500. In the vicinity of Paler river, alluvial deposits can be found in the form of discontinuous patches along the meanders, especially towards its Northeastern boundary.

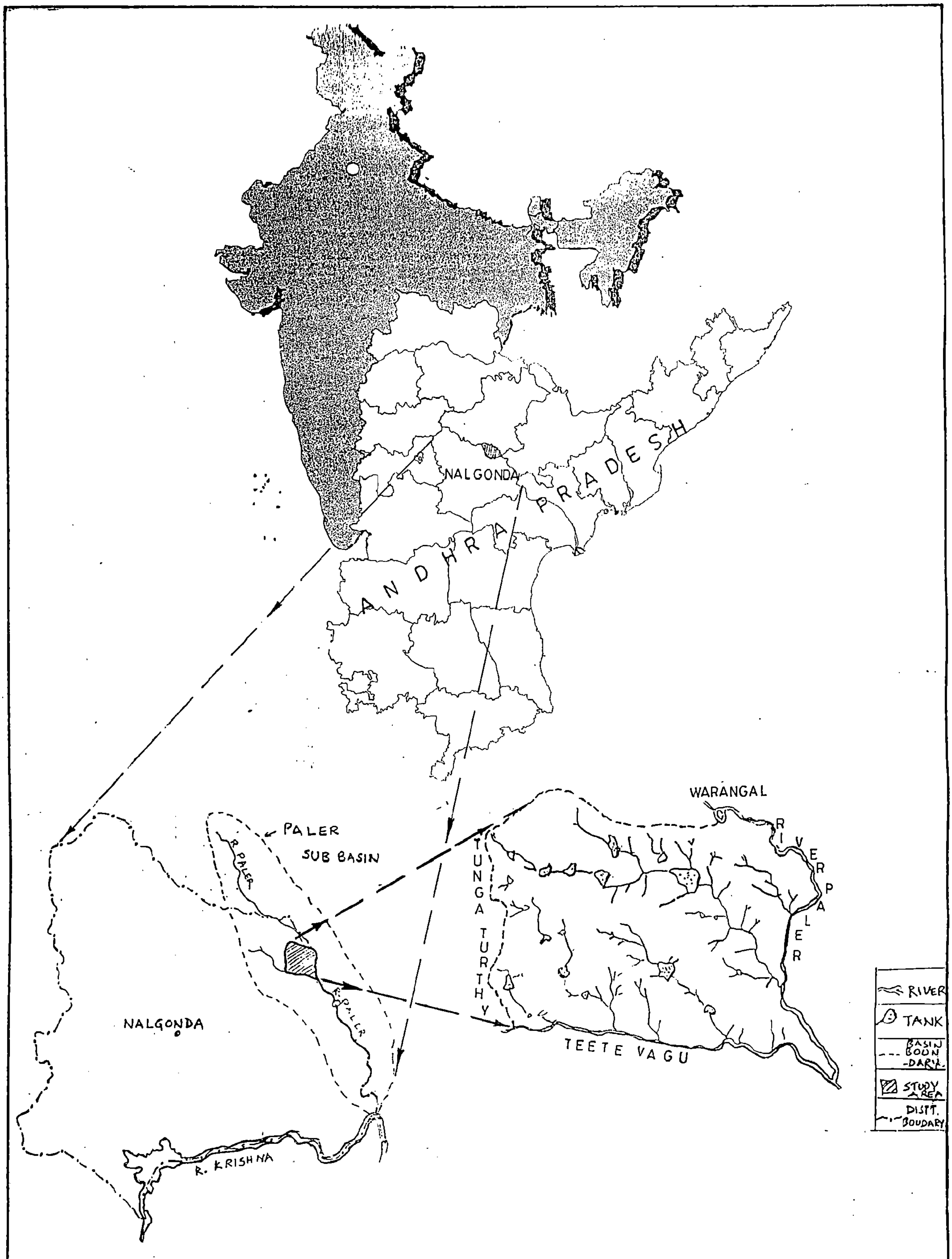


FIG. 2·1-LOCATION MAP OF STUDY AREA

2.3 DRAINAGE

The major river in the study area is the Paler, a tributary of River Krishna. The paler river which is ephemeral in nature, drains the eastern part of the study area and flows in Southeast direction. The trend of the river is controlled by a major lineament along NW - SE. All lower order streams in the area also are controlled by minor lineaments. The over all drainage pattern is dendritic to sub-dendritic, a characteristic of the granitic terrain. Most of the streams are ephemeral in nature thus having flow only during the monsoon. The drainage is generally effluent in nature. The drainage map of the study area with village boundaries is depicted in Fig 2.2.

2.4 CLIMATE

As per Indian Meteorological Department (IMD), the area is categorised as dry weather agro-climatic zone with extremely hot summer and moderate cold winter. The temperature varies from 36^0 to 45^0C in summer and 16^0 to 25^0C in winter. Relative humidity is over 70% during monsoon and 35 to 40% during summer (Firozuddin and Rao, 1993). Mean daily temperature of the area for different months is shown in Table 2.1

Table 2.1 Normal monthly temperature (in °C)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
24	26	28.9	32	33.8	31.4	27.4	27.7	27.5	26.9	24	22.3

The rainfall in the basin occurs mainly through Southwest monsoon. The average annual rainfall is 830 mm. About 85% of annual rainfall is received during Southwest monsoon i.e., mid June to mid October. The highest rainfall recorded in the area was 386.2 mm for

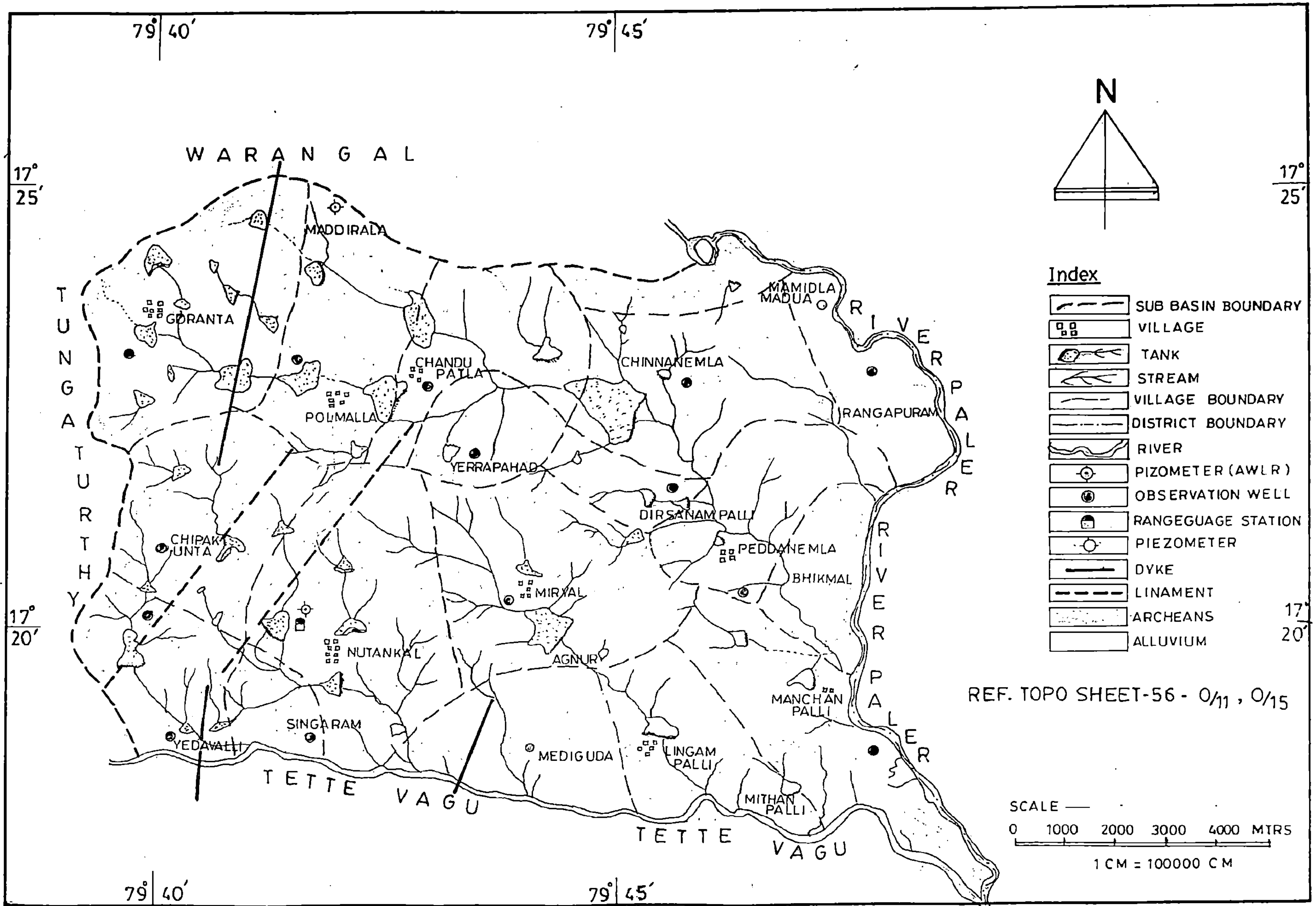


FIG. 2·2 MAP SHOWING HYDROGEOLOGY AND DRAINAGE IN THE STUDY AREA

July'89, at Nutankal raingauge station. There are three raingauge stations in adjacent mandals, viz., Tungaturthy, Torrur and Atmakur surrounding the study area. The monthly rainfall data of these stations, for the period 1989-98, ~~is~~ are presented in Appendix 2. The month-wise mean rainfall of the area, for this period is given in Table.2.2

Table 2.2 Mean monthly rainfall (in mm), for 10 years period (1989-98)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.3	8.3	4.8	10.0	48.2	115	190	160	170	92	23	5

The data of evapotranspiration collected from the hydro-meteorological station at Khammam and mean daily evapotranspiration for different months is shown in Table 2.3

Table 2.3 Month wise Mean daily Evapo transpiration (ET_o) (in mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.61	4.69	5.80	6.36	6.81	5.02	4.16	3.96	3.84	3.73	3.40	3.15

The average annual potential evaporation for study area is 1381mm. (Source: Indian Meteorological Department, Hyderabad). The climate of study area is charaterised as dry and semi-arid with little or no surplus water.

2.5.1 GEOLOGY

The study area is underlain by Peninsular gneissic complex rocks of Archean age. The most common rock type is granite usually coarse grained, with hypidiomorphic to porphyritic texture or a gneissic structure (Reddy and Pradeep Raj, 1997). It is highly leucocratic within shades of gray or pink. It is extensively weathered and fractured. The granites are at places, intruded by dolerite dykes which are often weathered. These hard and compact rocks lack primary porosity. The weathered residuum and fractured zones constitute main repository of groundwater. Recent alluvium occurs as thin discontinuous patches along river tributaries.

2.6 HYDROGEOLOGICAL CONDITIONS

Groundwater in the study area occurs under unconfined conditions in weathered zones for development through open wells and also under semi-confined to confined conditions in
9 fractured zones for development through dug-cum-borewells and borewells. A random well inventory of the area shows the general lithology of the area to be weathered granite residuum of approximate thickness 15m. This zone forms the phreatic aquifer with average yield being 25 m^3/day. The saturated fracture zones of depth range 15 to 25m, constitute deeper aquifers, and are tapped by dug-cum-borewells and borewells. The fractured rock is followed by hard impervious bedrock. The lithologic fence diagram is depicted in Fig 2.3.

The farmers have started resorting to dug-cum-borewells and borewells, during the last few years in order to tap the depleting water table in the area. The depth to water level in the study area varies from 9.0 to 12.0 m below ground level (bgl), during pre-monsoon period and 6.50 to 9.50 m bgl, during post-monsoon period of a normal monsoon year. The water table contours for pre-monsoon and post-monsoon period for years 1992 and 1998 are presented in Figure 2.4 to Figure 2.5. A comparison of these two figures clearly indicates that within a

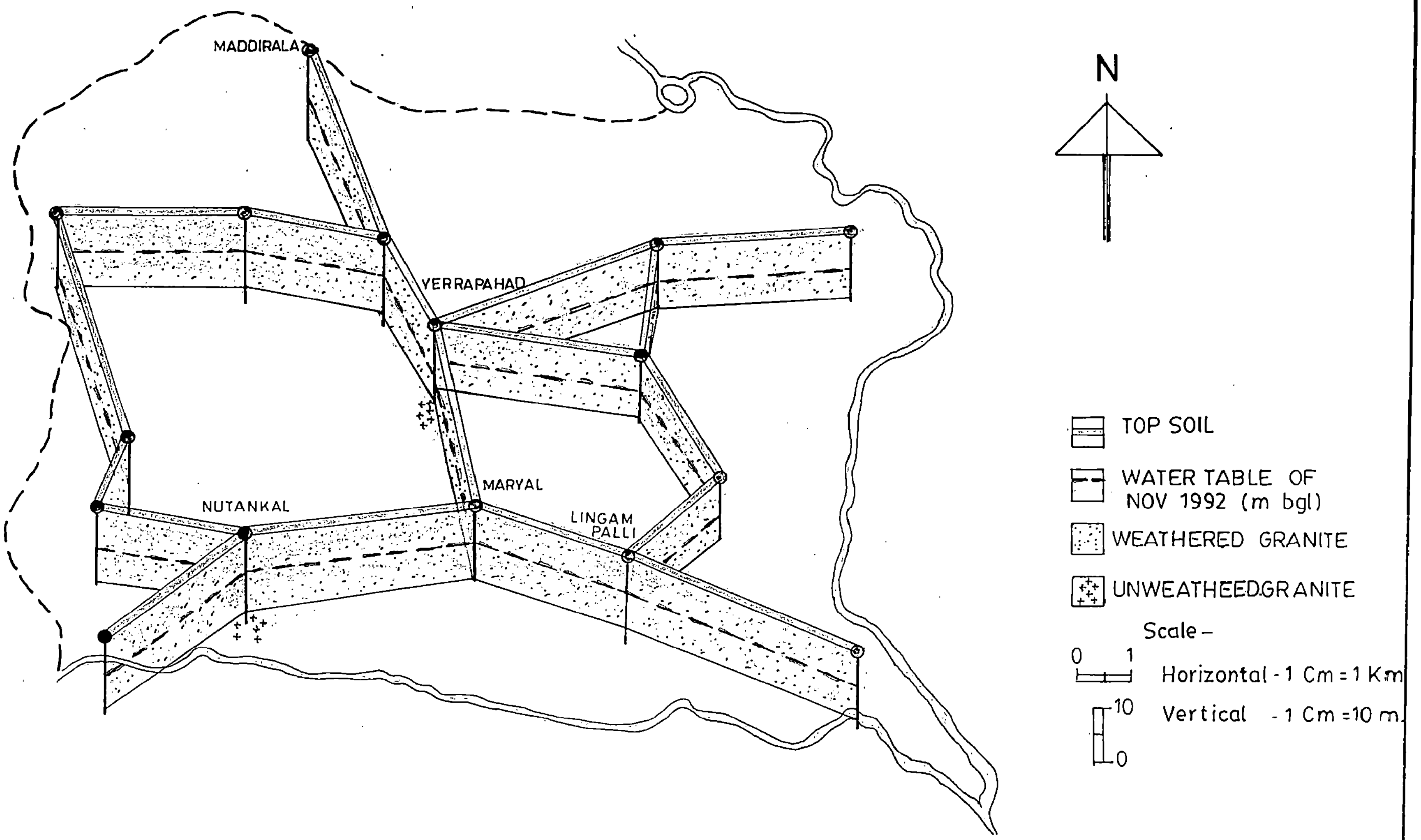


FIG. 2·3 LITHOLOGICAL FENCE DIAGRAM (AFTER A.P. GROUNDWATER DEPTT.)

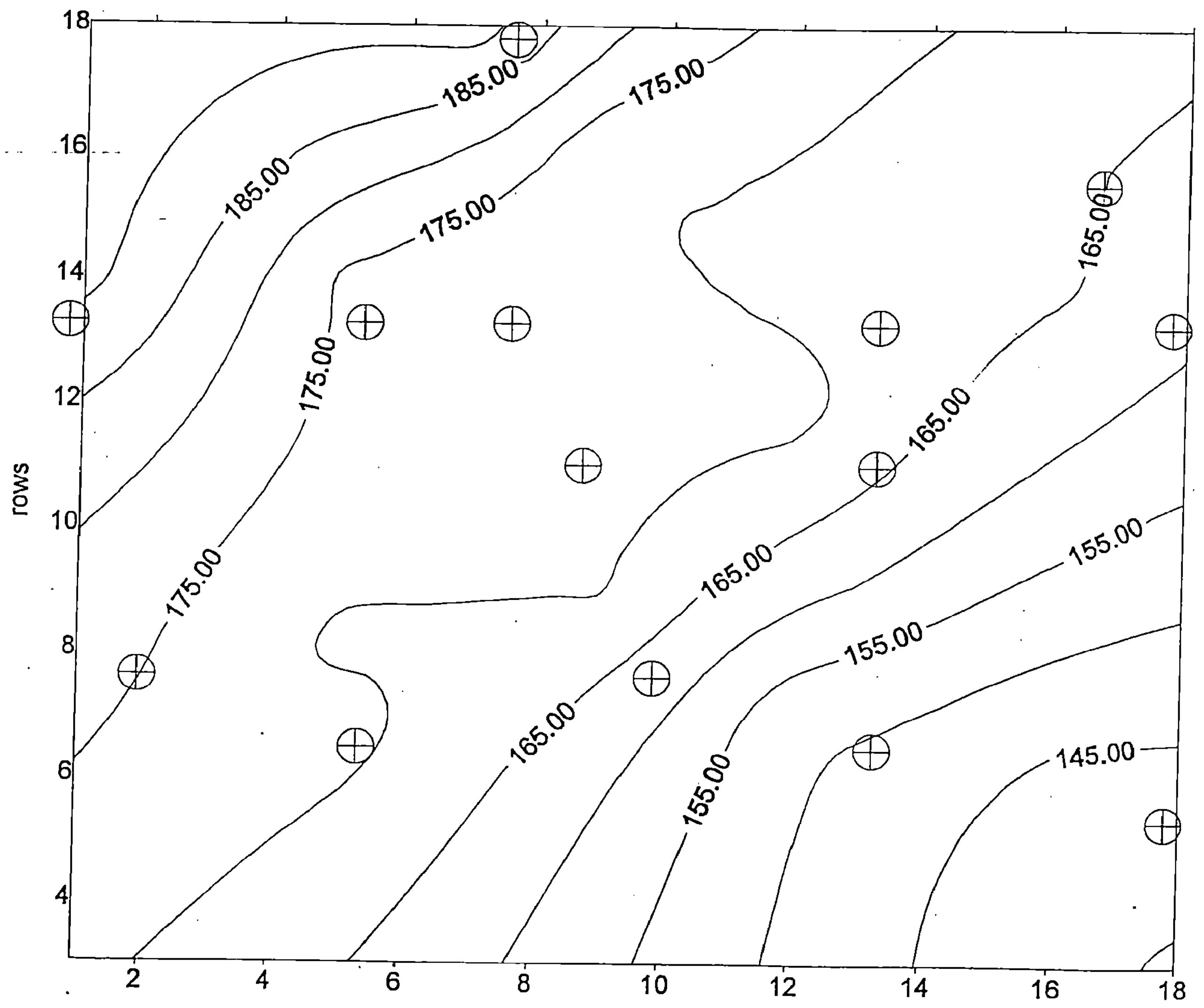


Fig 2.4a: Water table(m AMSL) contours of premonsoon (May)'92 of study area.

⊕ -- observation well

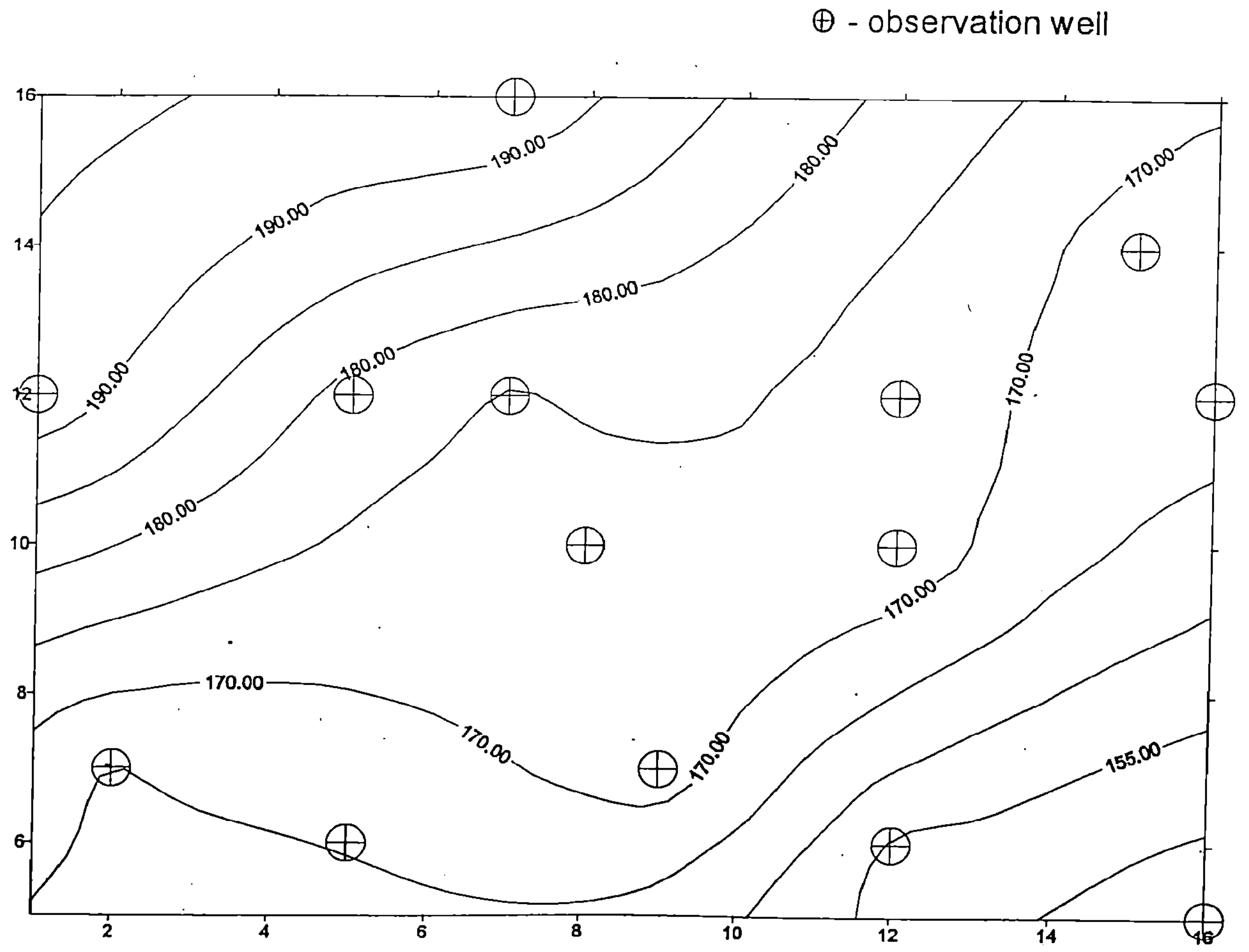


Fig 2.4b: water table contours of observed for Nov'92 in the study area.

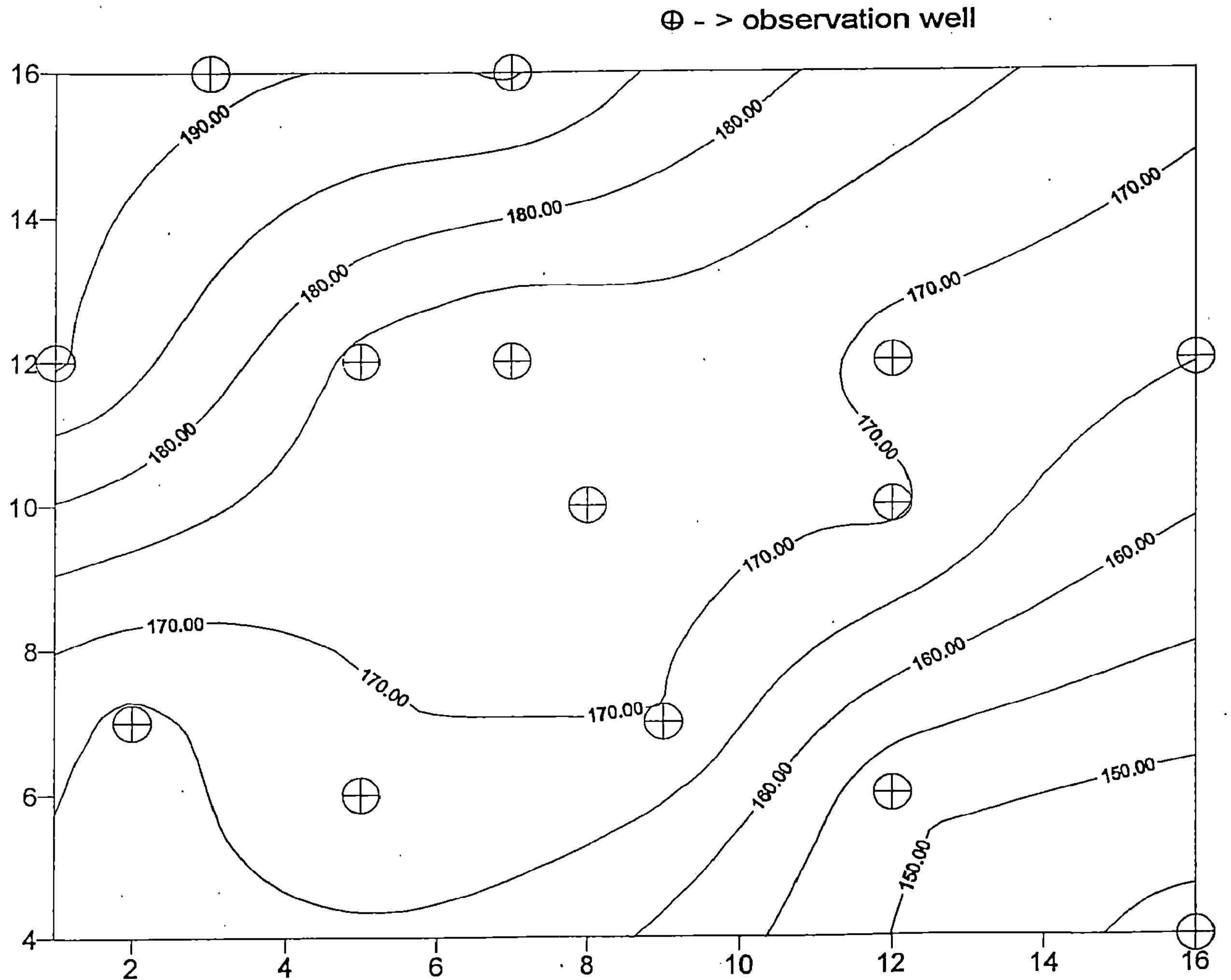


Fig 2.5a: Water table contours of premonsoon '98 for the study area.

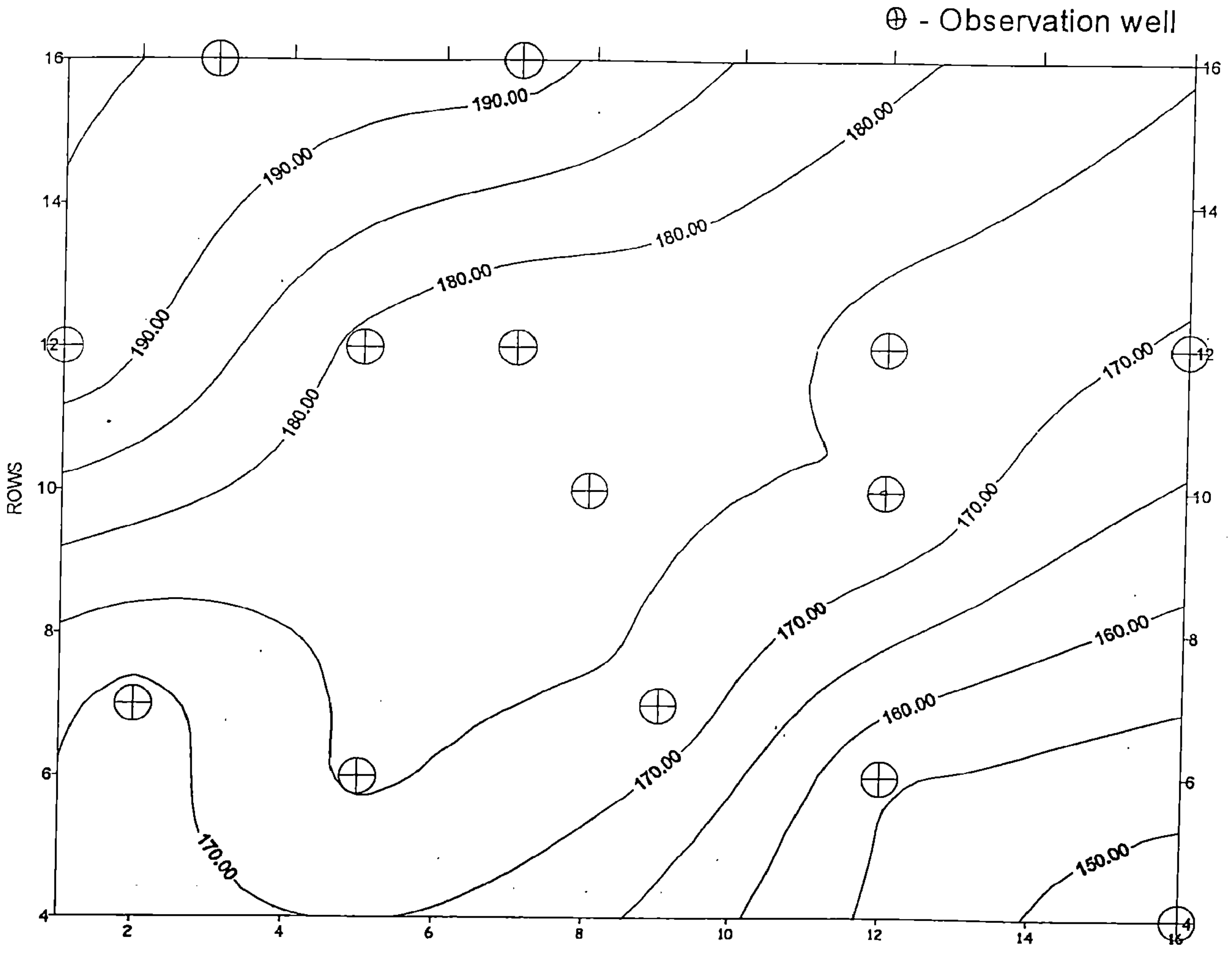


Fig 2.5b: Water table(m AMSL) contours of Nov'98, observed data for the study area

period of six (6) years, there is a significant lowering of water table to the extent of 5 to 6 m at the location of hydrograph stations in the area. A similar declining trend of water table can also be observed from hydrographs at Yerapad village (Fig. 2.6) and at Nutankal (Fig 2.7) as a result of low annual rainfall. There was no much fluctuation between Pre and post monsoon water table during 1992 to 1994 which was a drought period. A rise in water table between Nov'95 and Nov'98 reflects the effect of increasing annual rainfall during the years 1995 to 1998.

The seasonal water table fluctuation in the study area is about 2 to 4 m, but for the year 1998, the water table fluctuation recorded for observation well at Nutankal and Maddirala village was 7 m and 3.5 m respectively. The observed depth to water level in the study area for year 1999 varied from 8.85 to 12.2 m bgl, during pre monsoon period and 6.80 to 9.0m bgl during post monsoon period. The elevation of water table in the study area varied from 185 to 135 m AMSL for May 92 and ranged from 190 to 140 m AMSL in Nov. 92. General flow direction is towards Southeast.

2.6.1 Groundwater Exploitation

The groundwater is extracted through dug wells, dug-cum-borewells and borewells in the study area. There are 3007 dug wells, 923 dug-cum-bore wells and 501 borewells irrigating an area of 3482, 2147 and 1263 acres of paddy respectively, for the year 1995-96 (Source: Mandal revenue office, Nutankal). Table 2.4 shows data of groundwater exploitation structures which indicate a clear increase in groundwater abstraction during the last ten (10) years.

Fig. 2.6: Well hydrograph against Rainfall at Yerapad observation well

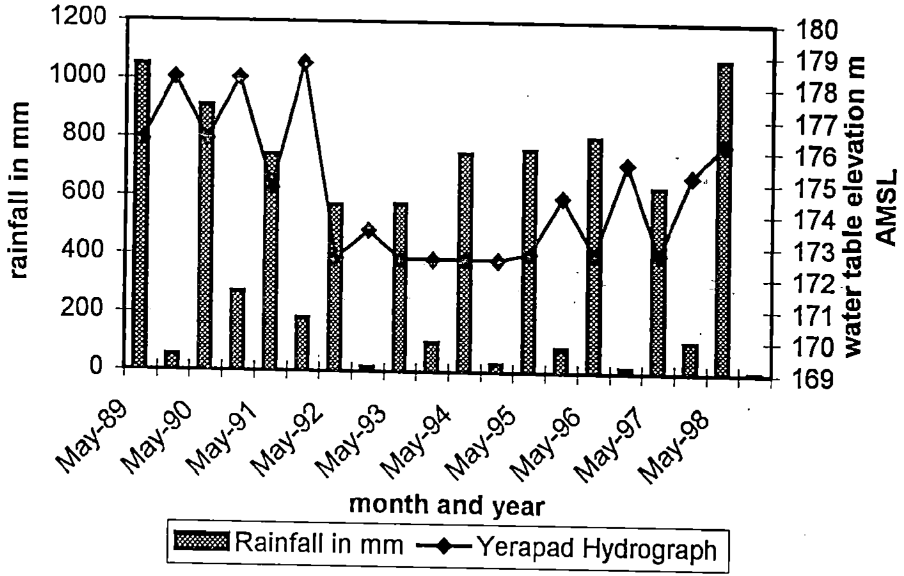


Fig. 2.7: Well hydrograph against Rainfall at Nutankal observation well

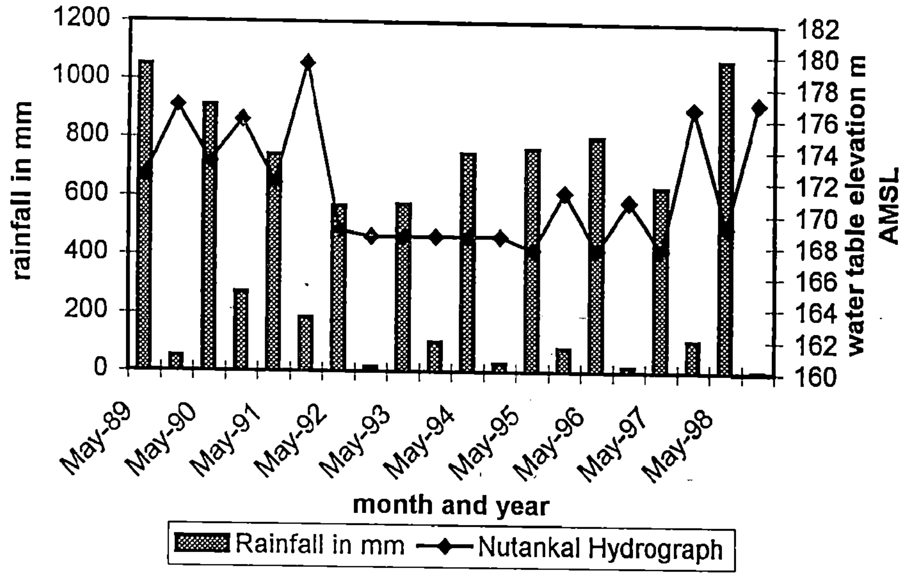


Table 2.4 : Year wise data of ground water structures in Nutankal mandal

YEAR	Dug wells	Dug-cum-borewells	Borewells	Total Groundwater structures
1988	653	113	35	798
1992	612	603	57	1278
1993	808	1152	257	2217
1995	1600	569	300	2469
1998	1800	2200	400	4400

(Source: Mandal revenue office, Nutankal Mandal, Nalgonda, A.P.)

The depth of dug wells piercing the thickness of weathered zone ranges from 9 to 15 m and depth to water level varies from 8 to 13m bgl during postmonsoon period yielding 35 to 50 m^3/day and these wells generally dry up during premonsoon period. The transmissivity values evaluated from the pump tests are 4.4 to 71.8 m^2/ day.

The dug cum bore wells are the dug wells piercing the thickness of weathered zone with depth ranging from 15 to 30m and connected by in-well-bores through fractured zone. Such wells yield 35 to 60 m^3/day and the water table generally dries up in the dug portion during summers.

The borewells drilled in the area range in depth from 30 to 50m tapping the fractured zone and joints in granites. The fractured zone normally occurs along certain lineaments, usually corresponding to surface drainage. It is observed that the producing zone, in these wells is found to be at depth 30 to 40m. The borewells piercing the fractured zone yield 30 to 250 lpm (rarely 600 lpm). The transmissivity values from the pump tests conducted are 5 to 126 m^2/day. Specific capacity ranges from 10^{-4} to 10^{-5} m^3 / day/ m.

It is clear from the above discussion that the study area is over exploited due to increasing groundwater withdrawals accompanied by drying of dug wells and lowering of water table.

2.7 LAND USE

Land use particulars of study area in Nutankal mandal based on Agriculture census, for the period 1990-91 are given in Table 2.5.

Table 2.5: Land use particulars

Sl.No.	Particulars	Area (ha)	Percentage (%)
1	Geographical area	180.32	100
2	Barren and Uncultivable land	885.0	5
3	Land put to Non-Agriculture use	534.7	3
4	Grazing lands	504.5	3
5	Land under Miscellaneous use	106.4	1
6	Cultivable waste	310.6	2
7	Other fallows	122.1	1
8	Current fallows	984.2	5
9	Net area sown	15143.2	81
10	Total cropped area	12102.5	65
11	Area sown more than twice	4662.4	25

(Source: Mandal Revenue Office, Nutankal, Nalgonda.)

2.8 SOILS AND CROPPING PATTERN

The soils in the study area are red loamy, clay loamy and sandy loam. The thickness of the soil varies from 0.5 to 1.5m. Generally, the soils are fertile with moderate to good Infiltration rates. There are two major cropping periods in the area viz., Kharif (Abi) from June to October i.e. during monsoon period and Rabi (Tabi) during Nov to March during non monsoon period.

Paddy and Groundnut are the two major crops grown in the study area. The area irrigated by ground water for Paddy is about 2500 ha, in Kharif season, for the year 1995-96. Other crops include, rain fed crops like pulses, Red gram and Green gram and Bajra, Jowar and Sunflower. The total crop area under these crops for 1995-96 was about 8000 ha. The state government has been encouraging farmers to go for horticulture by providing subsidies on drip irrigation installations and plants. Thus the study area is having citrus orchards viz., lemon, Guava, Pomegranate, Mosambi and Mango covering an area of about 450 ha.

2.9 SURFACE WATER IRRIGATION

The study area is mostly flat, with gentle slope and little undulations having a good network of Irrigation tanks connected by small streams. Since the only source of groundwater supplied is directly or indirectly from rainfall in the catchment, rainfall is the main controlling factor for water resource availability in the area. These tanks get filled during monsoon and are used for irrigation through tank sluices and field channels. The water is available for irrigation of paddy for atleast one crop during post monsoon period, under these tanks. The total registered irrigation potential (ayacut) in the area is 960 ha. However, in 1995-96, 1998-99 irrigated area was reduced to 146 ha and 77 ha respectively, due to aforesaid problems.

CHAPTER 3

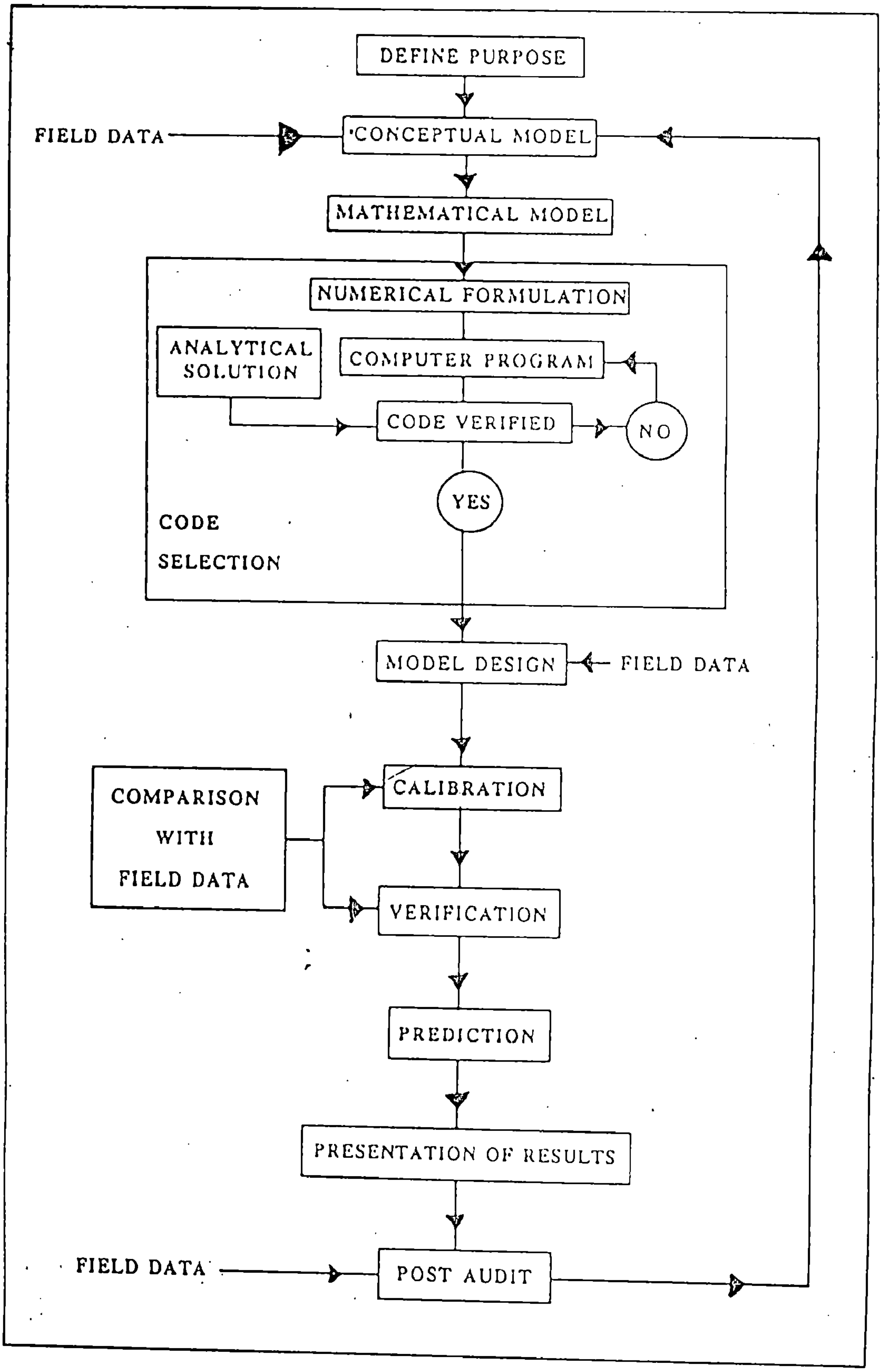
A CONCEPTUAL MODEL OF GROUNDWATER FLOW

3.1 INTRODUCTION

A model is a device that represents approximately the field conditions. A mathematical model simulates the groundwater flow indirectly by means of governing equations thought to represent the physical processes that occur in the system, together with equations that describe heads or flows along the boundary of the model (Anderson and Woessner, 1992). The mathematical model can be solved either analytically or numerically. A numerical model is useful in the case of nonhomogeneous terrain where the variation in the properties is to be included to approximate the field situations. The model allows more effective use of available data; more complexities can be accounted for; and the implications of the assumptions used in the analysis and the management decisions can be evaluated (Hamilton, 1982). The Regional Aquifer System Analysis (RASA) program of USGS (Sun, 1986; Weeks and Sun,1987) has established the importance of modeling to improve the understanding of the regional flow system.

Once the need for numerical modeling is established, the task of model design and its application begins. The steps involved in model development (flow chart) are schematically presented in Figure 3.1.

Nowadays, the computer model MODFLOW is being applied widely in hydrogeological practice for simulating groundwater flow. This is a Modular three dimensional finite difference groundwater flow model (McDonald and Harbaugh,1988) which simulates transient and steady state groundwater flow in a groundwater basin considering various natural hydrological processes and human activities. Strongly Implicit Procedure (SIP) has been used for solving the system of equations. The model is very versatile and user friendly.



(After Anderson and Woessner, 1992)

Fig. 3·1 Flow chart of Model Formulation.

The model has the following modules for specification input data

1) **Grid**:This module facilitates user to choose and edit number of rows and columns of the model grid, mesh size i.e., dimensions of the cell and Layer type to mention the type of the aquifer to be modelled such as unconfined, confined and semi-confined etc.
2) **Boundary Conditions** (IBOUND):It is common that a hydrogeologist encounters natural boundaries such as rivers, dykes and canals in a basin. These boundaries influence the groundwater flow in the basin. MODFLOW allows various types of boundaries to be specified by user, viz., i) Specified head boundary or Dirichlet boundary e.g. Canals, reservoirs and perennial rivers etc. ii) Neumann boundary or Specified flux boundary (GHB1) and iii) Time - variant - specified head boundary (CHD1), to specify stream gauging data.
3) **Initial Conditions:** For transient simulations, one needs data of initial piezometric heads or water table data at the beginning of the simulation which is provided by this module.
4) **Aquifer characteristics (Parameters):** This module is for specification of aquifer characteristics such as Transmissivity, Storage coefficient/Specific yield, horizontal hydraulic conductivity and vertical hydraulic conductivity etc.
5) **Recharge** (RCH1): This module is used to specify recharge to the groundwater basin due to precipitation or return flow from irrigation etc. The recharge can be provided either cell by cell or by zones.
6) **Groundwater Draft** (WEL1): This module is used for specifying abstraction or ground water draft in the basin.
7) **Processing simulation results** (RUN): The RUN module provides the post simulation results. The results include generated water table elevations or piezometric heads for each cell and volumetric water budget or water balance at the end of each stress period for

simulated time period, for the basin. The theory behind the flow equations, the program design and the modules used for the current study is given in Appendix.

3.2 SPATIAL DESCRETIZATION

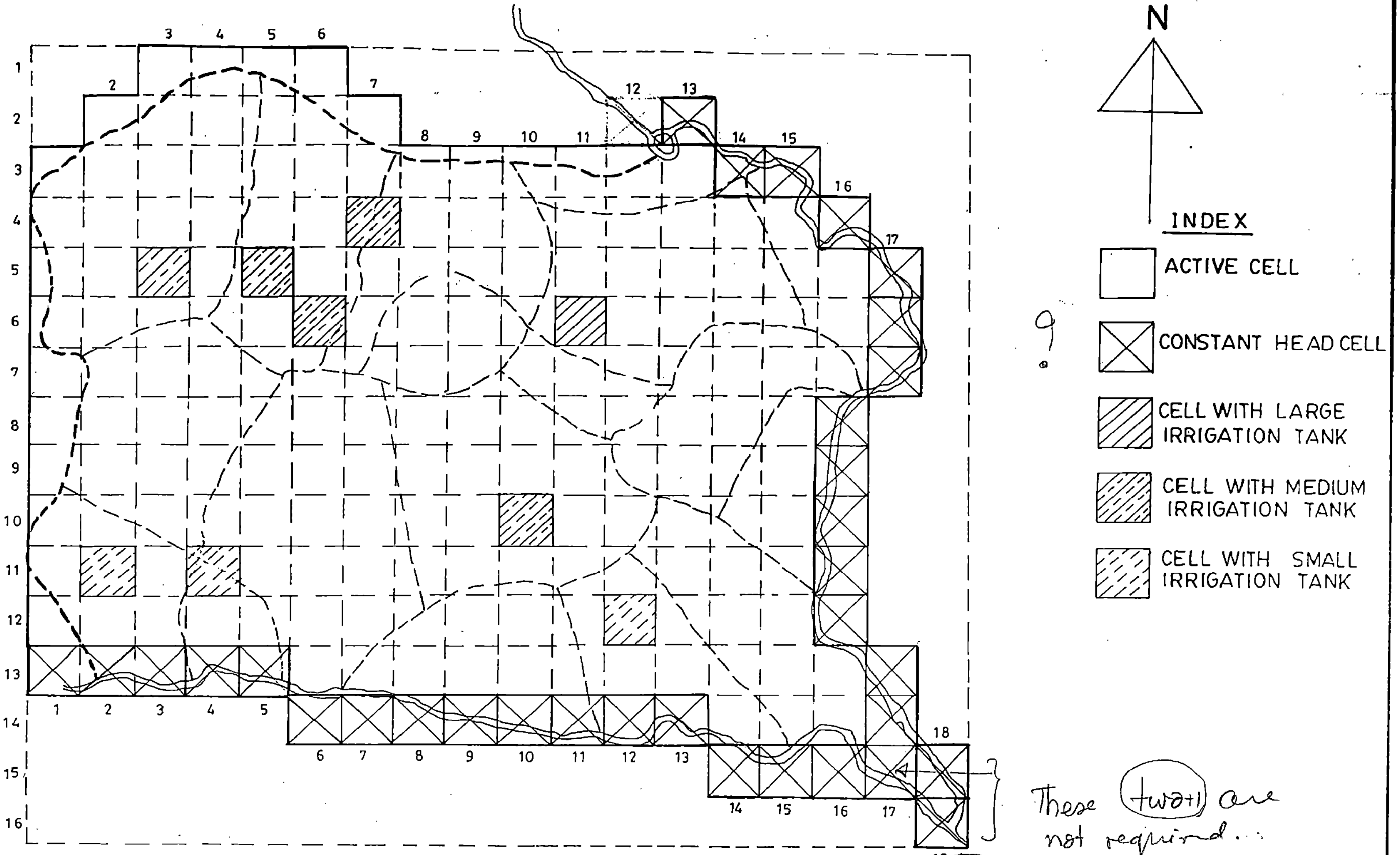
The study area is divided into 203 uniform finite difference grid blocks each having dimensions of 1 km x 1 km. A grid of 16*18 cells is designed for the study area as shown in Fig 3.2. The lithology of the area suggests that the aquifer is under unconfined conditions at a depth of about 20 m below the ground surface. Hence the basin is considered as an unconfined aquifer, underlain by impervious bedrock.

3.3 TEMPORAL DESCRETIZATION

During monsoon season (1st June to 31st October), the simulation period is divided into five stress periods of 30 days each, thus a month representing a stress period. Every stress period is further divided into time steps of one day each. The input of daily average areal recharge from the monthly rainfall for the year under consideration, is computed and assigned to all the time steps of each stress period. During nonmonsoon season (1st Nov to 31st May), the simulation period is divided into four stress periods (1st Nov - 30th Nov; 1st Dec to 28th Feb; 1st Mar to 31st Mar; 1st Apr to 31st May).

3.4 MODEL INPUTS

The model inputs include i) Hydrogeological parameters, ii) Areal recharge, iii) Abstraction iv) Initial conditions and v) Boundary conditions. Each of these hydrological phenomena is simulated in MODFLOW by a separate module.



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These (two+1) are not required . . .

FIG. 3·2 GRID MAP OF STUDY AREA

3.4.1 Hydrogeological parameters

Hydrogeological parameters are supplied to the model by PARAMETERS module. Since the study area is being modelled as an unconfined aquifer, the relevant hydrogeological parameters, hydraulic conductivity (K) and the specific yield (S_y) are to be provided. The hydraulic conductivity values are obtained from the pump tests conducted at Nutankal and Yerapad by Andhra Pradesh Ground Water Department and CGWB, respectively. The hydraulic conductivity, in the study area varies from 1 to 5 m/day. The recommended average value specific yield, for weathered granites is 0.03 as per GEC norms. A uniform initial value of specific yield 0.03, was assigned for all the cells in the study area.

3.4.2 Areal Recharge

The areal recharge is supplied to the MODFLOW through Recharge (RCH) module. The recharge is obtained, from the precipitation, using the relation, $R=\alpha * P$, where R is areal recharge, 'α' is the infiltration factor of recharge and P is precipitation. A value of 0.15 was assigned to 'α', following the GEC norms, for weathered granites.

The daily recharge is computed from available monthly rainfall data, at four raingauge stations, in the study area and applied to the corresponding grid cells. Theisson polygon method is used, to determine the finite difference blocks influenced by each raingauge station. Theisson polygon used for recharge computation is shown in Fig 3.3

3.4.3 Abstraction

The abstraction rates are supplied to MODFLOW through WEL1 module. Agriculture census and Minor Irrigation census data ~~is~~ are collected from Mandal Revenue Office, Nutankal, Nalgonda District. The village-wise data on groundwater irrigation and number of groundwater structures ~~is~~ are shown in Table 3.1.

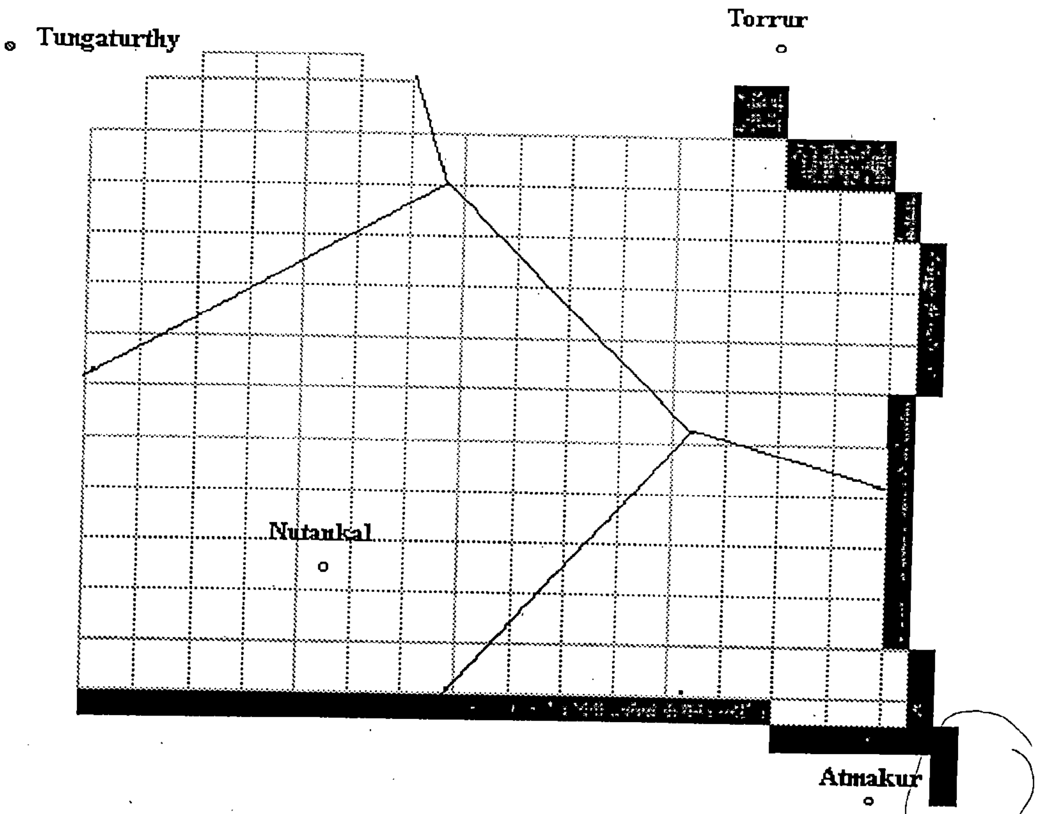


Fig 3.3 Theisson polygon of Rainguage stations for areal recharge

Table 3.1: Village wise data of wells, area irrigated and tank particulars of Nutankal of Paler sub-basin,Krishna basin, Nalgonda. for the year 1992-93

			Tanks			GROUNDWATER (GW) Details								Draft based on wells			Draft based on irrig._area		
Sl. No	VILLAGE	GEO.AREA ha	IP_crtd Registered	Wt_SpA	irrg. Karif	Paddy area irrigated by GW DW	DCB	BW	TOTA	GW structures (1992-93) DW	DCB	BW	TOTAL	Gross Draft	mon soon	nonmon soon	Gross draft	monsoon period	nonmonsoon period
			ha	ha		ha	ha	ha	6+7+8				10+11+12	MCM	m3/day	m3/day	MCM	m3/day	m3/day
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Gorantla	2122.8	117.6	58.8	nil	36.4	2.4	2.2	41	112	9	5	126	0.472	**66.7**	**155.5**	0.861	121.7	283.9
2	Polumalla	1276.0	129.6	64.8	nil	52.8	7.2	0	60	181	26	0	207	0.730	**171.7**	**400.5**	1.260	296.2	691.2
3	M.madva	481.6	4.8	2.4	nil	0.8	16.8	0	17.6	3	62	0	65	0.412	**256.8**	**599.3**	0.370	230.2	537.2
4	ChinaNemila	1452.4	100.8	50.4	nil	18	5.6	3.2	26.8	61	21	7	89	0.418	**86.3**	**201.5**	0.563	116.2	271.2
5	Chandupatla	865.6	101.6	50.8	nil	4.8	6.8	10.4	22	17	23	16	56	0.413	**143.3**	**334.3**	0.462	160.1	373.6
6	Yerapad	503.2	56	28	nil	8	2.4	2.4	12.8	30	10	8	48	0.264	**157.2**	**366.7**	0.269	160.3	373.9
7	Nutankal	1634.8	124	62	nil	0.62	69.64	0	70.26	3	119	0	122	0.783	**143.7**	**335.2**	1.475	270.8	631.8
8	Chilpakunta	1350.0	78.4	39.2	nil	0	25.16	0	25.16		100	0	100	0.650	**144.4**	**337.0**	0.528	117.4	274.0
9	Yadavally	671.6	50.4	25.2	nil	4.56	8.04	0	12.6	6	11	0	17	0.090	**40.2**	**93.9**	0.265	118.2	275.8
10	G.Singaram	229.6	8.8	4.4	nil	3.6	8.2	0	11.8	7	20	0	27	0.152	**198.2**	**462.5**	0.248	323.8	755.5
11	Miryal	1787.6	80	40	nil	4.6	5.24	1.8	11.64	12	43	2	57	0.343	**57.6**	**134.4**	0.244	41.0	95.7
12	Dirsanpally	324.0	20	10	nil	3.2	7.2	0	10.4	11	22	0	33	0.177	**164.0**	**382.6**	0.218	202.2	471.9
13	PedaNemila	633.2	60.8	30.4	nil	14.4	9.6	0	24	58	36	0	94	0.414	**196.1**	**457.5**	0.504	238.8	557.2
14	Bikumalla	470.8	37.6	18.8	nil	9.6	2.4	2.4	14.4	32	11	7	50	0.263	**167.7**	**391.2**	0.302	192.7	449.6
15	Machanpally	1044.4	23.2	11.6	nil	4.8	0.8	0	5.6	18	4	0	22	0.082	**23.5**	**54.8**	0.118	33.8	78.8
16	Lingampally	686.4	55.2	27.6	nil	0	19.4	0	19.4		23	0	23	0.150	**65.3**	**152.5**	0.407	178.1	415.5
	Totals	~~18032.5~~	~~1050~~	526	nil	166.2	196.9	22.4	385.5	551	540	45	1136	5.812	**96.7**	**225.6**	8.095	134.7	314.2

IP_crtd : Irrigation potential created

Wt_SpA : Water spread area

DW - Dugwell; DCB-Dug cum borewell
BW - Borewell

unit 9

NOTE:In the model Input, groundwater draft is computed from cropping data obtained from Revenue records.

The average daily draft in m^3/day for irrigation for different villages has been computed based on the crop area irrigated and net water requirement. The draft computation based on well census is not preferred, due to large variation between the actual number of wells ascertained from the field. Uniform pumping rate is assigned to the grid blocks, falling in the same village.

3.4.4 Boundary Conditions

The study area is bounded by a drainage divide, both on Northern side and Western side. Hence, a noflow boundary is assigned for these two boundaries. Towards Northeast and Eastern side, is the river Paler and on the Southern side is Tette vagu, a local stream. River Paler and Tette vagu are ephemeral in nature and dry up during nonmonsoon season. Two types of boundary conditions are assigned to these boundaries. In the first type these river boundaries are considered as Dirichlet boundaries and the heads at these boundaries are specified as water table obtained from the interpolation of available water table contours. In the second type, Tettevagu, Southern boundary is treated as a noflow boundary. The reason behind considering these two types of boundaries is, to analyse the influence of the river flow, when the river is contributing to the groundwater flow and the influence of drying up of the river on the groundwater flow in the basin during nonmonsoon.

3.4.5 Initial Conditions

For transient flow simulations the model needs water table elevations at the starting of the simulation for each of the cells in model grid, from the study area. Usually this information is obtained from the water table contours of the study area. From the contours water table elevation for each cell is obtained by interpolation. The water table contours are obtained from water table data of 12 observation wells for the year 1992, in the study area. SURFER package was used for interpolation and plotting contours.

CHAPTER 4

ANALYSIS AND INTERPRETATION

4.1 MODEL CALIBRATION

Prior to the application of any model for assessment and management of groundwater resources it is necessary to check that model prediction closely resembles the field observations for a given excitation. The model parameters are to be estimated in such a way that, the difference between the model simulated water table elevations and observed water table elevations is a minimum.

There are two methods of model calibration: trial-and-error adjustment of parameters and automated parameter optimization. In the present study calibration was carried out by trial-and-error procedure. For the purpose of calibration of numerical model, in the present study pre-monsoon (May'92) water table data for the year 1992 is used to predict the post-monsoon (Nov'92) water table elevations. The measured water table data of 12 observation wells in the study area is considered. In the first run, uniform values of aquifer parameters (K, S_y) are assigned to each cell for simulation. Areal recharge and abstraction details for monsoon and non monsoon periods for the year 1992 are given in Table 4.1 and 4.2.

The difference 'S', between model predicted and measured values of water table elevations is determined using the relation

$$S = \sqrt{\frac{\sum_{i=1}^{N}(S_{p,i} - S_{o,i})^2}{N-1}},$$

where, $S_{p,i}$ is the model simulated (predicted) water table elevation and $S_{o,i}$ is the field observed water table elevation at 'i' th observation well and N is the number of observation wells.

Table 4.1: Recharge due to Rainfall of four raingauge stations considered for the study area - 1992

Rainfall

Stress Period	year 1992	Tungaturthy		Nutankal		Atmakur		TORRUR	
		monthly rainfall(mm)	daily average recharge(m)	*monthly* rainfall(mm)	daily average recharge(m)	*monthly* rainfall(mm)	daily average recharge(m)	*monthly* rainfall(mm)	daily average recharge(m)
1	jun	52.4	**0.00026**	64.0	**0.00032**	114.8	**0.00057**	81.2	**0.00041**
2	jul	143.8	**0.00072**	142.7	**0.00071**	122.4	**0.00061**	178.8	**0.00089**
3	aug	219.0	**0.00110**	216.7	**0.00108**	212.1	**0.00106**	232.6	**0.00116**
4	sep	58.2	**0.00029**	101.6	**0.00051**	157.2	**0.00079**	50.4	**0.00025**
5	oct	42.7	**0.00021**	45.8	**0.00023**	20.4	**0.00010**	110.0	**0.00055**
6	nov	18.6	**0.00009**	9.8	**0.00005**	18.6	**0.00009**	0.0	

Table 4.2: Village wise abstaction rates for monsoon and nonmonsoon period, for the study area - 1992

(m3/day)

sl.no	VILLAGE	Monsoon	Nonmonsoon
1	Gorantla	122	284
2	Polumalla	296	691
3	M.madva	230	537
4	c.Nemila	116	271
5	C.Patla	160	374
6	Yerapad	160	374
7	Nutankal	271	632
8	C.kunta	117	274
9	Yadavally	118	276
10	G.Singaram	324	755
11	Miryal	41	96
12	Dirsanpally	202	472
13	P.Nemila	239	557
14	Bikmalla	193	450
15	Machanpally	34	79
16	Lingampally	178	415

The aquifer parameters are modified in the subsequent simulations such that 'S' gets reduced during each simulation. Figures 4.1 and 4.2 show the typical discretization for assigning the hydraulic conductivity (K) values in the study area for the trial 3 and trial 6. Higher 'K' values are assigned at places where high groundwater yields are observed. Table 4.3 shows the simulation details.

Table 4.3 - Aquifer parameters assigned for different trial runs of calibration.

Trial Number	**Hydraulic Conductivity (K) (m/day)**	**specific yield S_y**	**S (*rms*) (m)**
1	uniform value of 6	0.03	1.96
2	2,3 and 6	0.03	1.56
3	1,2,3,5 and 6	0.03	1.41
4	1, 3 and 5	0.03	1.15
5	0.5,2 and 3	0.025	1.21
6	1,3 and 5	0.025	1.02

9

It can be seen from the above table that the trial run 6 gives the minimum 'S' value (1.02) between model predicted and observed values of water table elevations. This is also evident from the figures 4.3 and 4.4 where contours of simulated water tables are plotted against the observed water table elevations for trial runs 3 and 6. The contours match closely for trial 6, in Fig 4.4 as compared to trial 3 in Fig 4.3. Hence the parameters corresponding to the Trial 6 are used for validation and sensitivity analysis. Fig 4.5 shows the well hydrographs (observed and predicted) at five observation wells for trial 6. It is clear from Fig 4.5, that there is a reasonably good match between the model prediction and observed water table elevations in most of the observation wells. Fig. 4.6 a) shows the scattered plot of observed and predicted water table elevations, Fig. 4.6 b) shows the plot of the observed and

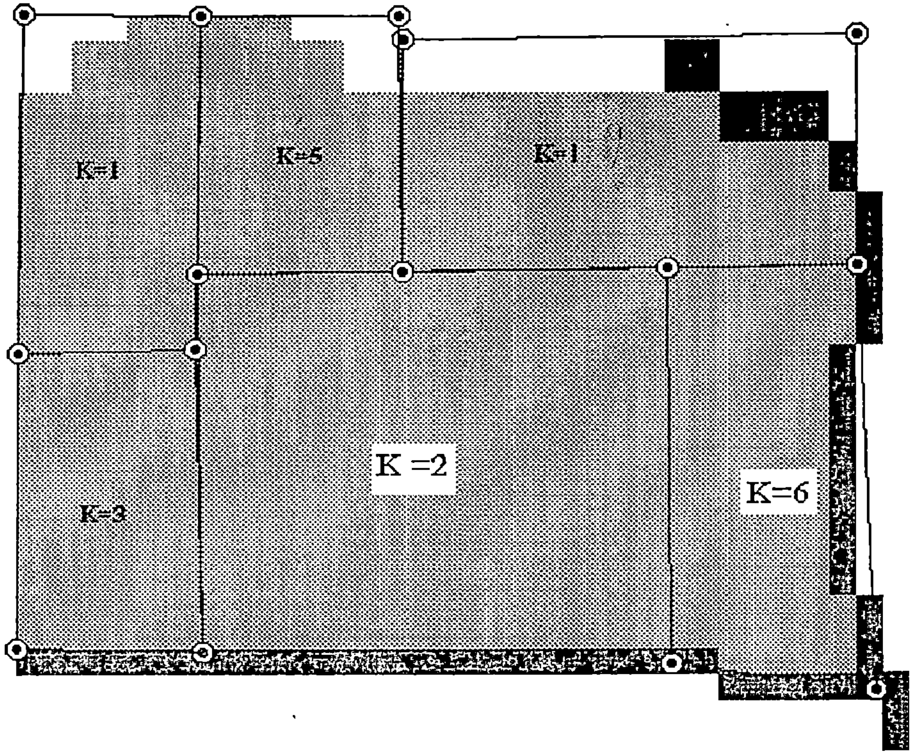


Fig. 4.1 Hydraulic conductivity(K) values assigned for Trail 3 (in m/day)

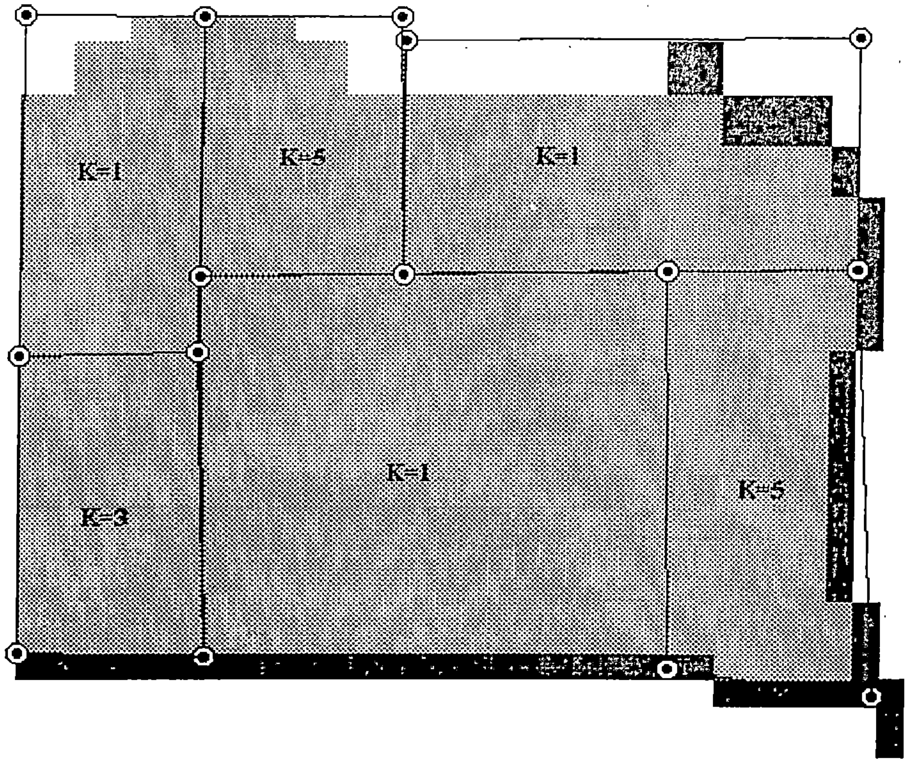


Fig. 4.2 **Hydraulic conductivity(K) values assigned for Trail 6** (in m/day)

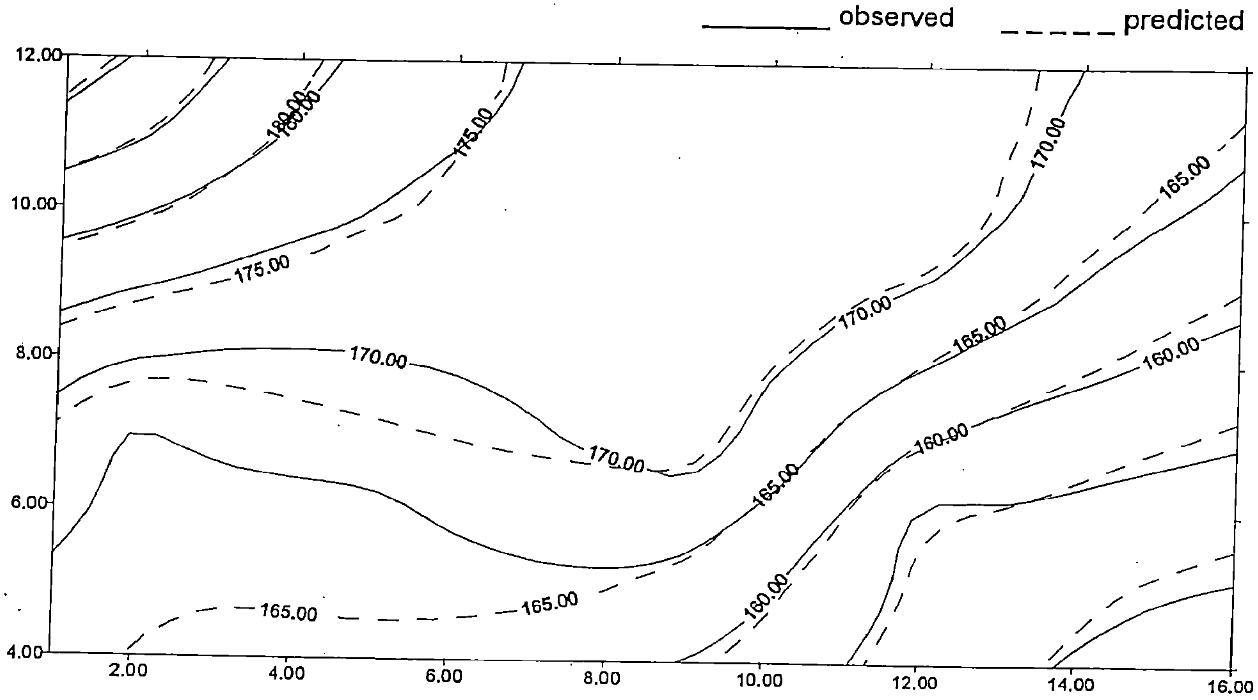


Fig 4.3 - Water table contours of observed and predicted data for K values 1,2,3,5and 6 for the study area (Trial 3)

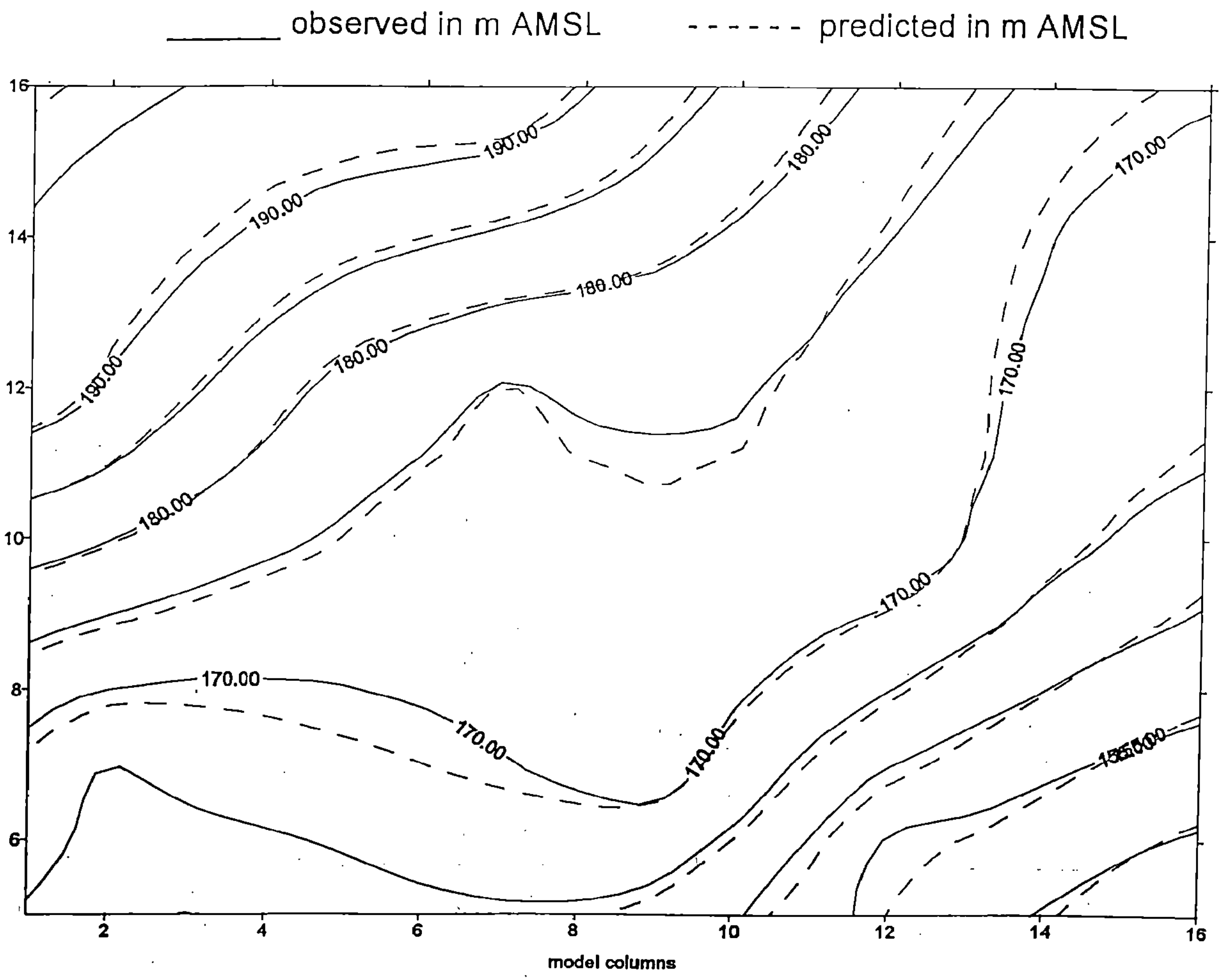


Fig 4.4: water table contours of observed and predicted for Nov'92 (Trial 6)

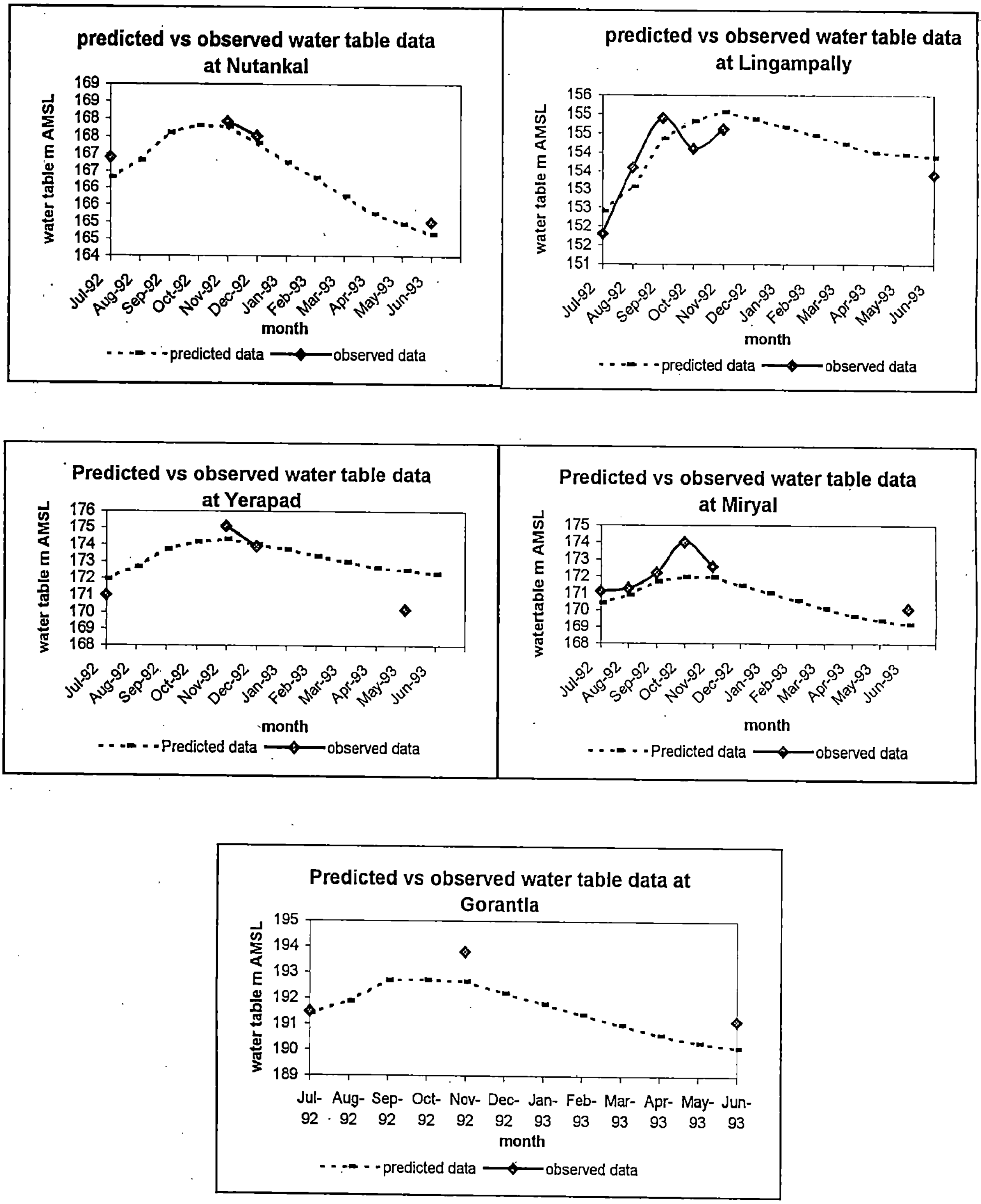


Fig. 4.5: Well hydrographs (observed and predicted) of selected observation wells after final calibration (Trial 6)

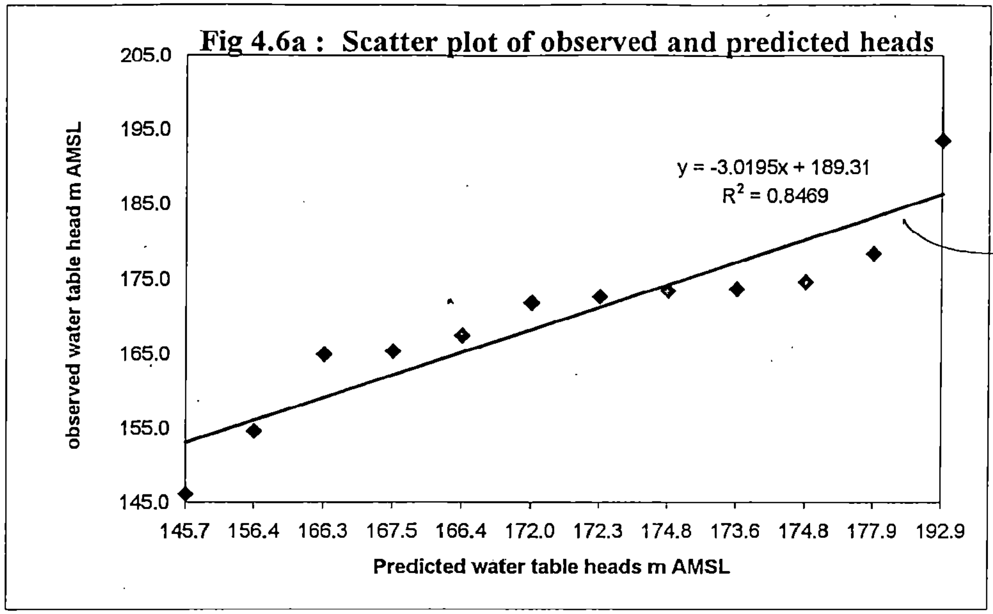


Fig 4.6a : Scatter plot of observed and predicted heads

9. Why you have shown this line ?

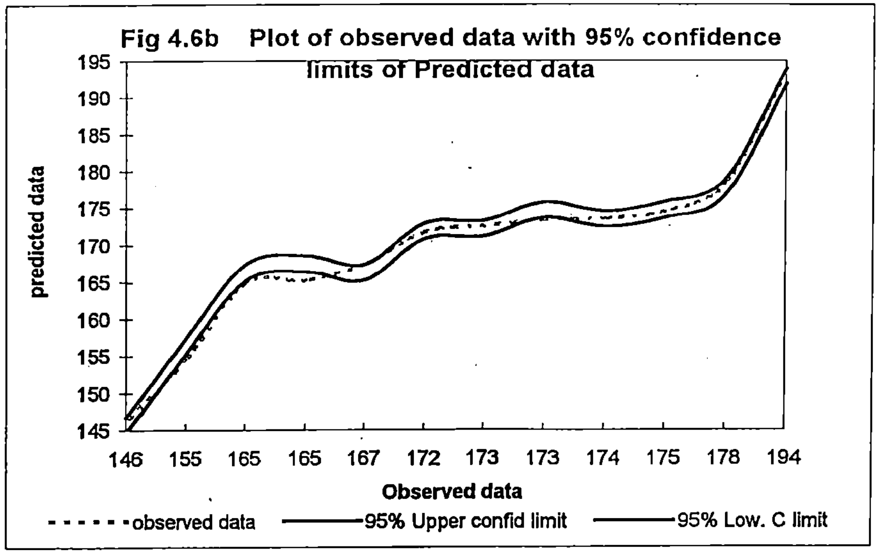


Fig 4.6b Plot of observed data with 95% confidence limits of Predicted data

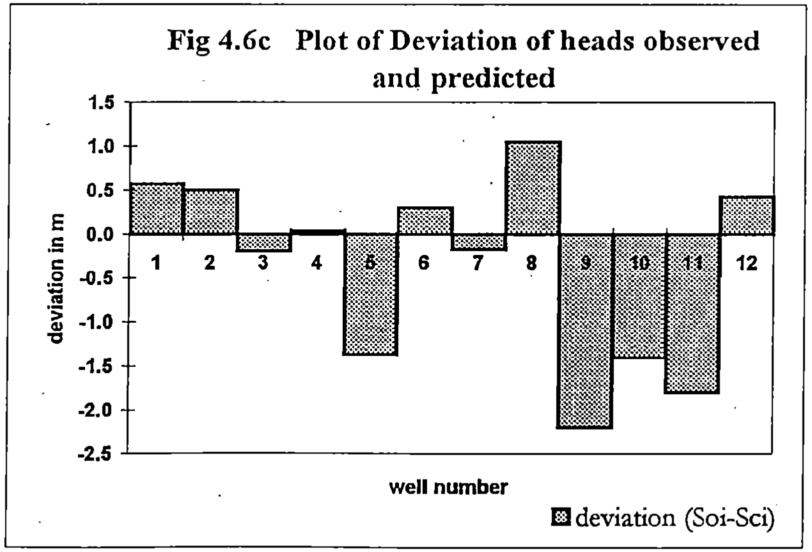


Fig 4.6c Plot of Deviation of heads observed and predicted

Fig 4.6 : Graphical representation of calibration results.

predicted water table elevations along with 95% confidence limits of predicted data. Fig. 4.6 c) show the plot of deviations between observed and predicted water table elevations data. The maximum deviation of 2.20 m is observed for observation well 9 at Nutankal. The field observation indicates that higher abstraction is taking place in this area resulting in deeper water tables.

4.1.1 Water budget components from simulation results

A summary of the comparison of water balance computed using both the lumped model and the distributed model (MODFLOW), for the year 1992-93 is given below (Table 4.4). Groundwater balance using lumped model (GEC 1997) for five years during 1988 to 1998 is shown in Table 4.5. A detailed computation for year 1992 is given in Appendix . A perusal of results of water budget components derived from the calibrated model for study area for the year 1992 are presented in Table 4.6. It can be seen from the table that discrepancy is negligible for most of the stress periods. This strengthens the validity of overall model (Anderson and Woessner, 1992).

Table 4.4: Summary of groundwater balance for 1992-93 using Lumped and distributed models

Sl.no	Particulars	Lumped model	Distributed model
1	Recharge	9.501	9.661
2	Draft from Wells	10.212	11.747
3	Change in storage by Nov’92	10.557	10.057
4	% utilization	107	122
5	stage of development	over exploited	over exploited

Table 4.5 Groundwater assessment using lumped model (GEC 1997) for the study area - during 1988 - 1998

GroundWater Monsoon Recharge (watertable flucuation)										*RIF method*		Paddy	*Return flow seepage from S/W Irrg.*					@1.4mm/d	Draft	A WTF	B RIF	(A-B)/B PD	Adopted	TOTAL
year	G.area	HILLY	Wat_S	Net_area	MAY	NOV	fluct.	Sy.	GS	IMD norm	RF.Infilt	karif /	paddy	RF (mm)	non	RetflowSeepSW		Tank	MONSOON	Norm.mon	method		RECH	RECH
	sqkm	sqkm	sqkm	sqkm	m	m	m		MCM	RF (mm)	factor	Rabi	WR (m)	monsoon	nonm	monsoo	nonmon	Seepage	DW(MCM)	-soon Rech	MCM		MCM	MCM
1988	180.32	1.9	5.024	173.4	8.65	4.21	4.44	0.03	23.1	662.3	12.699	50	1.25	1031	0	0.120		1.266	4.038	15.63	12.699	0.23	15.239	15.359
										Granites		100	1.25				0.00021							
1992	180.32	1.9	0	178.42	12.20	11.28	0.92	0.03	4.924	11	12.998	50	1.25	570	0	0.079		0.000	2.056	7.18	12.998	-0.45	10.478	10.557
										RGS														
1993	180.32	1.9	0	178.42	15.05	14.05	1.00	0.03	5.353	Suryapet	12.998	100	1.25	576	0	0.158		0.000	4.246	9.15	12.998	-0.30	10.557	10.714
												200	1.25				0.00041							
1995	180.32	1.9	5.249	173.17	13.20	9.61	3.59	0.03	18.65		12.686	361	1.25	747	0	0.519		1.323	6.379	18.58	12.686	0.46	15.742	16.261
												50	1.25				0.00010							
1998	180.32	1.9	5.468	172.95	9.17	1.92	5.36	0.03	27.81		12.673	185	1.25	977	0	0.231		1.378	10.616	22.44	12.673	0.77	15.438	15.669
					11.70	8.23	3.47					250	1.25				0.00051							

Groundwater DRAFT

					Area irrigated by GW					Draft based on		Draft for				NET	1997 Revised norms				
year	DW	DCB	BW	TOTAL	kharif	Rabi	total	horti	G_Nut	wells	irrig_area	mon	RF mm	Gro draft	RECH	Annual	DEV	population	@60 Lt	util_Rch	stage of
u_drf>	0.0065	0.0091	0.013	wells	80%	20%	draft	ac	ac	MCM	MCM	soon	monso	MCM	MCM	GW avail	%	@2%	MCM	MCM	devp.
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*40%*(12)*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*
1988	653	113	32	798	1650	416	2066	482	1102	*5.6888*	10.096	4.038	1031	***10.096***	**15.359**	*14.591*	*69*				
1992	610	605	57	1272	771	192	963	502	100	*10.212*	5.140	2.056	570	***5.140***	**10.557**	*9.501*	*107*	83000	**1.818**	8.739	*117*
1993	808	1152	257	2217	1203	247	1450	1200	1175	*19.076*	10.614	4.246	576	***10.614***	**10.714**	*9.643*	*110*				
1995	1600	569	300	2469	2600	976	3576	917	59	*19.478*	15.948	6.379	747	***15.948***	**16.261**	*14.634*	*109*				
1998	1800	2200	400	4400	2940	2654	5594	957	1200	*36.92*	26.539	10.616	977	***26.539***	**15.669**	*14.102*	*188*	96280	**2.109**	13.561	*196*
2001																		99600	**2.181**		
											average			***13.667***	***13.539***	***11.509***	***119***				

Table 4.6 :

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD
------------------------------------------------------------------------------
   CUMULATIVE VOLUMES       L**3               RATES FOR THIS TIME STEP      L**3/T
   ------------------                                     ------------------------

At the end of monsoon (Nov'92)

                IN:                                               IN:
                ---                                               ---
          STORAGE =       0.24523E+06                        STORAGE =     3661.8
    CONSTANT HEAD = 16501.                             CONSTANT HEAD =       45.683
            WELLS =       0.00000                              WELLS =        0.000
         RECHARGE =       0.15369E+08                       RECHARGE =     50913.
         TOTAL IN =       0.15631E+08                       TOTAL IN =     54620.

       OUT:                                                    OUT:
       ----                                                    ----
        STORAGE =    0.10297E+08                             STORAGE =    18371.
  CONSTANT HEAD =    0.43955E+06                       CONSTANT HEAD =     3618.9
          WELLS =    0.48946E+07                               WELLS =    32631.
       RECHARGE =    0.00000                                RECHARGE =         0.00000
      TOTAL OUT =    0.15631E+08                           TOTAL OUT =    54621.
       IN - OUT =   -73.000                                 IN - OUT =        -0.59766
PERCENT DISCREPANCY = 0.00                       PERCENT DISCREPANCY =     0.00
```

```
 VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  4 IN STRESS PERIOD  9
 ------------------------------------------------------------------------------
      CUMULATIVE VOLUMES       L**3           RATES FOR THIS TIME STEP      L**3/T
      ------------------                      ------------------------

      At the end of the year( May'93)

                IN:                                                IN:
                ---                                                ---
          STORAGE =  0.12996E+08                              STORAGE =    35852.
    CONSTANT HEAD =  0.11011E+06                        CONSTANT HEAD =    920.76
            WELLS =  0.00000                                    WELLS =   0.00000
         RECHARGE =  0.15369E+08                             RECHARGE =   0.00000
         TOTAL IN =  0.28475E+08                             TOTAL IN =    36772.

               OUT:                                               OUT:
               ----                                               ----

          STORAGE =  0.10297E+08                              STORAGE =   0.00000
    CONSTANT HEAD =  0.72396E+06                        CONSTANT HEAD =    481.89
            WELLS =  0.11747E+08                                WELLS =    32631.
         RECHARGE =  0.57078E+07                             RECHARGE =    3658.9
        TOTAL OUT =  0.28475E+08                            TOTAL OUT =    36772.
         IN - OUT = -110.00                                  IN - OUT =   0.83984
 PERCENT DISCREPANCY =        00                 PERCENT DISCREPANCY =                    0.00
```

It is clear from Table 4.6 that, over exploitation is evident, since total ground water recharge is consumed by well extraction. This alarming figure emphasizes the need for a sound groundwater management policy.

4.2 MODEL VALIDATION

The calibrated model is verified with the recent historical data of monsoon season of 1998. Table 4.7 shows the rainfall and abstraction data for the year 1998. The aquifer parameters obtained from the calibration are used for validation. As explained in the preceding sections, observed water table elevation, at all the cells is obtained by interpolation. Figure 4.7 shows the simulated and observed water table contours for November 1998. It is clear from the figure 4.7 that the simulated water table contours closely match with that of observed data. The average root mean square error (S) between the simulated and observed water table elevation data is about 1.16 m. The results of validation corroborate the parameters estimated from the calibration.

4.3 SENSITIVITY ANALYSIS

The parameters obtained from calibration procedure will have uncertainty associated with them during estimation procedures. This is particularly so, when many of the parameters are to be optimized by calibration. Sensitivity analysis helps a hydrogeologist to understand the influence of various aquifer parameters on the difference between the model predicted and observed water table elevations. Thus the sensitivity analysis gives an idea of which parameters have to be estimated accurately, in order to minimize the deviations. The parameters considered for sensitivity analysis in the study are hydraulic conductivity (K), specific yield (S_y).

Table 4.7: Daily average recharge from rainfall and abstraction rates for monsoon and non monsoon period for the study area - 1998

Recharge data for 1998

Stress	NUTANKAL		daily average
Period	**1998**	*monthly(mm*	***recharge(m)***
1	jun	97.8	**0.00049**
2	jul	259.4	**0.00130**
3	aug	223	**0.00112**
4	sep	269	**0.00135**
5	oct	223	**0.00112**
6	nov	2	**0.00001**
7	dec	0	**0.00000**

Abstraction rates in cum/day for the year 1998

sl.no	VILLAGE	Monsoon	nonmonsoon
1	Gorantla	122	284
2	Polumalla	296	691
3	M.madva	230	537
4	c.Nemila	116	271
5	C.Patla	160	374
6	Yerapad	160	374
7	Nutankal	271	632
8	C.kunta	117	274
9	Yadavally	118	276
10	G.Singaram	324	755
11	Miryal	41	96
12	Dirsanpally	202	472
13	P.Nemila	239	557
14	Bikmalla	193	450
15	Machanpall	34	79
16	Lingampally	178	415

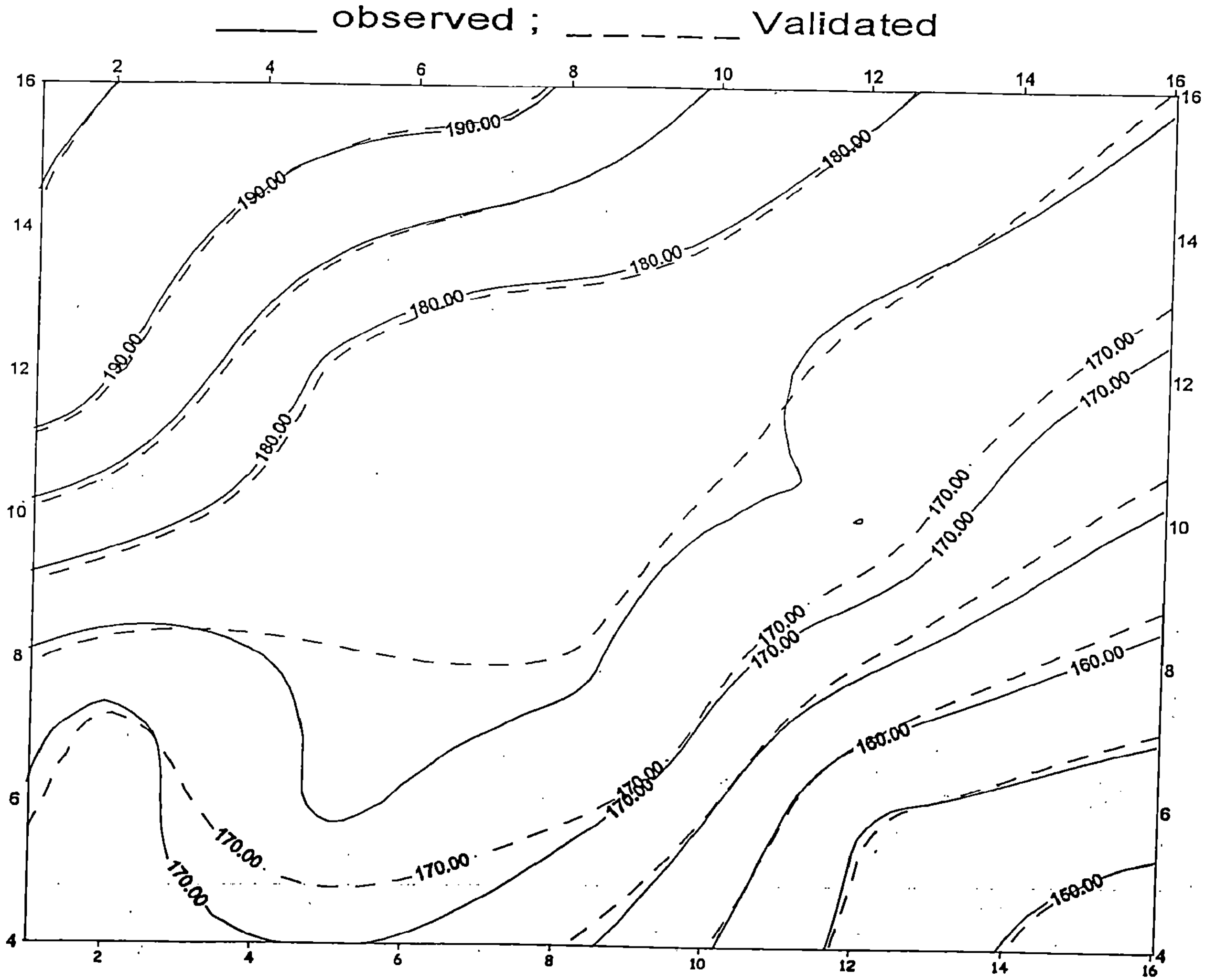


Fig. 4.7: Water table contours of observed and validated data for Nov'98 of the study area

4.3.1 Sensitivity to Hydraulic Conductivity

In the analysis, the calibrated hydraulic conductivity (K) values are reduced by 50% and are used in the simulation. Figure 4.8 shows the contours of observed and predicted water table elevations, for November 1992. Comparison of Figures 4.4 and 4.8 show that the change in hydraulic conductivity (K) causes minor change in predicted water table elevations and are given in Table 4.8.

4.3.2 Sensitivity to Specific Yield

The specific yield is changed from its calibrated value of 0.025 to 0.03. Figure 4.9 shows the water table contours for November 1992 with specific yield equal to 0.03. Comparison of figure 4.4 and 4.9 indicates that the influence of specific yield is prominent. So, the specific yield is found to be more sensitive than hydraulic conductivity parameter, as corroborated from Table 4.8.

Table 4.8: Sensitivity of parameters Hydraulic Conductivity(K) and Specific yield (S_y)

Sensitivity to Hydraulic conductivity (K)			
Sl. No.	Value of Hydraulic conductivity (K)	Value of Specific yield (S_y)	Root Mean Square Error (RMSE)
1	1,3 and 5	0.025	1.02
2	0.5, 2 and 4	0.025	1.21
Sensitivity to Specific yield (S_y)			
Sl. No.	Value of Specific yield (S_y)	Value of Hydraulic conductivity (K)	Root Mean Square Error (RMSE)
1	0.02	1,3 and 5	1.68
2	0.025	1,3 and 5	1.02
3	0.03	1,3 and 5	1.16

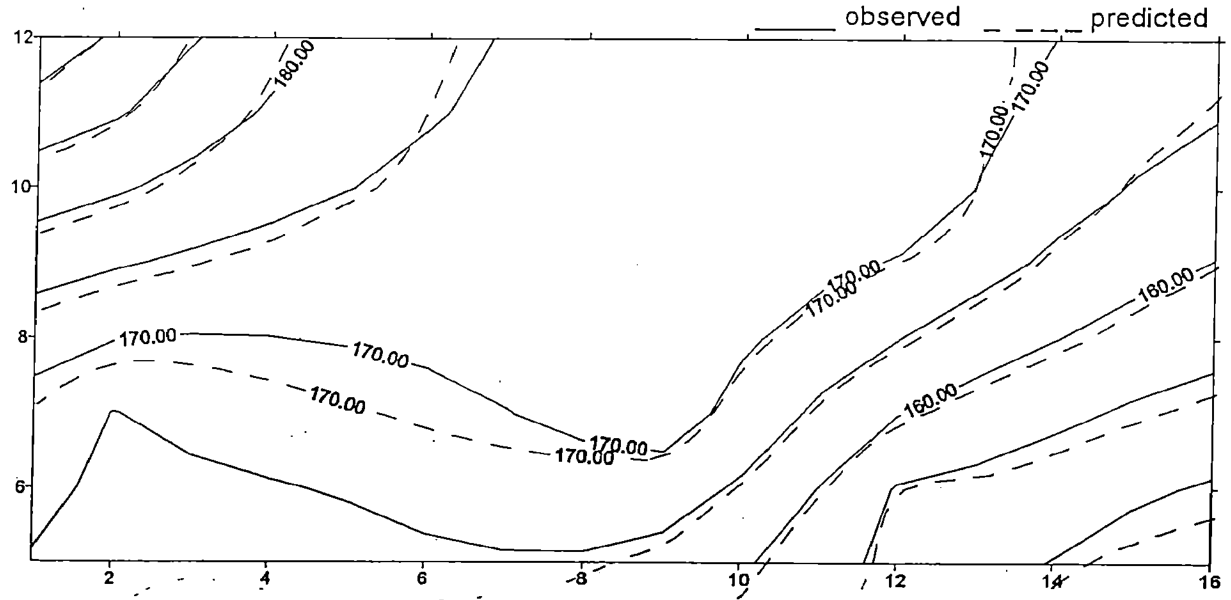


Fig 4.8 Contours of observed and predicted water table (m) AMSL for reduced K values for Sensitivity Analysis.

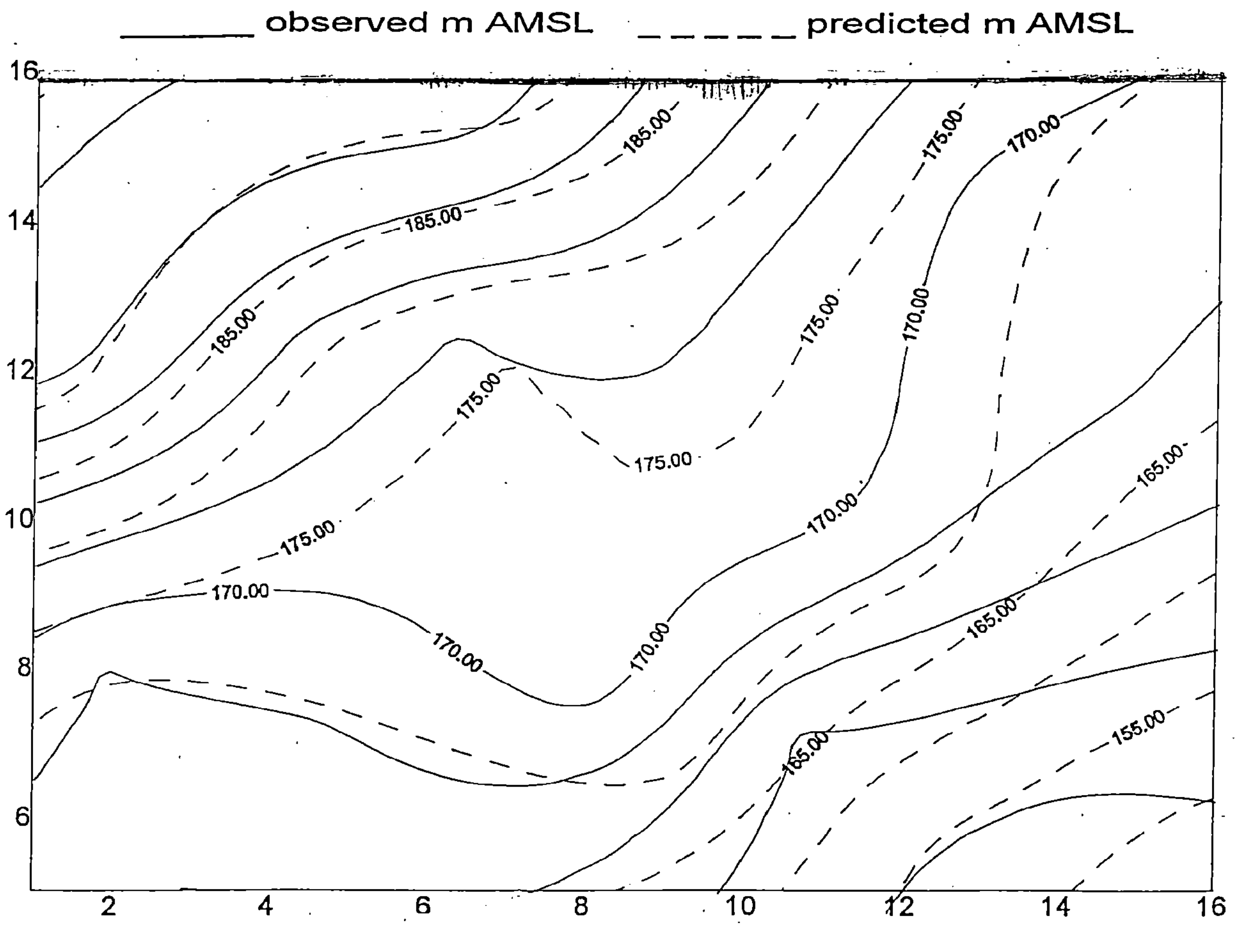


Fig 4.9 : Water table contours observed and predicted data, Nov'92 for K = 1,3 and 5 ; Sy =0.03 (trial 5)

4.4 Projection and Results

4.4.1 Projections

The validated model is used to arrive at steady state water table elevations distribution, corresponding to the four different strategies by projecting the simulation for period of three years.

Strategy 1

The existing aerial recharge and abstraction rates for the year 1998 (Table 4.7) are considered for projection in the strategy.

Strategy 2

Inducing artificial recharge through nine existing irrigation tanks in the study area (Fig. 3.2), after monsoon period, during the months November to February, by allowing marginal recharge of 0.001 m/day for large tank at China nemila, 0.00075 m/day for medium tanks and 0.0005 m/day through small tanks (Reddy and Gurnadha Rao, 1991).

Strategy 3

The projections are made for three years by inducing the artificial recharge twice the quantity adopted in strategy 2 during the same period.

Strategy 4

Increasing the pumping rate by 10% for areas where the present ground water abstraction rates are low and reducing the pumping rate by 10% where the present abstraction rates are high. The aquifer parameters are identical to those obtained from calibration.

4.4.2 Results

The pre and post monsoon water levels for different strategies at four observation wells in the study area for three years (1998 to 2001) is shown in Table 4.9. Figure 4.10 gives well hydrographs of these wells located at Yerapad, Maddiral, Nutankal and Lingampally.

Strategy 1

With the existing pumping rates and aerial recharge there is no much difference in pre and post monsoon water tables of successive years at all the observation wells. A rise in water table elevation is observed may be due to good rainfall recharge, for the year 1998 considered for projection.

Strategy 2

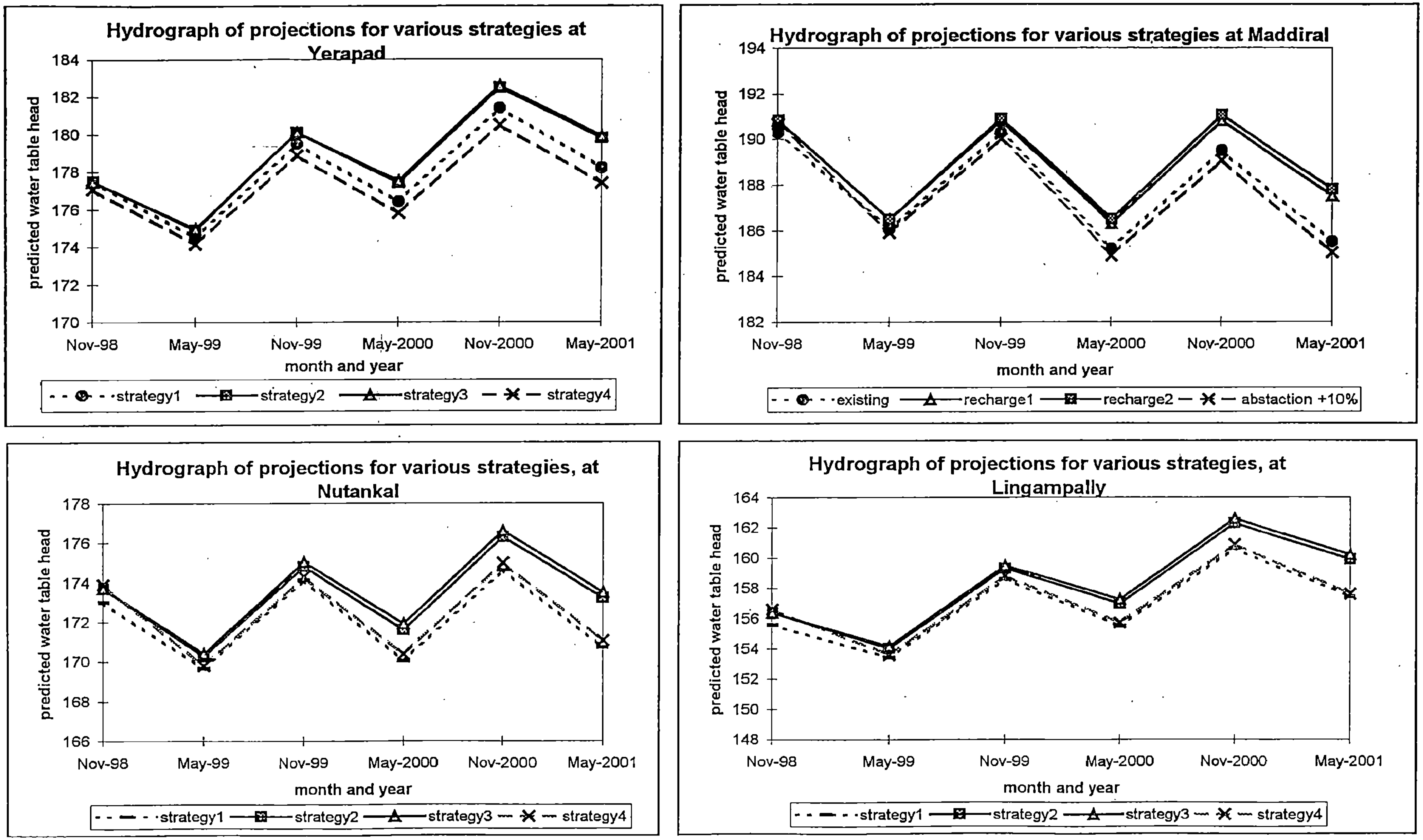
In this strategy, there is a rise of water table by 2.5 and 5 m for pre and post monsoon periods, for observation well at Yerapad and Lingampally which are closer to the irrigation tanks, inducing recharge at the end of year 2 and 3 respectively. However, for the observation well at Nutankal, the rise in water table is 1.3 and 2.9 m only, at the end of year 2 and 3 respectively. The marginal rise of 1 m at Maddiral observation well at the end of year 3, is observed due to non-proximity to the irrigation tanks inducing recharge.

Strategy 3

In this strategy, the recharge from the tanks is doubled the recharge rate of strategy 2. However, the average rise in water table elevation at an observation well due to the increased recharge rate in marginal (0.10 to 0.30 m) in comparison to strategy 2 at the end of year 3 which is evident from well hydrographs, at all the observation wells.

Table 4.9 : Projections of predicted water table at four observation wells for various strategies for three years.

Sl.No.	Well Location	COLUMN	ROW	Predicted water table elevation im m AMSL for pre and post monsoon for three years						
				Strategies	Nov-98	May-99	Nov-99	May-2000	Nov-2000	May-2001
1	YERAPAD	8	7	strategy1	177.50	174.50	179.50	176.40	181.40	178.20
				strategy2	177.50	174.90	180.10	177.40	182.50	179.80
				strategy3	177.49	174.95	180.10	177.50	182.60	179.90
				strategy4	177.07	174.15	178.90	175.80	180.50	177.40
2	MADDIRAL	6	1	strategy1	190.30	186.05	190.30	185.20	189.50	185.50
				strategy2	190.83	186.50	190.80	186.30	190.80	187.50
				strategy3	190.83	186.50	190.90	186.50	191.04	187.80
				strategy4	190.70	185.90	190.00	184.90	189.05	185.02
3	NUTANKAL	5	11	strategy1	172.99	169.66	174.10	170.04	174.60	170.70
				strategy2	173.70	170.26	174.80	171.60	176.30	173.20
				strategy3	173.70	170.40	175.03	171.90	176.60	173.50
				strategy4	173.90	169.80	174.30	170.36	175.00	171.05
4	LINGAMPALLY	12	11	strategy1	155.57	153.40	158.60	155.50	160.60	157.40
				strategy2	156.40	154.03	159.30	156.97	162.30	159.90
				strategy3	156.40	154.14	159.50	157.25	162.60	160.20
				strategy4	156.60	153.60	158.80	155.70	160.90	157.60



Hydrograph of projections for various strategies at Yerapad

Hydrograph of projections for various strategies at Maddiral

Hydrograph of projections for various strategies, at Nutankal

Hydrograph of projections for various strategies, at Lingampally

Fig 4.10: Projected well hydrographs at four observation wells (Predicted water table) for various strategies, for three years.

Strategy 4

With strategy 4 the water table elevations have declined in observation wells located at Yerrapad and Maddiral ranging from 0.20 to 0.60 m. However, a rise in water table elevation of range 0.20 to 0.40 m, in observation wells at Nutankal and Lingampally, where the abstraction rates were reduced by 10 %.

In the light of the above discussions, it is amply clear that, strategy 2 involving induced recharge through the existing tanks to the extent of 0.001 m/day for large tank at China nemila, 0.00075 m/day for medium tanks and 0.0005 m/day through small tanks is a viable alternative for improving the existing ground water situations in the area.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Nutankal mandal of Nalgonda district in Andhra Pradesh has been studied in the present dissertation for analysing ground water flow in view of the existing over exploitation. The main aim of the study is to assess the impact of groundwater recharge from existing nine irrigation tanks of different sizes. Hydrogeology of the area is characterised by granitic terrain with weathered and fractured granites occurring as the main unconfined aquifers. Over the recent 5-6 years a persistent decline of 4-5 m in water levels has been observed in the area and many of the dug wells have gone dry. The study led to the following conclusions.

1. Initially the water balance for the study area has been carried out, as a lumped model for the year 1992-93. It has been found that there is an annual recharge of 9.501 MCM the annual draft of 10.406 MCM with change in storage at the end of monsoon period 1992 is 10.557. This indicates that the groundwater in the study area is being overexploited.

2. A distributed modeling for the study area is carried out. A grid of 16*18 cells is designed for the study and a finite difference groundwater flow model, MODFLOW is used for the simulation studies. The study area is treated as an unconfined aquifer in the simulation. The results of the distributed model show that there is an annual recharge of 9.661 MCM while the annual draft is 11.747 MCM with a change in storage at the end of monsoon period 1992 is 10.057 MCM. The model has been calibrated for the year 1992-93 and validated using water table contour map and water table hydrographs for the year 1998 at some selected observation wells.

3. A predictive simulation period of three years is considered and various scenarios of inducing artificial recharge plans through the nine existing irrigation tanks in the study area is carried out. The strategy2 where the recharge induced is less than the half of possible recharge from the surface water bodies is found to be most suitable. Strategy2 is practical in the field, because the closure of the tank sluices for a limited period of one to two months, will induce the artificial recharge. About 1 to 5 m rise of water table elevation at the end of the three years is observed as a result of this strategy, which seems to be satisfactory.

4. As an alternative, a 10% decrease in pumpage in places where high abstraction is observed, is also considered. A marginal increase in the water table elevation is observed. However this alternative is rather difficult to implement in the field.

5.2 RECOMMENDATIONS AND SCOPE FOR FURTHER STUDY

The above analysis shows that there is an urgent need for rehabilitation of groundwater table in the area since the groundwater is overexploited. A possible solution appears to be augmentation of surface water sources by the construction of additional artificial recharge structures. However, the construction of these structures may take considerable time. An alternative is to convert the existing or breached tanks into storage ponds which minimise the costs. Since the network of tanks is intact and the irrigation department has the authority to convert the tanks into storage ponds, this strategy can be implemented expeditiously. The water users associations in the state are actively participating and themselves approaching the government and concerned departments, to take up these measures as they are yielding appreciable results at many places.

The model can be refined provided the data of stream gauging and piezometric heads data and aquifer parameters for deep aquifer is made available. The automated method of parameter estimation can also be tried for better approximation of the aquifer parameters.

The GIS techniques for cross checking actual cropped area under different crops in the study area, availability of storage in tanks etc., can be verified if the satellite imageries, for the study area are available. This would authenticate the proposal on more sound footing. The network of observation wells in the study area, has to be increased to improve the understanding of the behaviour of the aquifer. Similarly better controls for adopting the values of aquifer parameters (Transmissivity, Specific yield) are also required.

An economic analysis of different artificial recharge strategies may bring out an optimum recharge plan. A similar technique can be used to arrive at suitable crops to be grown in the area, based on availability of groundwater, in terms of net returns and nutrition values. Thus suitable cash crops which require lesser water may be suggested for the study area, replacing Paddy.

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APPENDIX-I

The three - dimensional movement of groundwater of constant density through porous earth material may be expressed by a partial difference equation.

$$\frac{\partial}{\partial X}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = S_s * \Delta h/\Delta t \qquad (1)$$

Where

X, Y & Z - principal permeability directions

h potentiometric head (L^{-1})

W - volumetric flux per unit volume and represents source / sink (t^{-1})

S_s - specific storage of porous material (L^{-1})

Δt - time step

The permeability and specific storage are function of space, while volumetric flux and head are functions of space and time. Hence, the above equation represents the ground water flow under non-equilibrium condition in a heterogeneous and anisotropic medium. The above equation with a specification of flow/or head condition at the boundary of an aquifer system and specification of initial head condition constitutes a mathematical model of the groundwater flow.

The development of groundwater flow equation in finite difference form is carried out by applying the continuity equation. The sum of inflow and outflow must be equal to the change in storage within the cell.

$$\mathbf{Q_i = S_i * (\Delta h/\Delta t) * V} \qquad (2)$$

Where

Q_i = flow rate in to the cell($L^3 T^{-1}$)

S_i = Specific storage as volume of water taken in or released by the unit Volume of the aquifer material per unit change in head (L^{-1}).

V = Volume of the cell (L^3)

Δh= change in head over a time interval of length t (L).

The equation (2) is stated in terms of inflow and storage gain. The outflow and losses can be represented as negative inflow and gain.

PROGRAM DESIGN

The MODFLOW contains a main program and a large number of highly independent subroutines called modules. A overall program structure of MODFLOW is given Figure 3. The Main is an organized collection of FORTRAN CALL STATEMENTS, which invoked modules to read data, perform calculations and print results. The modules called directly by Main are termed as Primary Modules and modules called by Primary Modules are called Secondary Modules.

The Modules can be grouped by Packages. Each Package consists of all Modules associated with a particular hydrologic feature, a solution method or the overall control of the simulation.

The packages are completely independent of each other and they can be added or removed without affecting the other packages. However, there are three packages, viz., Basic package, Block Centred Flow package and a solver package, which are mandatory for the simulation studies. The list of packages with their brief description is given Table 1.

In the present study, the following packages have been used for the groundwater flow modeling.

1. Basic package
2. Block Centred Flow
3. Well
4. Recharge
5. Constant Head Boundary
6. Strongly Implicit Procedure

1. **Basic Package**: The package deals with the administrative tasks of the model. The user specifies the discretization of space and time into cells and time steps respectively, initial and

boundary conditions, initial heads, volumetric budget, control of output results and specification of program option to be used.

2. **Block Centred Flow Package (BCF):** The BCF package computes conductance components of finite difference equation, which determines the flow between the adjacent cells. It also computes the terms that represent the rate of movement of water from and to the storage. In the calculations, it is assumed that a node is located at the centre of each cell and thus the name BCF is given to the package. The BCF package incorporates this into RHS of the finite difference equation during the calculations.

3. **Well Package:** A recharging well can be viewed as a source of water which is not affected by the head in the aquifer, a discharging well is a recharging well with a negative recharge rate. It is assumed that a well is situated in a single cell only. Thus for each call containing a well, a recharge rate must be added for each iteration to the RHS of the finite difference equation.

4. **Recharge Package**: Infiltration from precipitation generally occurs evenly over large area. Hence, it is called areally distributed recharge. In the formulation phase of each iteration, the recharge rate is added to the accumulator in which RHS is formulated for the appropriate cell at each nodal location. In case of multi layer model, the recharge to the particular layer can also be specified and accordingly, RHS is modified during the computation for each layer.

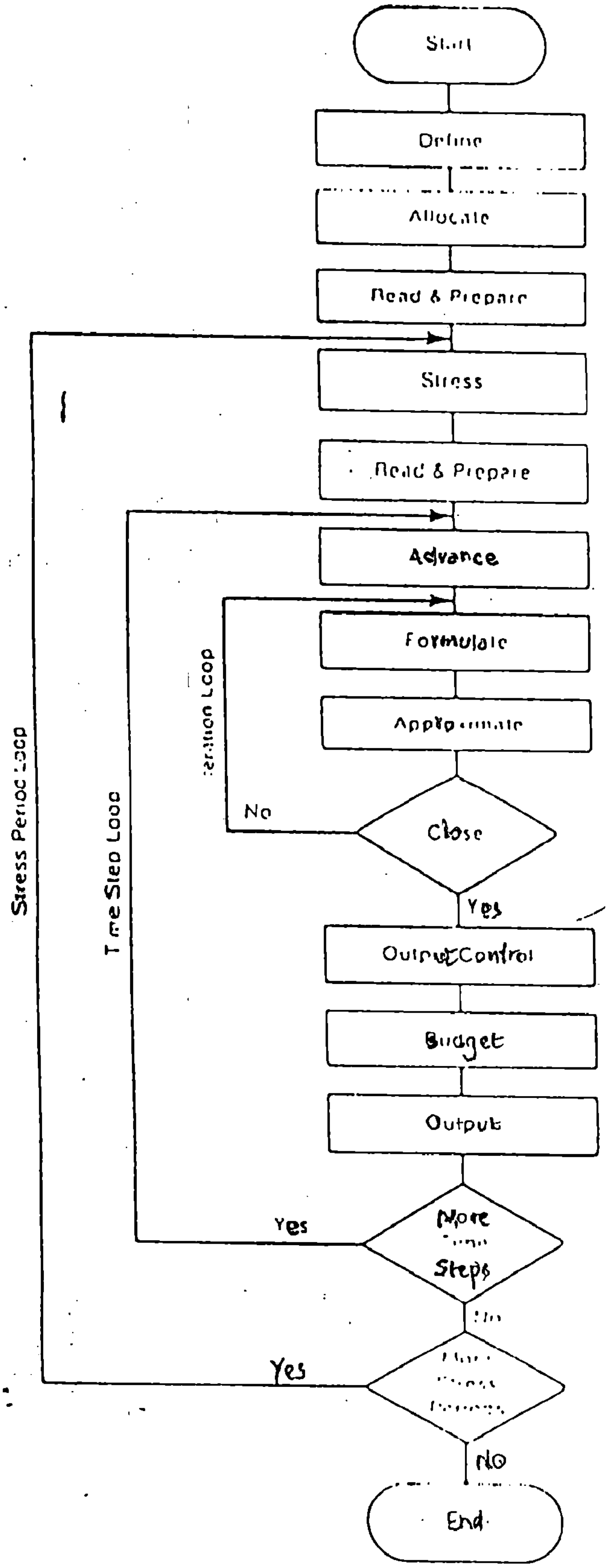
Table 1 List of packages in MODFLOW program

Package Name	Abbreviation	Package Description
Basic	BAS	Handles those tasks that are part of the model as a whole. Among those tasks are: specification of boundaries, determination of time step length, establishment of initial conditions, and printing of results.
Block-Centered Flow	BCF	Calculates terms of finite-difference equations which represent flow within the porous medium; specifically, flow from cell to cell and flow into storage.
Well	WEL	Adds terms representing flow to wells to the finite-difference equations.
Recharge	RCH	Adds terms representing areally distributed recharge to the finite-difference equations.
River	RIV	Adds terms representing flow to or from rivers to the finite-difference equations.
Drain	DRN	Adds terms representing flow to drains to the finite-difference equations.
Evapotranspiration	EVT	Adds terms representing ET to the finite-difference equations.
General-Head Boundaries	GHB	Adds terms representing general-head boundaries to the finite-difference equations.
Strongly Implicit Procedure	SIP	Iteratively solves the system of finite-difference equations using the Strongly Implicit Procedure.
Slice-Successive Overrelaxation	SOR	Iteratively solves the system of finite-difference equations using slice-successive overrelaxation.

Appedix-II

Table - 2: Monthly rainfall of four rainguage stations in the study area from 1989-1998

cod	Location	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	annual
	1989													
114	Tungaturthy			29.5		10.5	100.3	424.8	166.1	162.7	13.4			**907.3**
116	Nutankal			28		24.2	112.2	386.2	211.7	321.7	18			**1102**
120	Atmakur			45			103.8	452	226.8	275.8	14.4			**1117.8**
141	TORRUR						136	649.4	156.8	320.8	7.2			**1270.2**
	1990													
114	Tungaturthy	3			22	229.8	159	142.8	144.7	203	285.6	36		**1225.9**
116	Nutankal	6.6		39	44.8	198.4	82.2	103.6	172.6	181.8	311	40		**1180**
120	Atmakur		15			162.6	57.3	81	160	151.8	225.4	7		**860.1**
141	TORRUR		27	20.8		222.4	108.6	42.4	178.8	146.6	270.6	10.8		**1028**
	1991													
114	Tungaturthy	27.0				100.6	192.0	157.4	159.2	165.9	44.0	41.0	0.0	**887.1**
116	Nutankal	17.6				165.6	163.4	106.8	163.2	192.0	57.0	60.6		**926.2**
120	Atmakur	10.0				51.8	140.1	94.2	196.1	181.2	15.0	43.2		**731.6**
141	TORRUR	8.8				94.8	210.0	119.4	145.8	90.4	12.0	70.2		**751.4**
	1992													
114	Tungaturthy	5.6					42.4	143.8	219.0	58.2	42.7	18.6		**530.3**
116	Nutankal					5.0	64.0	142.7	216.7	101.6	45.8	9.8		**585.6**
120	Atmakur						38.4	122.4	258.0	92.4	54.2	6.0		**571.4**
141	TORRUR	8.8				25.2	81.2	178.8	232.6	50.4	110.0			**687.0**
	1993													
114	Tungaturthy			14.0	24.2	83.2	113.6	314.0	96.0	140.0	87.2		7.8	**880.0**
116	Nutankal			47.0	8.0	47.6	56.4	194.0	42.2	100.6	173.6		7.2	**676.6**
120	Atmakur				6.0	89.6	71.0	134.5	56.0	107.3	77.0			**541.4**
141	TORRUR			11	3.2	108.4	52.6	232.4	75.5	99.5	66.1		4	**652.7**
	1994													
114	Tungaturthy						84.9	163.4	215.0	64.0	228.8	51.4		**807.5**
116	Nutankal		2.0				29.0	200.0	200.2	10.4	273.4	64.8		**779.8**
120	Atmakur													**0.0**
141	TORRUR		13.0		18.0	47.6	42.4	152.6	336.0	54.0	119.0	17.0		**799.6**
	1995													
114	Tungaturthy	32.0				46.6	44.2	204.0	159.2	47.8	330.9			**864.7**
116	Nutankal	20.2				62.2	16.2	152.4	127.6	142.0	326.8			**847.4**
120	Atmakur									115.0	282.0			**397.0**
141	TORRUR				31.6	28.0	87.0	166.1	103.8	124.6	338.0			**879.1**
	1996													
114	Tungaturthy						158.8	339.1	278.2	133.1	101.2	31.0		**1041.4**
116	Nutankal						123.6	152.2	313.0	128.0	89.4	18.0		**824.2**
120	Atmakur				24.0		81.0	171.6	161.3	91.2	72.9	20.0		**622.0**
141	TORRUR				38.6	43.0	163.9	356.8	368.4	96.4	73.4	33.0		**1173.5**
	1997													
114	Tungaturthy				63.4		34.6	169.4	119.0	160.6	38.8	97.0	48.0	**730.8**
116	Nutankal				82.8		94.6	186.4	133.6	196.0	25.8	6.2	19.4	**744.8**
120	Atmakur				50.0		95.0	246.3	91.5	86.6	17.5	34.0	17.0	**637.9**
141	TORRUR						27.8	133.8	78.4	NR	NR	NR	NR	**240.0**
	1998													
116	Nutankal	0	0	0	0	0	259.4	0	221	266.4	231	2	0	**979.8**



DEFINE — Read data specifying number of rows, columns, layers, stress periods, and major program options

ALLOCATE -- Allocate space in the computer to store data

READ AND PREPARE -- Read data which is constant throughout the simulation. Prepare the data by performing whatever calculations can be made at this stage

STRESS – Determine the length of a stress period and calculate terms to divide stress periods into time steps

READ AND PREPARE -- Read data which changes from one stress period to the next. Prepare the data by performing whatever calculations can be made at this stage

ADVANCE – Calculate length of time step and set heads at beginning of a new time step equal to heads calculated for the end of the previous time step

FORMULATE – Calculate the coefficients of the finite difference equations for each cell

APROXIMATE – Make one cut at approximating a solution to the system of finite difference equations

OUTPUT CONTROL — Determine whether results should be written or saved on disk for this time step. Send signals to the BUDGET and OUTPUT procedures to indicate exactly what information should be put out

BUDGET – Calculate terms for the overall volumetric budget and calculate and save cell-by-cell flow terms for each component of flow

OUTPUT - Print and save heads, drawdown and overall volumetric budgets in accordance with signals from OUTPUT CONTROL procedure

Fig. A-1 Over all program structure

GROUNDWATER ASSESSMENT BASED ON NORMS RECOMMENDED BY GROUNDWATER ESTIMATION COMMITTEE (GEC)'97

State	: Andhra Pradesh	Basin :	Nutankal
District	: Nalgonda	sub basin:	Paler

A. Estimation of Annual Utilizable Groundwater Resources for Irrigation

I. Monsoon Recharge

(a)	(i) Total Geographical Area (sq.km.)	180.32
	(ii) Total hilly Area (sq.km.)	1.90
(b)	Area not suitable for Groundwater recharge, viz. high hilly regions, etc. (sq. km.)	1.90.
(c)	Net area suitable for Groundwater recharge (a(i)-(b))(sq.km)	178.42
(d)	Year of observation.	1992
(e)	Average depth to water table (April/May) (m)	12.20
(f)	Average depth to water table (November)(m)	11.28
(g)	Water table Fluctuation (Rise) (m)	0.920
(h)	IMD Normal yearly rainfall (mm)	792.3
(i)	IMD Normal monsoon rainfall (mm)	662.30
(j)	IMD Normal non-monsoon rainfall (mm)	130.0
(k)	Monsoon raifall of the year under consideration (mm)	570.0
(l)	Non-Monsoon rainfall of the year under consideration (mm)	15.6
(m)	Specific yield in the zone of water table fluctuation.	0.03

(n) Monsoon Recharge (MCM) (GS) = Area (c) * Water Level fluctuation (g) * Sp.yield (m)

= 178.42 * 0.92 * 0.03

GS = 4.924 (MCM)

II (a). Return seepage from Surface Water Irrigation : (R_{is})

S. No.	Crop type	Area Irrigated (ha)	Average depth (m)	Average depth of water applied (ha.m)	Seepage factor (%)	Seepage (MCM)
A.	**Monsson**					
1	Paddy	20.	(1.25-0.285)	0.965	0.4	0.0772
2	Sugar Cane	-	-	-	-	-
3	I.D.	-	-	-	-	-
						0.0772
B.	**Non-Monsoon**					
1	Paddy	0.00	1.25	1.2	0.4	
2	Sugar Cane	-	-	-	-	
3	I.D.	-	-	-	-	

II (b) Return Seepage from Groundwater Irrigation (R_{gw})

S. No.	Crop type	Area Irrigated (ha)	Average depth (m)	Average depth of water applied (ha.m)	Seepage factor (%)	Seepage (MCM)
A.	**Monsoon**					
1	Paddy	308.4	(1.25-.285)	0.965	0.35	1.0416
2	Sugar Cane		-	-	-	-
3	I.D.	-	-	-	-	-
						1.0416
B.	**Non-Monsoon**					
1	Paddy	76.80	1.25	1.25	0.15	0.144
2	Sugar Cane	-	-	-	-	-
3	I.D.	240.8	0.500	0.500	0.15	0.1806
						0.3246

III. Normalization of Monsoon Rainfall Recharge

All figures in (MCM)

Change in GW	Gross GW draft during monsoon (DW)	Recharge from canal seepage monsoon during (RS)	Return flow surface water monsoon (Ris)	Return flow from Gr. Irrigation (Rigw)	Normalization NF:Normal Monsoon RF of the year
4.924	4.1624	Nil	0.0772	1.0416	NF= 662.3/570= 1.162

Recharge during MONSOON by Water Table Fluctuation **(A)**:

= (GS+DW-Rs-Ris-Rigw) NF+Rs+Ris

=[4.924 + 4.1624 –Nil - 0.0772 - 1.0416] * 1.162 + Nil + 0.0772 = **7.182** (MCM) ....(A)

IV (a). Recharge from Tanks and Ponds

Recharge = 0.00144 * Average water spread area * No. of days water available * 0.01

= NIL (MCM)

IV (b). Recharge from Artificial Recharge Structures

Recharge = 0.5 * Storage capacity * Number of fillings = - NIL -

CHECK: *by Rainfall Infiltration Method* **(B)**

Recharge = Net area suitable for recharge * IMD normal monsoon Rainfall * RF Infil.Factor

= 178.42 * 0.6623 * 0.11 = 12.998 **.......(B)**

As difference %difference = (A-B)/B*100 = (7.182-12.998) / 12.998 * 100 = -45 % > 20%

Hence Recharge by RIF method is adopted & Monsoon Rech = 1.2 * RIF Recharge =0.8 * 12.998 =**10.478** **..............................BASED ON......GEC 1997**

V. TOTAL GROUND WATER RESOURCES

Recharge during monsoon	10.478
Nonmonsoon rainfall recharge	Nil
Seepage from canals during nonmonsoon period	Nil
Return flow from irrigation during non monsoon period	0.000 (SW)
	0.325 (GW)
Inflow from influent rivers	Nil
Recharge from Tanks /Lakes/Ponds	NIL
Recharge from Artificial Recharge structures	NIL
	10.557 (MCM)

VI. Allocation of Groundwater for Domestic and Industrial Use :

As per 1991 census Population in Study area = 39,350

Percentage growth per year = 2.5

Population projected for 2025 $= 39350\,(1+2.5/100)^{34}$

$= 83000 \times 60 \times 365 \times 10^{-3} \times 10^{-6} = 1.8276$ MCM

Which is equal to 8.7% of total Groundwater resources.

VII. Gross Annual Groundwater Draft :

S. No	Groundwater Structure	Nof of Groundwater Structures	UNIT			
		No.s	DRAFT (MCM)	Monsoon 40% (DW)	Non Monsoon (60%	Annual
1	Dug wells with P.S	610	0.0031	1.5624	2.3436	3.906
2	Dug cum borewells with P-S	605	0.0095	2.299	3.449	5.748
3	Shallow tube wells	57	0.0132	0.3008	0.4512	0.752
4	Deep tube wells	-	-	-	-	-
	TOTAL			4.1624	6.2436	10.406

IX. Net Groundwater Availability :

Net Groundwater availability

= [Total Annual Gw resources]-[10% of total annual rech. for unaccounted losses,RIF]

= 10.557 – 1.056

= 9.501 (MCM)

X. Stage of Groundwater Development

Stage of Ground water development = C/Bx100

Where C = Current annual gross Groundwater draft = 10.406

B = Net annual groundwater availability = 9.501

Stage of Groundwater development of study area (As on 1998) = 10.406 / 9.501 * 100 = 107 %

XI. Categorization of Study area based on GEC'97 Norms :

Since stage of development of Groundwater utilization was more than 100% (i e.,107%) and the water table during Pre & post monsoon intervals were showing in a falling trend (as per Hydrographs) the study area still be categorized as OVER EXPLOITED and as per GEC'97 methodology, and it was recommended to adopt the following measures in the basin area, if it falls under OVER EXPLOITED category.

1) Increase of observation well density.
2) Implementation of artificial recharge structures.
3) Micro level study.
4) No further ground water development in the area.

APPENDIX-IV

STATEMENT SHOWING THE GROSS WATER REQUIREMENT EFFECTIVE RAINFALL AND NET WATER REQUIREMENT OF MAJOR CROPS IN ANDHRA PRADESH STATE, IN NALGONDA DISTRICT (SOUTHERN TELENGANA)2

Sl No.	Crop	Season	Duration in Days	Water requirement in mm	Rainfall contribution in mm		Net water requirement in mm (5-7)	IRRIGATION SCHEDULING		
					TOTAL	Effective		Number	Interval (Days)	Quantity in mm
1	2	3	4	5	6	7	8	9	10	11
1.	Paddy	Abi/Sarva/Vanakaru	120-150	1250	824	540	750	Maintain 2.5 to 5 cms waterlevel by frequent irrigation according to stage of crop, which will be escaped when heavy rains are received.		
	-do-	Tabi/Dalva/Endakaru	120-135	1220	60	40	1180			
		Summer	110-120	1270	355	220	1050			
2.	Jowar (Seed Production)	Rabi (Summer)	110	400	44	25	375	6-8	15-20	60-70
3.	Ragi	Rabi	80-90	300	88	50	250	3-5	10-15	60-70
4.	Wheat	Rabi	100-110	375	88	50	325	5-7	10-15	60-70
5.	Maize	Rabi	100-120	400	153	90	310	5-7	10-15	60-70
		Summer	100-120	450	44	25	425	8-10	8-12	60-70
B. PULSES										
1.	Green/black gram	Rabi	80-90	250	88	50	200	3-4	10-15	60-70
		Summer	80-90	300	44	25	275	5-6	10-12	60-70
2.	Bengalgram	Rabi	90-100	300	153	90	210	3-4	10-15	60-70
								(Irrigate when moisture stress is noticed)		
C. OIL SEEDS										
1.	Groundnut	Kharif	105-120	500	765	500	-	-	-	-
		Rabi	105-120	550	88	50	500	6-8	10-15	60-70
		Summer	105-120	600	44	25	575	8-10	10-12	60-70
2.	Sunflower	Kharif	80-100	350	564	350	-	-	-	-
		Rabi	80-100	350	88	50	300	5-6	10-15	60-70
		Summer	80-100	400	44	25	375	6-7	10-12	60-70
3.	Sesamum	Rabi	80-90	300	88	50	250	3-4	10-15	60-70
D. COMMERCIAL CROPS										
1.	Cotton	Kharif to Rabi	140-180	750	824	550	200	3-4	10-15	60-70
								(For long duration varities)		
2.	Tobbaco	-do	120	400	378	225	175	2-3	10-15	60-70
3.	Chillies	Kharif to Rabi	120-150	600	732	450	150	2-3	10-15	60-70
		Rabi to Summer	150	650	113	75	575	8-10	8-12	60-70
4.	Turmeric	Kharif to Rabi	250	1400	853	550	850	15-20	8-10	60-70
5.	Sugarcane	Annual	365	2000	925	700	1300	25-30	8-15	60-70
6.	Mulbery	Annual	365	1200	925	550	650	12-15	12-15	60-70
F. VEGETABLES										
		Kharif	90-120	500	765	500	-	-	-	-
		Rabi	90-120	550	219	150	400	6-8	10-12	60-70
		Summer	90-120	600	85	50	550	8-10	8-10	60-70

(1) CRITICAL STAGES OF CROP GROWTH FOR WATER REQUIREMENT OF IMPORTANT CROPS.

(2) THE CRITICAL SOWING PERIODS (Months) OF MAJOR CROPS IN ANDHRA PRADESH (Region wise)

P.T.O.

RITICAL STAGES OF CROP FOR WATER REQUIREMENT OF [illegible]

1. Paddy : Primordial development, heading and flowering.
2. Jowar : Booting, Blooming and milky stages.
3. Ragi : Primordial initiation and flowering
4. Wheat : Grown root initiation shooting and carning
5. Maize : Taseeling Silking stages until early grain formation.
6. Green/Black gram : Blooming to seed formation.
7. Bengalgram : Blooming to seed formation.
8. Groundnut : Flowering, Peg penetration and seed development.
9. Sunflower : Two weeks before flowering to two weeks after flowering.
10. Sesamum(gingally) :Blooming stage to maturity.
11. Cotton : Flowering to boll development.
12. Tobacco : Immediately after transplanting and when it is 18" high upto full blook or topping stage.
13. Chillies :Flowering
14. Turmeric : Rhizome development stage.
15. Sugarcane : Formative phase.
16. Mulbery : After pruning
17. Vegetables : Flowering and fruit set or bulb formation.

THE CRITICAL SOWING PERIODS (Months) OF MAJOR CROPS IN ANDHRA PRADESH (Region wise).

Sl. No.	Crop	Telangana region	Rayalaseema region	Coastal Andhra region
		KHARIF		
1.	Jowar	June, July	June, July, September	July, September
2.	Paddy	June, July, August	July, August	June, July, August.
3.	Bajra	May, June	June, July	July, August
4.	Maize	May, June, July	May	July, September
5.	Minor millets	July	July	August, September
6.	Rainfed paddy	May, June, July	-	May, June
7.	Redgrams	June, July	June, July, August	July, August
8.	Greengram	June	August	May, June
9.	Black gram	June, July	June, August	May, June
10.	Groundnut	June, July	June, July, August	May, June
11.	Horsegram	September	September	--
12.	Sesamum	June, July	--	May, August
13.	Castor	July	June, July, August	July
14.	Cotton	June	July	July
15.	Mesta	--	--	May, June
16.	Chillies	August	September	May, June.
17.	Tobacco	--	August	August
		R A B I		
1.	Jowar	September/October January (Summer)	January (Summer)	--
2.	Paddy	November-January April/May (Summer)	November/December/ January	November/December
3.	Maize	October/January	--	-
4.	Wheat	November/December	November/December	--
5.	Green/Blackgram	February/March	January	December/January
6.	Bengal gram	October/November	November	--
7.	Groundnut	October to January	October, January, April	January
8.	Chillies	January/February	January	January
		ANNUAL CROP		
1.	Sugarcane	June/December/	June/December	June/December/January