STUDY OF GROUNDWATER SYSTEM IN THE MYMENSINGH-TANGAIL AREA USING NUMERICAL MODELS

Submitted by

SHABBIR AHMED

In partial fulfilment of the requirements
for the Degree of Master of Science
in Engineering (Water Resources)

Department of Water Resources Engineering
Bangladesh University of Engineering and Technology
Dhaka

February, 1986.

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF WATER RESOURCES ENGINEERING

February 26,1986

WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY MR. SHABBIR AHMED ENTITLED STUDY OF GROUNDWATER SYSTEM IN THE MYMENSINGH-TANGAIL AREA USING NUMERICAL MODELS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES).

Chairman of the Committee	(Dr. J. U. Chowdhury)
Member	(Dr. A. Hannan)
Member	(Dr. M. K. Alam)
Member	(Mr. M.A. Karim)
Head of the Department	(Dr. A. Hannan)

ABSTRACT

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF WATER RESOURCES ENGINEERING

February 26,1986

WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY MR. SHABBIR AHMED ENTITLED STUDY OF GROUNDWATER SYSTEM IN THE MYMENSINGH-TANGAIL AREA USING NUMERICAL MODELS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES).

Chairman of the Committee (Dr. J. U. Chowdhury)

Member (Dr. A. Hannan)

Member (Dr. M. K. Alam)

Member (Mr. M.A. Karim)

Head of the Department (Dr. A. Hannan)

schematic representation of the study area. They are, a network of regular polygons and a network of regular rectangles. The schematization involves 63 internal nodes and 26 external nodes. Accuracy of Gauss-Jordan elimination method has been found greater. However, Gauss-Seidel iteration method with one iteration requires smaller computer time. Results obtained from rectangular grid and polygonal grid schematizations are almost identical.

The numerical model generates time history of water level at the centroid of every polygon. The model has been calibrated by several trial computer runs with changed parameters. The calibration is complete when computed water level variation agrees acceptably with observed water level variation in 54 observation wells in the year 1979-'80. It has been found that the recharge parameter dominates the calibration process. Maximum deviation of computed water level has been found to occur during irrigation season. Higher computed water level suggestes an underestimation of withdrawal volume than the actual volume and this is due to the lack of sufficient field data. Finally, groundwater recharge in the year 1982-'83 has been determined by applying the model. Then the monthly recharge values in every upazilla in the study area has been computed. Total recharge values of 21.146 cm and 18.147 cm in the period

1979-'80 and 1982-'83 respectively have been found. Investigation of monthly recharge values shows that the highest recharges equal to 7.355 cm and 9.487 cm occur in July and June during 1979-'80 and 1982-'83 respectively in the model area.

ACKNOWLEDGEMENT

The author gratefully acknowledges his profound gratitude and indebtedness to his supervisor Dr. Jahir Uddin Chowdhury, Associate Professor and Director, Institute of Flood Control and Drainage Research, for his guidance, assistance and encouragement throughout the course of this study.

Grateful acknowledgements are due to Dr. A. Hannan, Professor and Head, Dept. of Water Resources Engineering, for his help and encouragement at all stages of the study. Sincere gratitude is also expressed to Dr. M.K. Alam, Associate Professor, Dept. of Water Resources Engineering, for his valuable suggestions, comments and guidance. Sincere thanks are expressed to Mr. M.A. Karim, Director, Ground Water Investigation Circle, Bangladesh Water Development Board, for his interest in going through the manuscript and making valuable comments.

The author wishes to express his sincere gratitude to Mr. M.F.A. Siddique, the then Chairman, Bangladesh Water Development Board, for his heartfelt care, help and providing necessary permission to undergo the post-graduate course in Bangladesh University of Engineering and Technology on deputation.

The author acknowledges the cooperations of Bangladesh Water Development Board, Bangladesh Agricultural Development Corporation, Department of Public Health Engineering, Bangladesh Krishi Bank, Bangladesh Rural Development Board and Master Plan Organization in data collection for this study. Sincere thanks are due to Mr. S.M. Parvez, Local Consultant (Junior level), Master Plan Organization, for his help in the procurement of data.

The author is indebted to Computer Centre, Bangladesh University of Engineering and Technology, for providing computer facility without which this work would not have been possible.

Finally, the author acknowledges the contribution of Mr. Yousuf Harun and Mr. Md. Hasan Ali respectively for their excellent drafting and typing.

INDEX

NOTATIONS

A_s	Area of node (km^2)
$a_{i,j}$	Elements of the coefficient matrix [A].
$D_{i,s}$	Saturated thickness of the aquifer (m)
E	Extraction
f_i	Elements of the right hand side column matrix [f]
h_i	Groundwater level at node i (m)
h_s	Groundwater level at node s(m)
i	Hydraulic gradient
j	Present time level
j+1	Forward time level
$K_{i,s}$	Hydraulic conductivity of the path between nodes i and s (m/day)
$L_{i,s}$	Distance between nodes i and s(m)
Q_R	Recharge in time interval Δt (m)
Q_E	Withdrawal in time interval Δt(m)
R	Recharge
RES	Residual flow (m^3/day)
RELAX	Relaxation coefficient
S_s	Storage coefficient of node s (dimensionless)
SI	Subsurface inflow

SO	Subsurface outflow
$SF_{i,s}$	Subsurface inflow/outflow between nodes i and s.
$s(r,t)$	Drawdown at a distance r from a pumping well at time t(ft)
ΔS	Change of storage (dimensionless)
$T_{i,s}$	Coefficient of transmissivity of the path between nodes i and s (m^2/day)
t	Time (days)
Δt	Time interval (days)
$V_{i,s}$	Velocity of the subsurface flow from node i to node s (m/day)
$W_{i,s}$	Width of the side between nodes i and s (m)
$Y_{i,s}$	Conductance of path between nodes i and s (m^2/day).

CHAPTER ONE

INTRODUCTION

Groundwater is an important source of irrigation during dry season in many areas of Bangladesh. Extensive exploitation of this resource through tubewells started in 1972 (MPO, 1984). Uplanned rapid increase of irrigation wells caused decline in groundwater level in the northwest and northeast regions. As a result, several shallow tubewells (STW) and hand pump tubewells (HTW) became incapable of pumping (MPO,1984). In the third five year plan installation of more 13000DTWs, 46,000 STWs and 150,000 HTWs have been planned (Planning Commission, 1985). Successful implementation of this plan is dependent on how thoroughly the groundwater system is understood and how accurately the available groundwater resources is determined. Numerical models are useful tool in such investigation (Southern desert model, Jordan (Thomas, 1973), vega de Granada, Spain model (Thomas,1973), coastal plain of los Angeles county (Thomas, 1973), Northwest Bangladesh groundwater model (Sir M. MacDonald & Partners, 1982)).

Numerical modelling of groundwater system is at a very early stage in Bangladesh. Seven applications of groundwater models in different parts of Bangladesh since 1976 have been summarized by Master Plan Organization (1984). All those model studies have been done by expatriate consultants.

It is now utmost necessity to develop local expertise in this field. Development of computer facilities at BUET has created opportunity to do groundwater model studies. None of the seven model studies has included the Mymensingh-Tangail area, which has a very high groundwater potential. This encouraged me to take the present study.

Groundwater table fluctuation in Bangladesh has an annual cycle. A good numerical model should be capable of simulating this fluctuation. In order to be able to use a large time step of the order of 15 days in the simulation, it was decided that implicit finite-difference model would be developed. Numerical modelling of groundwater involves discretization of the aquifer and there are several ways of doing it. It has been felt that the discretization techniques should also be investigated for groundwater conditions in Bangladesh. The water years 1979-'80 and 1982-'83 have been selected as simulation period for present study since amount of data in these periods is better. It was further decided that the main model application will be determination of groundwater recharge. Then the main objectives of present study may be summarized as:

i) to develop a numerical model for simulating groundwater water movement in the aquifer of Mymensingh-Tangail area,

ii) to investigate accuracy and computational efficiency of numerical solution methods and schematization techniques,

iii) to determine aquifer characteristics and groundwater recharge in the study area.

CHAPTER TWO

CONCEPTUAL BASIS OF THE MODEL

2.1.0 MATHEMATICAL DESCRIPTION

2.1.1 Governing Equation

Basically two equations are required to represent groundwater movement in an aquifer. These are Darcy's law and equation of continuity. Darcy's law is used to compute the subsurface flow in an aquifer (Fig. 2.1). It can be expressed as:

$$V = K\,i \quad \ldots\ldots\ldots\ldots \tag{2.1}$$

where V = velocity (m/day)

K = hydraulic conductivity (m/day)

i = hydraulic gradient

The equation of continuty is used to compute the change of storage in the aquifer. It can be expressed as (Fig. 2.1):

$$SI - SO + R - E = \Delta S \quad \ldots \tag{2.2}$$

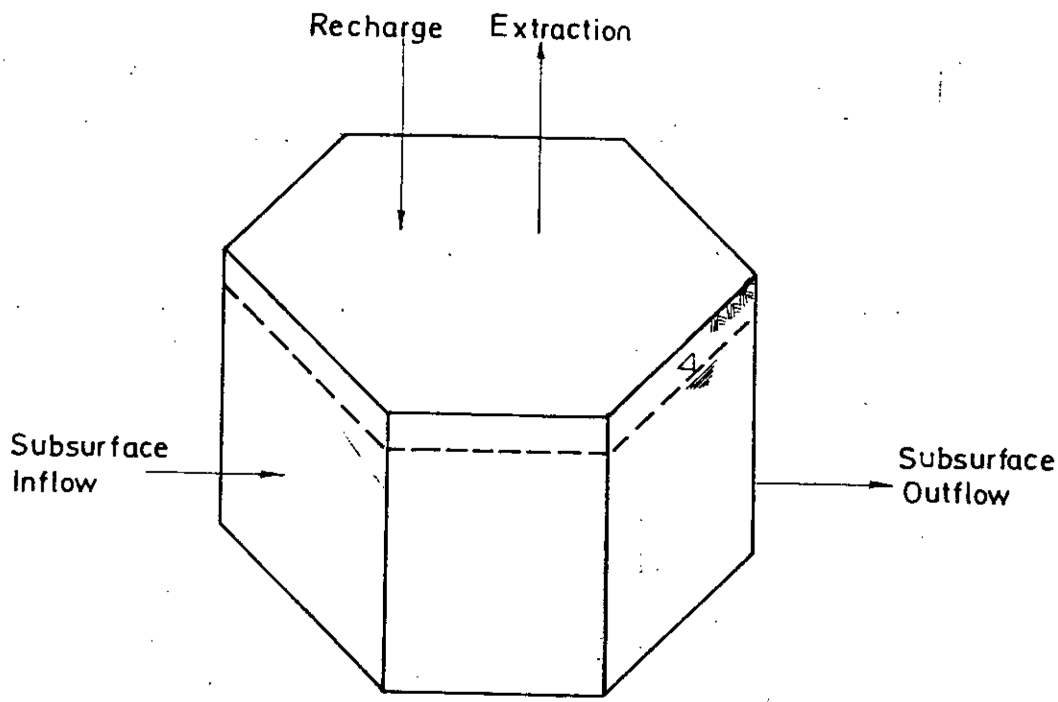
where SI = Subsurface inflow

SO = Subsurface outflow

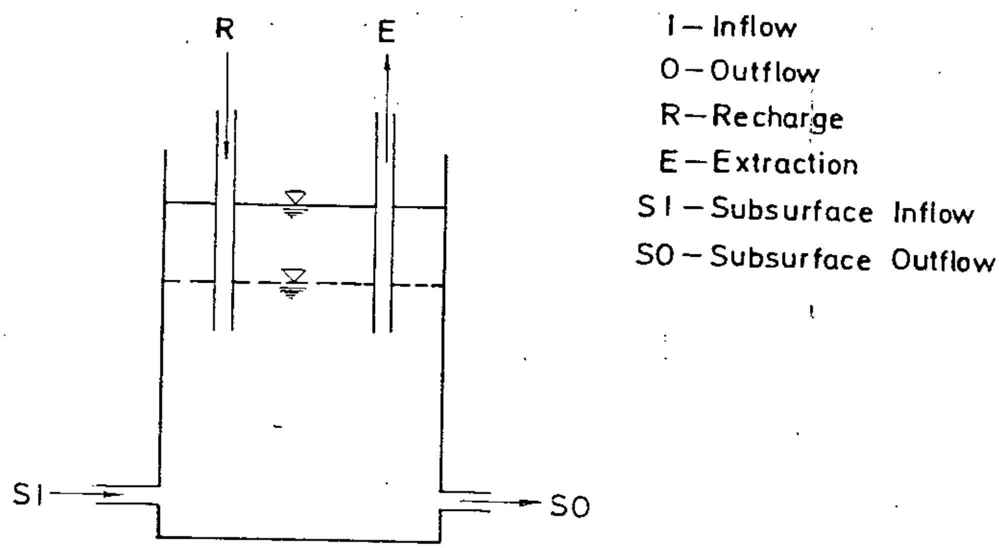
R = Recharge

E = Extraction

ΔS = Change of storage



(a) An Aquifer Element



(b) Schematic Representation of an Aquifer Element

FIG. 2.1 REPRESENTATION OF FLOWS IN AN AQUIFER ELEMENT

2.1.2 Assumptions

Groundwater modelling is based on some simplifying assumptions. These are as follows:

i) The medium through which flow occurs is porous.

ii) Linearity between velocity and hydraulic gradient exists.

iii) The flow is horizontal and uniform everywhere in a vertical section.

iv) The pressure- head distribution along any vertical is hydrostatic.

v) All variables in the equation are defined on the macroscopic level i.e. in terms of volume elements. On this basis, the flow is considered irrotational.

2.2.0 NUMERICAL MODEL

2.2.1 Schematization

Numerical modelling of groundwater movement in an aquifer requires schematization of the model area by a network of polygons (Fig. 2.2). Each polygon is represented by a node at its centroid. Then the equation (2.1) and (2.2) are applied to each polygon. Sometimes rectangles ((Mercer & Faust,1981), (Fig. 2.2(b))) and squares ((Thomas, 1973), (Fig. 2.2(c))) are also used which are also polygons. In the present study a network of regular polygons and a network of regular rectangles have been used.

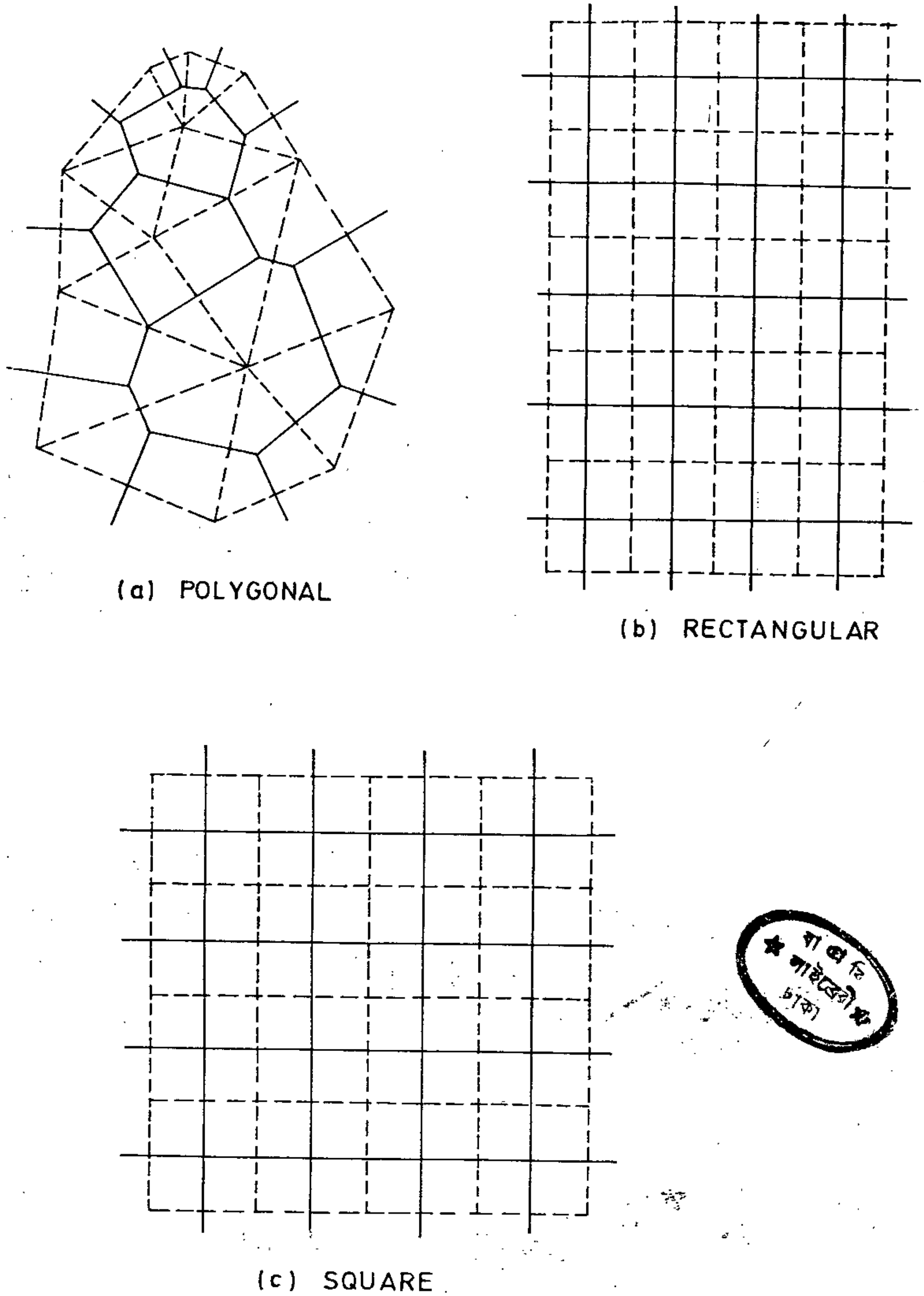


FIG. 2.2 DIFFERENT TYPES OF SCHEMATIZATION

2.2.2 Development of finite-difference equation

The velocity of horizontal subsurface flow from an adjacent node i to the solution node s (Fig. 2.3) is given from equation (2.1) as follows:

$$V_{i,s} = K_{i,s} \frac{(h_i - h_s)}{L_{i,s}} \quad \ldots \quad (2.3)$$

Therefore, the subsurface inflow/outflow can be given by:

$$SF_{i.s} = K_{i,s} \frac{(h_i - h_s)}{L_{i,s}} D_{i,s} W_{i,s}$$

$$= \frac{T_{i,s} W_{i,s}}{L_{i,s}} (h_i - h_s)$$

$$= y_{i,s} (h_i - h_s) \quad \ldots \quad (2.4)$$

where $V_{i,s}$ = Velocity of the subsurface flow from node i to node s (m/day).

$SF_{i,s}$ = Subsurface inflow/outflow from node i to node s (m^3/day).

$K_{i,s}$ = Hydraulic conductivity of the path between nodes i and s (m/day).

$D_{i,s}$ = Saturated thickness of the aquifer (m).

$W_{i,s}$ = Width of the side between node i and s (m).

$L_{i,s}$ = Distance between nodes i and s (m).

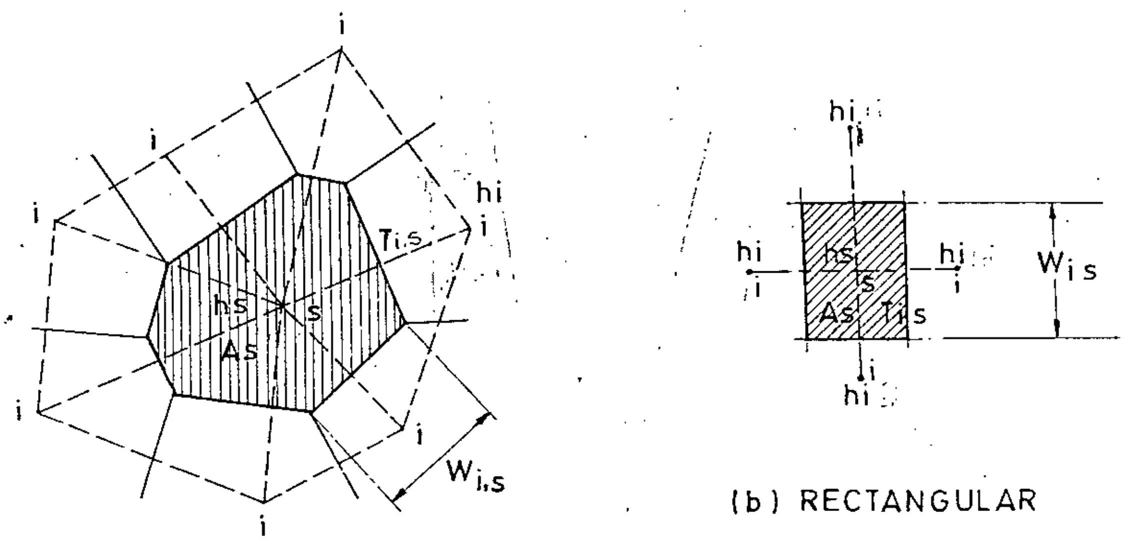
h_i = Groundwater level at node i (m).

h_s = Groundwater level at node s (m).

$T_{i,s}$ = Coefficient of transmissivity of the path between nodes i and s (m^2/day)

$$Y_{i,s} = \frac{W_{i,s} T_{i,s}}{L_{i,s}}$$

= Conductance of path between nodes i and s (m^2/day).



(a) POLYGONAL

(b) RECTANGULAR

FIG. 2.3 TYPICAL NODES

The net subsurface inflow/outflow to the node s from surrounding nodes i is given by (equation: 2.2):

$$SI - SO = \sum_i SF_{i,s}$$

$$= \sum_i Y_{i,s} \; (h_i - h_s) \quad \ldots \qquad (2.5)$$

The net vertical inflow/outflow in node s (equation: 2.2) is:

$$R - E = A_s \; \frac{(Q_R - Q_E)}{\Delta t} \quad \ldots \qquad (2.6)$$

where A_s = Area of node s (m^2)

Q_R = Recharge (m) in time interval Δt

Q_E = Withdrawal (m) in time interval Δt

Thus the rate of change of storage that occurs in node s (equation: 2.2) is given by:

$$\Delta S = A_s \; S_s \; \frac{dh_s}{dt} \quad \ldots \qquad (2.7)$$

where S_s = Storage coefficient in node s (dimensionless)

t = Time (days)

Combining equations (2.5), (2.6) and (2.7) and using these in equation (2.2) we get:

$$\sum_i Y_{i,s} \; (h_i - h_s) + A_s \; (\frac{Q_R - Q_E}{\Delta t}) = A_s \; S_s \; \frac{dh_s}{dt} \quad \ldots \qquad (2.8)$$

Applying finite difference technique to $\frac{dh_s}{dt}$ in equation (2.8), we get:

$$\sum_i Y_{i,s} \ (h_i - h_s) + A_s \ (\frac{Q_R - Q_E}{\Delta t}) = \frac{A_s \ S_s}{\Delta t} \ (h_s^{j+1} - h_s^j) \quad \ldots (2.9)$$

Where the superscripts j and j+1 indicate present and forward time level respectively.

The dependent variables h_i and h_s of the left hand side may be defined at present time level (j) and it results explicit expression. Explicit method imposes a restriction of maximum size of time step. Alternatively, the left hand side may be defined at forward time level (j+1) and it results implicit expression. It is given by:

$$\sum_i \ (h_i^{j+1} - h_s^{j+1}) \ Y_{i,s} + A_s \ (\frac{Q_R - Q_E}{\Delta t}) = \frac{A_s S_s}{\Delta t} \ (h_s^{j+1} - h_s^j) \quad \ldots \quad (2.10)$$

The implicit method has the advantage that it does not restrict the size of the time step and hence requires less computing time. In the present study the implicit method with a time step of 15 days has been adopted.

Equation (2.10) can be rearranged as

$$- h_s^{j+1} \left(\sum_i Y_{i,s} + \frac{A_s S_s}{\Delta t} \right) + \sum_i h_i^{j+1} Y_{i,s}$$

$$= A_s \left(\frac{Q_E - Q_R}{\Delta t} \right) - \frac{A_s S_s}{\Delta t} h_s^j \quad \ldots \quad (2.11)$$

For n numbers of polygons, n numbers of equations of the type (2.11) are obtained. They may be expressed in matrix form as:

$$[A] \; [h] = [f] \quad \ldots \quad (2.12)$$

where $[A] = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$

$h = \begin{bmatrix} h_1^{j+1} \\ h_2^{j+1} \\ \vdots \\ h_n^{j+1} \end{bmatrix} \qquad f = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix}$

There are different numerical methods to solve these system of equations (2.12). In the present study Gauss-Seidel iteration and Gauss- Jordan elimination methods have been used.

2.2.3 Gauss-Seidel Iteration

In the Gauss-Seidel iteration method, the system of finite-difference equations (2.12) are solved by iteration process with successive approximation. The values of the dependent variables i.e. groundwater levels (h_i and h_s) are assumed for the interior nodes. Improved values are then calculated with the known initial and boundary conditions. The discrepancy between the successive values of water table elevations which exists, causes a residual flow rate. For satisfactory solution of the dependent variable the residual is gradually diminished by the process known as relaxation (Scarborough, 1966).

Initial water table elevations are prescribed to all the nodes in equation (2.11). Boundary conditions are also given in the external nodes for each time steps. All flows are balanced at each node by setting their sum equal to the residual term. After each iteration the sum of all the residual flows for all the nodes is calculated (TOTRES) to compare with a maximum tolerable value (TOLER). The iteration process is repeated to get improved values if the sum (TOTRES) is equal to or less than the prescribed threshold value. For the present model the threshold value has been estimated as 10% of the average absolute values of net vertical flow (Boonstra and Ridder, 1981). Also a toerable limit of discrenancy between consecutive iterations can be used as the threshold value. In the present study this has also been tested.

From equation (2.10) and referring to Fig. 2.3 the residual at s is :

$$RES = \sum_i (h_i^{j+1} - h_s^{j+1}) \quad Y_{i,s} - \frac{A_s S_s}{\Delta t} (h_s^{j+1} - h_s^j)$$

$$+ A_s \left(\frac{Q_R - Q_E}{\Delta t}\right) \quad \ldots \quad (2.13)$$

Adding Δh_s to h_s^{j+1} in equation (2.10) results in (Jamilur, 1981):

$$\sum_i (h_i^{j+1} - h_s^{j+1} - \Delta h_s) \; Y_{i,s} = \frac{A_s S_s}{\Delta t} (h_s^{j+1} + \Delta h_s - h_s^j)$$

$$- A_s \left(\frac{Q_R - Q_E}{\Delta t}\right) \quad \ldots \quad (2.14)$$

From equations (2.13) and (2.14), Δh_s is:

$$\Delta h_s = \frac{RES}{\sum_i Y_{i,s} + \frac{A_s S_s}{\Delta t}} \quad \ldots \quad (2.15)$$

This coefficient of residual (RES) is termed as the relaxation coefficient and written as:

$$RELAX = \frac{1.0}{\sum_i Y_{i,s} + \frac{A_s S_s}{\Delta t}} \quad \ldots \quad (2.16)$$

Thus the water table elevation at node s for the new time step $t = j + 1$ is:

$$h_s \text{ (new)} = h_s \text{ (old)} + RELAX * RES \quad \ldots \quad (2.17)$$

This solution is done simultaneously for all nodes at $t = j + 1$ which is unconditionally stable. In this model, the water-table elevations at the end of a time step serves as the starting conditions for the next time step. The flow chart of the iteration process is given in Fig. 2.4.

Boonstra and Ridder (1981) used this method for solution of groundwater flow equation and observed that the method requires less computing time.

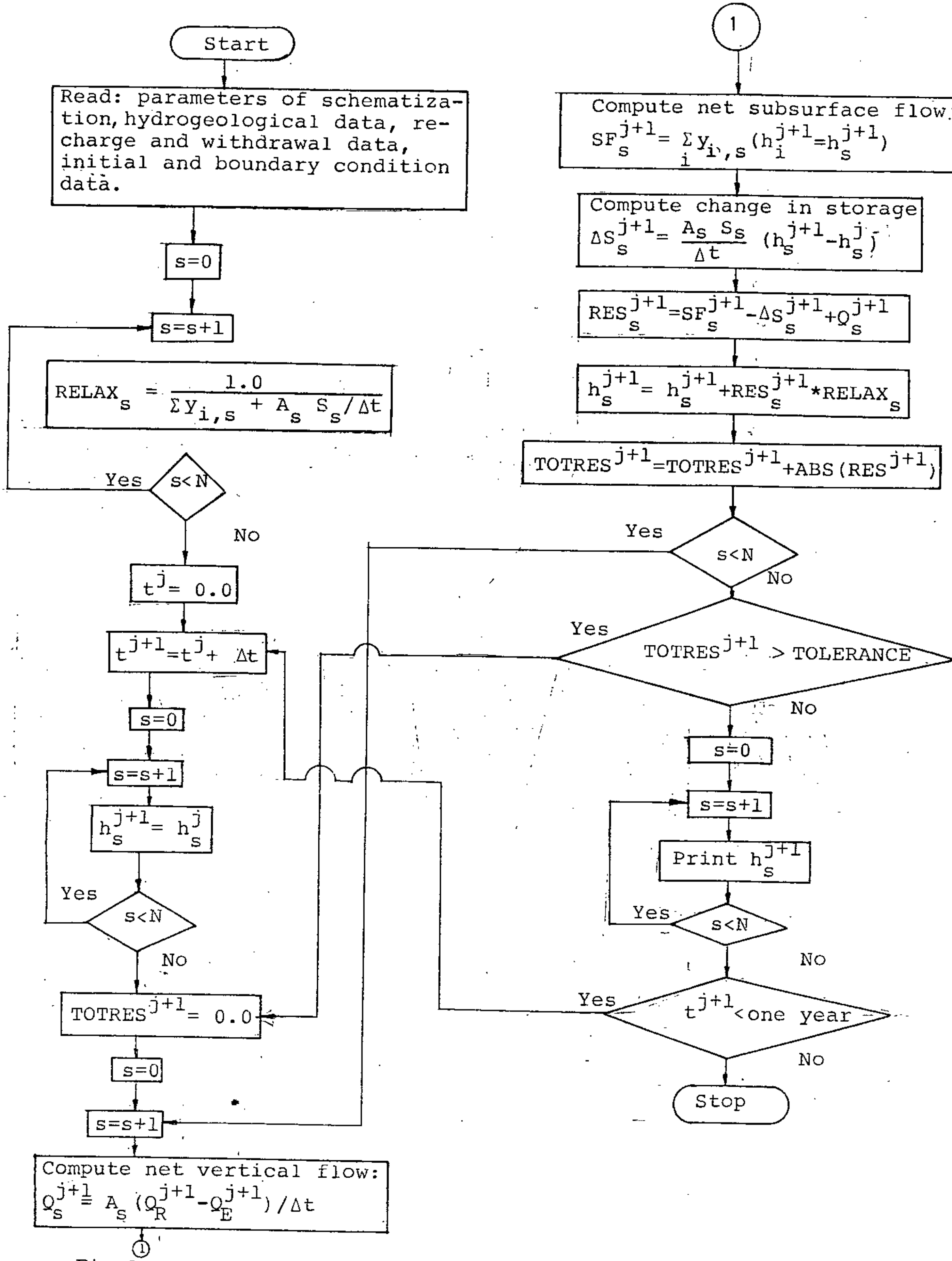


Fig.2.4: Flow chart of Gauss-Seidel iteration method.

2.2.4 Gauss-Jordan elimination

In the Gauss-Jordan method the coefficient matrix [A] in equation (2.12) is reduced to a diagonal matrix. In this process the ith row is used to eliminate the coefficients above and below it in the ith column. Thus at the end of the solution the diagonal elements of [A] become unity with zero values in the remaining elements. The elimination process to make zero in the ith column of [A] with the corresponding operations in the right hand side column voctor [f] can be given by:

$$a_{i,j}^{(i+1)} = \frac{a_{i,j}^{(i)}}{a_{i,i}^{(i)}} \quad , \quad J = i \ , \ n$$

$$a_{k,m}^{(i+1)} = a_{k,m}^{(i)} - a_{k,i}^{(i)} * \frac{a_{i,m}^{(i)}}{a_{i,i}^{(i)}} \ , \ k = 1,n, m = i,n, k \neq i$$

$$f_{i}^{(i+1)} = \frac{f_{i}^{(i)}}{a_{i,i}^{(i)}}$$

$$f_{k}^{(i+1)} = f_{k}^{(i)} - a_{k,i}^{(i)} * \frac{f_{i}^{(i)}}{a_{i,i}^{(i)}} , \ k = 1,n, \ k \neq i$$

Rearrangement of rows and colums called pivoting is performed when a diagonal element is nearly zero to ensure numerical stability (Dahlquist & Bjorck, 1974). The finite difference equations (2.10) retain large values of the diagonal elements at each step of elimination. Hence no such rearrangement or pivoting is required in this solution at any step. The flow chart of the elimination process is given in Fig. 2.5.

Boonstra and Ridder (1981) obtained solution by this method and found that the method required more computer memory which is due to the storing of large matrices.

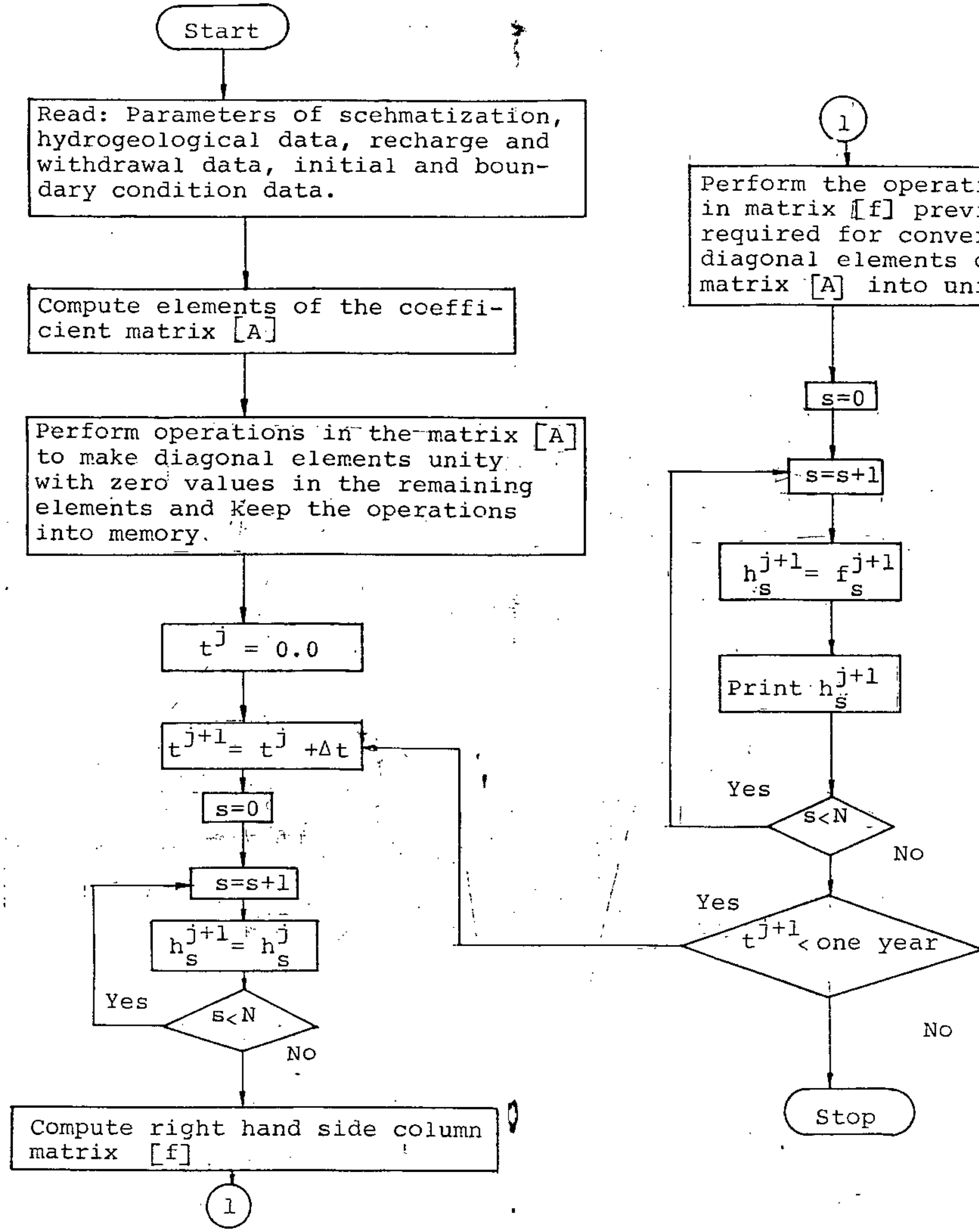


Fig. 2.5: Flow chart of Gauss-Jordan elimination method.

CHAPTER THREE

COMPARISON WITH ANALYTICAL SOLUTION

3.1.0 INTRODUCTION

This chapter evaluates the performance of numerical solution techniques. Analytical solution exists for unsteady radial flow to a pumping well. Performance of numerical solution is evaluated by comparing the numerical solution results with the analytical solution. Analytical derivation is difficult to obtain for the complex groundwater flow equation including all components of flow condition. However, some confidence in numerical modelling is gained if it can reproduce analytical solution.

3.2.0 THEISS EQUATION

Theiss solution for unsteady radial flow to a pumping well is given by the non-equilibrium equation (Walton,1970):

$$s(r,t) = \frac{Q}{4\pi T}\left[-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} \ldots\ldots\right] \qquad (3.1)$$

Where $u = \frac{r^2 s}{4Tt}$

The derivation of this equation is based on the assumptions as follows (Walton,1970):

i) The aquifer is homogeneous, isotropic, infinite in areal extent and is of the same thickness throughout.

ii) The wells completely penetrate the aquifer and flow is radial.

iii) The diameter is infinitesimal and the water removed from storage is discharged instantaneously with the decline of head.

iv) The production well is pumped at a constant rate.

v) The values of storage coefficient for upward and downward movement of the watertable are equal and the gravity yield is instantaneous.

3.3.0 NUMERICAL EXPERIMENT

3.3.1 Nodal Configuration

An area of influence of a pumping well is schematized to obtain analytically and numerically computed values of water level at different distances. Schematization is shown in Fig. 3.1. There are 61 nodal areas involving 49 internal and 12 external nodes.

External boundary of the scheme is considered head controlled with constant heads at each external node. For analytical and numerical computation of drawdown at each internal node a tubewell of 2 cfs capacity is pumped at

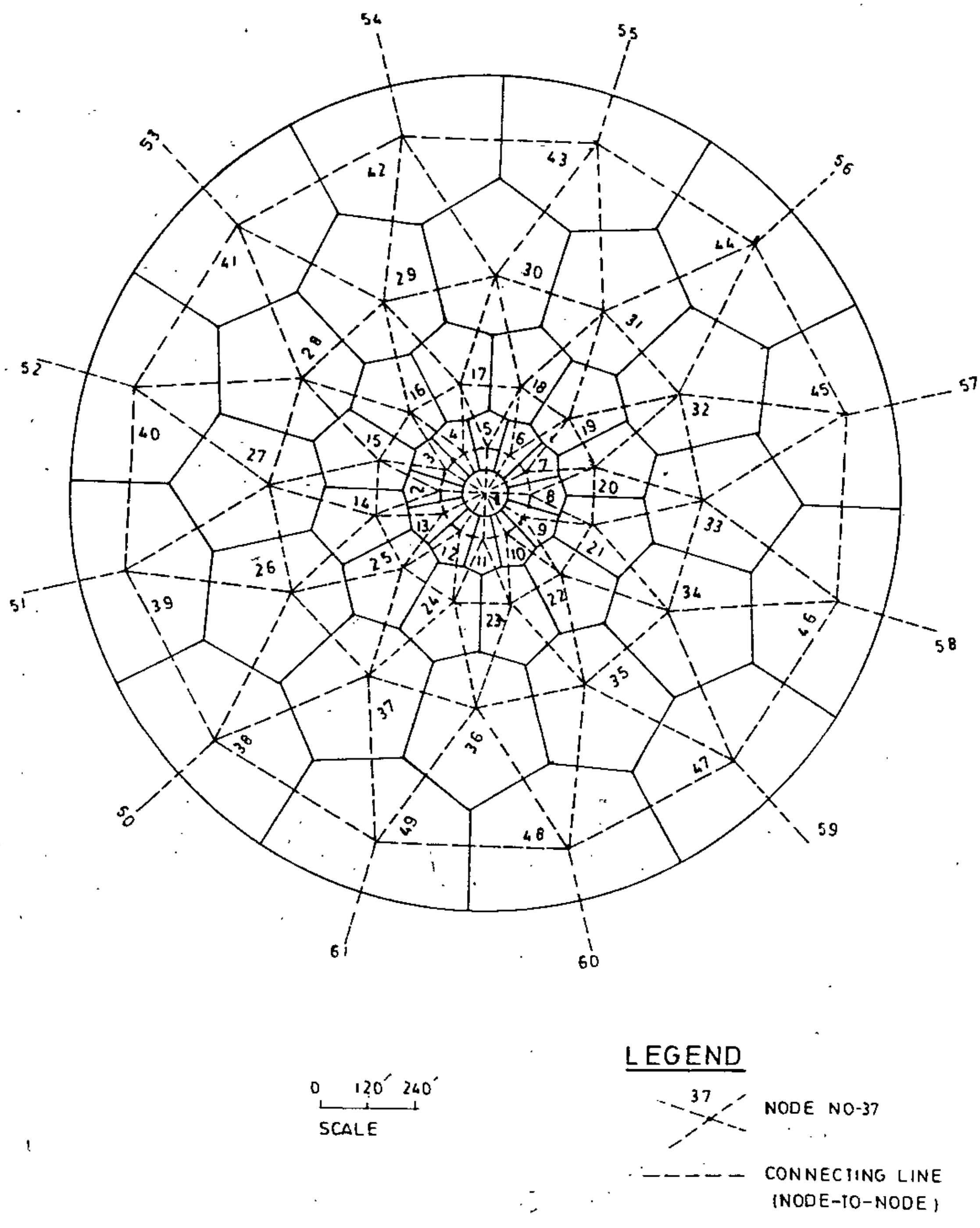


FIG. 3.1 SCHEMATIC REPRESENTATION OF THE AREA OF INFLUENCE OF A PUMPING WELL IN THE NUMERICAL MODEL

the central node 1. Owing to steep hydraulic gradient a fine mesh of network of smaller areas is constructed around this point. The area of nodes increases with increasing distance and diminishing hydraulic gradient. A total of 144 connecting lines exist which indicates schematically the subsurface flowpath from node-to-node.

3.3.2 Accuracy

Accuracy is interpreted as the ability of the numerical model to reproduce the analytical solution. To obtain the numerical and theiss solution, assumed values of transmissivity and storage are taken as 33.38 ft^2/ min and 0.1 respectively for the whole area. The computation was carried out for a total time period of 1000 minutes at a time interval of 50 minutes.

Analytically and numerically computed variations of drawdowns at two points are shown in Fig. 3.2. Variations of drawdown as obtained from the numerical and analytical solution at two different times are shown in Fig. 3.3. Errors involved in numerical solution are also shown in Fig. 3.2 and 3.3. Fig. 3.2 shows that the error increases with time. In the case of Gauss- Jordan elimination rate of increase is very small. Maximum error of 0.07435 ft and

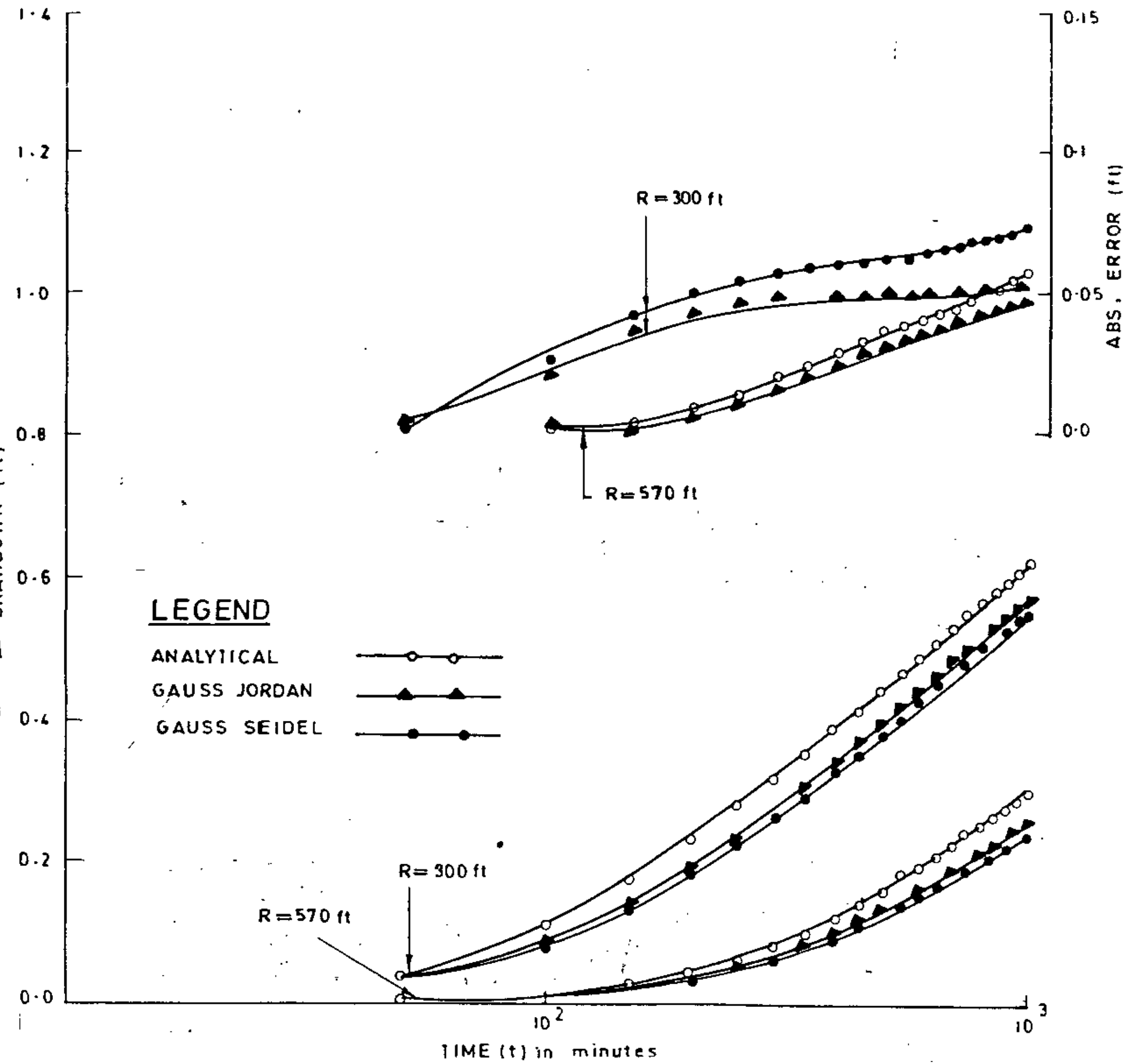


FIG. 3.2 COMPARISON OF ANALYTICALLY AND NUMERICALLY COMPUTED VALUES OF DRAWDOWN WITH TIME

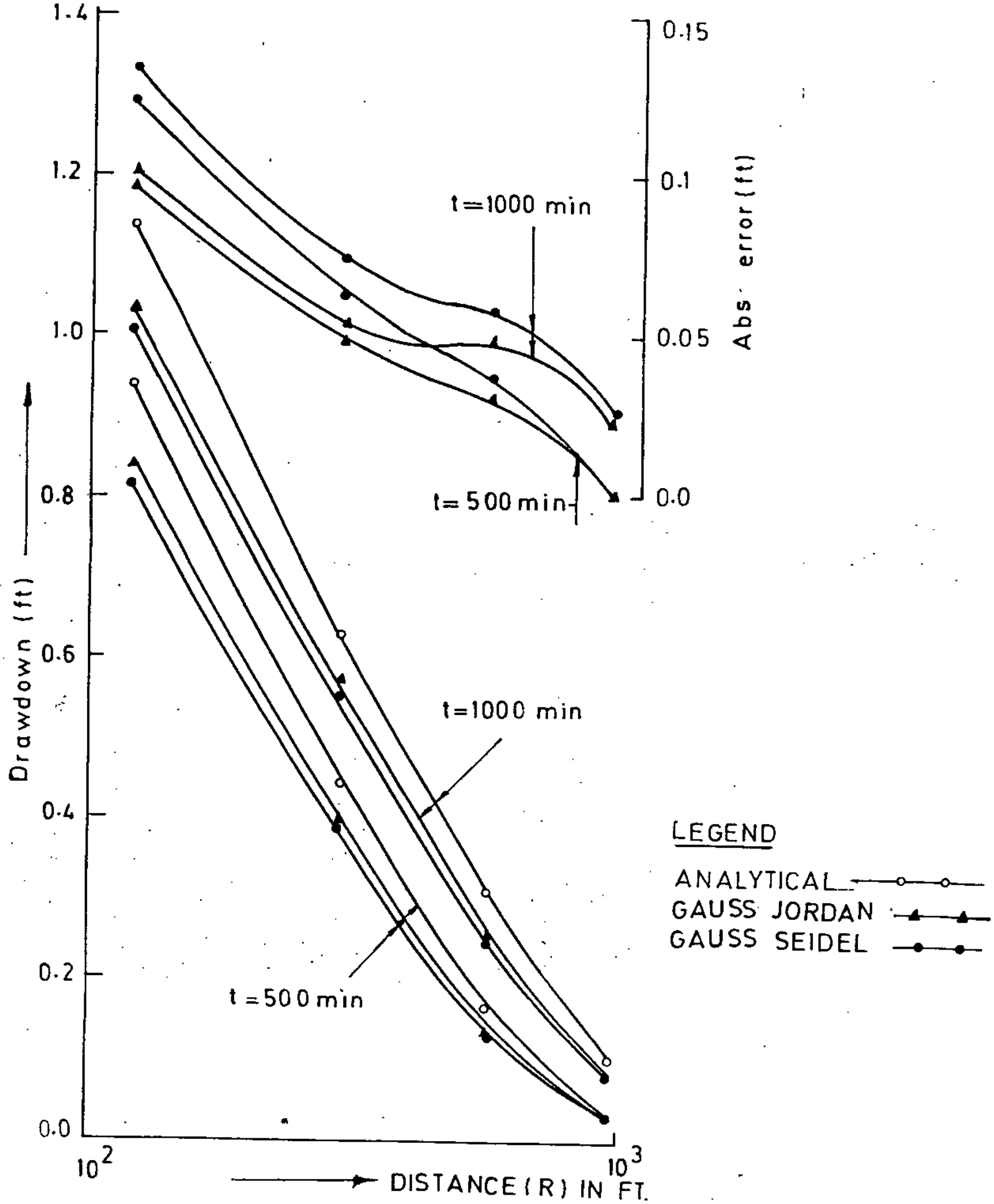


FIG.3.3, COMPARISON OF ANALYTICALLY AND NUMERICALLY COMPUTED VALUES OF DRAWDOWN WITH DISTANCE

0.05388 ft occurs at a distance of 300 ft at time 1000 minutes which are only 1.59% and 1.15% with respect to drawdown at the well in case of Gauss-Seidel iteration and Gauss-Jordan elimination methods respectively. These deviations are negligible and accepted for all practical purpose.

The analytical solution is based on a point sink at the central nodal point 1, while it is assumed in the numerial model that discharge Q is distributed over the central nodal point 1. Hence the analytical solution represents point drawdown which in numerical models represent average drawdown. This is the main reason behind the discrepancy.

3.4.0 CONCLUSION

Conclusion of this chapter can be made as follows:

1) The numerical model give acceptable results in comparison with Theiss analytical solution.

2) The numerical solution obtained by the Gauss- Jordan elimination method has greater accuracy compared to that obtained by Gauss-Seidel iteration method.

CHAPTER FOUR
DATA COLLECTION AND ANALYSIS

4.1.0 INTRODUCTION

Data defining the physical framework and hydrogeological characteristics of the aquifer have been analysed. The total data may be classified into four groups as listed in Table 4.1. The source of various types of data are given in Table 4.2. This chapter briefly explains the collection and processing of the data required for the models. The calibration parameters are coefficient of transmissivity, storage coefficient and recharge. An initial estimate of these parameters have been made which are subjected to change during calibration.

Table 4.1 Data required for the model.

Aquifer characteristics	Coefficient of transmissivity, storage coefficient.
Boundary data	Water level (R.L) of Jamuna and Brahmaputra.
Hydrological data	Groundwater table elevation, Rainfall, Recharge.
Artificial withdrawal data	Number of deep tubewells, shallow tubewells, hand pump tubewells and manually operated shallow tubewells for irrigation.

Table 4.2 Source of data

Data	Name of the Organization	Year
Coefficient of Transmissivity	Bangladesh Water Devlopment Board	1982
Storage Coefficient	-do-	1984
Weekly value (R.L.) of ground-water level	-do-	1979-'80 and 1982-'83
Daily value(R.L) of water level of Jamuna and Brahmaputra	-do-	1979-'80 and 1982-'83
Rainfall	-do-	1979-'80 and 1982-'83
Recharge		1984
Nos. of deep and shallow tube-wells	Bangladesh Agricultural Development Corporation, Bangladesh Krishi Bank and Master Plan Organization	1979-'80 and 1982-'83
Nos. of hand pump tubewells	Department of Public Health Engineering and Bangladesh Bureau of Statistics.	1979-'80 and 1982-'83
Manually operated shallow tube-wells for irrigation	Bangladesh Rural Development Board and Bangladesh Krishi Bank	1979-'80 and 1982-'83

Zone-wise monthly withdrawal rates	Master Plan Organization	1985
District map of Mymensingh,Tang-ail, Dhaka and Jamalpur	Office of the Land Records and Surveys	1968
Maps showing location of ground-water observation wells,river gauge stations and zone-wise divisions for different withdrawal rates	Bangladesh Water Development Board and Master Plan Organization	1983 and 1984

4.2.0 DESCRIPTION OF THE MODEL AREA

The model area lies between the rivers Jamuna flowing in a braided course in the western side and old Brahmaputra in the eastern side. The area involves Tangail, part of Mymensingh situated on the western side of Brahmaputra and small portions of Jamalpur and Dhaka as shown in Fig. 4.1. It lies between 89°45' to 90°40' latitude and 24°10' to 24°55' longitude.

The model area is composed mainly of alluvial flood plain sediments, deposited by Brahmaputra - Jamuna river system (UNDP,1982). The surface deposit consists of mostly red and arrange clay deposits at a higher altitude in Madhupur area. The rest of the maximum area comprises of silt, sand

and gravel deposits (BWDB, 1978). The lithological sections of the model area are shown in Fig. 4.2 (BWDB , 1979). It is observed that the aquifer is composed of water bearing formation having thckness greater than 25 m. It has been reported (BWDB, 1980) that the rise of water table in this region continues according to intensity and duration of rainfall. The monthly values of rainfall for the model region has been estimated by the Thiessen method (Linsley, Kohler and Paulhus, 1958) from the data of BWDB gauge stations. The rainfall histograms prepared from these monthly values for 1979-'80 and 1982-'83 are shown in Fig. 4.3. Variation of groundwater level for two observation wells of Tangail and Mymensingh districts are also shown in Fig. 4.3. From the hydrographs of observation wells it is observed that in the model region water table starts rising in May and reaches its maximum in August at the rate of approximately 0.56 m per month. It is also observed that the water level begins to recede from October at the rate of approximately 0.33 m per month and reaches its minimum in April. From the hydrographs it is observed and also reported by BWDB (1980) that groundwater level remains almost in the same level in the month of August and September.

From the long term hydrograph analysis of some selected observation wells in Tangail district a slight declining tendency of water level with the fluctuation of highest and

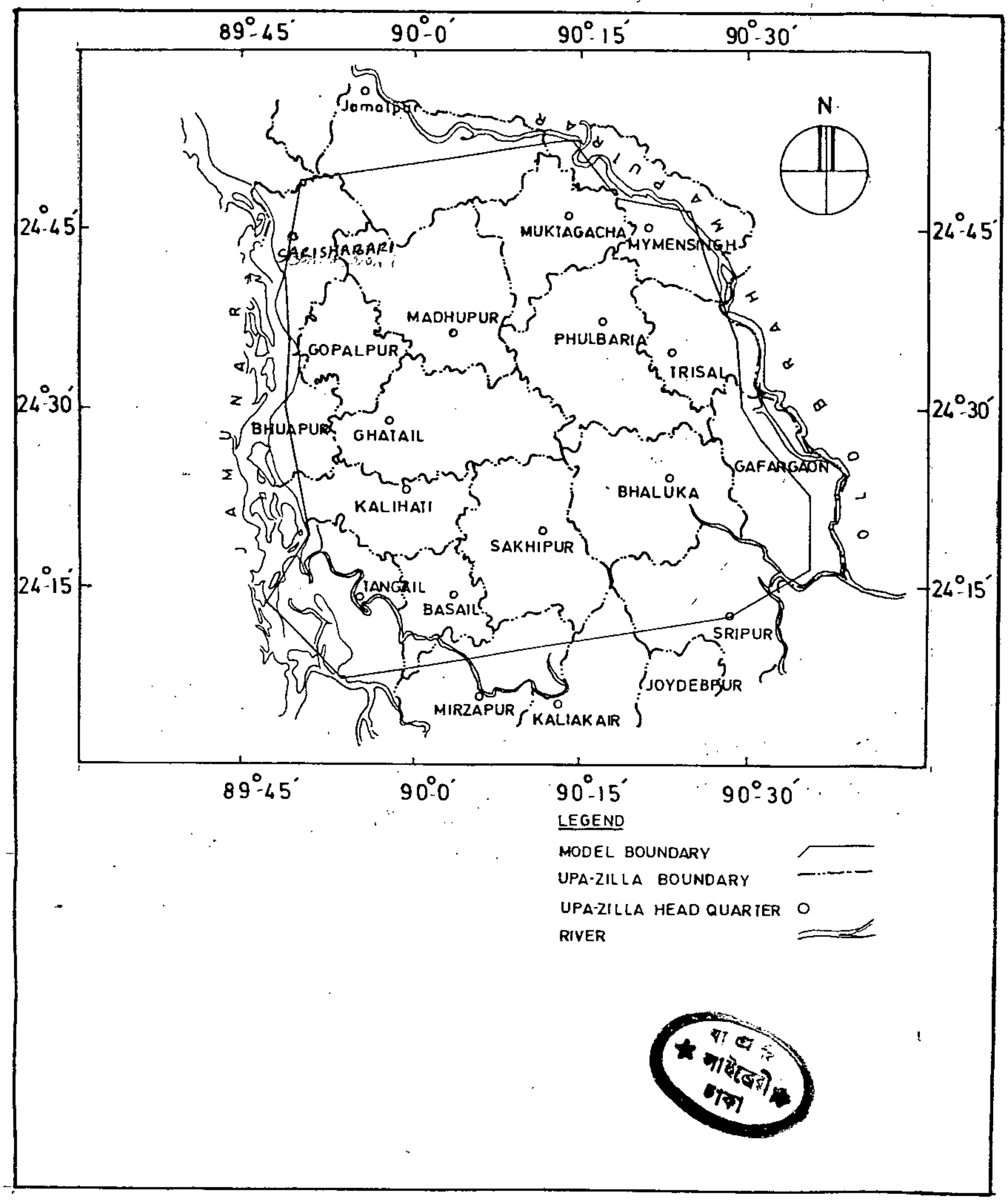


FIG. 4.1 MODEL AREA

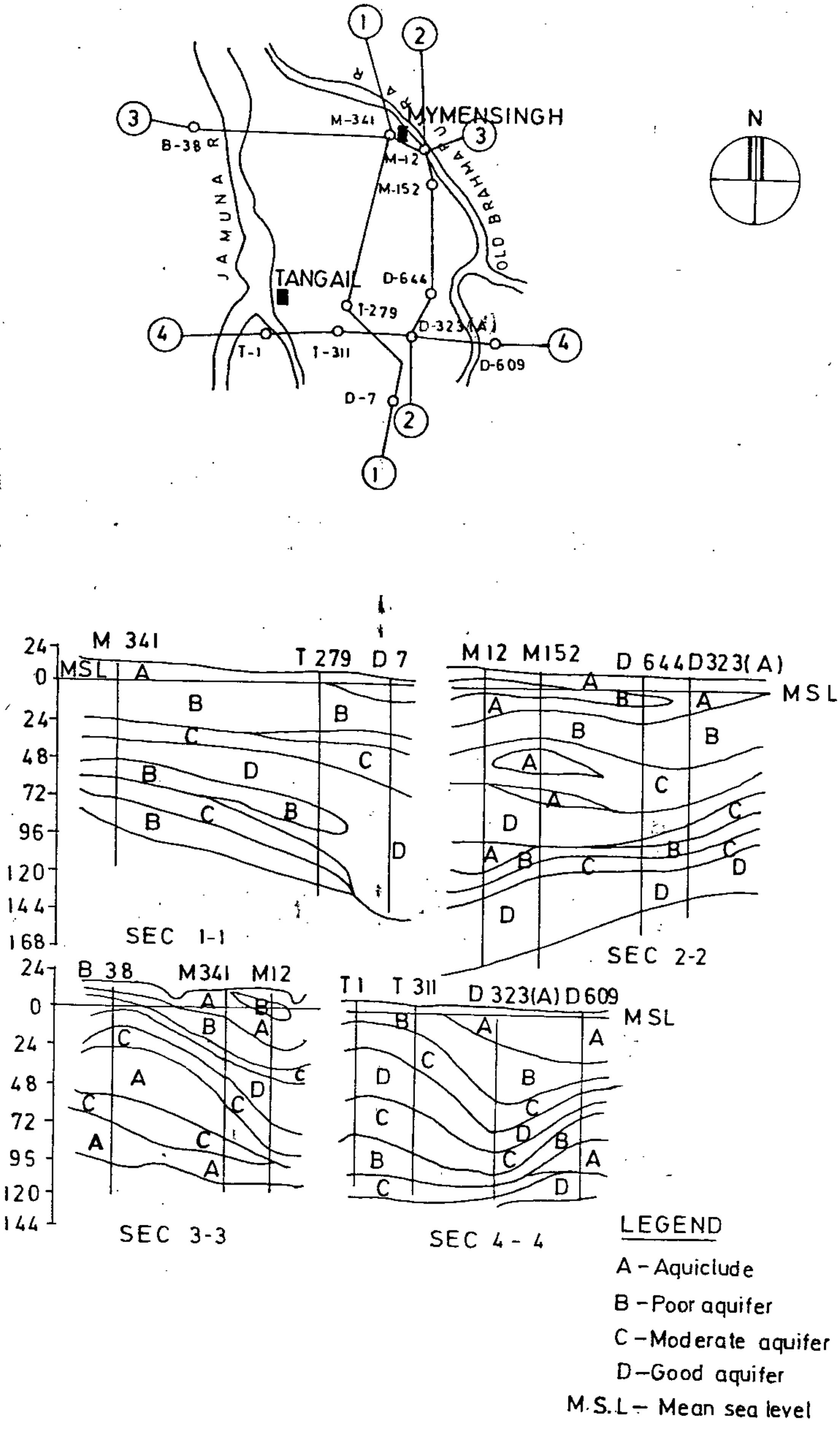


FIG. 4.2 LITHOLOGICAL SECTIONS OF THE MODEL AREA

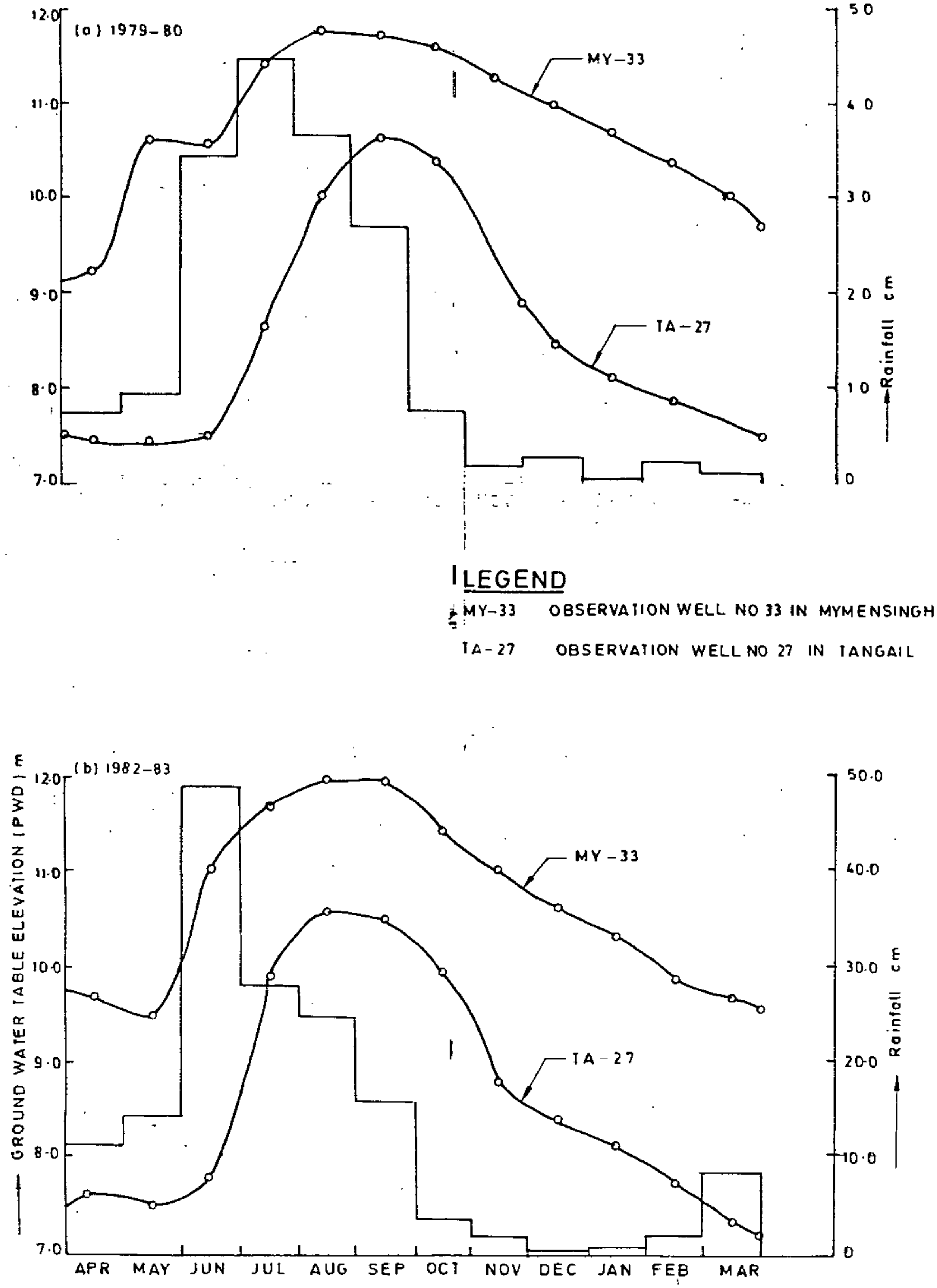


FIG. 4.3 RAINFALL HISTOGRAM AND GROUND WATER LEVEL VARIATION

lowest water level ranging from 3 to 4.5 meters is observed (BWDB, 1984). Such analysis for Mymensingh district reveals the same declining tendency with a range of fluctuation varying from 2 to 8 meters. The declining tendency as found is reported to be due to the exorbitant extraction of groundwater by tubewells in the dry period.

The study of the physiographic units of Bangladesh (Karim, 1984) reveals that the part of the model area remains deep flooded at a depth of flooding greater than 2 meter. Low lying area exists in Mymensingh district at a depth of flooding less than 2 meter. This indicates that aquifer is also recharged through percolation of floodwater.

4.3.0 SCHEMATIC REPRESENTATION OF THE AREA

Two types of schematization have been used in the present model study. These are a network of regular hexagons and a network of regular rectangles as shown in Fig. 4.4. The following criteria were considered to be fulfilled in the schematization of the model area:

i) Number of internal and external nodes should be same for both types of schematization. There are 63 internal and 26 external nodes in each of the two types of networks.

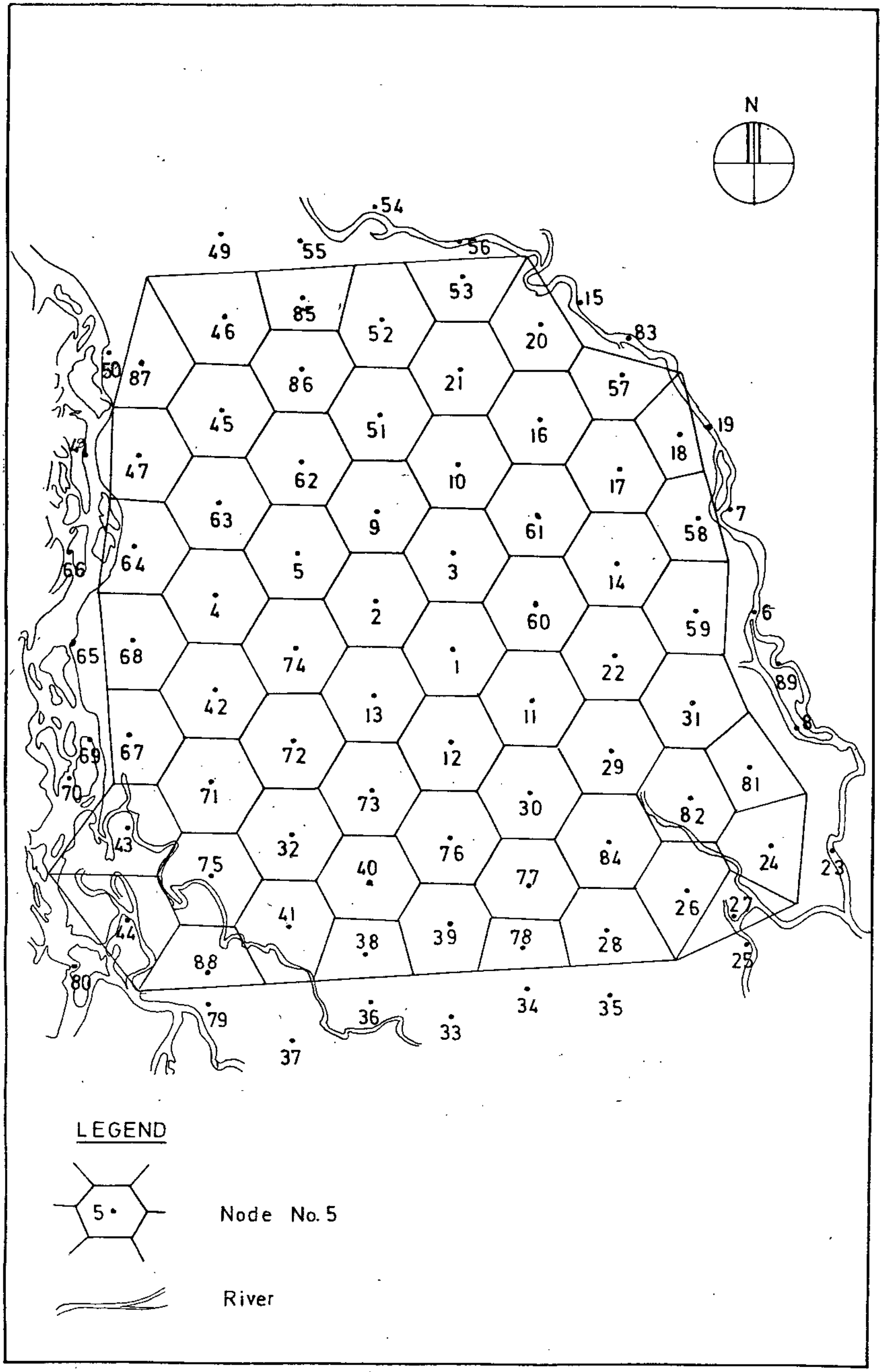


FIG. 4.4a POLYGONAL GRID SCHEMATIZATION

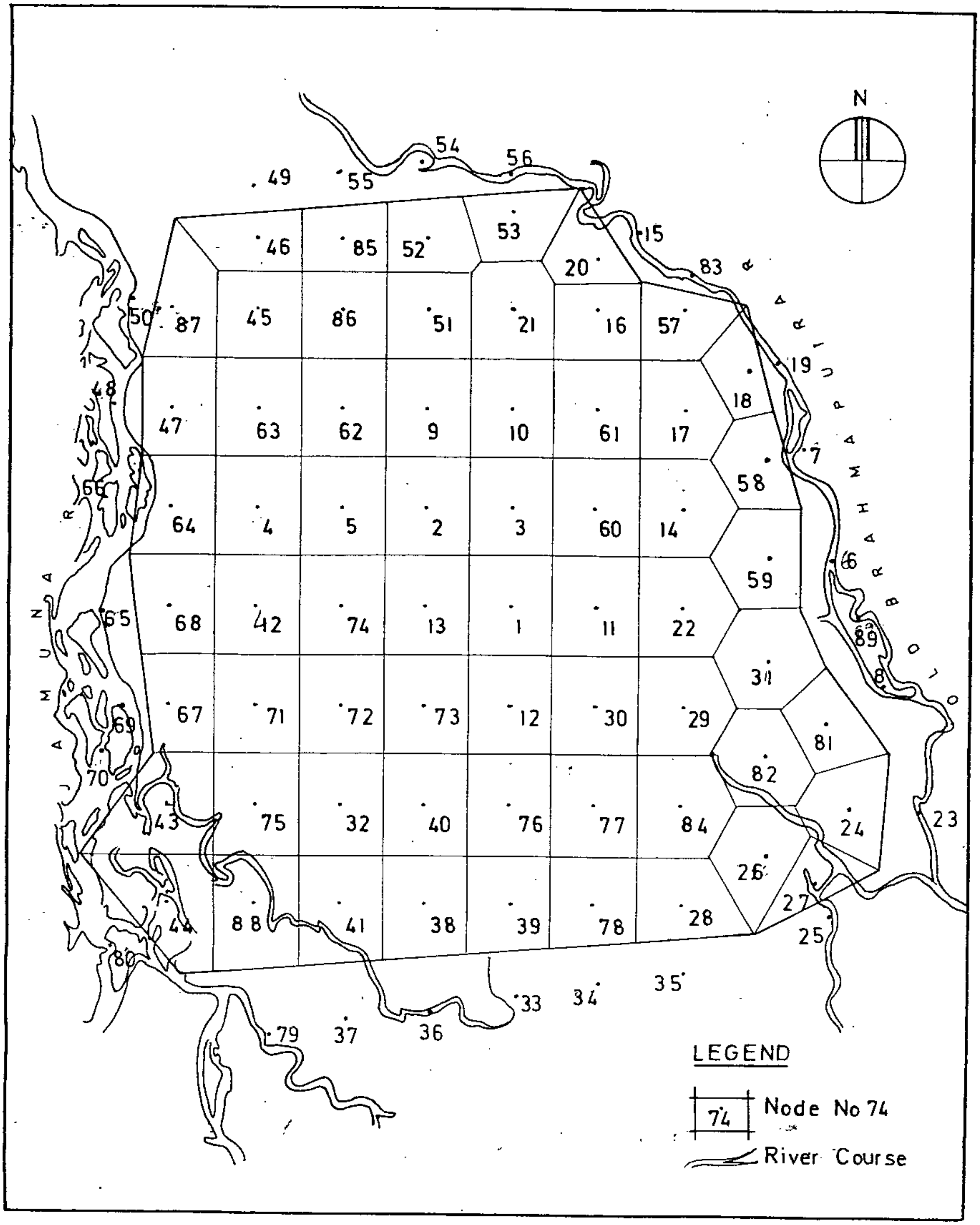


FIG.4.4b RECTANGULAR GRID SCHEMATIZATION

ii) Area of internal nodes should be same in the two types of networks. The area of internal nodes except those near the boundaries are same for both the networks and is equal to 86.603 km^2.

iii) Effort has been made to coincide centroid of the maximum number of internal nodes of the two networks. The centroid of a total of 39 internal nodes coincides in both types of networks.

4.4.0 INITIAL ESTIMATION OF CALIBRATION PARAMETERS

4.4.1 Coefficient of Transmissivity

Most reliable value of transmissivity is obtained from pumping test data. United Nations Development Program (1982) carried out pumping tests on BADC irrigation tubewells in Bangladesh. The test sites and the values of transmissivity therein have been put to the purpose of drawing transmissivity contour map of the model area as shown in Fig. 4.5(a). For the model network geometry, transmissivity value at each polygonal side is required. This was achieved by superimposing the model network map upon transmissivity contour map as shown for a typical configuration in Fig. 4.5(b). A weighted mean value at the polygonal sides were obtained as follows.

$$\text{Transmissivity at node 1} = \frac{T_1 . A_1 + T_2 . A_2 + T_3 . A_3}{\text{Area of node 1}} \quad ...(4.1)$$

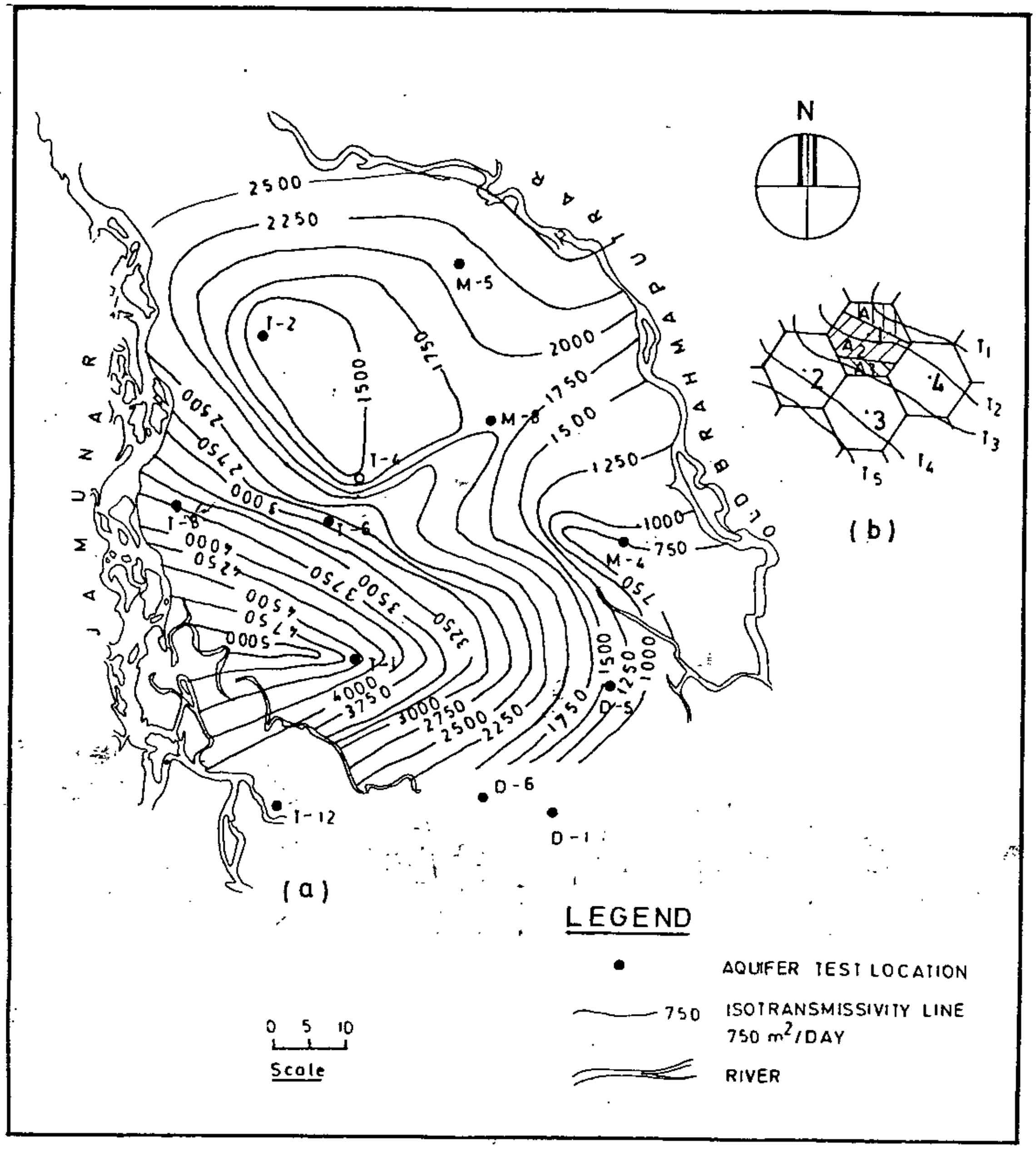


FIG. 4.5 TRANSMISSIVITY CONTOUR MAP (INITIAL ESTIMATE)
(a) ISO TRANSMISSIVITY LINES
(b) SUPERIMPOSED CONDITION

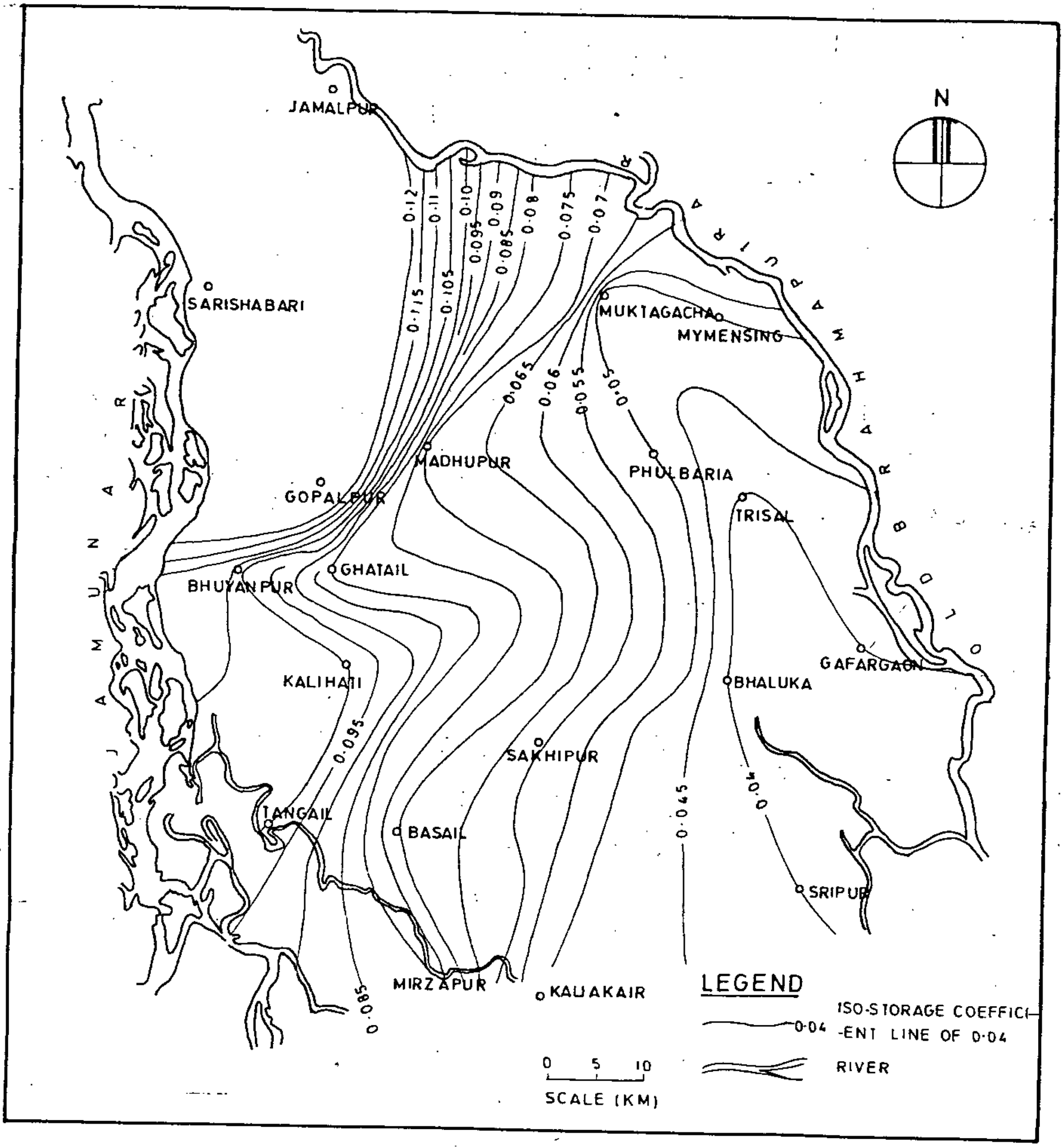


FIG. 4.6 STORAGE CO-EFFICIENT CONTOURS (INITIAL ESTIMATE)

These transmissivity values for adjacent nodes were averaged to represent the transmissivity value of the common side of the two nodes. In this way, initial estimates of the transmissivity values at the polygonal sides have been made.

4.4.2 Storage Coefficient

Storage coefficient can be determined from the aquifer test data. Karim (1984) summarized upazilla-wise values of storage coefficient determined from lithologic and aquifer test data. These values were employed to draw a storage coefficient contour map of the model area as shown in Fig. 4.6. The polygonal network map of the model area was superimposed upon this map. A weighted mean storage coefficient over the nodal area was then calculated for each node as an initial estimate.

4.4.3 Recharge

For the existing conditions of Bangladesh recharge to aquifer occurs mainly by percolation of rainwater, seepage from rivers and return flow from irrigated lands. Karim (1984) summarized upazilla-wise annual recharge values determined from annual groundwater table fluctuation. The monthly recharge values of this annual recharge was estimated from the percentage of annual rainfall occurring at that month. From the monthly values, recharge for each time interval was obtained. Due to the unavailability of monthly recharge values, this rough and very approximate estimate was made. This estimate was subjected to change during calibration and then improved values were obtained.

4.5.0 ESTIMATION OF WITHDRAWAL

The appliances for abstraction from the aquifer comprise deep tubewells (DTW) and shallow tubewells (STW). These are installed mainly by Bangladesh Agricultural Development Corporation and Bangladesh Krishi Bank. Manually operated shallow tubewells for irrigation (MOSTI) and hand pump tubewells (HTW) also play role in the withdrawal of groundwater in the model area. The MOSTIs are set up by Bangladesh Rural Development Board and Bangladesh Krishi Bank. The HTWs are estiablished mainly by the Public Health Engineering Department.

Upazilla-wise number of DTWs, STWs, MOSTIs and HTWs were arrayed for different organizations and added up to get the total number of each type of tubewells as given in Table 4.3 for 1979-'80 and 1982-'83. DTWs and STWs are operated 12 hours per day for 150 days in each year (BWDB,1979). MOSTIs are operated 7 hours per day (MPO, 1984) and considered to be used for the purpose of irrigation from November to May (MPO,1985). To find out extraction by HTW,Farooque (1981) showed that one tubewell is working approximately for 260 people and collection from each tubewell is:

For dry season : 4.02 gallons/capita/day

For rainy season : 3.07 gallons/capita/day

These data were used to obtain the discharge rates of HTW. By means of these available information the abstraction characteristics of DTW, STW, MOSTI and HTW were estimated and given in Table 4.4. The upazilla-wise values of annual extraction has been estimated and given in Table 4.5 for the period 1979-'80 and 1982-'83.

The model area has been divided into three zones to obtain the percentage of monthly distribution of total annual abstraction (MPO,1984) as shown in Fig. 4.7. The zone-wise percentage of monthly distribution of annual extraction by DTWs and STWs are given in Table 4.6. These values were used to determine extraction for different time intervals.

In the model network a certain node may fall in more than one upazilla. The volume of extraction for different portion of the area of node lying in different upazillas were estimated and added up to get the model extraction. A SUBROUTINE was used for the purpose.

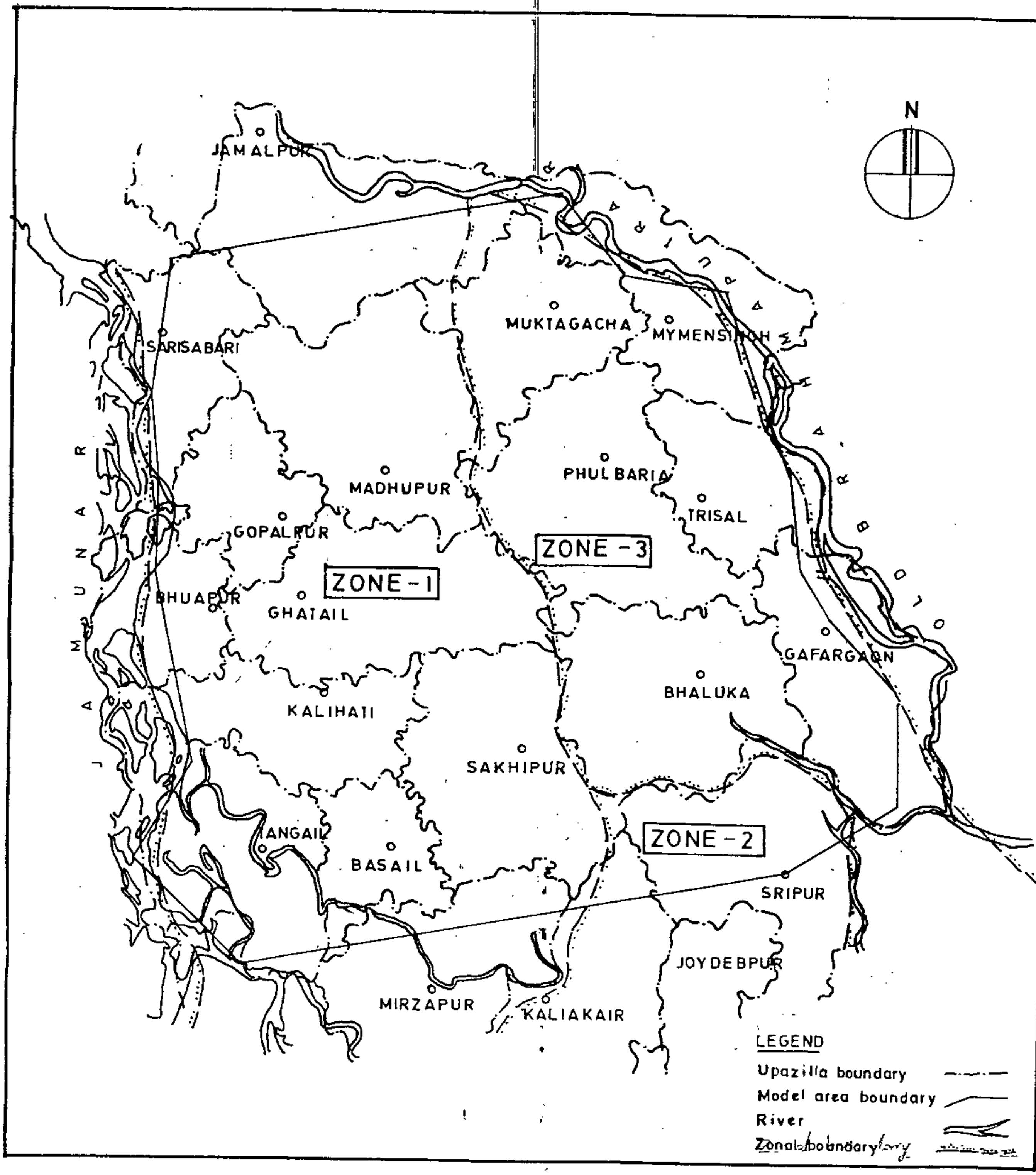


FIG. 4.7 DIFFERENT ZONES FOR VARIATION OF WITHDRAWAL

Table - 4.3: Upazilla-wise total number of tubewells

Name of Upazilla	Total number of tubewells							
	DTW		STW		MOSTI		HTW	
	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83
Jamalpur	126	230	154	1230	266	461	1592	1980
Sarishabari	54	66	94	508	37	145	882	1096
Madhupur	217	209	299	1105	583	604	1487	2194
Gopalpur	141	157	163	1035	3439	3449	697	1029
Bhuyanpur	12	29	79	517	46	58	823	1215
Ghatail	139	173	314	1176	980	1000	1428	2108
Kalihathi	54	89	207	1035	655	668	974	1438
Sakhipur	107	139	102	556	80	100	1436	2108
Tangail	150	152	87	916	1321	1339	1268	1872
Basail	65	90	53	778	131	138	546	806
Mirzapur	121	165	98	852	166	182	1184	1736
Kaliakair	175	213	45	287	146	155	1531	1996
Sreepur	204	210	56	179	68	80	2234	2912
Bhaluka	34	51	62	168	63	206	1525	1894
Gafargaon	88	159	78	108	256	386	1372	1703
Phulbaria	75	251	84	241	74	242	1787	2219
Trisal	62	112	48	69	247	354	1137	1412
Mymensingh	58	96	65	258	54	178	1317	1636
Muktagacha	84	190	88	134	245	348	1092	1356

Table - 4.4: Abstraction rates of tubewells.

Unit	Rated discharge(l/ see)	Actual discharge(l/ see)	Duration of operation	Collection per day (m^3)	Actual annual abstraction (m^3)
DTW	57	43	12 hrs per day for 150 days per year	1857.60	278640.00
STW	21	14	-do-	604.80	90720.00
MOSTI	0.85	0.5	212 days (Mid.October to Mid May.)	12.60	2671.20
HTW	-	0.30	whole year	4.751(November to April) 3.6285 (May to October)	1527.58

Table - 4.5: Upazilla-wise annual extraction

Name of Upazilla	Total extraction per year (million m^3)							
	DTW		STW		MOSTI		HTW	
	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83
Jamalpur	35.10864	64.0872	13.97088	111.5856	0.71055	1.23123	2.43178	3.0242
Sarishabari	15.04656	18.39024	8.52768	46.08576	0.099	0.38789	1.34692	1.6738
Madhupur	60.46488	58.23576	27.12528	100.2456	1.55738	1.6133	2.27105	3.351124
Gopalpur	39.28824	43.74648	14.78736	93.8952	9.18589	9.21268	1.06506	1.571713
Bhuyanpur	3.34368	8.08056	7.16688	46.90224	0.1223	0.1549	1.25682	1.855883
Ghatail	38.73096	48.20472	28.48608	106.68672	2.6174	2.6711998	2.180945	3.219435
Kalihathi	15.04656	24.79896	18.77904	93.8952	1.74958	1.784294	1.487848	2.19654
Sakhipur	29.81448	38.73096	9.25344	50.44032	0.213165	0.26675	2.193652	3.219435
Tangail	41.796	42.35328	7.89264	83.09952	3.52829	3.57674	1.937206	2.859372
Basail	18.1116	25.0776	4.80816	70.58016	0.34945	0.36867	1.065059	1.23117
Mirzapur	33.71544	45.9756	8.89056	77.29344	0.4438	0.48620	1.808983	2.651673
Kaliakair	48.762	59.35032	4.0824	26.03664	0.39022	0.41398	2.338047	2.730721
Sreepur	56.84256	58.5144	5.08032	16.23888	0.18171	0.21375	3.412347	4.44795

Table-4.5 (contd.)

Name of upazilla	Total extraction per year (million m^3)							
	DTW		STW		MOSTI		HTW	
	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83	1979-80	1982-83
Bhaluka	9.47376	14.21064	5.62464	15.24096	0.167736	0.550268	2.32938	2.892987
Gafargaon	24.52032	44.30376	7.07616	9.79776	0.683758	1.03111	2.095463	2.601308
Phulbaria	20.898	69.93864	7.62048	21.86352	0.198022	0.6465	2.729647	2.389475
Trisal	17.27568	31.20768	4.35456	6.25968	0.659297	0.94585	1.736208	2.156687
Mymensingh	16.16112	26.74944	5.8968	23.40576	0.14444	0.47525	2.00998	2.498961
Muktagacha	23.40576	52.9414	7.98336	12.15648	0.654637	0.92954	1.668053	2.071205

Table- 4.6: Zone - wise percentage of annual extraction by DTW & STW for different months (MPO,1985)

	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Zone-1	DTW	17.0	19.9	30.6	23.9	5.4	0.0	0.0	0.0	0.0	0.0	0.0	3.2
	STW	19.9	19.1	31.1	20.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	8.7
Zone-2	DTW	13.1	17.8	30.4	25.8	9.9	0.3	0.3	0.0	0.0	0.0	0.0	2.5
	STW	17.2	22.9	28.2	24.0	2.6	0.1	0.0	0.0	0.0	0.0	0.0	5.0
Zone-3	DTW	14.9	19.5	29.9	26.1	7.9	0.0	0.0	0.0	0.0	0.0	0.0	1.8
	STW	16.2	24.6	27.0	23.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	7.2

CHAPTER FIVE

SIMULATION OF GROUNDWATER MOVEMENT

5.1.0 PREVIOUS MODEL STUDIES IN BANGLADESH

Till now seven groundwater model studies have been done in Bangladesh. These studies have been discussed in the second interim report of Master Plan Organization (1984). Various parameters of these models are given in the Table 5.1. It is observed that all of the model studies have been done by foreign consulting firms.

Table- 5.1: Parameters of model studies in Bangladesh.

Project	Year	Model Type	Location of model application	Model area (km^2)	Representation of aquifer	Grid system	Objective
BADC/IDA Tubewell project	1977	Finite difference single layer model	North of the Atrai basin of the North-west region and the area between the rivers Atrai and Ganges.	29500	Semiconfind or unconfind	Regular hexagonals	Forecast of DTW development.

Table 5.1 (contd.)

Project	Year	Model type	Location of model application	Model area (km^2)	Representation of aquifer	Grid system	Objective
ADB tubewell project North Bangladesh	1980	Finite difference single layer model	Part of Dinajpur and Rangpur districts.	-	Unconfined	Polygons varying in size, shape and orientation	Forecast of DTW development and refinement of Northwest region model studies.
Rajshahi, Pabna groundwater system	1980	Two layer finite-difference model	Rajshahi and Pabna districts	-	Confined aquifer over lain a semi-confining layer	-do-	Forecast of DTW development
Development plan for water supply and waste water systems for Dhaka metropolitan area	1980	Single layer finite-difference model	Dhaka metropolitan area	5380	Semiconfined	Regular network	Assessment of piegometric declines under different future abstraction for period 1980-2010
ADB 2 DTW project	1982	Single cell model	Areas of Northwest region	-	-	-	To simulate aquifer response and to test the effect of river level fluctuation on the aquifer.

Table 5.1 (contd.)

Project	Year	Model type	Location of model application	Model area (km^2)	Representation of aquifer	Grid system	Objective
Southwest rural development project	1984	Finite difference layer model	Jessore, Kushtia and Faridpur	14,500	Semiconfined	square polygons	Forecast of STW/ DTW development potential
Northwest Bangladesh groundwater system	-	Two layer finite-difference model	Rajshahi division	-	Single aquifer overlain by a semiconfining layer	Polygons varying in size, shape & orientation.	To obtain estimates of STW development levels

5.2.0 INITIAL CONDITION

An unsteady state problem is solved numerically for simulation of groundwater movement. This requires initial conditions to be defined in the nodal configuration. The initial conditions are the values of the dependent variable i.e. groundwater level specified at the centriod of nodes at the start of the computation.

Water table observation wells serve the purpose of establishing water table elevation for each node of the model network geometry. The observation wells installed by Bangladesh Water Development Board and lying within the the model area are shown in Fig. 5.1. From the existing data fortnightly water table elevations were computed by interpolation for each observation well. This was done after each 15 days time interval for the whole year of the data of 1979-'80 and 1982-'83.

Groundwater level contour maps were drawn representing iso-water table elevation lines with the help of the observation wells groundwater level. Groundwater level contour map on Ist April, 1979 and 1982 are shown in Fig. 5.2. Superimposing the nodal network map upon these maps a weighted mean value with respect to each of the nodal areas were computed from iso-water table elevation lines. These computed

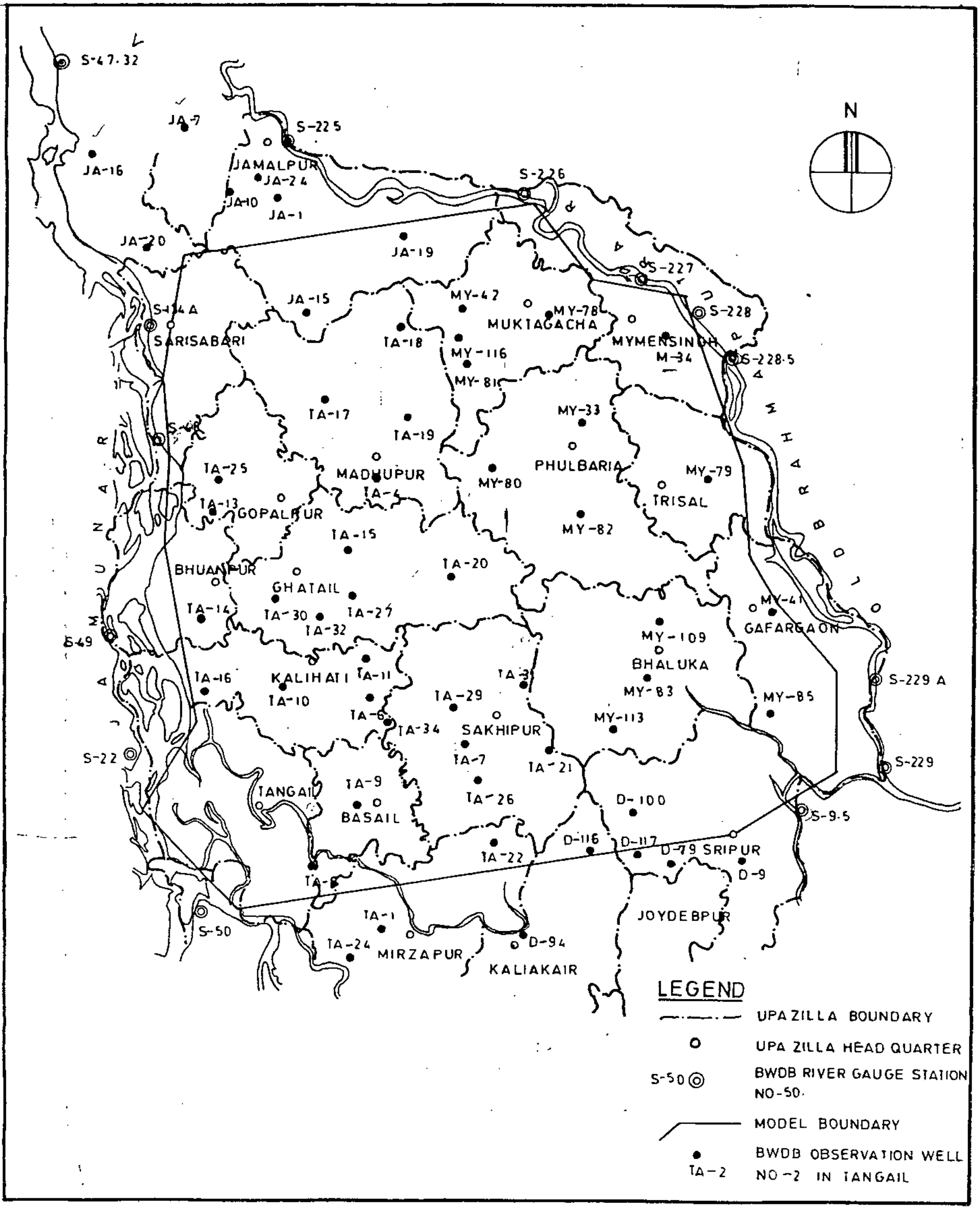


FIG. 5.1 LOCATION OF OBSERVATIONWELLS AND RIVER GAUGE STATION

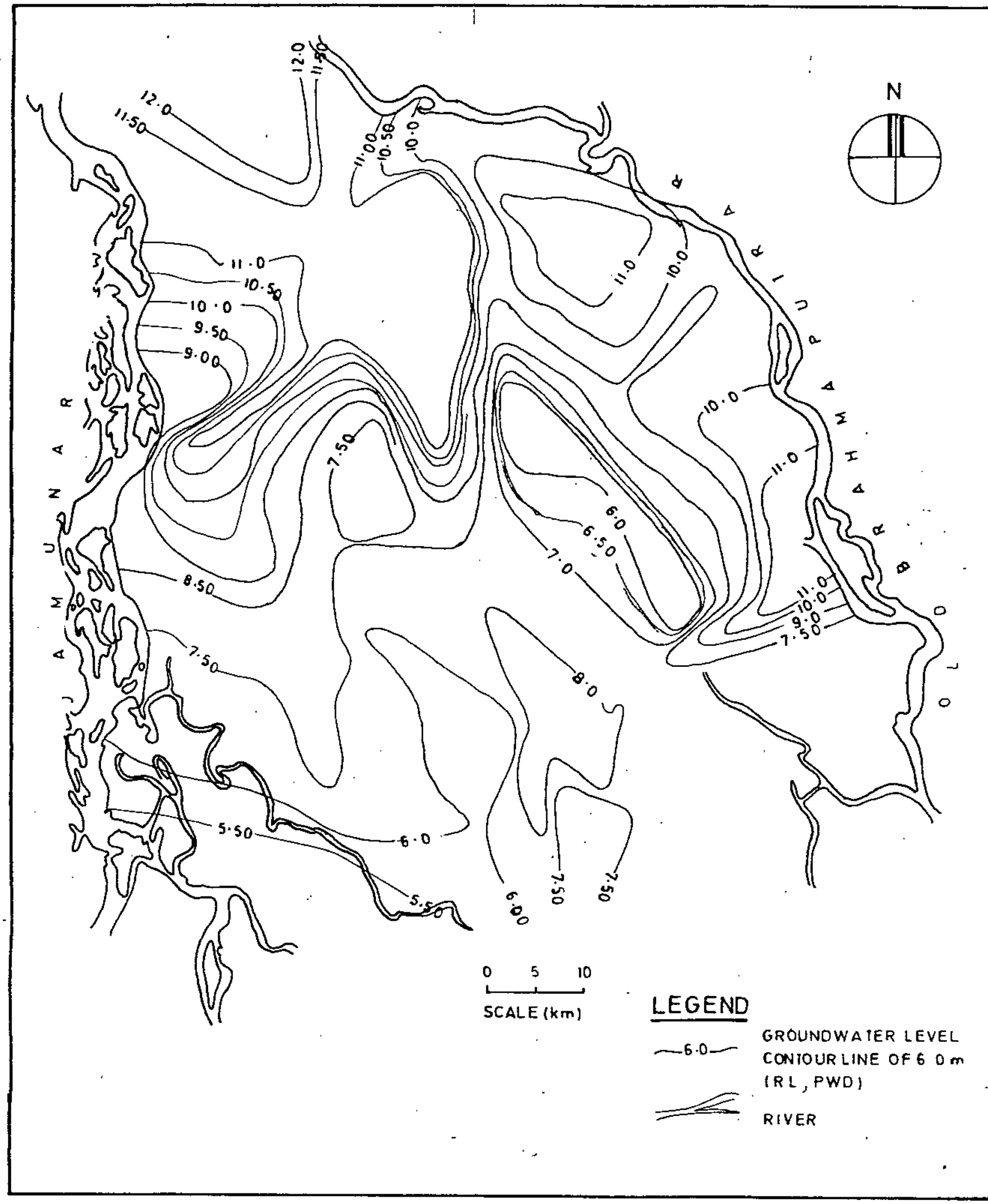


FIG.5.2a GROUNDWATER LEVEL CONTOUR MAP ON APRIL 1, 1979

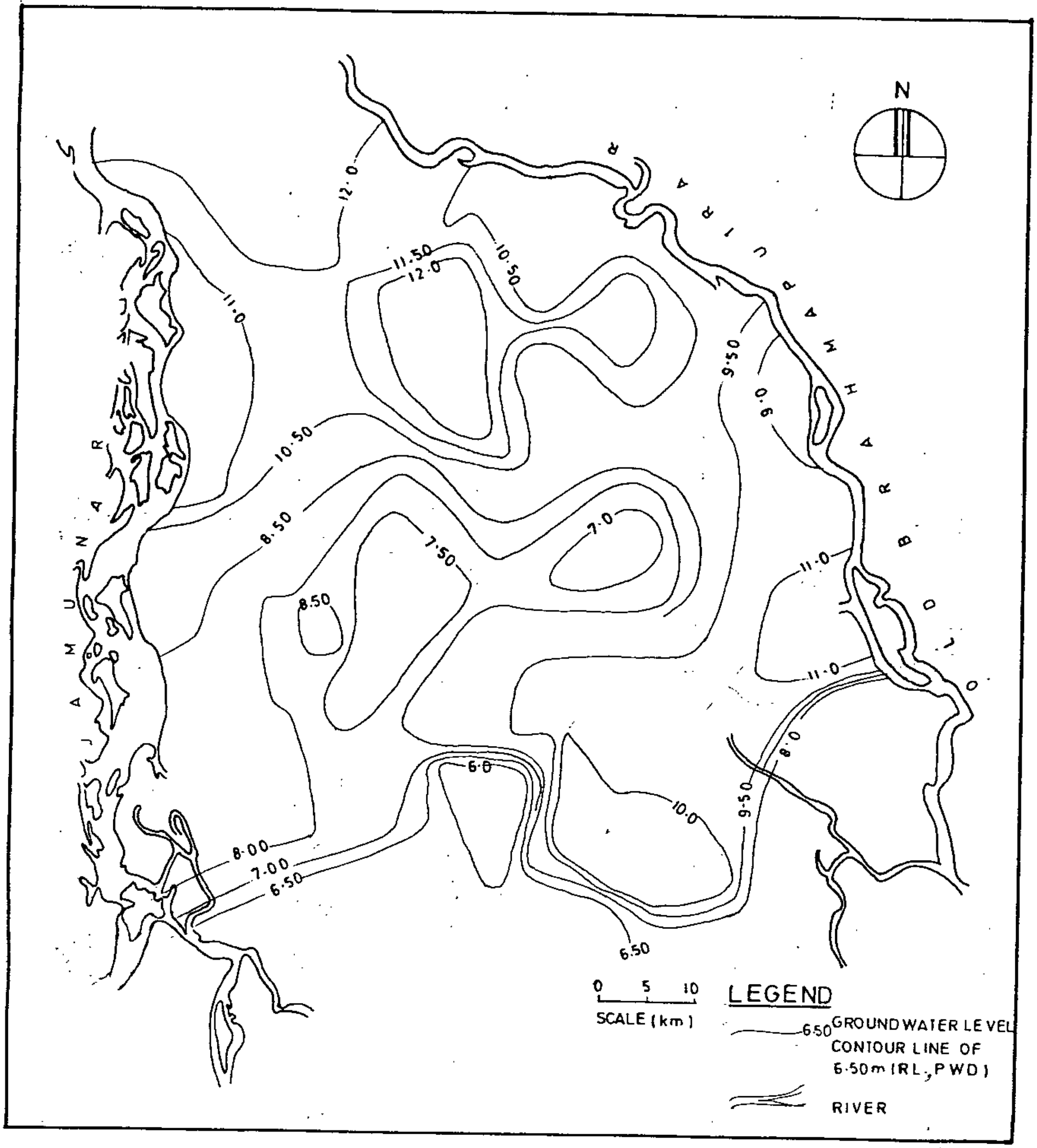


FIG. 5.2b GROUND WATER LEVEL CONTOUR MAP ON APRIL 1, 1982

values represent initial groundwater table elevation at each node.

5.3.0 BOUNDARY CONDITION

5.3.1 Head Controlled Boundary

The head controlled boundaries, defined by the river Jamuna to the west and Brahmaputra to the east are shown in Fig. 5.1. River water levels were allocated to external boundary nodes. The daily records of the water level variation of the rivers Jamuna and old Brahmaputra were available at the stations as shown in Fig. 5.1. The annual water level variation of the rivers Jamuna and old Brahmaputra at two selected stations are shown in Fig. 5.3 and 5.4. It is observed that the yearly water level fluctuation is 6.7 m and 5.18 m for Jamuna and old Brahmaputra respectively.

From the data of gauge stations, the water level profiles of the two rivers at each time step were drawn for the years 1979-'80 and 1982-'83. That required a total of 100 profiles of the two rivers. Of them, Fig. 5.5 and 5.6 show the observed profiles of the two rivers representing variations in dry and wet season. Superimposing the nodal network map upon the station map (Fig. 5.1) the position of the external nodes in respect of the gauge stations were

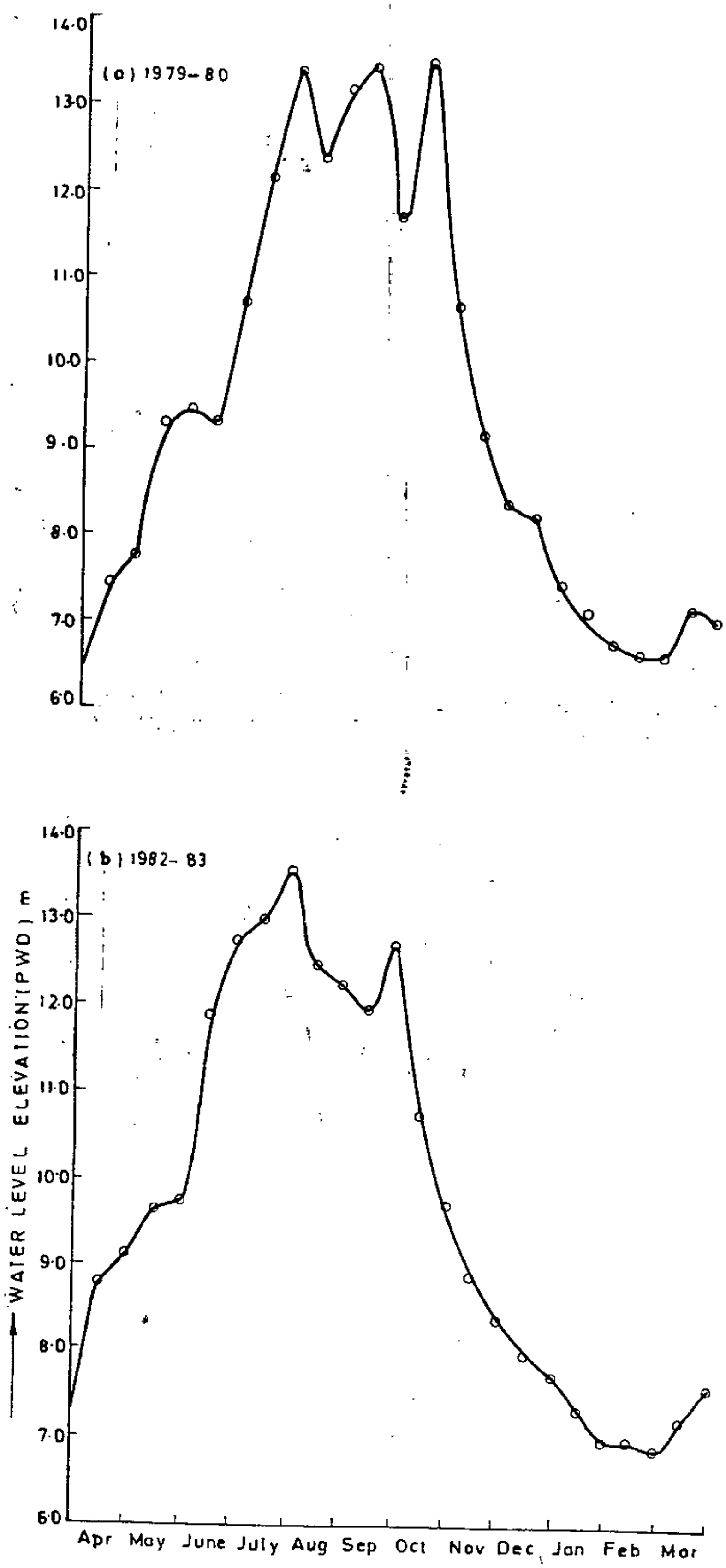


FIG. 5.3 ANNUAL WATER LEVEL VARIATION OF JAMUNA (BWDB STATION NO: S-49)

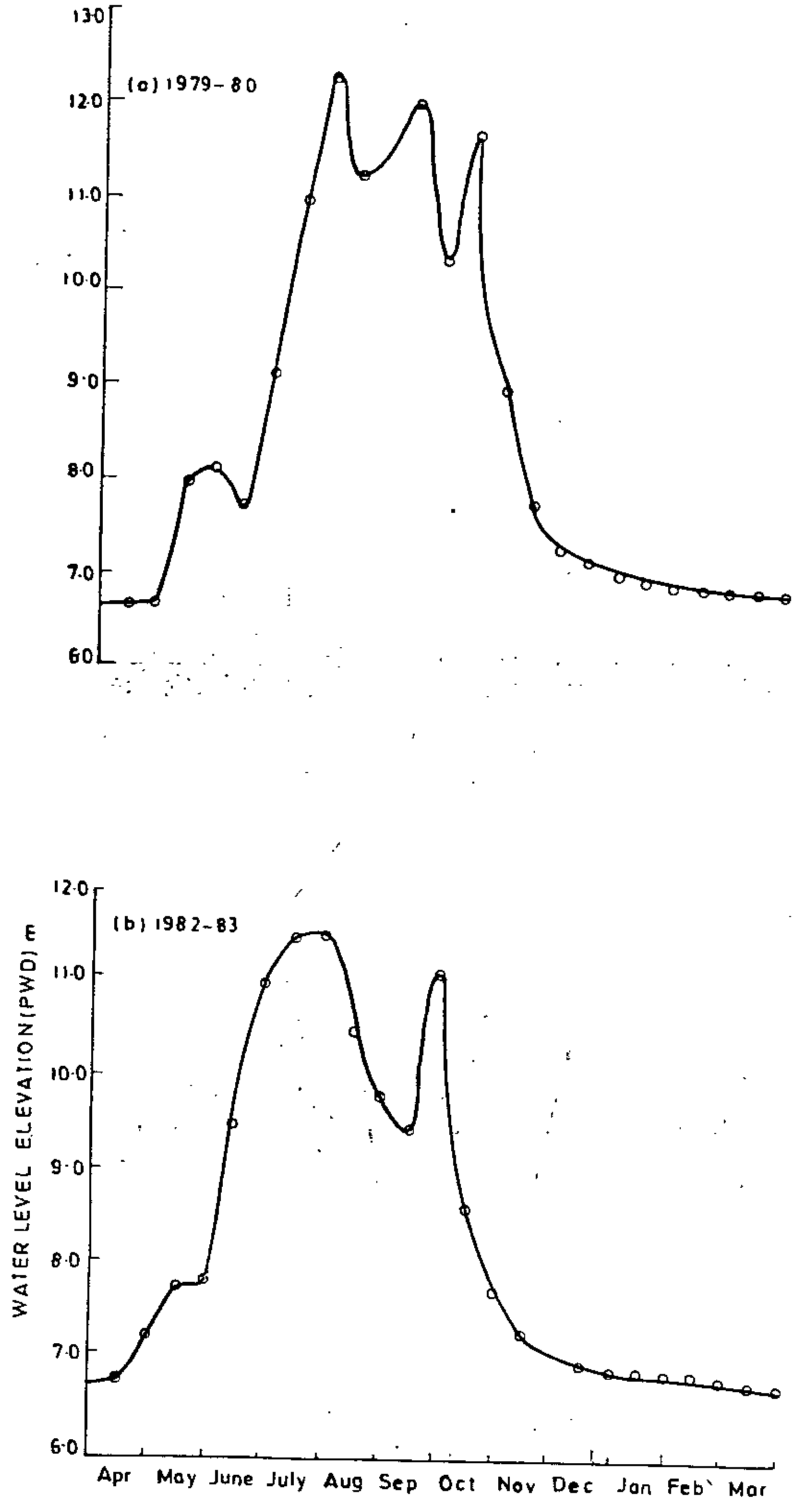


FIG.5.4 ANNUAL WATER LEVEL VARIATION OF OLD BRAHMAPUTRA (BWDB STATION NO:S-228)

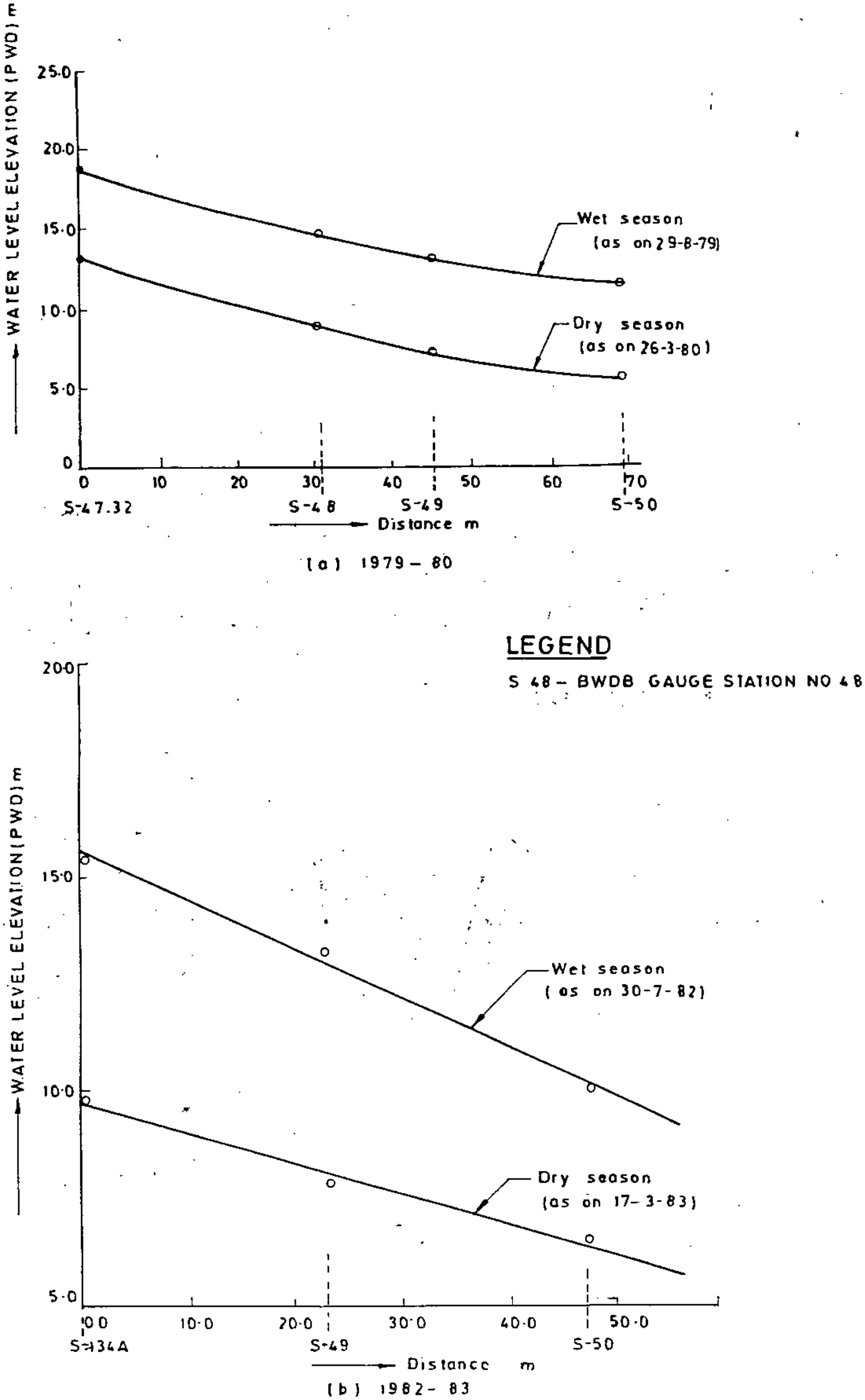


FIG.5.5 WATER LEVEL PROFILE OF JAMUNA

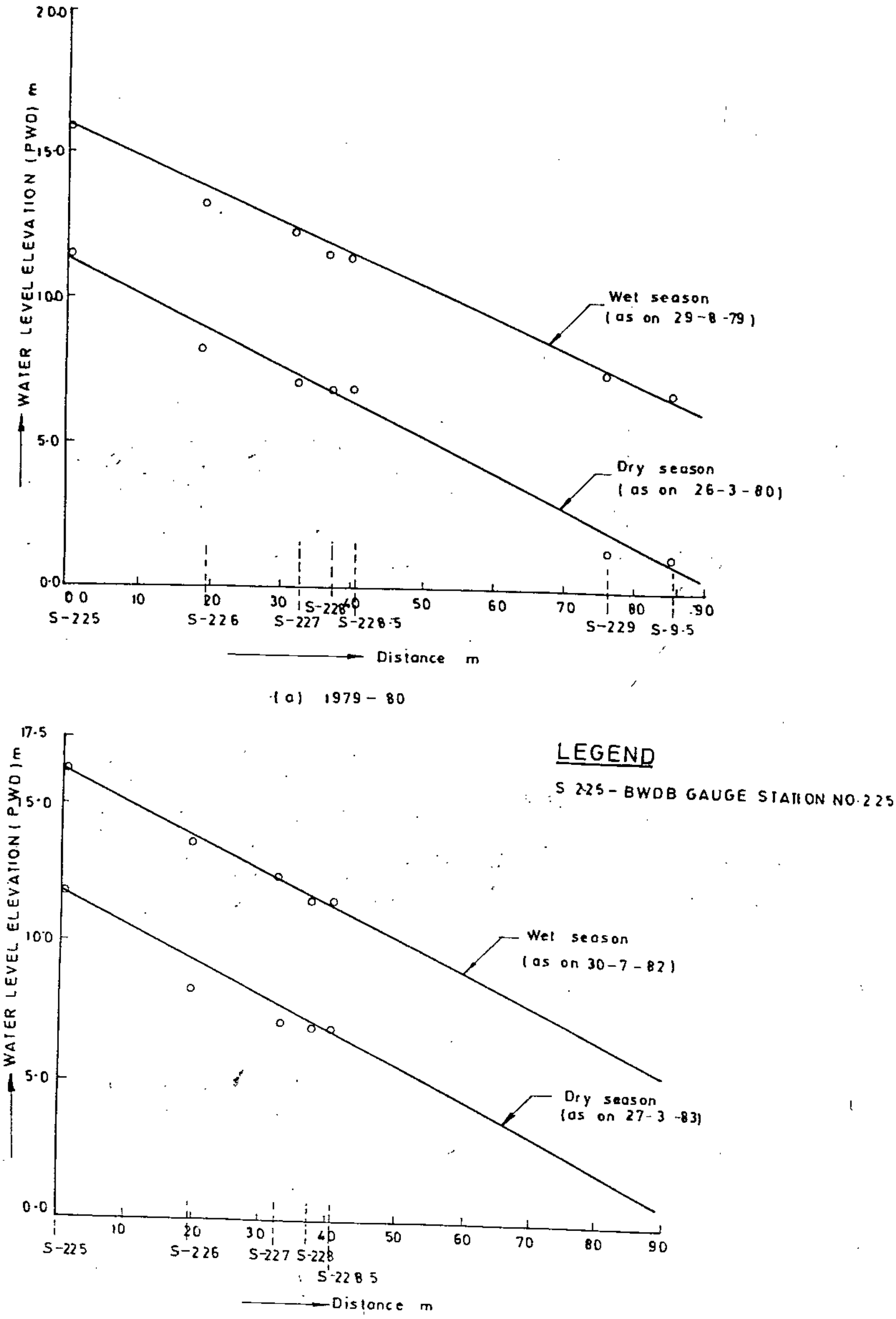


FIG. 5.6 WATER LEVEL PROFILE OF BRAHMAPUTRA

found out. Knowing this, the value of water level for each external node was obtained from the river profiles at each time step.

5.3.2 Gradient Specified Boundary

The north and south border of the model area are considered as gradient specified boundaries (Fig. 5.1). They were defined by the slope of the flow line associated with the boundary node. The iso-water table elevation lines those pass through these boundaries were drawn for each time step. Then the slope of the flow lines passing through each of the boundary nodes were computed. These values were allocated as gradients for each of the boundary nodes at each time step.

5.4.0 SENSITIVITY TEST

A sensitivity analysis has been done by making arbitary changes in calibration parameters. Four tests have been made. They involved 10% decrease in coefficient of transmissivity, 10% increase in coefficient of storage, 10% decrease in recharge and 10% change simultaneously in each of the three parameters. The resulting changes in computed water level in polygon 1 and 76 have been compared in the Fig. 5.7.

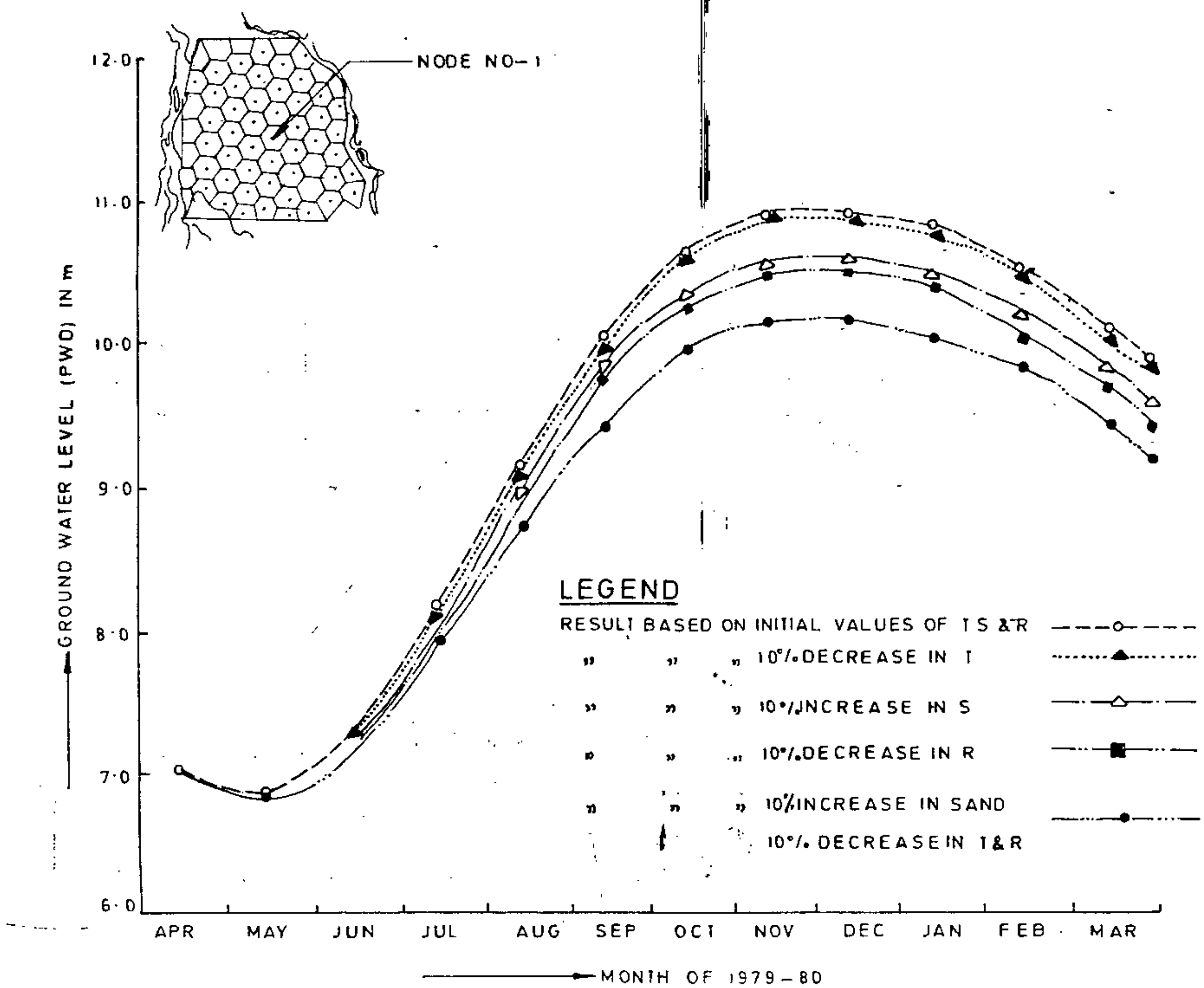
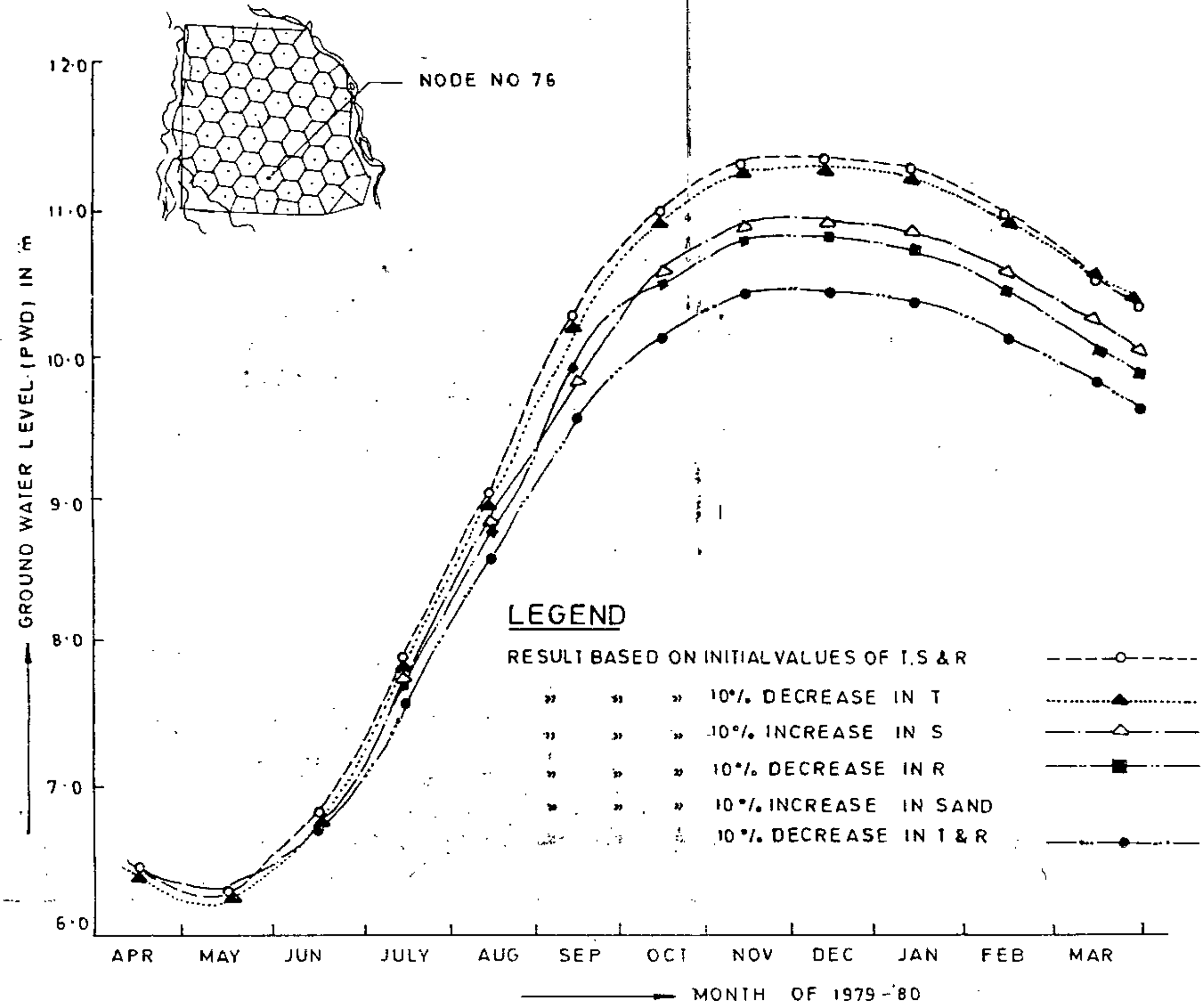


FIG 5.7a TYPICAL RESULTS OF SENSITIVITY TEST: COMPUTED WATER LEVELS AT NODE NO-1



66123

FIG. 5·7b TYPICAL RESULTS OF SENSITIVITY TEST; COMPUTED WATER LEVEL AT NODE NO-76

It shows that the groundwater table is most sensitive to vertical recharge while it is least sensitive to the coefficient of transmissivity. Boonstra and Ridder (1981) also observed that recharge reacts more sharply than the parameters S and T and this was also found to be true for most groundwater basins.

5.5.0 CALIBRATION

The calibration process involved adjustment of S,T and R until reasonable agreement between groundwater level contours drawn from observed and computed water levels in April'79 to March'80 was obtained. It was observed that the computed groundwater level was mainly higher than the observed value when the model was run wtih preliminary estimated values of S,T and R. The difference was large in the period September'79 to March'80 when most of the withdrawal takes place. Adjustment in T and S has been made to obtain agreement during October to March (no recharge season) in the year 1979-'80. Then the recharge has been adjusted at every time step at every polygon to obtain agreement during the period April to September (recharge season) in the year 1979-'80.

Comparison between computed and observed water level variation at polygon 1,14,62 and 76 are given in Fig. 5.8. Comparison of water level contours drawn through observed and computed water levels are shown in Fig. 5.9. These comparisons show that the simulations are acceptable for all practical purpose. Contours drawn through calibrated values of T and S are shown in Fig. 5.10. Upazilla-wise values of T and S are also given in the Table 5.2.

Monthly recharge values in each of the 19 upazillas in 1979-'80 are determined from calibrated values of recharge in the polygons. They are given in Table 5.3. A typical comparison of monthly recharge and monthly rainfall in Bhaluka upazilla is given in Fig. 5.11. The observed groundwater level variation in that upazilla is also shown in the same figure. The annual recharge in each of 19 upazillas in 1979-'80 are also determined. They are given in the Fig. 5.12. Then total monthly recharge in the whole model area is determined. A comparison of monthly recharge values and montly rainfall for the whole model area is shown in the Fig. 5.13.

It is impossible to determine the groundwater withdrawal accurately in each of the polygon. Groundwater withdrawal was estimated by collecting information on the number of deep, shallow, hand pump tubewells and manually operated shallow tubewells for irrigation. Next, an withdrawal rate is obtained. MPO suggested pumping hours 1000 for DTW and 900 for STW per season while BWDB suggested pumping hours 1800 for DTW and STW per season. The model was run separately using MPO values and BWDB values of withdrawal rates. It was observed that model results corresponding to BWDB withdrawal rates agree closely with observed values.

A typical comparison of computed water level with observed water level is given in Fig. 5.14. It shows that computed water level corresponding to MPO withdrawal rates is much higher. This indicates under-estimation in the MPO suggested withdrawal rates.

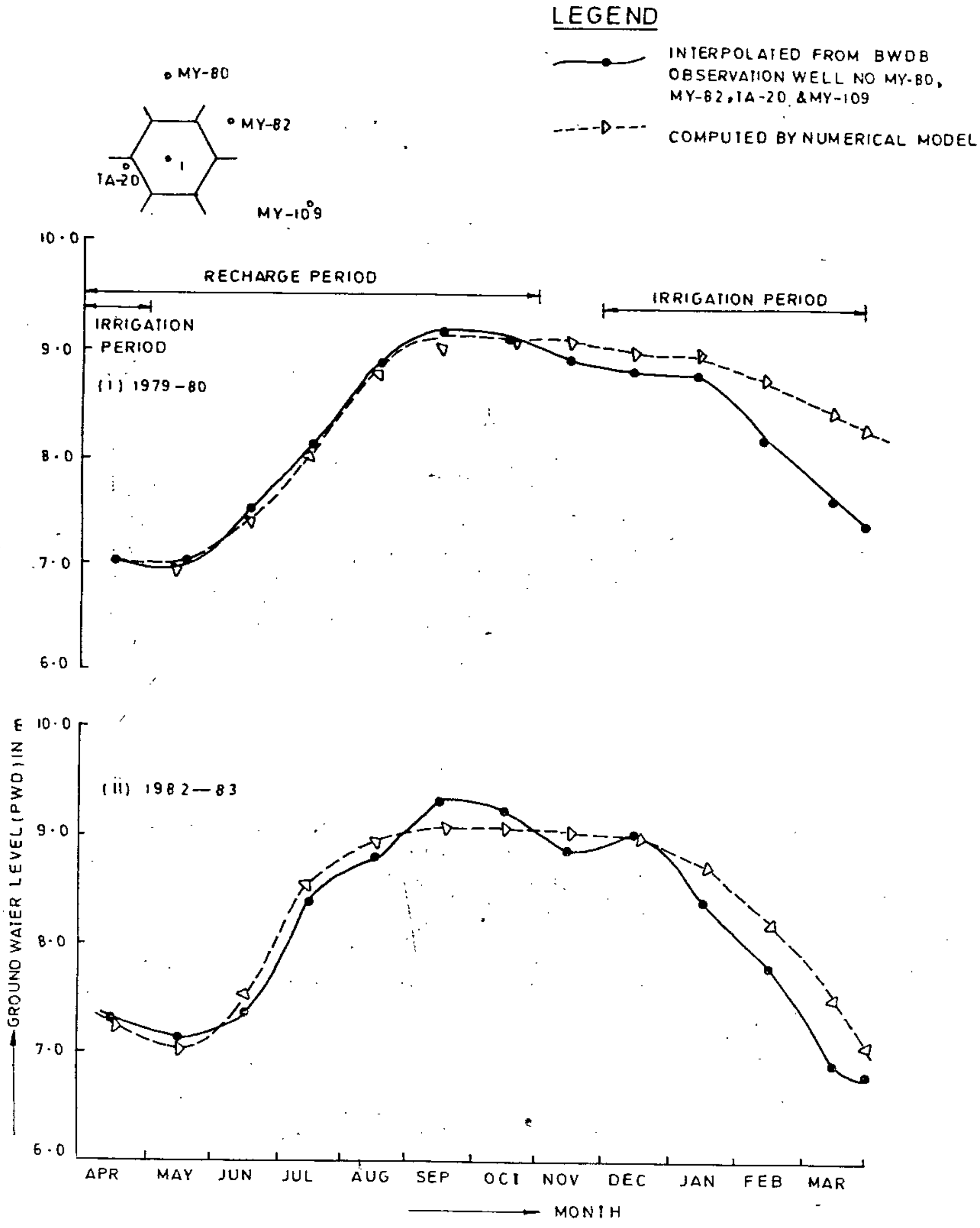


FIG. 5.8a. COMPARISON OF COMPUTED AND OBSERVED GROUND-WATER LEVEL AT NODE NO.1

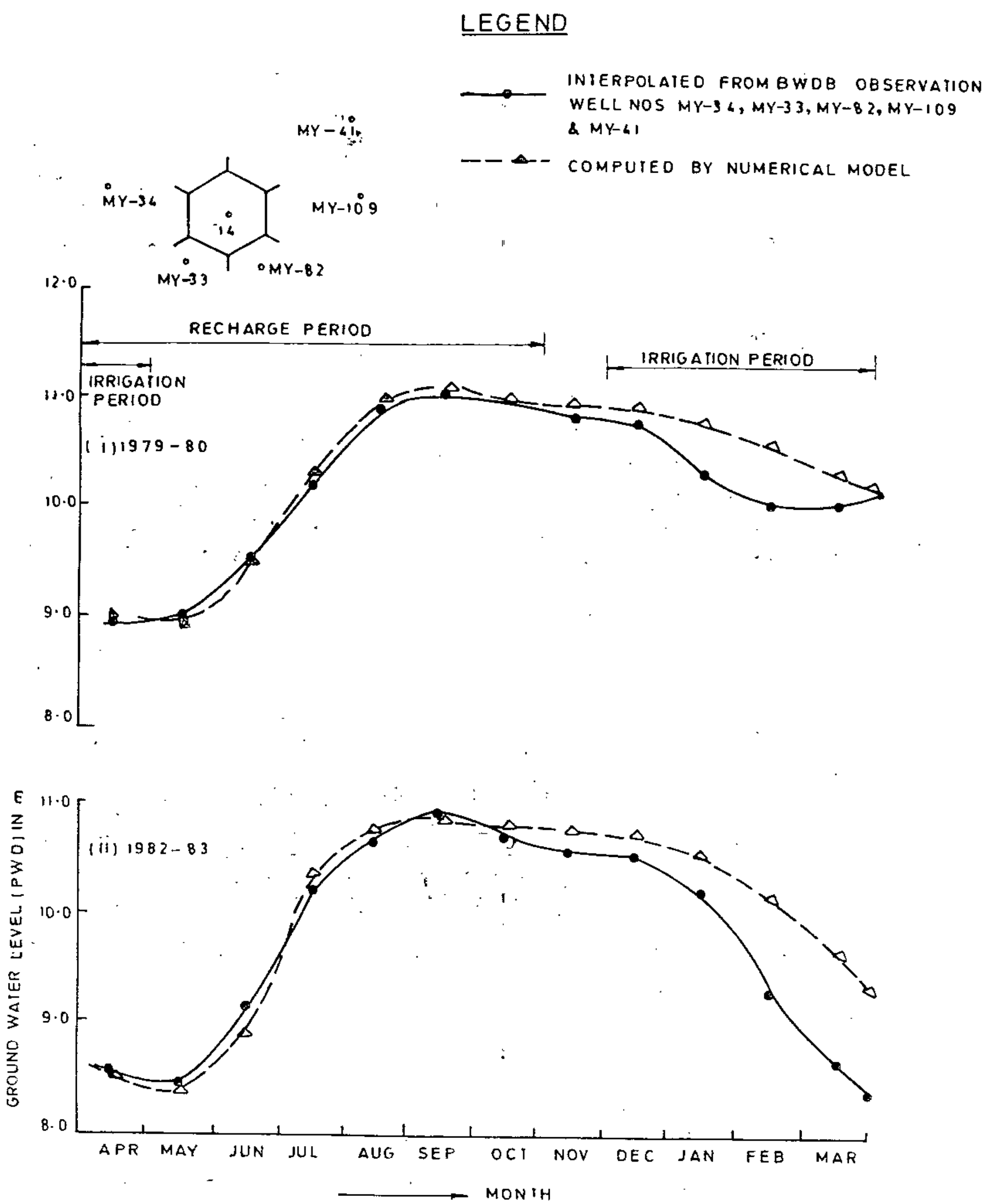


FIG. 5.8b COMPARISON OF COMPUTED AND OBSERVED GROUND WATER LEVEL AT NODE NO. 14

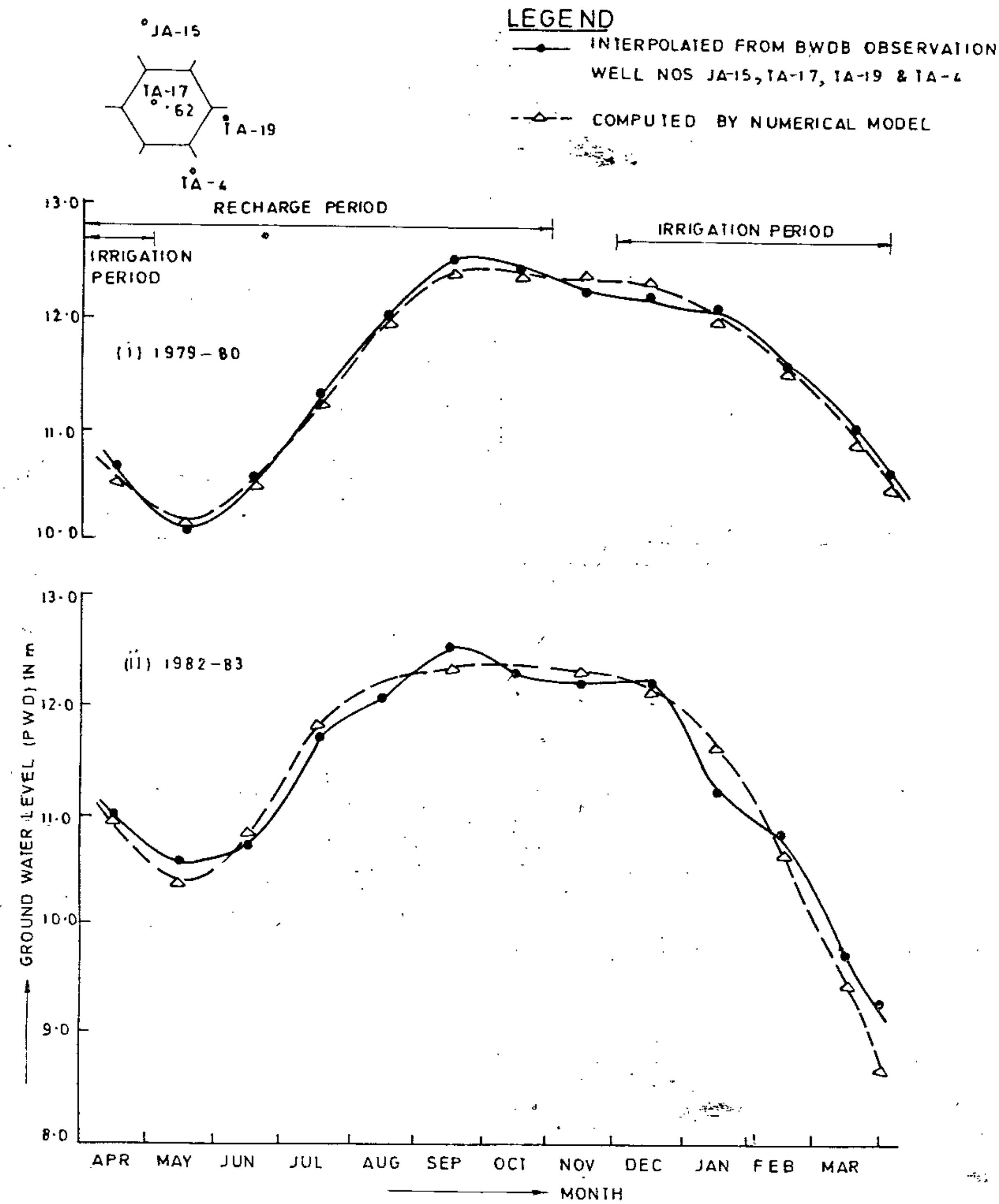


FIG. 5.8c COMPARISON OF COMPUTED AND OBSERVED GROUND WATER LEVEL AT NODE NO. 62

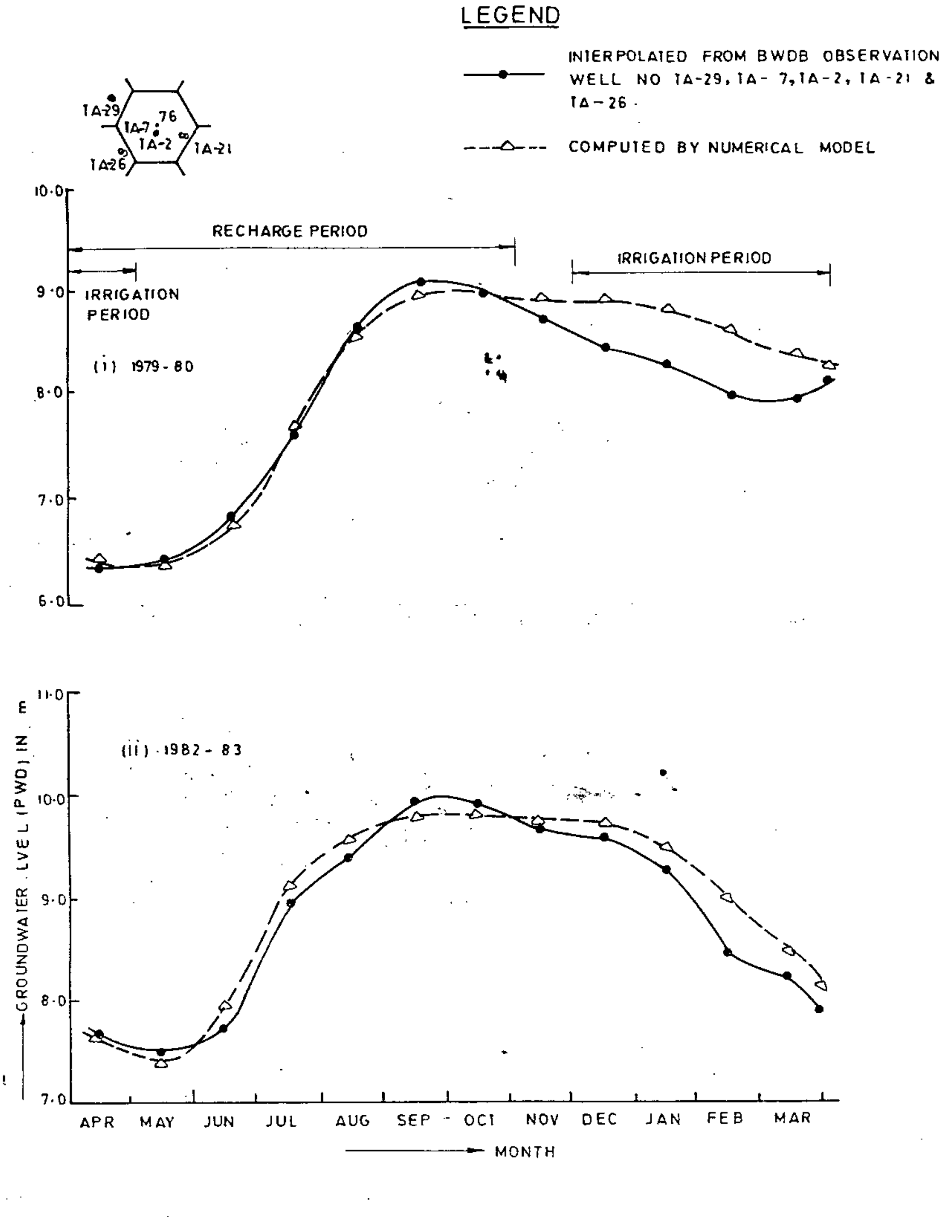


FIG.5.8d COMPARISON OF COMPUTED AND OBSERVED GROUND WATER LEVEL AT NODE NO. 76

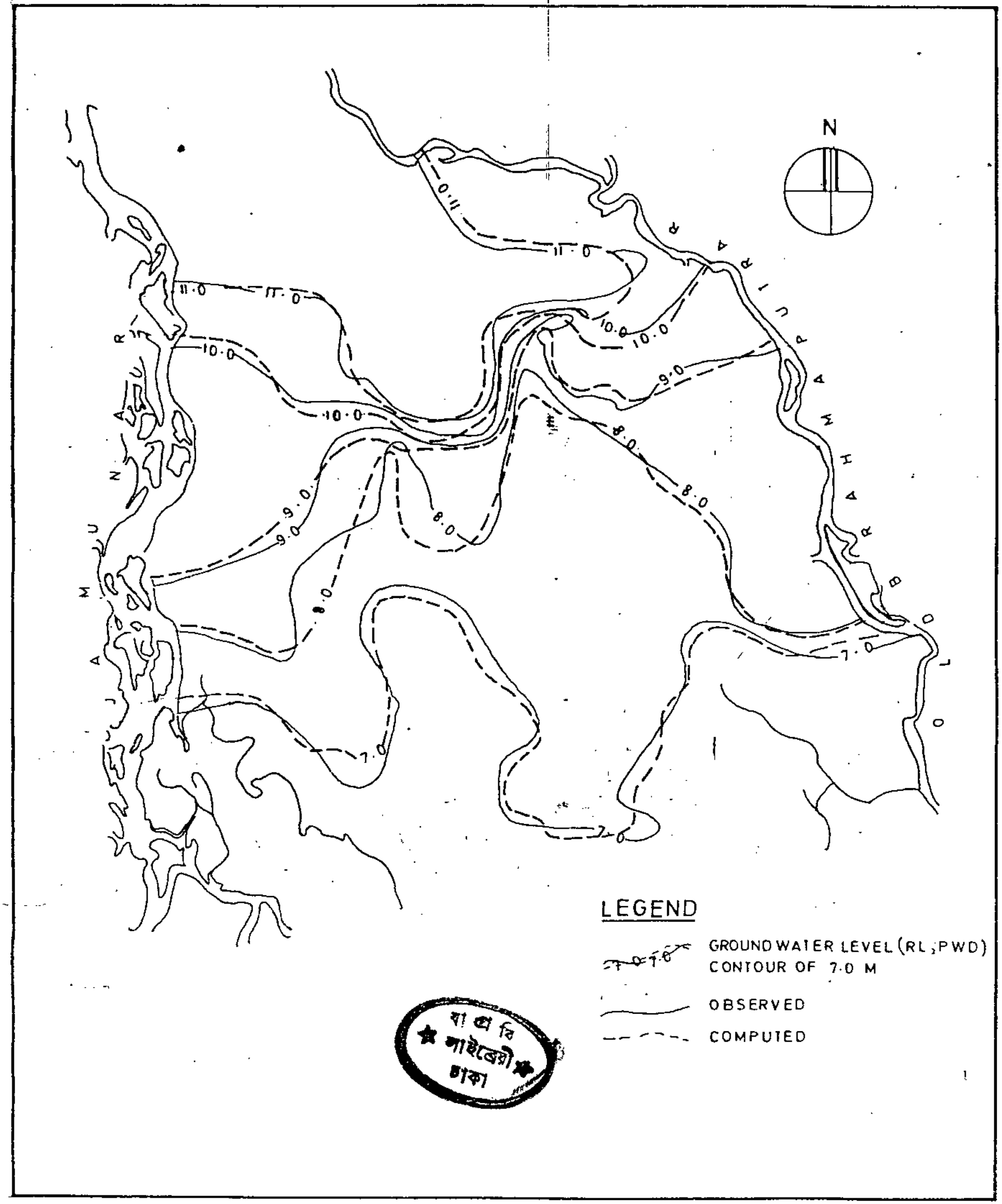


FIG. 5.9a COMPARISON OF COMPUTED AND OBSERVED GROUND WATER LEVEL CONTOURS ON 16-04-79.

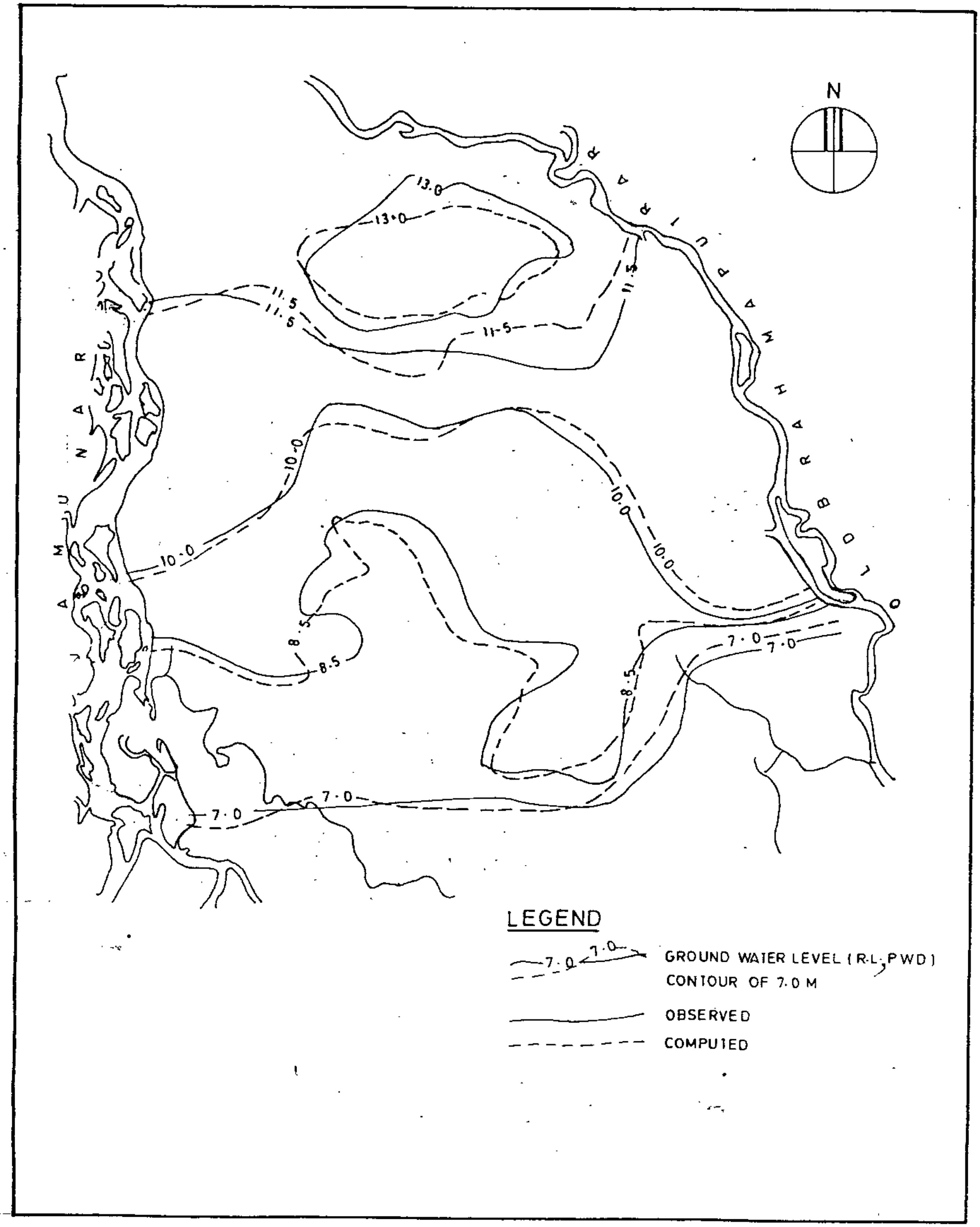


FIG. 5.9b COMPARISON OF COMPUTED AND OBSERVED GROUNDWATER LEVEL CONTOURS ON 15-07-79

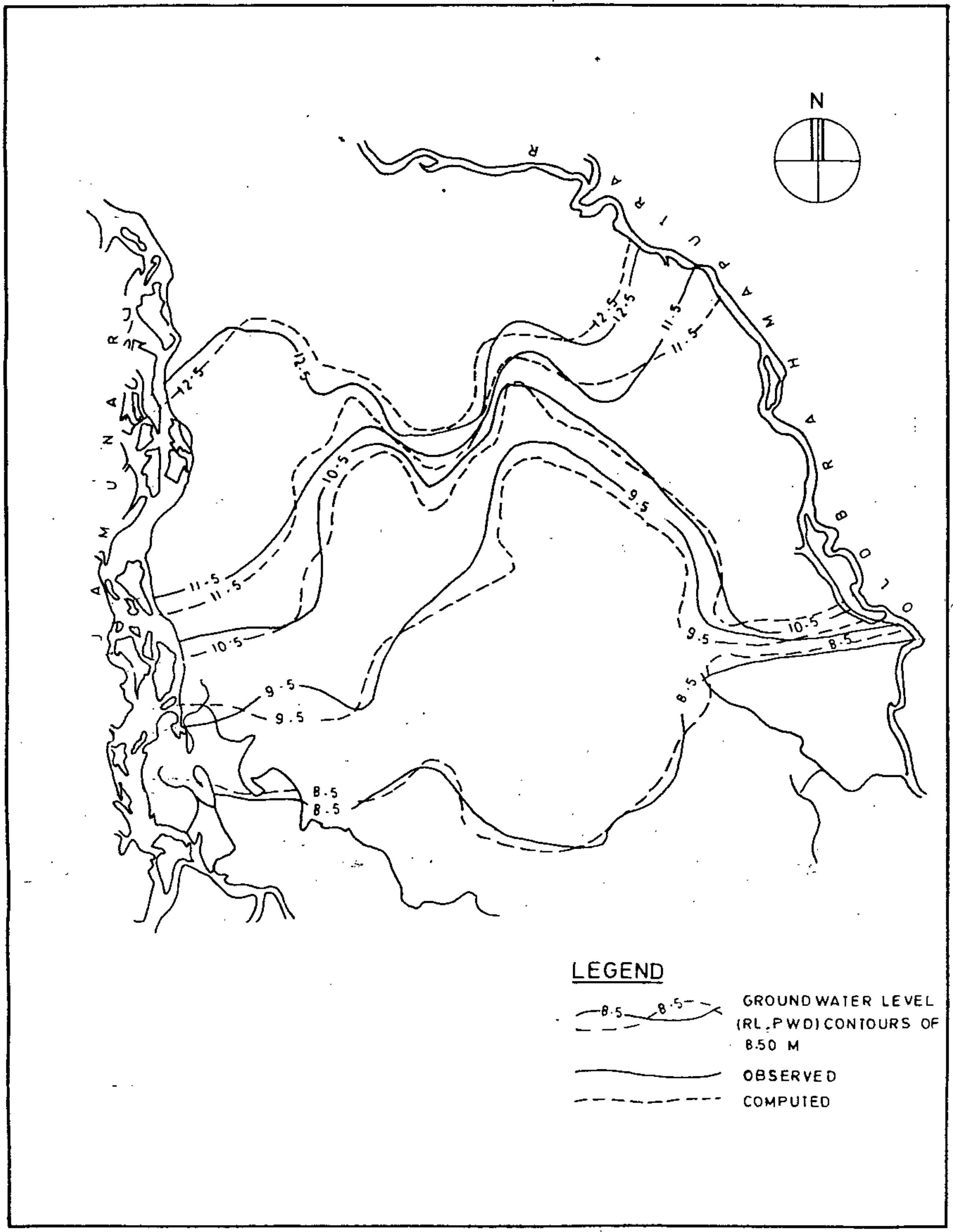


FIG. 5.9c COMPARISON OF COMPUTED AND OBSERVED GROUND WATER LEVEL CONTOURS ON 12-11-79

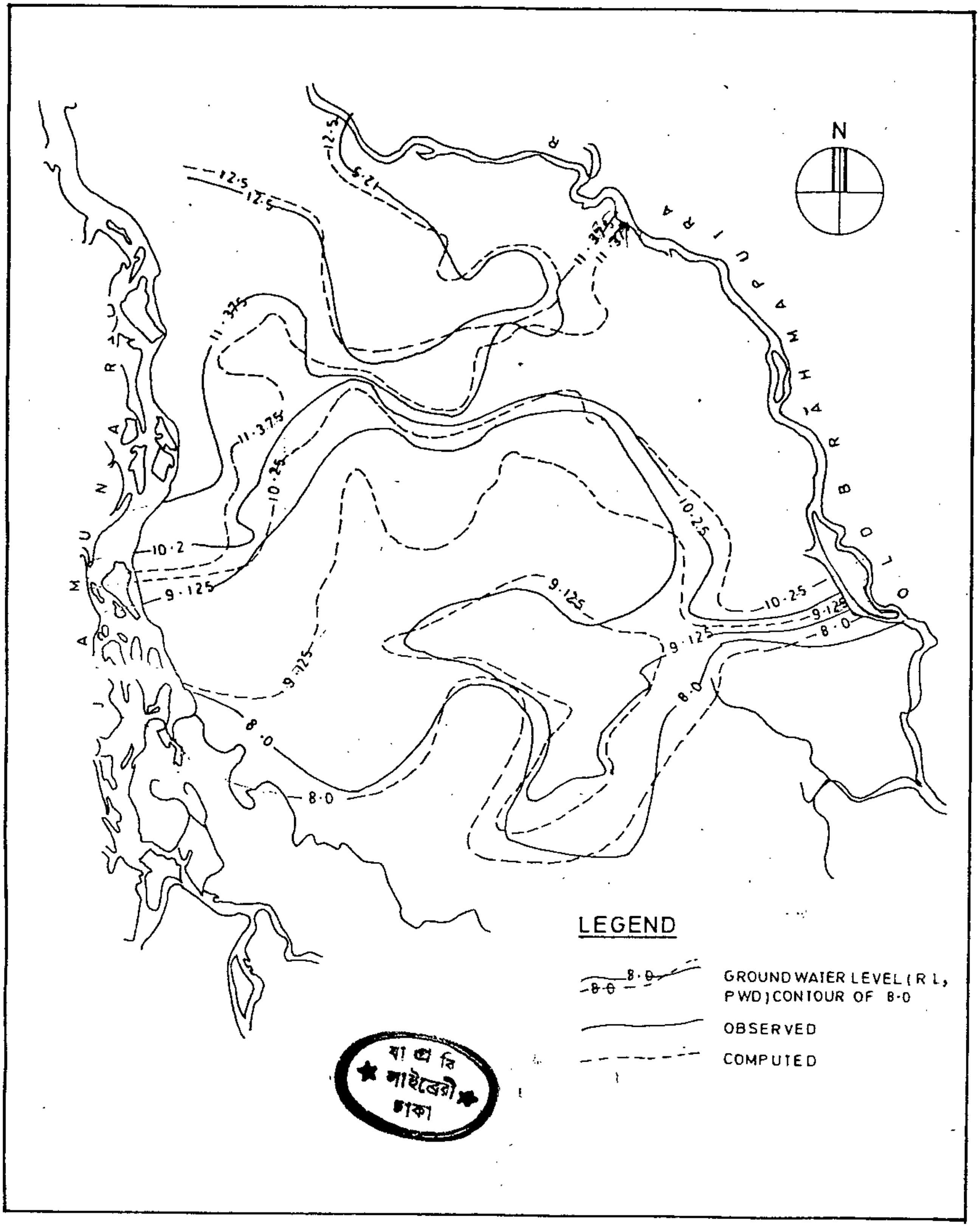


FIG. 5.9d COMPARISON OF COMPUTED AND OBSERVED GROUNDWATER LEVEL CONTOURS ON 11-03-80

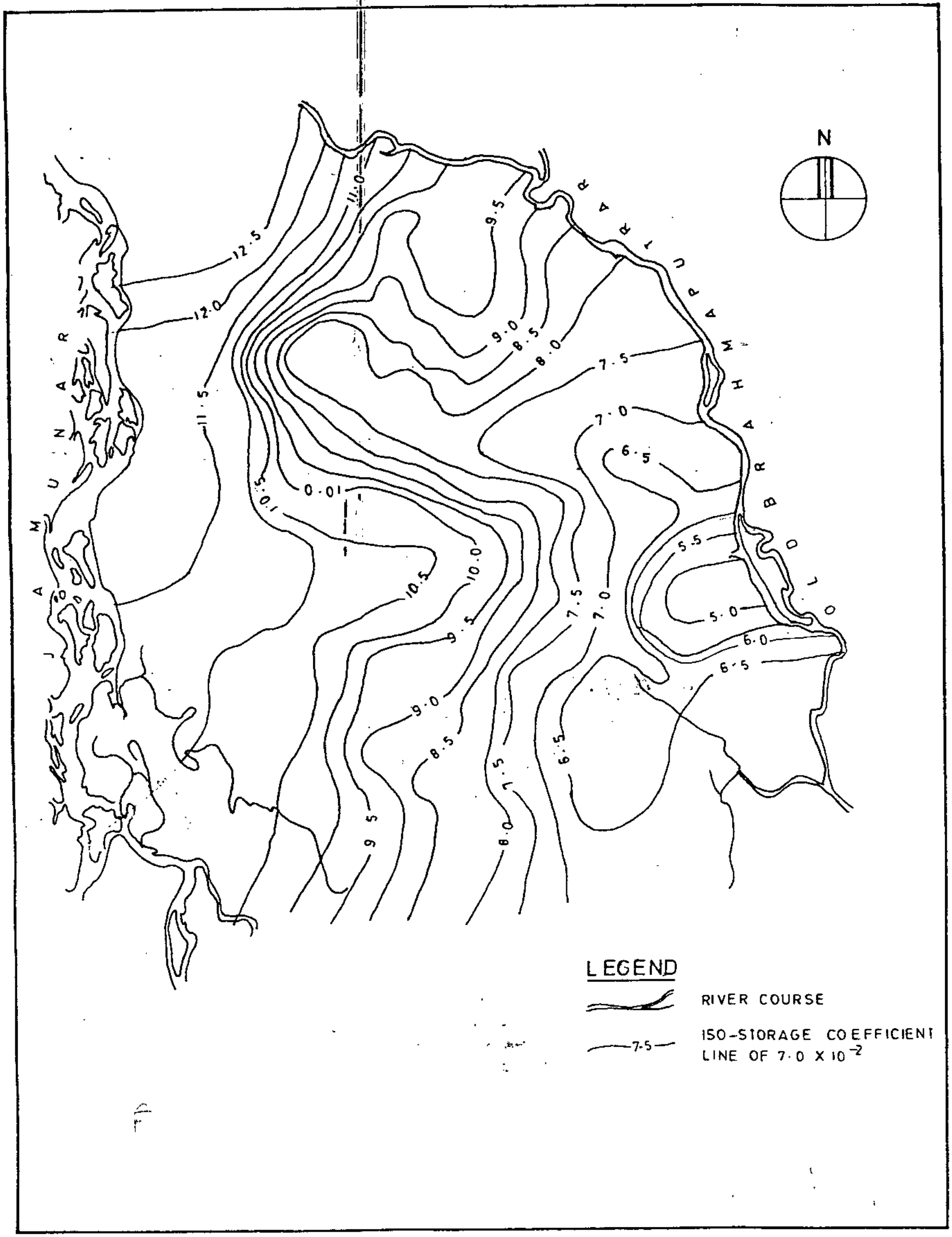


FIG. 5.10a STORAGE CO EFFICIENT CONTOURS (AFTER MODEL CALIBRA-TION)

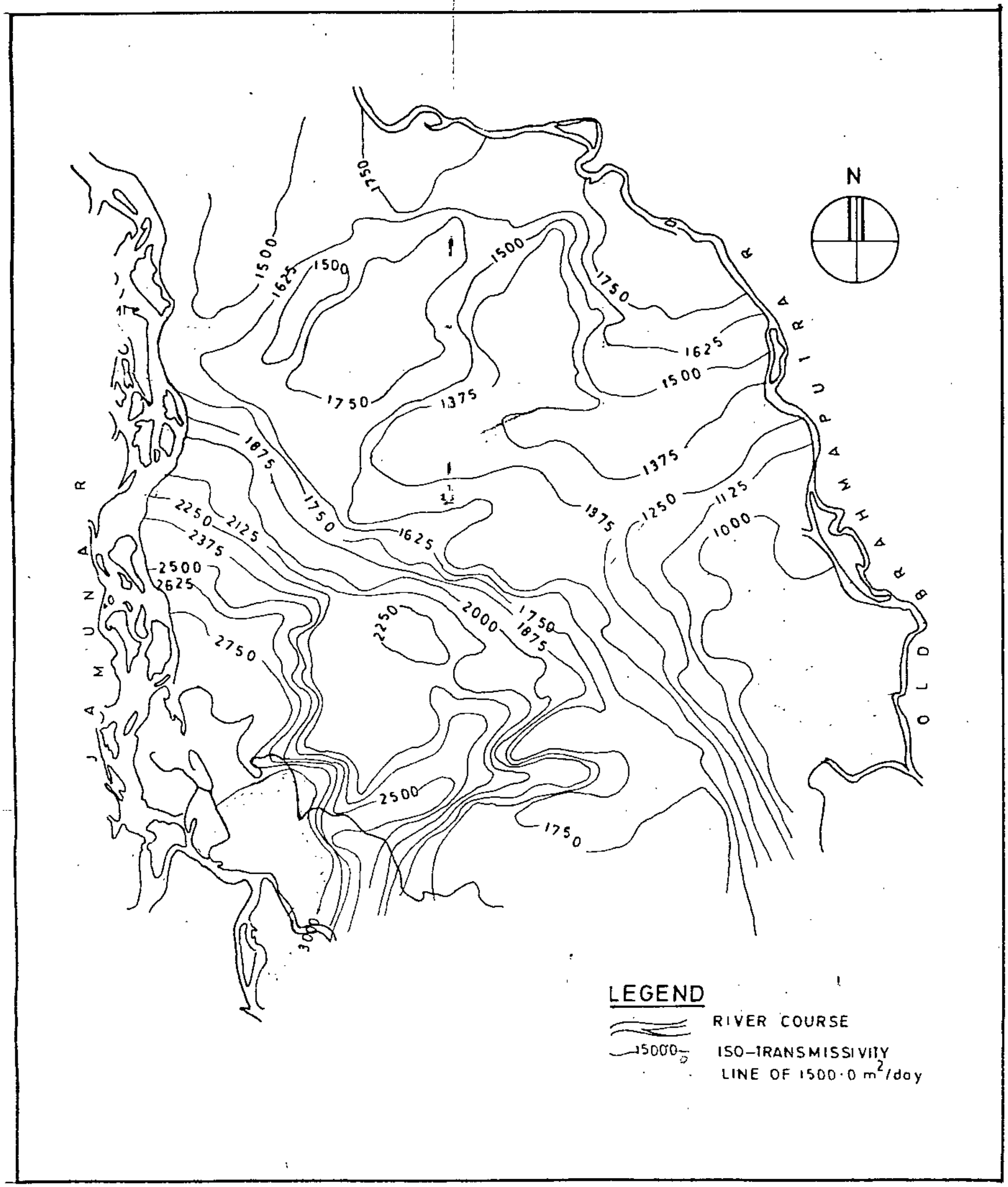


FIG. 5.10b TRANSMISSIVITY CONTOUR MAP(AFTER MODEL CALIBRATION)

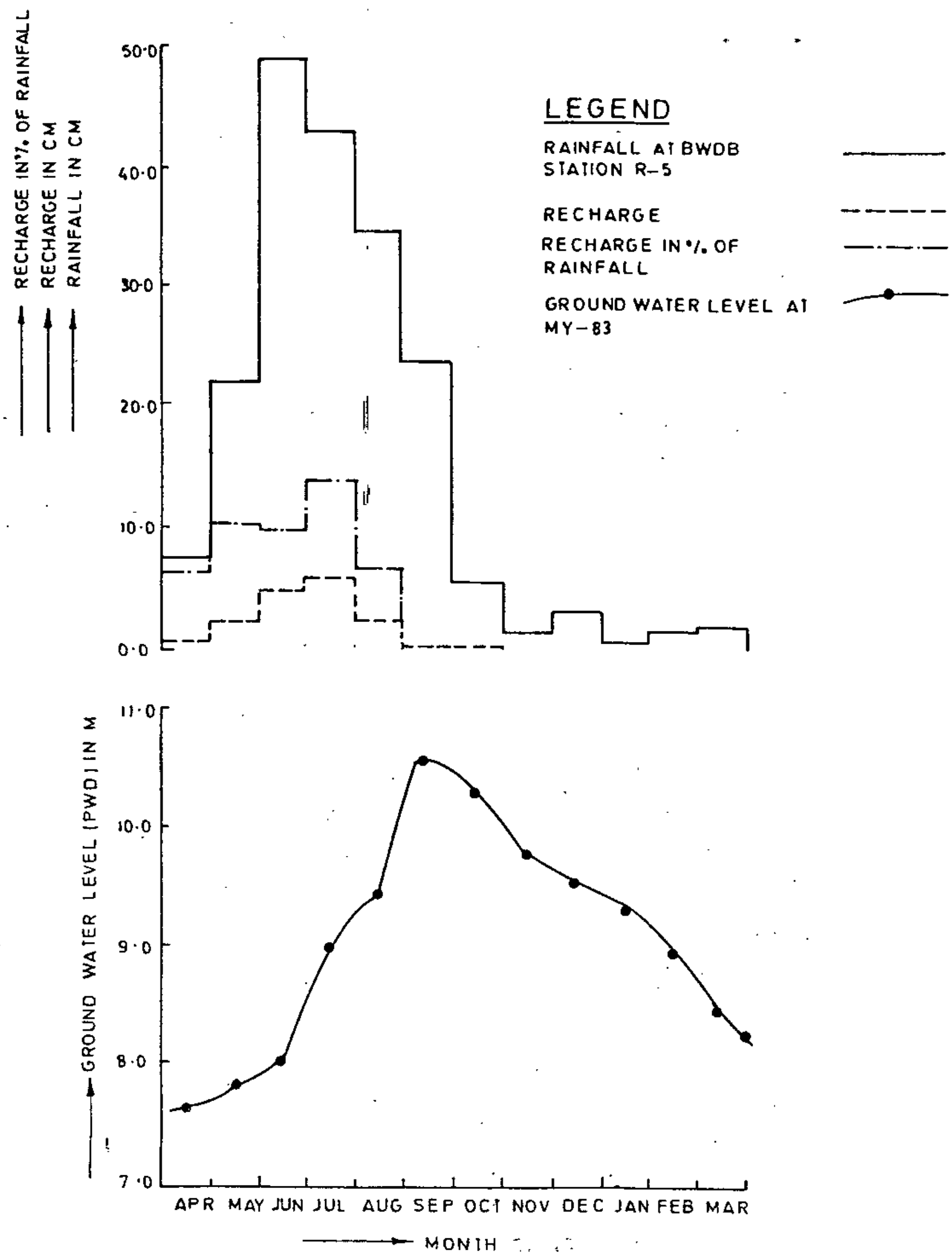


FIG.5.11 VARIATION OF RAINFALL, RECHARGE AND GROUND WATER LEVEL AT BHALUKA IN 1979–80.

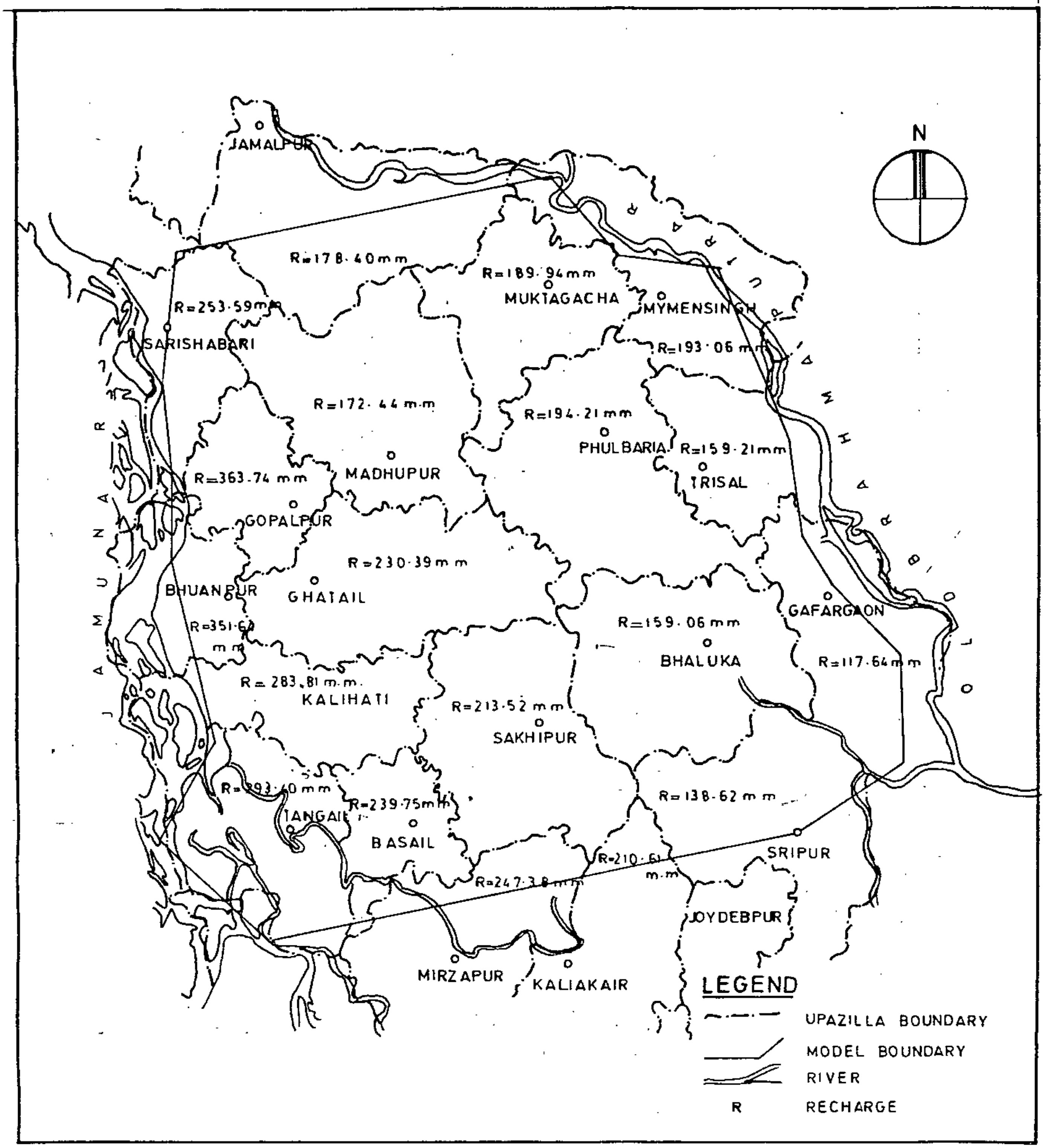


FIG. 5.12 UPAZILLA WISE TOTAL RECHARGE IN 1979–80

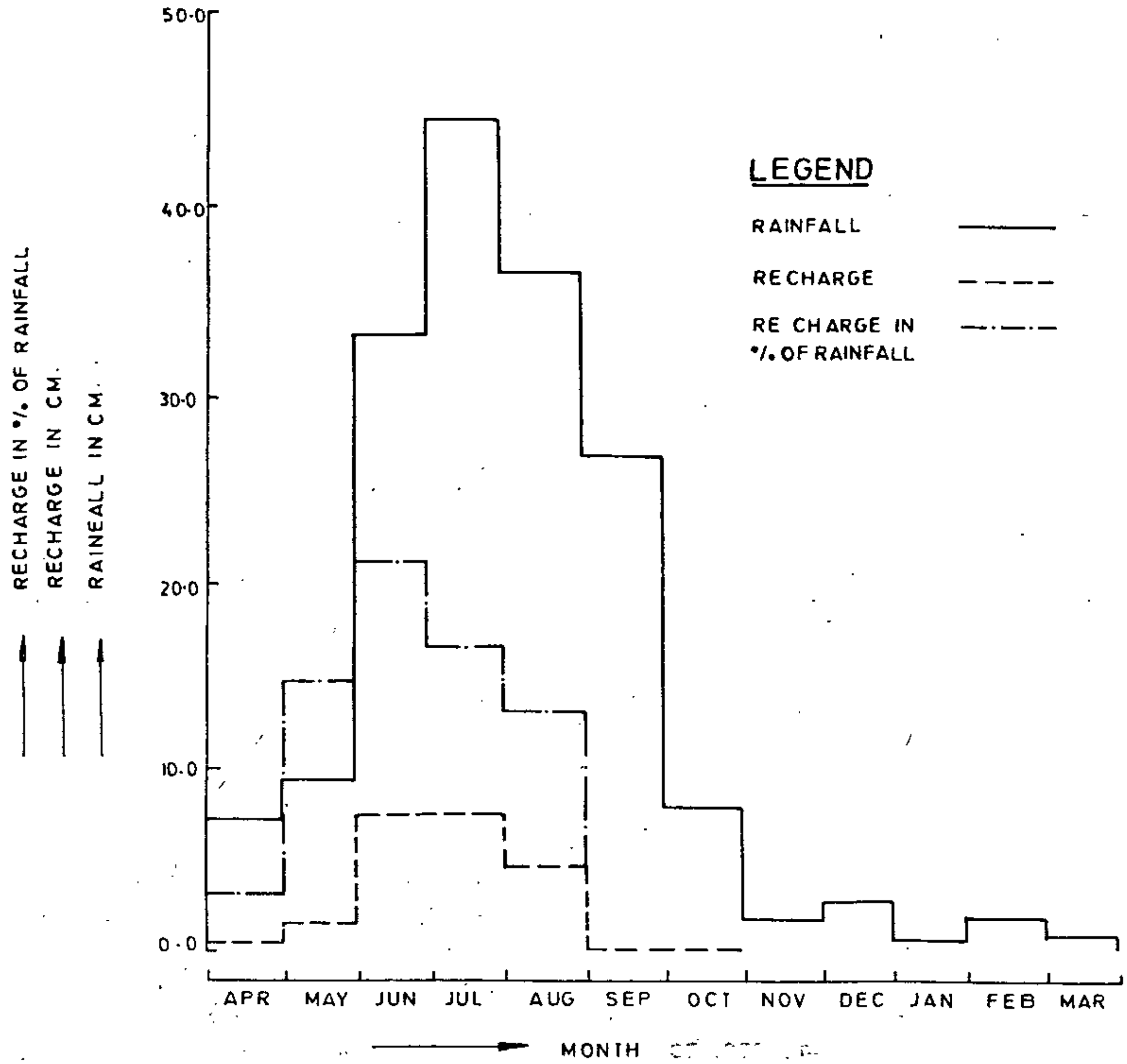


FIG. 5.13 VARIATION OF RAINFALL AND RECHARGE IN THE MODEL AREA IN 1979—80

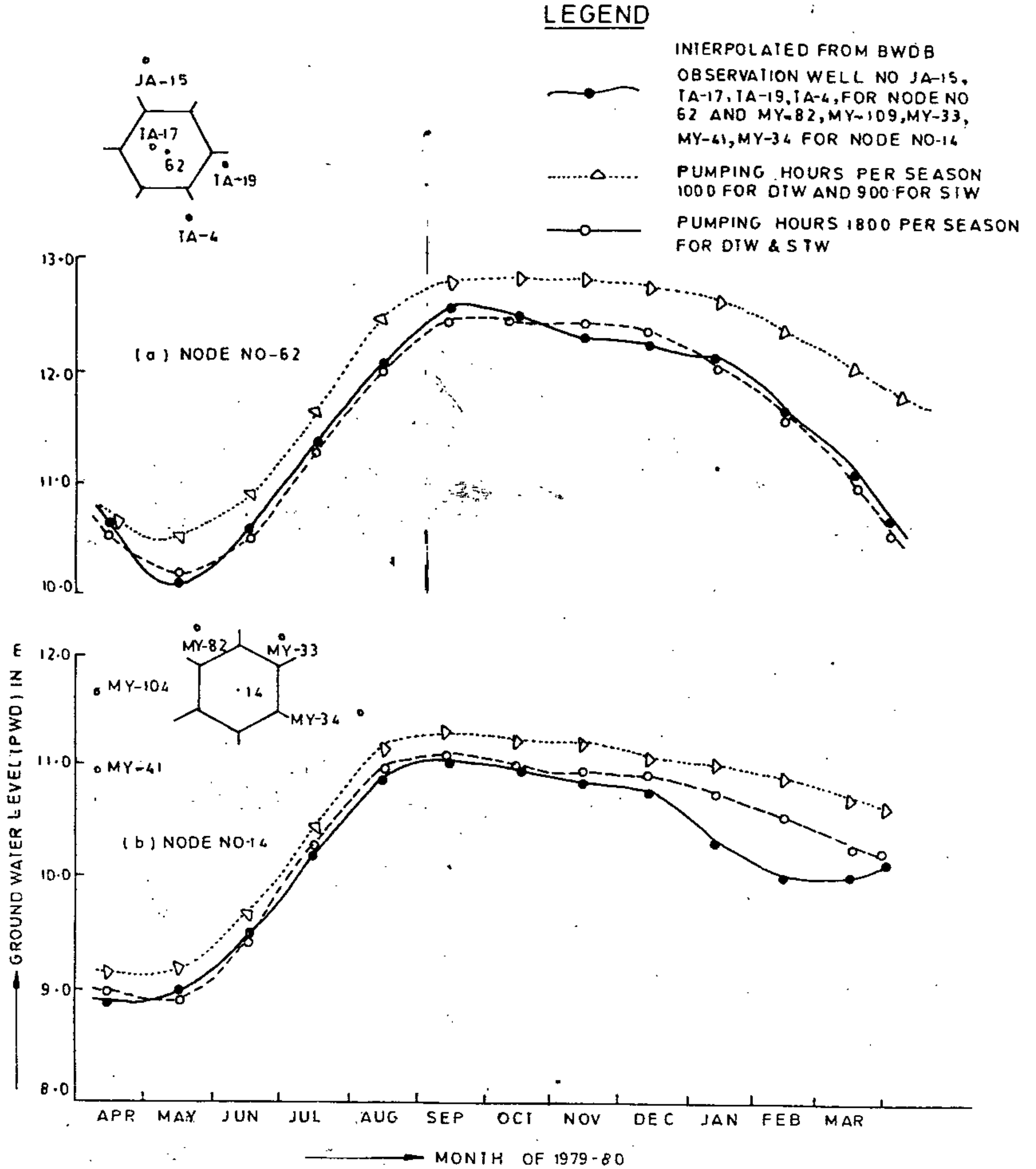


FIG.5.14 EFFECT OF (ASSUMED) PUMPING HOURS UPON COMPUTED WATER LEVEL

Table 5.2: Upazillawise values of storage coefficient and transmissivity.

Name of upazilla	Area (km^2)		Storage coefficient		Coefficient of Transmissivity m^2/day	
	Total	Under model region	Initial estimate from Karim (1984)	After calibration	Initial estimate from UNDP (1982)	After calibration
Jamalpur	456.0	231.0	0.105	0.10945	2736.354	1782.268
Sarishabari	252.0	169.30	0.114	0.12194	1944.01	1824.257
Madhupur	458.0	458.0	0.07	0.089	2723.503	1875.070
Gopalpur	215.0	215.0	0.15	0.11338	2100.503	1734.111
Bhuyanpur	252.0	114.25	0.10	0.10768	2252.209	1627.309
Ghatail	437.0	437.0	0.08	0.10697	2045.671	1547.781
Kalihathi	300.0	251.11	0.10	0.11253	2058.911	1485.742
Sakhipur	441.0	441.0	0.064	0.09191	1743.635	1530.142
Tangail	391.0	335.77	0.10	0.11146	2466.853	1476.013
Basail	168.0	167.13	0.07	0.10375	1472.605	1255.732
Mirzapur	364.0	90.14	0.08	0.09473	1247.210	1103.641
Kaliakair	314.0	51.06	0.05	0.07854	2206.158	1669.219
Sreepur	460.0	277.14	0.04	0.06051	2066.654	1555.901
Bhaluka	437.0	437.0	0.04	0.06811	1317.921	1122.474
Gafargaon	392.0	216.43	0.04	0.06195	2034.682	1586.943
Phulbaria	513.0	513.0	0.05	0.07774	2664.331	1821.913
Trisal	326.0	200.32	0.04	0.06727	3108.733	1999.079
Mymensingh	378.0	137.74	0.05	0.07824	2394.919	1731.202
Muktagacha	313.0	313.0	0.05	0.09120	2477.957	1755.355

Table 5.3: Upazilla-wise monthly recharge values in 1979-'80.

Name of the upazilla	Area (km^2)		Recharge in mm									
	Total	Under model region	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
Jamalpur	456.0	231.0	6.20	21.18	47.47	92.15	10.98	0.31	0.11		0.0	
Sarishabari	252.0	169.30	8.35	27.45	58.89	136.75	21.47	0.49	0.20		0.0	
Madhupur	458.0	458.0	1.10	4.97	62.46	58.19	45.10	0.37	0.25		0.0	
Gopalpur	215.0	215.0	0.97	5.30	135.88	117.14	103.09	0.80	0.57		0.0	
Bhuyanpur	252.0	114.25	0.0	2.24	134.59	107.09	106.37	0.78	0.58		0.0	
Ghatail	437.0	437.0	0.35	3.04	88.41	71.90	68.79	0.51	0.37		0.0	
Kalihathi	300.0	251.11	0.0	1.80	108.63	86.43	85.85	0.63	0.47		0.0	
Sakhipur	441.0	441.0	0.49	3.51	80.73	65.52	62.47	0.47	0.34		0.0	
Tangail	391.0	335.77	0.0	1.87	112.30	89.35	88.75	0.65	0.48		0.0	
Basail	168.0	167.13	0.0	1.52	91.77	73.01	72.52	0.53	0.39		0.0	
Mirzapur	364.0	90.14	0.12	2.11	94.52	75.26	74.41	0.55	0.40		0.0	
Kaliakair	314.0	51.06	6.28	29.34	71.81	60.58	41.97	0.41	0.21		0.0	
Sreepur	460.0	277.14	4.53	21.05	46.22	40.85	25.58	0.26	0.13		0.0	
Bhaluka	437.0	437.0	4.82	22.30	48.64	59.02	23.92	0.27	0.10		0.0	

Table 5.3 (contd.)

Name of the upazilla	Area (km^2)		Recharge in mm							
	Total	Under model region	April	May	June	July	Aug.	Sep.	Oct.	Nov.,Dec.,Jan.
Gafargaon	392.0	216.43	3.83	17.63	35.06	44.81	16.05	0.19	0.06	0.0
Phulbaria	513.0	513.0	5.19	27.33	58.94	73.04	28.55	0.32	0.12	0.0
Trisal	326.0	200.32	5.18	23.86	47.45	60.65	21.72	0.26	0.08	0.0
Mymensingh	378.0	137.74	6.30	28.87	57.37	74.18	25.93	0.31	0.10	0.0
Muktagacha	313.0	313.0	6.03	27.17	56.60	74.02	25.70	0.31	0.11	0.0

5.6.0 DETERMINATION OF GROUNDWATER RECHARGE IN 1982-'83

Groundwater recharge in the year 1982-'83 was determined by adjusting recharge reates in each of the polygon until close agreement between observed and computed water level was obtained. Values of T and S were constant. The monthly values of rainfall, recharge and the percentage of rainfall causing recharge in the model area in 1982-'83 are shown in Fig. 5.15. The rainfall, recharge and groundwater level variation of Bhaluka upazilla in 1982-'83 have been studied and are shown in Fig. 5.16. The rainfall from BWDB rainfall station R-5 of Bhaluka upazilla and groundwater level data of adjacent observation well My-83 have been plotted. The highest recharge is found to occur in June which is 19.42% of rainfall in that month. During recharge period it is observed that the increase of recharge is followed by the increase of groundwater level.

Upazilla-wise values of annual recharge computed in the present study in the year 1982-'83, potential and available annual recharge estimated by Karim (1984) are given in Table 5.4. Recharge varies from year to year due to the variation of hydrological conditions. The values of recharge in 1982-'83 is found to be decreased from the recharge values in 1979-'80 (Fig. 5.12). This is due to the smaller amount of annual rainfall in 1982-'83. Upazilla-wise monthly recharge values in 1982-'83 are also given in Table 5.5.

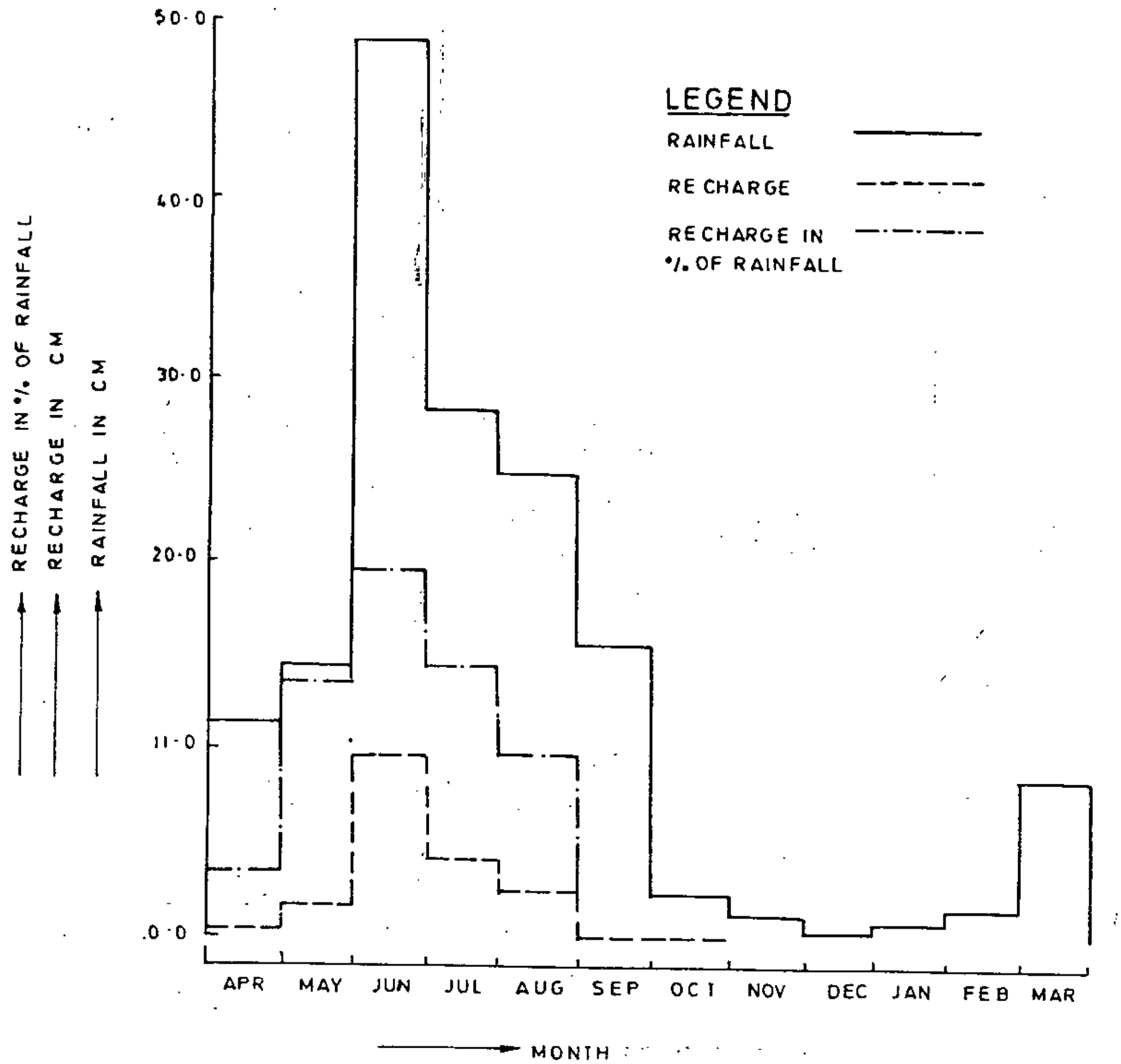


FIG.5.15 VARIATION OF RAINFALL AND RECHARGE IN THE MODEL AREA IN 1982 – 83

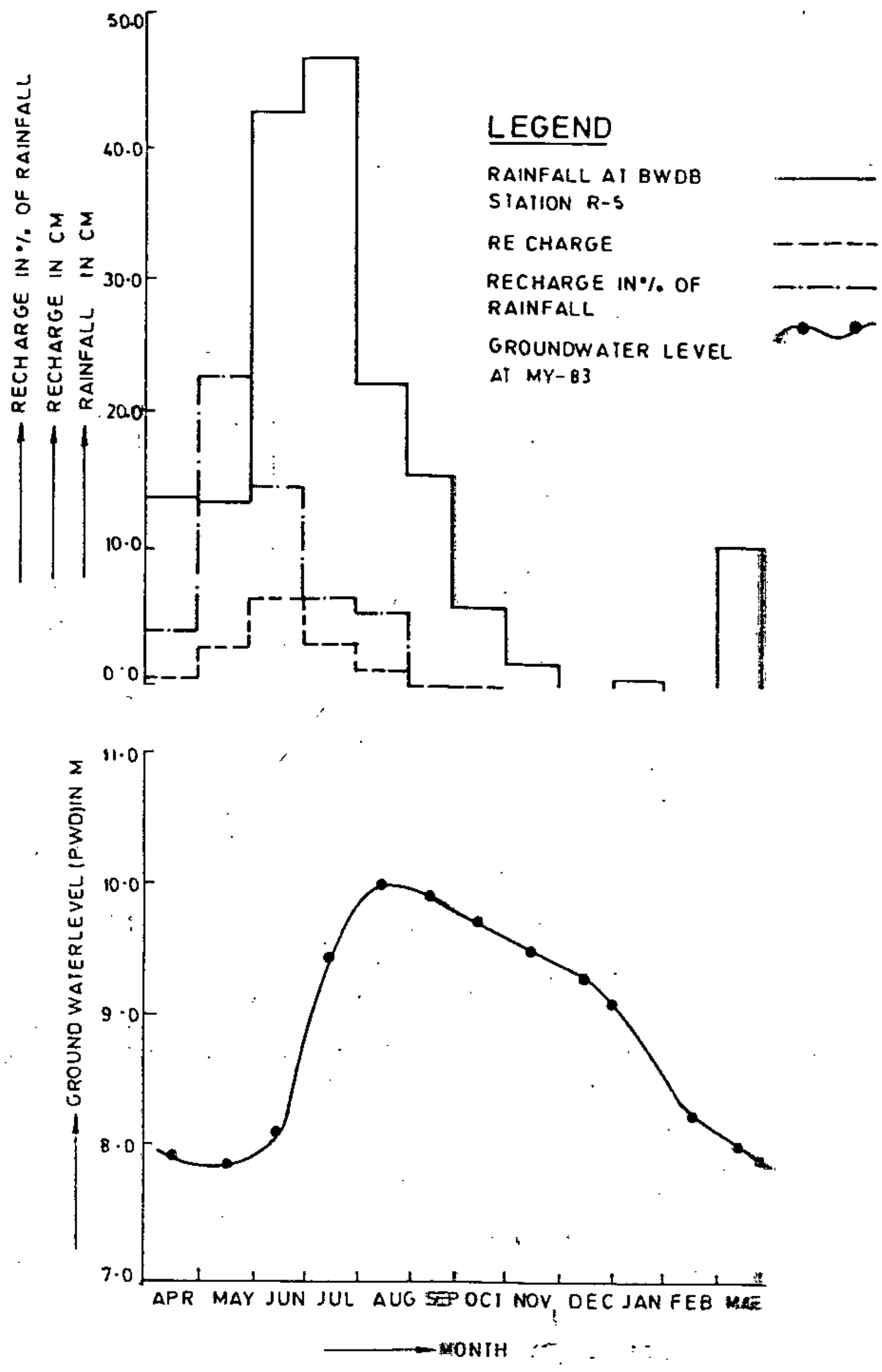


FIG. 5·16 VARIATION OF RAINFALL, RECHARGE AND GROUND WATER LEVEL AT BHALUKA IN 1982–8

Table 5.4: Upazilla-wise annual recharge in 1982-'83

Name of upazilla	Area (km^2) Total	Under model region	Vertical annual recharge in 1982-'83 computed in present study (mm)	Potential annual recharge estimated by Karim ((mm)	Available annual recharge estimated by Karim (mm)
Jamalpur	456.0	231.0	154.10	-	-
Sarishabir	252.0	169.30	209.74	-	-
Madhupur	458.0	458.0	144.16	212	147
Gopalpur	215.0	215.0	301.75	660	360
Bhuyanpur	252.0	114.25	290.90	500	368
Ghatail	437.0	437.0	193.96	320	160
Kalihathi	300.0	251.11	234.79	447	281
Sakhipur	441.0	441.0	178.05	-	-
Tangail	391.0	335.77	242.73	440	240
Basail	168.0	167.13	198.34	300	128
Mirzapur	364.0	90.14	205.06	421	288
Kaliakair	314.0	51.06	195.42	290	200
Sreepur	460.0	277.14	129.59	164	113
Bhaluka	437.0	437.0	143.87	186	106
Gafargaon	392.0	216.43	106.89	124	92
Phulbaria	513.0	513.0	175.46	240	144
Trisal	326.0	200.32	144.66	171	73
Mymensingh	378.0	137.74	175.27	230	130
Muktagacha	313.0	313.0	171.43	214	148

Table 5.5: Upazilla-wise monthly recharge values in 1982-'83.

Name of the upazilla	Area, km²		Recharge in mm							
	Total	Under model region	April	May	June	July	Aug.	Sept.	Oct.	Nov., Dec., Jan Feb. & March
Jamalpur	456.0	231.0	7.44	28.75	62.07	50.26	5.49	0.06	0.02	0.0
Sarishabari	252.0	169.30	10.02	37.25	77.01	74.59	10.73	0.10	0.04	0.0
Madhupur	458.0	458.0	1.32	6.75	81.68	31.74	22.55	0.07	0.05	0.0
Gopalpur	215.0	215.0	1.16	7.19	177.69	63.89	51.54	0.16	0.11	0.0
Bhuyanpur	252.0	114.25	0.0	3.03	176.01	58.41	53.18	0.16	0.12	0.0
Ghatail	437.0	437.0	0.42	4.13	115.61	39.22	34.40	0.10	0.07	0.0
Kalihathi	300.0	251.11	0.0	2.45	142.06	47.14	42.92	0.13	0.09	0.0
Sakhipur	441.0	441.0	0.58	4.76	105.56	35.74	31.24	0.09	0.07	0.0
Tangail	391.0	335.77	0.0	2.53	146.86	48.74	44.38	0.13	0.10	0.0
Basail	168.0	167.13	0.0	2.07	120.00	39.83	36.26	0.11	0.08	0.0
Mirzapur	364.0	90.14	0.14	2.86	123.60	41.05	37.21	0.11	0.08	0.0
Kaliakair	314.0	51.06	7.54	39.82	93.91	33.04	20.98	0.08	0.04	0.0

Table 5.5 (contd.)

Name of the upazilla	Area km^2		Recharge in mm							
	Total	Under model region	April	May	June	July	Aug.	Sept.	Oct.	Nov, Dec, Jan. Feb. & March
Sreepur	460.0	277.14	5.43	28.56	60.44	22.28	12.79	0.05	0.03	0.0
Bhaluka	437.0	437.0	5.78	30.26	63.60	32.20	11.96	0.05	0.02	0.0
Gafargaon	392.0	216.43	4.59	23.93	45.85	24.44	8.02	0.04	0.01	0.0
Phulbaria	513.0	513.0	7.09	37.09	77.07	39.84	14.28	0.06	0.02	0.0
Trisal	326.0	200.32	6.21	32.39	62.05	33.08	10.86	0.05	0.02	0.0
Mymensingh	378.0	137.74	7.56	39.18	75.02	40.46	12.97	0.06	0.02	0.0
Muktagacha	313.0	313.0	7.23	36.87	74.02	40.37	12.85	0.06	0.02	0.0

5.7.0 EFFECT OF SOLUTION TECHNIQUE

5.7.1 Numerical Solution

Two numerical techniques have been used to solve the discretized groundwater flow equation (equation 2.10). This was intended to investigate the effect of solution techniques upon model results. The techniques are Gauss-Seidel iteration and Gauss-Jordan elimination methods. Gauss-Seidel iteration involves iteration and effect of iteration upon model results was also investigated. Application of Gauss-Seidel iteration method requires a convergence criteria. Two criteria are investigated here. They are,

$$\sum_{i=1}^{63} |RES_i| < 0.1\ (R'-W)/T'$$

and $$\sum_{i=1}^{63} |\Delta h_i| < 0.0315$$

$$< 0.063$$

Where R' = Annual recharge in m^3

W = Annual withdrawal in m^3

T' = No. of days in the year

$h_i = h_i^k - h_i^{k-1}$

k = No. of iteration

Number of iterations required in each of the convergence criteria are shown in Fig. 5.17. Fewer number of iterations are observed for the convergence criteria $\sum_{i=1}^{63} |\Delta h_i|$ < 0.063. For each of the convergence criteria it is observed that the maximum number of iterations are required in the period of maximum vertical flow.

Applying Gauss-Seidel iteration method in polygonal network computed results for one, two, three iterations and satisfying convergence criteria $\sum_{i=1}^{63} |RES_i| < 0.1\ (R'-W)/T'$ were observed. The results for three nodes and at four dates are given in Table 5.6. It is observed that the results obtained by satisfying the convergence criteria requires large number of iterations (Fig. 5.17) and does not differ significantly compared with the results obtained by one, two and three iterations. So it is evident that the results do not increase or decrease significantly with the increase of the number of iterations. A maximum absolute difference of 0.094 m is observed between the results obtained from one iteration and satisfying convergence criteria for polygon 14 on the 11th Jan'80. These differences are negligible for all practical purpose. So Gauss-Seidel iteration method with one iteration can be considered as reasonably accurate for solution.

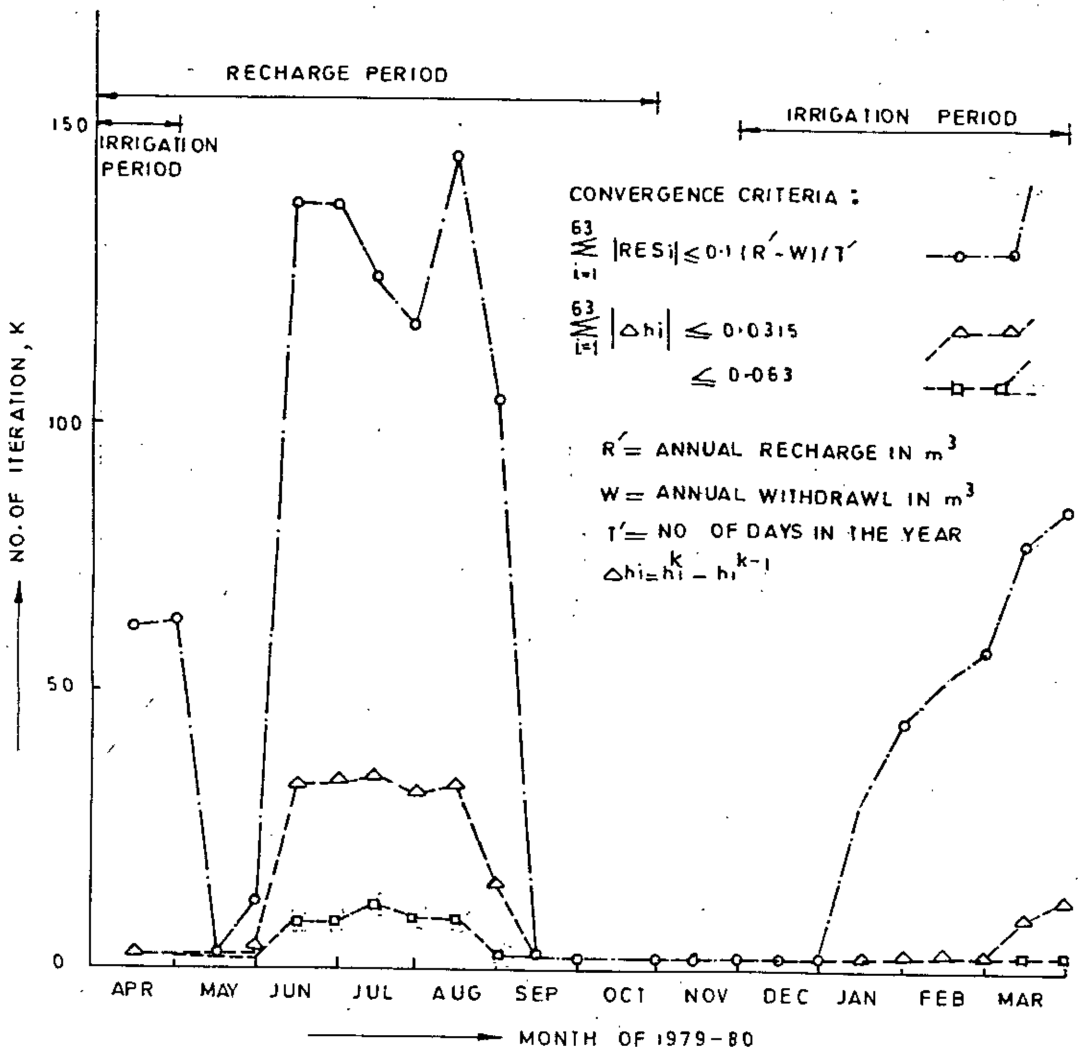


FIG. 5.17 EFFECT OF CONVERGENCE CRITERIA UPON ITERATION IN GAUSS SEIDEL ITERATION METHOD

Table 5.6: Computed results for different iterations

Time	Node no.	Computed water level in m.				
		1 iteration	2 iteration	3 iteration	satisfying convergence criteria	
					water level m,	No. of iteration
15th June'79	1	7.353	7.355	7.355	7.355	141
	14	9.428	9.452	9.458	9.453	
	62	10.501	10.499	10.499	10.499	
14th Aug.'79	1	8.804	8.819	8.820	8.82	149
	14	10.903	10.987	10.990	10.990	
	62	12.021	12.043	12.043	12.043	
11th Jan'80	1	8.957	8.976	8.977	8.977	29
	14	10.695	10.786	10.789	10.789	
	62	12.067	12.087	12.087	12.089	
11th March'80	1	8.463	8.480	8.480	8.480	78
	14	10.222	10.301	10.304	10.304	
	62	10.915	10.920	10.921	10.923	

Note: Convergence criteria = $\sum_{i=1}^{63} |RES_i| < 0.1\ (R'-W)/T'$

R' = Annual recharge in m^3, W = Annual withdrawal in m^3

T' = No. of days in the year.

Table 5.7: Computed results based on Gauss-Seidel iteration and Gauss-Jordan elimination methods.

Date	Computed water level in m					
	Node no. 1		Node. 14		Node no. 62	
	G.S.I.	G.J.E	G.S.I	G.J.E.	G.S.I.	G.J.E
16th April'79	7.063	7.063	9.069	9.069	10.50	10.500
Ist May'79	6.935	6.935	8.930	8.930	10.182	10.182
16th May'79	6.949	6.949	8.982	8.982	10.135	10.135
31st May'79	6.977	6.977	9.092	9.092	10.090	10.090
15th June'79	7.355	7.355	9.453	9.453	10.499	10.499
30th June'79	7.730	7.730	9.802	9.802	10.909	10.909
15th July'79	8.093	8.093	10.280	10.280	11.257	11.257
30th July'79	8.427	8.427	10.726	10.726	11.575	11.575
14th August'79	8.820	8.820	10.990	10.990	12.043	12.043
29th August'79	9.076	9.076	11.127	11.127	12.357	12.357
13th Sept.'79	9.092	9.091	11.103	11.102	12.375	12.375
28th Sept. '79	9.097	9.097	11.071	11.071	12.381	12.381
13th Oct.'79	9.101	9.101	11.040	11.040	12.386	12.386

Table 5.7 contd.

Date	Node no. 1		Node no. 14		Node no. 62	
	G.S.I	G.J.E	G.S.I	G.J.E	G.S.I	G.J.E
28th Oct.'79	9.106	9.106	11.010	11.010	12.391	12.392
12th Nov.'79	9.107	9.107	10.979	10.979	12.392	12.392
27th Nov.'79	9.107	9.107	10.949	10.949	12.390	12.390
12th Dec.'79	9.085	9.085	10.910	10.910	12.340	12.340
27th Dec.'79	9.055	9.055	10.868	10.868	12.273	12.273
11th Jan.'80	8.977	8.977	10.789	10.789	12.089	12.089
26th Jan.'80	8.875	8.875	10.693	10.693	11.847	11.847
10th Feb.'80	8.762	8.761	10.579	10.578	11.581	11.582
25th Feb.'80	8.641	8.641	10.453	10.453	11.300	11.300
11th March'80	8.480	8.480	10.304	10.304	10.923	10.923
26th March'80	8.306	8.306	10.148	10.147	10.513	10.513

Note: G.S.I. = Gauss-Seidel iteration

G.J.E. = Gauss-Jorder elimination.

Comparison was made for the computed results obtained for Gauss-Seidel iteration and Gauss-Jordan elimination methods. The results are given in Table 5.7. No significant difference of the results are observed. A maximum variation of 0.001 m is observed between the results of the two methods at a very fewer number of time steps. Therefore it is evident that the two methods give almost the same results.

5.7.2 Schematization

In order to examine the effects of nodal configuration upon model results, variation of computed water levels were studied for rectangular and polygonal network. The computed water level variation for these two networks by Gauss-Seidel iteration method for polygon 1 and 14 are shown in Fig. 5.18. It is observed that in polygon 14 computed results for the rectangular network shows more deviation from the polygonal network. The deviation gradually increases with time and a maximum difference of 0.4 m is observed in March'80. However in polygon 1 the difference between the computed results using polygonal and rectangular network is not found significant.

Effect of schematization upon iteration required in Gauss-Seidel iteration method have been investigated and is shown in Fig. 5.19. The rectangular grid schematization is

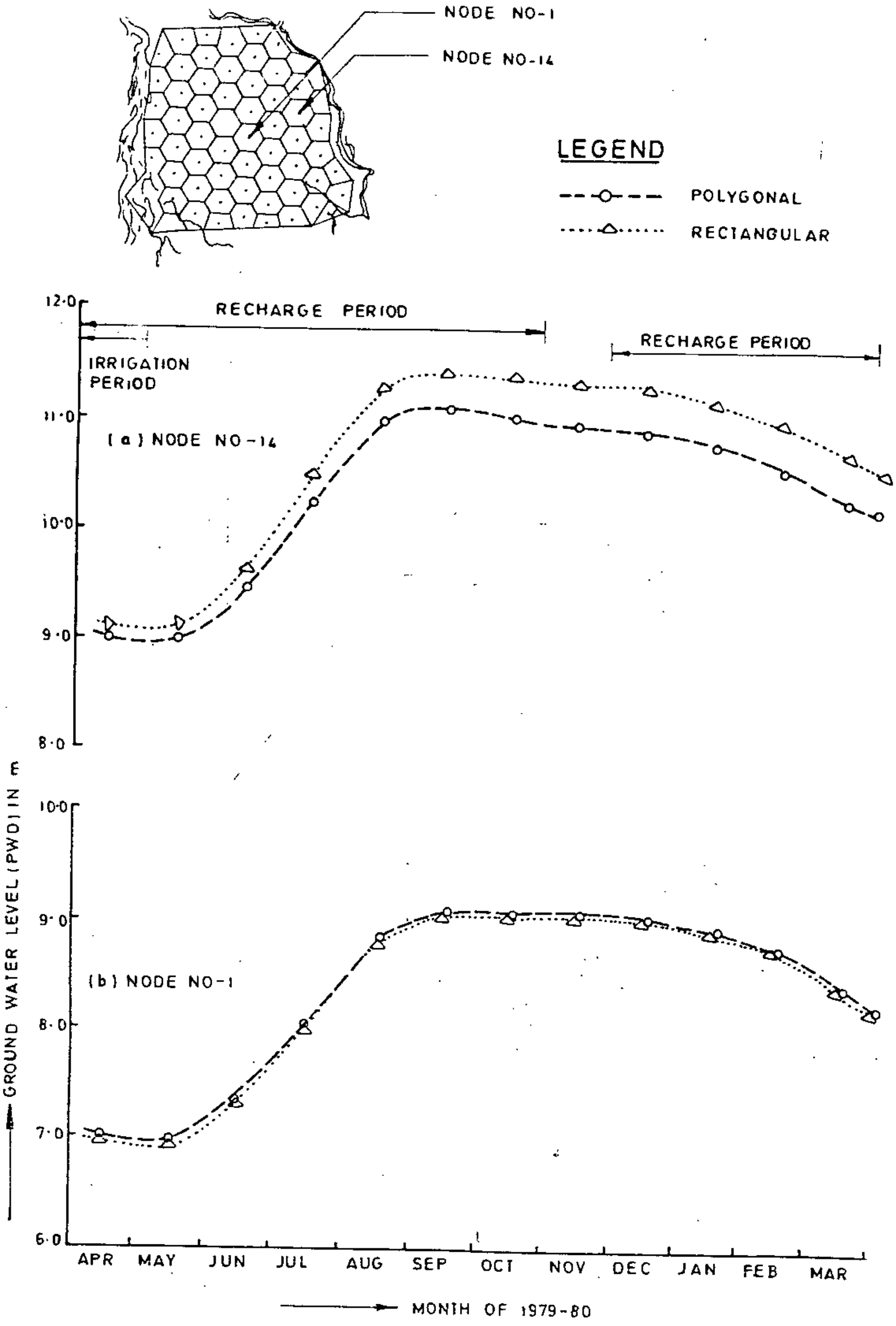


FIG. 5.18 EFFECT OF SCHEMATIZATION UPON COMPUTED WATER LEVEL

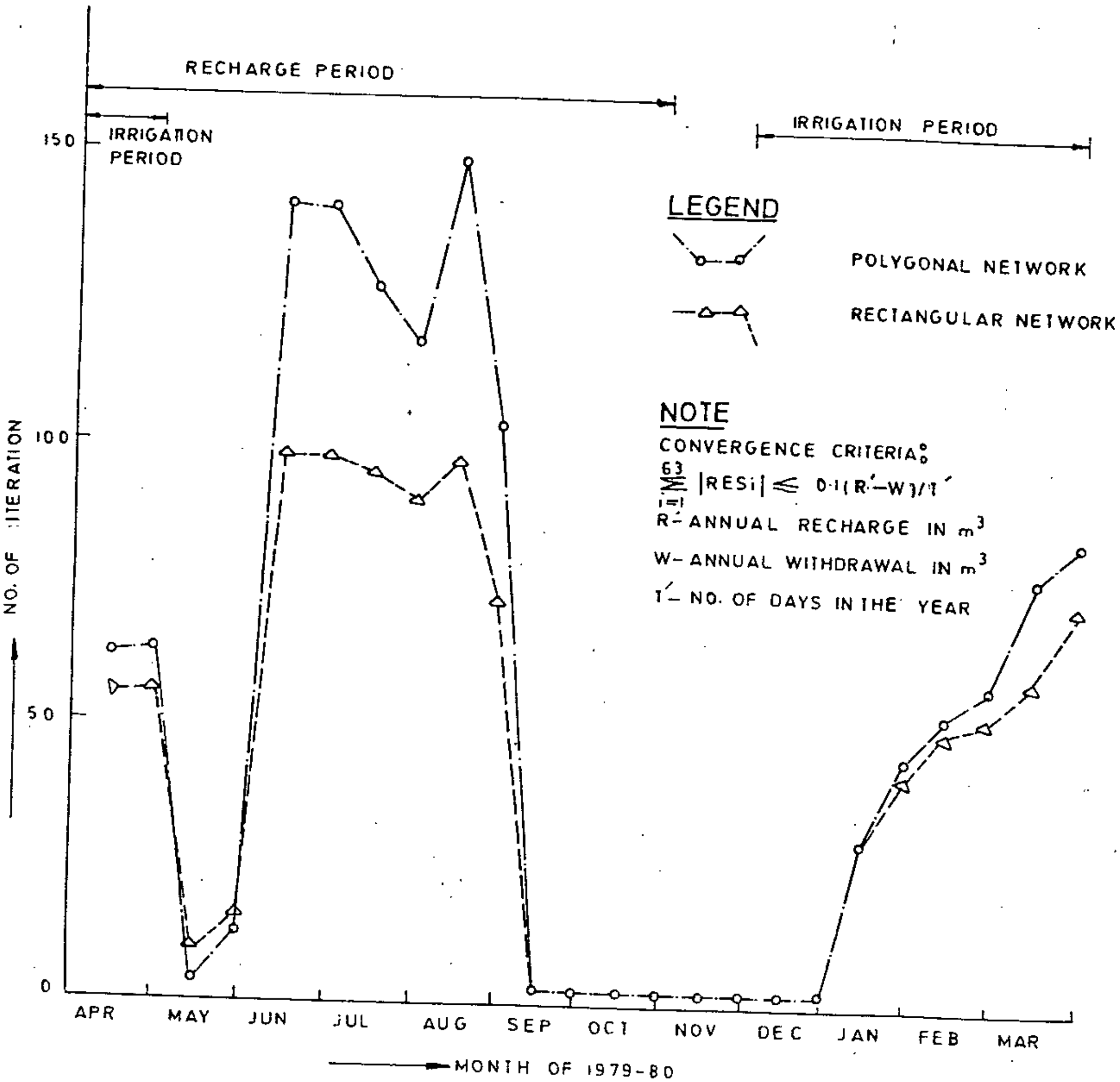


FIG. 5.19 EFFECT OF SCHEMATIZATION UPON ITERATION IN GAUSS SEIDEL ITERATION METHOD

found to require less iteration than the polygonal grid schematization. A maximum of 149 iterations are required for polygonal grid schematization to obtain results on 14th Aug.'79 whereas a maximum of 98 iterations are required for rectangular grid schematization to obtain results on 30th June'79. So it is evident that the solution by Gauss-Seidel iteration technique converge earlier in rectangular grid schematization.

5.8.0 COMPARISON OF COMPUTER TIME AND STORAGE

The model was run on the IBM 4331 MODEL KOL Computer system available at BUET Computer Centre. A comparison of CPU time corresponding to the two solution techniques and two schematizations is given in Table 5.8. It is observed that for polygonal grid schematization more CPU time is required than the rectangular grid schematization in case of both the Gauss-Seidel iteration and Gauss-Jordan elimination methods. However, for Gauss-Seidel iteration technique with one and two iteration the same CPU time is required for both the schematizations.

Much less CPU time is required for the Gauss-Jordan elimination method than the Gauss-Seidel iteration method satisfying convergence criteria $\sum_{i=1}^{63} |RES_i| < 0.1\ (R'-W)/T$. However less CPU time is required for one iteration in the Gauss-Seidel iteration method than the Gauss-Jordan elimination method.

Table 5.8: Comparison of CPU time

Type of network	CPU Time in Secs.						
	Gauss-Seidel iteration						Gauss-Jordan elimination
	1 iteration	2 iteration	3 iteration	Satisfying Convergnece Criteria			
				a	b	c	
Polygonal	47	54	60	373	108	63	89
Rectangular	47	54	56	262	93	58	83

Note:

$$a = \sum_{i=1}^{63} |RES_i| < 0.1 \ (R' - W)/T'$$

$$b = \sum_{i=1}^{63} |\Delta h_i| < 0.0315$$

$$c = \sum_{i=1}^{63} |\Delta h_i| < 0.063$$

R' = Annual recharge in m^3

W = Annual withdrawal in m^3

T' = No. of days in the year

$\Delta h_i = h_i^k - h_i^{k-1}$

k = No. of iteration.

A greater storage of 280.151 Kilobytes are required when Gauss-Jordan elimination method is applied while the storage of 179.319 Kilobytes are required when Gauss-Seidel iteration method is applied. Boonstra and Ridder (1981) also found the greater storage requirement for Gauss-Jordan elimination method.

5.9.0 CONCLUSION

Conclusion following this chapter may be drawn as below:

1) The model result is most sensitive to vertical recharge while it is least sensitive to the coefficient of transmissivity.

2) The difference in results obtained by Gauss-Seidel iteration and Gauss-Jordan elimination methods is negligible.

3) Two convergence criteria, 10% of net vertical flow and difference of consecutive iteration were tested in the Gauss-Seidel iteration method. The latter requires fewer number of iteration and less computer time. The former requires greater computer time compared to the Gauss-Jordan elimination method.

4) Results obtained by polygonal grid schematization and rectangular grid schematization in Gauss-Seidel iteration method are almost identical. The latter requires fewer number of iteration and less computer time. So, it is evident that the solution converge earlier in the latter.

CHAPTER SIX

DISCUSSION, CONCLUSION AND RECOMMENDATION

6.1.0 DISCUSSION

One of the main objectives of the present study is to simulate the groundwater movement in the Mymensingh-Tangail area by applying numerical model. The achievement is judged by comparing computed water level variation with observed variation. The model computes groundwater level at 15 days interval during a yearly cycle in each of the 63 nodes. Results have been compared with observed groundwater level variation from 54 observation wells (Fig. 5.1). Average of absolute deviations over a yearly cycle in model results varies from 0.12 m to 0.283 m in the model area which is only 4.99% to 12.59% of the range of groundwater level fluctuation. This indicates that the present numerical model successfully simulated the groundwater system in the study area.

Fig. 5.8 shows that maximum deviation of computed water level from observed water level occurs during irrigation period and the computed water level is higher. This suggests that the estimated groundwater withdrawal is lower than the actual. It is impossible to estimate the withdrawal accurately mainly because of data of privately owned tube-wells are not known. An important finding of this study is that pumping hours of 1000 for DTW and 900 for STW per season suggested by MPO is an underestimate. Whereas satisfactory results have been obtained using pumping hours of 1800 suggested by BWDB for DTW and STW per season.

An important outcome of present numerical model study is the determination of groundwater recharge as a function of time in the year 1979-'80 and 1982-'83 as shown in the Fig. 5.13 and 5.15. It is seen that maximum recharge occurs generally in the month of June or July. The recharge values in the model area are 21.24% and 19.42% of rainfall in the year 1979-'80 and 1982-'83 respectively. The recharge stops when groundwater level reaches its maximum value. Table 5.4 further shows the upazilla-wise available annual recharge values estimated by Karim (1984) substantially differs from model results.

Another useful result of present study is the determination of aquifer characteristics in the model area. Contours presented in Fig. 5.10 shows the variation of storage coefficient and transmissivity in the study area. In some places radical variation of the parameters is observed. These results will be of great help in the future groundwater development plans in the study area.

Several numerical experiments have been performed in order to investigate how numerical aspects affect simulation results. Gauss-Seidel iteration and Gauss-Jordan elimination methods have been used to investigate the effect of numerical solution technique. Rectangular grid schematization and polygonal grid schematization have been used to investigate the effect of schematization process. Results are summarized in Table 5.7 and Fig. 5.18. It is found that both solution techniques give almost identical results while application of the Gauss-Seidel iteration method with one iteration requires least computer time (Table 5.8). It is also seen that there is no substantial variation in model results from the two types of schematization. However, the rectangular grid schematization needs smaller computer time.

The models are based on numerical solution of two dimensional unsteady groundwater flow equation. Accuracy of the solution has been investigated by making comparison with Theiss analytical solution as shown in Fig. 3.2 and 3.3. It is observed that the maximum error is less than 1.6% of drawdown at the pumping well. Although the Theiss solution is for a special flow condition yet the comparison reflects high degree of accuracy in the numerical solution. It further shows that Gauss-Jordan elimination method gives better accuracy compared to Gauss-Seidel iteration method.

The lithology of the model area (Fig. 4.2) suggests that the aquifer is multilayered. Mathematical formulation in the present model study is based on the single layer aquifer. Although the model does not consider variation of aquifer properties along vertical direction, it does consider variation along the two horizontal directions. In the absence of data on vertical variation of aquifer parameters, these limitations are acceptable for practical purposes. In fact, single layer aquifer model has been applied successfully in several places (Northwest region model (MPO, 1984), Varamin groundwater basin model (Ridder and Erez, 1977), ADB tubewell project, North Bangladesh (MPO, 1984)).

Permeability along a river boundary has been assumed equal to that in the adjacent aquifer. In actual consideration, the permeability may be significantly low due to the deposition of fine silty material on bank and river bed during recession of flood flow. This error in boundary condition may affect the model results along adjacent nodes. In the absence of data, this has been accepted in the present study.

In the present computer model there is no sequential restriction on sequence of indexing the nodes. This permits, without reindexing, inclusion of new nodal points or deletion of some of the existing nodal points. A SUBROUTINE is used to compute extraction at each node from the upazilla-wise values of the number of tubewells and their withdrawal rates. This saves substantial amount of effort by not requiring preparation and punching of node-wise withdrawals. Upazilla-wise values of recharge, storage coefficient and transmissivity are obtained from the nodal values with the help of another SUBROUTINE. This has been done with an objective of making the model useful to upazilla planning studies.

6.2.0 CONCLUSION

The conclusion of the present study may be drawn as follows:

1) The groundwater system in the Mymensingh-Tangail area has been simulated successfully by applying the numerical model.

2) Coefficient of transmissivity in the study area varies from 785.323 m^2/day to 4763.293 m^2/day while the storage coefficient varies from 0.04199 to 0.12981.

3) Highest recharge values of 7.355 cm and 9.487 cm occur in July and June during 1979-'80 and 1982-'83 respectively. Total recharge values of 21.146 cm and 18.147 cm in the period 1979-'80 and 1982-'83 respectively are obtained. Present numerical model is a reliable tool for determining both spatial as well as time variation of recharge.

4) Gauss-Jordan elimination technique gives better results than Gauss-Seidel iteration technique when compared with Theiss analytical solution.

5) Both Gauss-Jordan elimination and Gauss-Seidel iteration methods give almost identical simulation results. However, application of Gauss-Seidel iteration method with one iteration requires least computer time.

6) Both rectangular grid and polygonal grid schematizations also give close results although adoption of former schematization results less computer time.

6.3.0 RECOMMENDATIONS FOR FURTHER STUDY

As an extension of present investigation the following studies are recommended:

1) Present single layer aquifer model may be extended to multilayer aquifer model.

2) A recharge submodel may be developed so that it can provide vertical recharge input to the present model.

REFERENCES

Abnish C. Amar, 1975. Ground-Water Recharge Simulation, Journal of the Hydraulics Division, ASCE, Vol.101, No. HY9, September.

BWDB, 1983, List of Observation Wells, Automatic Water level Recorders & Groundwater Sampling Stations under Groundwater Division-1, Groundwater Investigation Circle, Dhaka.

BWDB Water Supply Paper-448, 1984, Groundwater Investigation in Dhaka, Tangail, Mymensingh and Jamalpur Districts for the year (1979-81), Groundwater Data Processing and Research Circle, BWDB,Dhaka.

BWDB Water Supply Paper-423, 1980, Report on depth and fluctuation of groundwater level in Bangladesh (for the years of 1968-1980), Groundwater Circle,BWDB,Dacca.

BWDB Water Supply Paper - 415, 1979, Report on "Revised Hydrogeological Map of Bangladesh" and Suggested Distribution of Tubewell Among Different Districts of Bangladesh, Groundwater Circle, BWDB,Dacca.

BWDB Water Supply Paper-455, 1984, Trend of Groundwater level in Bangladesh, Groundwater Circle-II, BWDB,Dhaka.

Bear Jacob, 1978, Hydraulics of Groundwater, McGraw-Hill Inc., Israel.

BWDB Water Supply Paper - 404, 1978, Groundwater Investigation in Dacca, Tangail, Mymensingh, Sylhet, Comilla, Noakhali, Chittagong and Chittagong Hill Tracts Districts for the year 1975 and 1976, Groundwater Circle, BWDB,Dacca.

BWDB Water Supply Paper-386, 1974, Report on Preparation of "Hydrogeological Map of Bangladesh" and suggested distribution of Tubewells Among Different Districts of Bangladesh, Groundwater Circle, BWDB, Dacca.

Boonstra J. and Ridder de N.A., 1981, Numerical Modelling of Groundwater Basins, International Institute for Land Reclamation and Improvement/ILRI P.O. Box 45, 6700 AA Wageningen, The Netherlands.

Dahlquist Germund and Björck Åke, 1974, Numerical Methods, Prentice-Hall, Inc., U.S.A.

Daniel D. Mc. Cracken and Dorn S. William, 1964, Numerical Methods and Fortran Programming, John Wiley and Sons, Inc., New York, London, Sydney.

Domenico Patrick A., 1972, Concepts and Models in Groundwater Hydrology, McGraw-Hill, Inc., U.S.A.

Farooque Ahmed, 1981, Design Parameters for Rural Water supplies in Bangladesh, M.Sc. Engg. (Civil) Thesis Bangladesh University of Engineering and Technology, Dhaka.

Hans Hydén, 1977, Simulation of the behaviour of Groundwater Aquifers, Seventeenth Congress of the International Association for Hydraulic Research, Hydraulic Engineering for Improved Water Management Proceedings, Volume 6, August.

Jensen Karsten Høgh, 1983, Simulation of Water Flow in the Unsaturated Zone Including Root Zone, Series Paper No. 33, Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark.

Jamilur Rahman, 1981, NW Groundwater Modelling Study, Training Model Report, Cambridge.

Jacquez John A., 1970, A First Course in Computing and Numerical Methods, Addison-Wesley Publishing Company, Inc., U.S.A.

Karim M.A., 1984, Upazilla-wise Groundwater Recharge Conditions of Bangladesh, Groundwater Investigation Circle, BWDB,Dhaka.

Linsley Ray K. JR., Kohler Max A. and Paulhus Joseph L.H., 1958, Hydrology for Engineers, McGraw-Hill Inc., Kosaido Printing Co. Ltd., Tokyo, Japan.

Mercer James W. and Faust Charles R., 1981, Ground-Water Modeling, National Water Well Association, Geo trans, Inc., P.O. Box 2550, Reston, Virginia 22090.

MPO, 1984, National Water Plan Project, Second Interim Report, Volume III- Groundwater Availability, Ministry of Irrigation, Water Development and Flood Control, Government of the Peoples Republic of Bangladesh.

MPO, 1984, National Water Plan Project, Second Interim Report, Volume v-Water use and Infrastructure, Ministry of Irrigation, Water Development and Flood Control, Government of the Peoples Republic of Bangladesh.

MPO, 1985, Draft Final Report, Volume II, Resource Availability and Demands, Alternative Investment Plans Recommendations, Ministry of Irrigation, Water Development and Flood Control, Government of the Peoples Republic of Bangladesh.

Perez-Franco D. and Perez-Monteagudo F., 1977, A Mathematical Model of Non-steady Nonlinear flow in a Phreatic Aquifer with Pumping and Recharge, Seventeenth Congress of the International Association for Hydraulic Research, Hydraulic Engineering for Improved Water Management Proceedings, Volume 2, August.

Planning Commission, 1985, The Third Five Year Plan, 1985-'90, Ministry of Planning, Govt. of the Peoples Republic of Bangladesh, Dhaka, December.

Ridder De N.A. and Erez A., 1977, Optimum use of Water Resources, International Institute for Land Reclamation and Improvement/ILRI, P.O. Box-45 Wageningen, The Netherlands.

Remson Irwin, Hornberger George M. and Molz Fred. J., 1971, John Wiley & Sons, Inc., U.S.A.

Sir MacDonald M. & Partners, 1977, BADC/IDA Tubewell Project, Consultants Report, Groundwater, Vol. III, Peoples Republic of Bangladesh Agricultural Development Corporation.

Sir MacDonald M. & Partners, 1977, BADC/IDA Tubewell Project Consultants Report, Appendices-Groundwater, Vol III A, Peoples Republic of Bangladesh Agricultural Development Corporation.

Sir MacDonald M. & Partners Ltd., 1982, Northwest Bangladesh Groundwater Modelling Study, Final Report, BADC, July.

Scarborough James B., 1966, Numerical Mathematical Analysis, Oxford and IBX publishing Co., New Delhi, India.

Southworth Raymond W. and Deleeuw Samuel L., 1965, Digital Computation and Numerical Methods, McGraw-Hill Book Company, USA.

Sir MacDonald M. and Partners Ltd., 1981, Northwest Bangladesh Groundwater Modelling Study, First Phase Model Report, Cambridge, England.

Shah C.R., 1977, Assessment of Groundwater Recharge by Mathematical Model, Seventeenth Congress of the International Association for Hydraulic Research, Hydraulic Engineering for Improved Water Management Proceedings, Volume 2, August.

Sonneville de J.L.J., 1977, Analysis and Simulation of River Basin and Groundwater Basin System, United Nations Development Program, OTC/SF Project- Ins- 70/527, UN.

Statistical Yearbook of Bangladesh, 1983-84, Bangladesh Bureau of Statistics, Government of the Peoples Republic of Bangladesh.

Todd D.K., 1959, Groundwater Hydrology, John Wiley & Sons, Inc., Printed in Singapore by Toppan Printing Co. (S) Pte. Ltd.

Thomas R.J., 1973, Groundwater Models, FAO Irrigation and Drainage Paper, Food and Agricultural Organization of the United Nations, Rome.

Trescott P.C., Pinder G.F. and Larson S.P., 1976, United States Geological Survey, Finite-Difference Model for Aquifer Simulation, United States Government Printing Office, Washington.

Tompkins Charles B. and Walter Wilson L. JR., 1969, Elementary Numerical Analysis, Prentice-Hall, Inc., U.S.A.

UNDP, 1982, Groundwater Survey, The Hydrogeologic Conditions of Bangladesh, UN.

Walton William C., 1970, Groundwater Resources Evaluation, McGraw Hill, Inc., Tokyo, Japan.

Whorter David B. Mc and Sunada Daniel K., 1977, Groundwater Hydrology and Hydraulics, Water Resources Publications, P.O. Box 303, Fort Collins, Colorado 80522, USA.