UM-7

FINITE ELEMENT AQUIFER FLOW MODEL

SATISH CHANDRA

DIRECTOR

STUDY GROUP

P V SEETHAPATHI

NATIONAL INSTITUTE OF HYDROLOGY

JAL VIGYAN BHAVAN

ROORKEE-247667(UP)

1984-85

CONTENTS

APPENDICES

LIST OF FIGURES

ABSTRACT

The purpose of this report is to describe how to model aquifer systems with AQUIFEM-1, a finite element aquifer flow model developed by Massachusetts Institute of Technology and implemented at the Institute for regional aquifer studies. The model has been very versatile and can be used for 2 dimensional groundwater flow problems. It is based on the hydraulic equations defining the horizontal flow but it can also be used for the analysis of vertical cross sectional flows as well. Galerkine finite element technique for linear interpolation function and basic triangular elements are employed in this model. Leakage from adjacent aquifer, pumping wells, lateral inflows and outflows, flowing wells, infiltration, evapotranspiration, rising water conditions and numerous other conditions are accounted. The model can be used both for steady state and transient flow problems for confined, unconfined or changing status aquifers.

Since the original manual prepared by MIT includes detailed mathematical formulation of the model, the same is not presented here. The input data are automatically checked for consistency and completeness and wherever necessary proper messages are generated. Output which can be printed, or saved on a file, includes a mimik of input and at each time step, heads, drawdowns, flow rates, optimal fluxes, aquifer status etc. CROUTES algorithm is used for solving the

equations. The detailed list of variables and description of input data requirements are presented.

1.0 INTRODUCTION

1.1 General

A general numerical model of a groundwater system, in the present case, AQUIFEM-1, is based on a general mathematical model of groundwater systems. The mathematical model is supposed to describe the physical behaviour of the groundwater in a quantitative way. The particular aspects of groundwater behaviour that are chosen to be described by the underlying mathematical model may be either very basic or very complicated, and the mathematical description of the behaviour may be either very exact or, on the other hand, approximate. AQUIFEM-1 can only be used to simulate the particular groundwater behaviour which is described by the mathematical model it is based on.

AQUIFEM-1 is a computer model that employs the finite element technique to simulate two-dimensional groundwater flow in an aquifer under varied physical conditions. The model was initially developed by J. Wilson and A.S. Costa at MIT, USA and applied under UNDP sponsorship to basins in Greece and Yugoslavia in 1976. The code was rewritten later by J. Wilson and L. Townley, MIT.

The algorithm solves the hydraulic equation numerically by using Galerkine finite element technique.

This programme is written in Fortran-IV for an IBM-370 system. The authors, later, modified it for use on ICL 1902. This version has been adopted and made operational on VAX-11/780 system for studying a field problem.

1.2 Capabilities :

a) Anistropic, heterogeneous properties of the aquifers can be incorporated while modelling.

b) Confined, unconfined, leaky types of aquifers can be modelled.

c) Time varying boundary conditions can be incorporated.

d) Change of aquifer status from confined to unconfined and vice versa is feasible.

e) Head prescribed, discharge prescribed or mixed boundary conditions can be incorporated which facilitates modelling of all types of wells, interaction with surface water bodies, evapotranspiration, rejected flows etc.

1.3 Limitations

The major restrictions of this model are

a) it can simulate only aquifers with primarily horizontal groundwater flows and aquifer structure.

b) it can simulate only aquifers in which consolidation do not take place.

c) The model can not be used for multilayer aquifer systems.

1.4 Scope

This report is only a supplementary to the users' manual presented by Lyold R. Townley and John L. Wilson, School of Engg., MIT. Neither, the detailed mathematical treatment of the algorithm used for the development of the AQUIFEM-1 code nor the programme listing are presented. The adaption of the programme to make it operational on VAX-11/780 system and the experience of using this programme for a real life situation (for a field problem) is presented herein. For easy follow-up, the symbols which are used in the original users' manual are adopted. A comprehensive list of input variables which is of primary interest to the user is given in the end.

2.0 GROUND WATER BALANCE

2.1 Balance Equation

Water balance study takes stock of the situation with respect to the water and keeps the account of the various components of the incoming and outgoing water from a basin/ region. Such study is necessary for evaluating the available water resources and for assessing the water utilizing pattern and practices. Also, the contribution of a particular component can be verified, provided that the contributions from the remaining components are well assessed and provided that the net effect of all the components on the system is known. The basic concept of the water balance is :

Input to the system - output to the system = change in storage of the system

The various components for the above equation are to be identified prior to the study and are to be properly assessed. Where the groundwater basin is predominantly characterised by major rivers, it is desirable that the doab should be considered for the study.

The groundwater balance equation can be written as :

$$I_B + R_P + R_{CS} + R_{DP} + R_{DS} - O_E - O_W - O_B - O_D = CS$$

R_P = Recharge from precipitation

R_{CS} = Recharge from canal system (seepage through main and branch canals, distributaries, minors and field channels)

R_{DP} = Recharge from deep percolation from cropped areas

R_{DS} = Recharge from depression storage like reservoirs, lakes and ponds.

I_B = Inflow through boundaries

O_E = Outflow through Evapotranspiration from phreotophytes

O_W = Outflow through well by pumping

O_D = Outflow through drains, nallas and rivers

O_B = Outflow through boundaries

CS = Change in storage.

2.2. Estimation of the Components of Water Balance Equation

Proper assessment of the values for the various components of the equation is very much necessary. Either over estimation or under-estimation of any of the components makes the water balance study erroneous.

a) Recharge from rainfall

Part of rain water that falls on the surface of the ground is infiltrated into the soil. This infiltrated water is utilised partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This latter part of water is termed as recharge from rainfall. There are various methods for the estimation of recharge from rainfall, most of them being empirical relationship.

Three such formulae are chosen in the programme developed for the assessment of the recharge due to rainfall. They are

i) Chaturvedi's formula

$$R = 0.254\ (P - 0.432)^{2/5} \qquad \ldots(1)$$

Where R is recharge in meters and P is the total annual precipitation in meters.

This is developed exclusively for the study conducted for the UGC command area. An area where the irrigation is minimal is chosen for this purpose. The rainfall data as well as the water table fluctuations are correlated considering the specific yield of the aquifer as one of the parameters. The formula, thus developed is presented herein, as

ii) Barber - Carr formula

$$R = S_y\ (1.6\ P_m - 0.27) \qquad \ldots(2)$$

Where

R = Recharge in meters

P_m = monsoon rainfall in meters

S_y = specific yield.

iii) Central Groundwater Board (CGWB) formula

By conducting extensive studies, the Central Groundwater Board developed formula which gives the recharge from rainfall as

$$R = 0.15\ P \qquad \ldots(3)$$

The programme can be used for either of the formulae However, if any other formula is required to be used, the programme has to be suitably modified.

(b) Recharge from seepage losses of canal system

Generally, canal system comprises of main/branch canals which are more or less perennial distributaries and minors which run intermittently on roster basis and field channels or guls which lead water to the irrigation fields. A number of investigations have been carried out to study the seepage losses from canal system. These investigations lead to various empirical relationships and other methodologies. USBR has recommended the following values for channel losses based on the channel bed material.

Material	Losses in $m^3/sec/10^6m^2$ of wetted area
Clay and clay loam	1.5
Sandy loam	2.4
Sandy and gravelly soil	8.03
Concrete lining	1.2

Inflow-outflow method was used for the estimation of seepage losses through main and branch canals. The studies conducted by various investigators on the UGC system are represented on a diagram from which an average loss coefficient (in mm/running day) was determined and adopted. The seepage losses through field channels were expressed as a percentage of flow through them.

(c) Recharge from deep percolation from cropped area

This consists of recharge from canal irrigation, recharge from well irrigation and recharge from unirrigated cropped areas. In the absence of any field investigations the coefficients are given as a fraction of the water applied on the field with the economical use of water, this fraction could be 0.3.

(d) Recharge from depression storage

The surface water may be stored in the depressions. The recharge from the depression storage can be determined by taking the observations at the beginning and at the end of the study period. But, generally, the contribution from the depression storage is negligibly small except in the regions where large reservoirs are present.

(e) Inflow and outflow from the basin

If a doab is considered for analysis it will be bounded on two sides by two streams and on the other two sides by other aquifers or extension of the same aquifer. In such analysis it is desirable to take these boundaries as one along a water table contour. The flow into the region or out of the region will be governed mainly by the hydraulic gradient and the transmissibility of the aquifer. This gradient of the aquifer can be determined by taking the slope of the W.T. normal to water table contour. Then the inflow or outflow can be determined by the following relationship :

$$Q = \sum^{L} T\, i \Delta L$$

Where T is the transmissibility, i is the hydraulic gradient averaged over a length ΔL.

L - total length of the contour line.

Also observing the hydraulic gradients the losses across the river or inflow from across the river can be worked out.

(f) Evapotranspiration

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the watertable is close to the ground surface, the evaporation from the soil and transpiration from the plant will be at the maximum possible rate i.e. at potential rate. This potential evapotranspiration will take place in a water logged tract due to the rise in the watertable or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such areas can be worked out by suual methods of computing evapotranspiration using the known data.

(g) Outflow through wells by pumping

Withdrawal is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal may be obtained by means of :

1. State tubewells
2. Private tubewells
3. Open wells

In case of State tubewells, information about the number of running hours and discharge is obtained to calculate the volume pumped in each month. The information is available with the various tubewell divisions of irrigation departments. Similar information is also needed for private tubewells and open wells (including those with mechanical devices) is maintained by Minor Irrigation Department. In order to find the draft from private tubewells and open wells, sample surveys have to be conducted regarding their number, discharge and withdrawals over the year. These sample surveys will update the information about the average discharge pumped by private tubewells and open wells.

In knowing the average draft rate for each type of well and their numbers, the discharge from the wells was estimated.

(h) Outflow/Inflow from rivers

The flow into the rivers or the river hydrograph is composed of the surface flow component and the ground water flow component. In certain reaches of the river the ground water levels being lower than the river, the influent seepage will take place. Also during floods a certain amount of water will enter the flood plain and may raise the watertable elevation reducing the contribution of the groundwater to the river. In some cases even for part of the period the river may become an influent stream and, may contribute to the ground water storage.

This water stored in the adjoining area to the river and flood plain is released as base flow during the receeding river stages. Thus, this storage will on the hand reduce the flow of ground water from storage to the river and on the other will release this temporarily stored water to the river as delayed flow making it more useful for utilisation downstream.

The programme considers the major rivers and drains as head fixed boundaries. Knowing the difference between the water levels in the drains and watertable elevation in the adjoining areas, and the transmissivity, the inflow/outflow to the rivers was computed by the model which requires verification from the river balance between the reaches under consideration.

(i) Change in groundwater storage

Water level fluctuations in wells indicate changes in storage resulting from recharge to or discharge from the groundwater reservoir. When recharge exceeds discharge, water levels rise, conversely, when recharge is less than discharge, water levels decline. The water levels are highest immediately after monsoon in the month of October or November and lowest just before rainfall in the month of May or June. The water levels are observed through a network of observation wells spread over the area. Change in storage for distribution model study can be computed from the following equation :

$$\text{Change in storage} = \Sigma\ h.\ A.\ S_y$$

in which

h = change in water level

A = Area influenced by that well

S_y = Specific yield

In case of lumped model studies, the average (weighted) depth of change in water level over the area is found. The specific yield of the area can be estimated by long term pumping out tests in shallow wells.

2.3 Data Preparation Process

Preparation of basic data maps

All the necessary documents (maps, graphs) which are required for the preparation of input data to the TWGWM.FOR and its allied programmes are described here under.

2.3.1 General feature map

A general feature map including all particular features of the prototype of the model area will serve as a reference to all other thematic maps. An appropriate scale must be chosen to represent the model area say 1 cm = 10 km. (1 in = 4 miles). This dimension is found suitable for precise graphical constructions of the grid network.

The features to represent on this map are :

- Boundaries and their type
- geological discontinuities (faults, feather-edge boundaries of geological layers., lateral changes in geological characteristics etc.)
- Major hydrographic points (Lakes, main water courses, discharging areas etc.)
- recharge/extraction area locations (wells, well fields, irrigated areas, springs, forests etc.)
- Any other relevant information

This map drawn on transparent paper will serve as good support for the grid network design and all other thematic maps.

The model area needs to be sub-divided into a number of triangular elements (as suggested in Section 2.4).

2.3.2 Contour maps

A set of two contour maps are necessary at the same sclae as the general feature map. They are :

i) Impervious basement of the groundwater aquifer system.

ii) topographic map (ground level contour map)

The elevations of these geological surfaces must be read and marked in the middle of each face on a copy of the grid map. Conflicts in the specification of the absolute elevation of the various geological surfaces often arise in practice due to the inherent imprecision of contour maps.

2.3.3 Distribution maps of hydraulic coefficients

The analysis of pump test executed in existing wells within or near the project area provides the basic data for the establishment of hydraulic coefficients.

i) Horizontal permeability

ii) Unconfined storage coefficient

Values of horizontal permeability can be derived from the simple Logan formula $x_n = 1.22\ (Q/s)D$ which has the advantage of providing rapidly a homogeneous series of values on which statistical grouping can be performed to identify sub-areas of common characteristics. Correct values of storage coefficients are provided by transient pump test analysis (Theis etc.) but these storage coefficient values are valid only at the late stage of the test when effects of delayed yield have disappeared.

It is common that values of hydraulic coefficients derived from pump test analysis have a wide areal variation even when the geological formation is homogeneous. This is due to inherent imprecisions, secondary effects and local disturbances of the well testing procedure. However, the model needs the introduction of large scale average values for each homogeneous geological unit. Individual test data should then be grouped by areas, their average values calculated and attributed within sub-divisions of the study area. Transitional zones between areas of constant characteristics may exist and should be attributed to contour lines of equal value. However, the distribution of hydraulic coefficients is provisory and is precisely the subject of adjustments which will be the object of the calibration phase.

2.3.4 Water table contour/piezometric head contour maps

A set of 4 to 6 piezometric maps are necessary for the calibration phase of the model study. These are established for each aquifer layer at 2 to 3 points in time.

i) Pre-development period (steady state)
ii) Present day
iii) If possible an intermediate situation.

The preparation of piezometric maps is based on the compilation of all pieces of useful information which can be:

i) Piezometric measurements
ii) Qualitative data collected from questionnaires
iii) Location of evaporation areas (lakes, ponds, springs, waterlogged areas etc.) which indicate a piezometric level at or above the topographic surface.

Each piece of data or relevant information is plotted on a map and piezometric contours are drawn. Areas or points of accurate piezometric control are indicated specially as these will serve as reference for calibration checking.

2.3.5 Piezometric hydrographs

A selection of piezometric hydrographs at chosen points is necessary for checking the transient-state calibration. The time span should extend from pre-development condtions to present day and should be chosen particularly in areas where important drawdowns have been experienced during the development period. A set of 10 hydrographs will generally suffice.

2.3.6 History of recharge and extraction development

The history of recharge and extraction development from pre-development until today must be reconstructed from existing documents, assessment of water consumption development for each user for groundwater etc. Each component of recharge and extraction must be identified in space and its development through time quantitatively determined in the form of graphs as function of time. Amongst these the more common are :

i) Pumping for agricultural, urban water supply and industrial purposes

ii) Evaporation from open water areas (water table lakes, ponds,river beds etc.)

iii) Recharge from recharging wells, irrigation, infiltration from water bodies rainfall etc.

Hydrological studies are necessary to assess the quantitative values through time which constitute the above documents.

2.4 Recharge/Abstraction Programme

The dicretized input data concerning the recharges/ abstractions are prepared by a specially developed computer programme at NIH.

Basically it has three subroutines dealing with the recharges and extractions. They are:

a) Subroutine RAIN

b) Subtroutine SURCON

c) Subroutine WELL

The main programme calls for these subroutines provided they are required. There are indicators for calling the subprograms. If the indicator is not specified or specified as zero, the corresponding subporgramme shall not be called. This will avoid unnecessary data preparation. For example, if the study area does not contain any canal , the data pertinent to it can be avoided, since the concerned subprogramme is not requisitioned.

Subroutine RAIN reads the nodal rainfalls, forest area in the polygons and computes the recharge through rainfall over each of the polygons. Three rainfall recharge formulae can be used, viz., i) Barber-carr formula, ii) Chaturvedi's formula iii) CGWB formula. Any one of the formulae can be chosen for computation of recharge through rainfall by providing appropriate indicator.

Subroutine SURCON, reads all the data pertinent to the canal command area, CCA to polygon distribution, volume of water flowing through each distributory and run days of each distributory. The governing field coefficients determined from the field tests for the estimation of seepage are also read and the following are computed.

i) seepage from distributories/minors

ii) seepage from field channels

iii) deep percolation from irrigated areas

The total seepage thus calculated for each distributory using the respective field coefficients is distributed to the polygons using the CCA-polygon transformation table.

Subroutine WELL reads the data pertaining to the blocks, the type of extraction devices and their seasonal extraction rates and the no. of devices in each type. The subroutine calculates the total extraction on blockwise and the same is distributed to various polygons using block-polygon transformation table. The recharge through ground-water irrigation was also computed and distributed to the polygon likewise.

The module MAIREC receives the information with regard to polygonal recharges and extractions and create a recharge abstraction file for subsequent utilization in the model study.

3.0 METHODOLOGY AND MODEL FORMULATION

3.1 Governing Differential Equation

The governing differential equation for two-dimensional essentially horizontal groundwater flow in a non-homogeneous, anisotropic,aquifer with leakage is (Figure 1)·

$$S \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} (T_{xx} \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y} (T_{yy} \frac{\partial h}{\partial y}) + Q \frac{K'}{B'} (h_a - h) \qquad \ldots(4)$$

where,

S = aquifer storage coefficient [dimensionless]

h = depth averaged piezometric head,usually denoted Ø for confined aquifers [L]

T_{xx} = aquifer transmissivity in the x-direction $[L^2/T]$

T_{yy} = aquifer transmissivity in the y-direction $[L^2/T]$

Q = net inflow/outflow from point or distributed sources (and sinks) [L/T]

K' = vertical permeability of the leaky semi-pervious layer above or below the aquifer [L/T]

B' = thickness of the semi-pervious layer [L]

h_a = piezometric head in a vertically adjacent aquifer. separated from the main aquifer by the semipervious layer L

x,y = cartesian coordinates (principal axes of the hydraulic conductivitiy or transmissivity tensor [L]

and t = time T

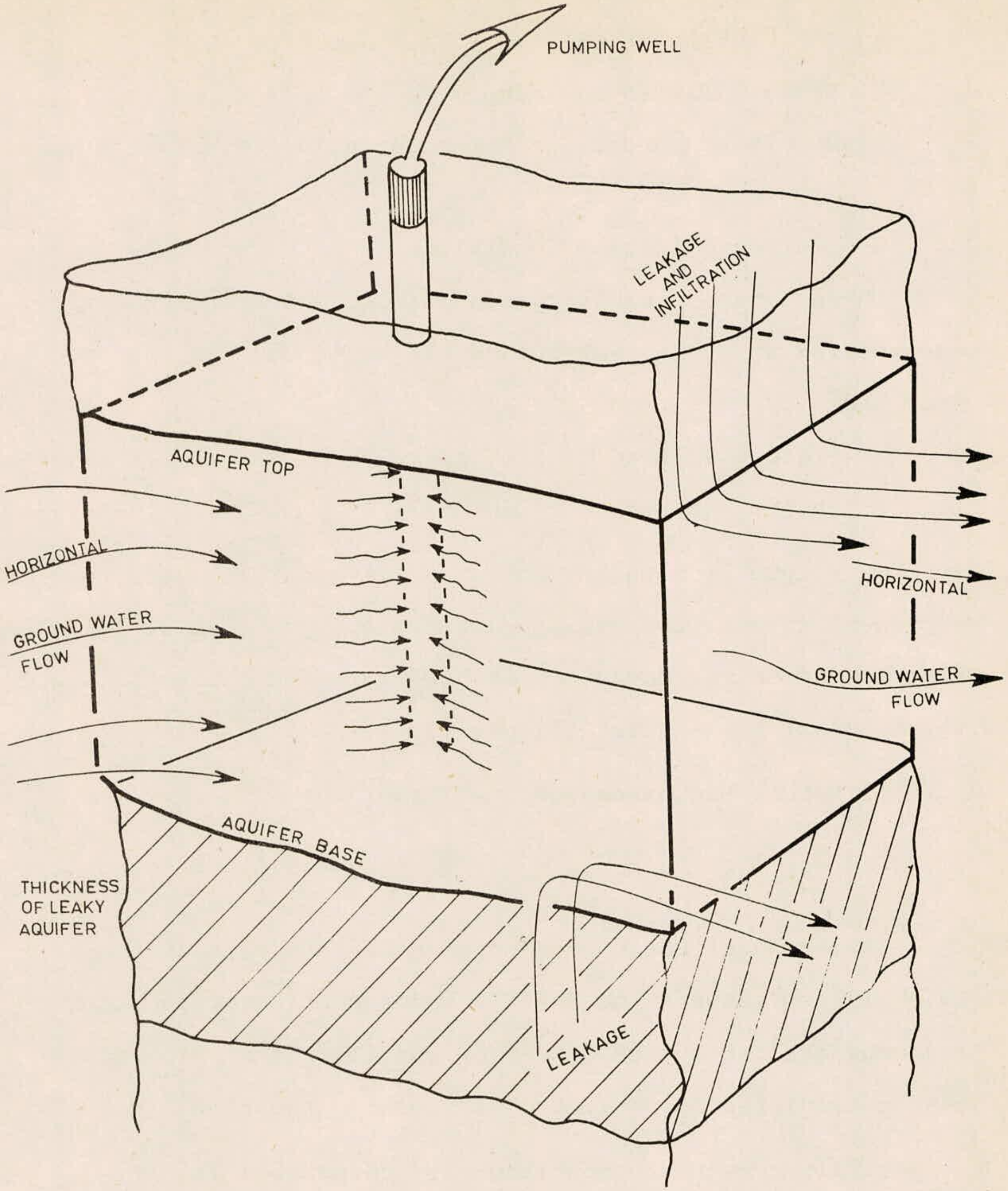

FIGURE 1 - MODEL AQUIFER WITH HORIZONTAL GROUNDWATER FLOW, VERTICAL LEAKAGE AND WELL

The basic assumptions in equation 1 are

a) The density of the fluid is constant

b) Darcy's law is applicable

c) Dupuit's approximation for unconfined aquifer is valid.

3.2 Boundary and Initial Conditions

Three types of boundary conditions, which are generally encountered in ground water flow can be imposed in this model They are ;

a) Prescribed head condition,as

$$h = h_1 \; (x,y,t) \text{ for region } \Gamma 1 \qquad ..(5)$$

This type of boundary condition is generally used to represent rivers, reservoirs, lakes etc., provided it is assumed that the effect of these bodies penetrate the entire saturated thickness of the aquifer (Figure 2).

b) Prescribed discharge condition,as

$$-\left(T_{xx} \frac{\partial h}{\partial x} \cdot n_x + T_{yy} \frac{\partial h}{\partial y} \cdot n_y \right) = Q_s(x,y,t) \text{ for region } \Gamma 2 \quad ...(6)$$

This type of boundary condition is used when there is lateral flow between the aquifer under consideration and an adjacent aquifer system. No-flow condition from a boundary can be simulated by setting Q_s to zero in equation

c) Mixed boundary condition is represented as

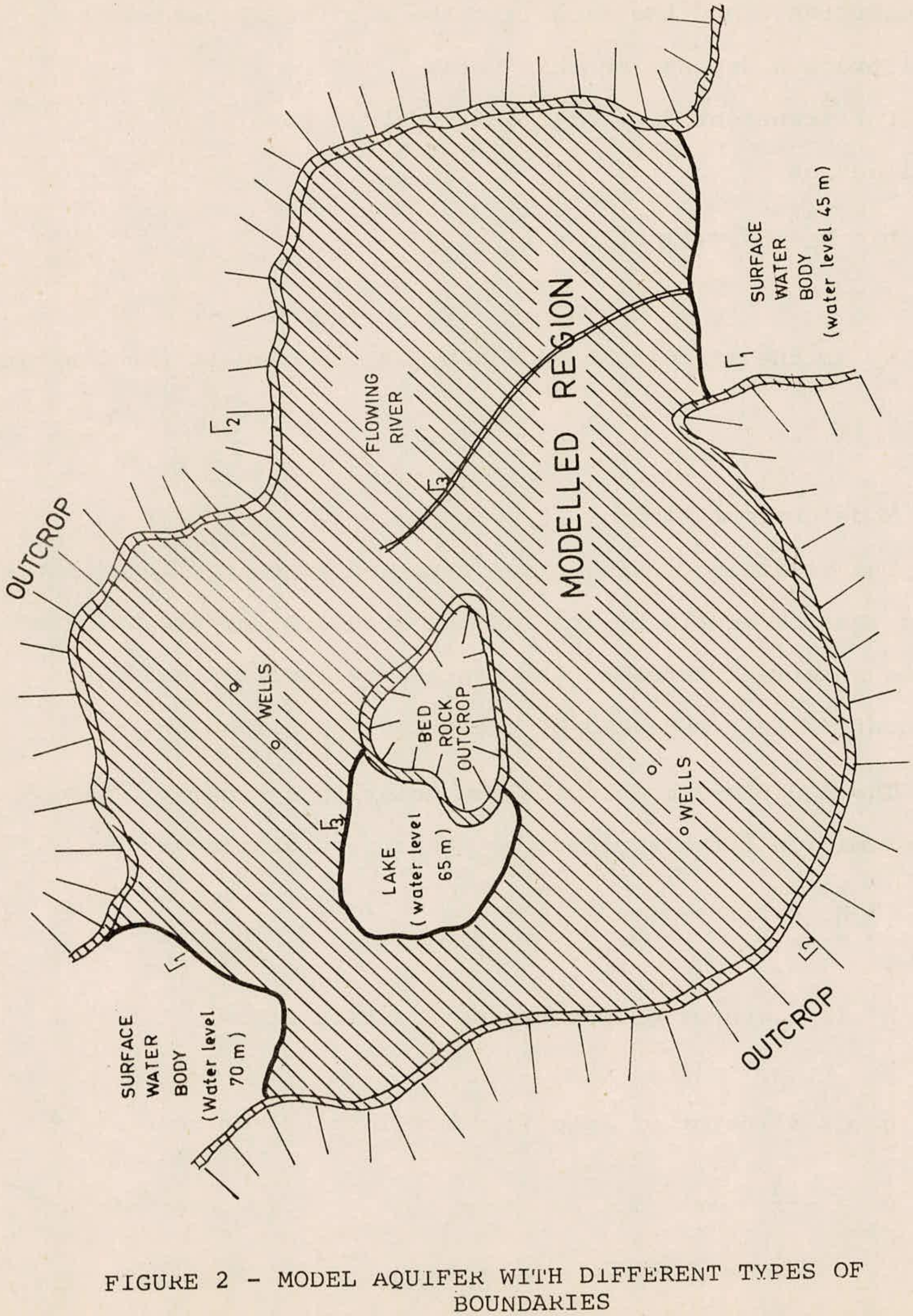

FIGURE 2 - MODEL AQUIFER WITH DIFFERENT TYPES OF BOUNDARIES

For representing partially penetrated rivers and ponds, this boundary condition is used. The term $\frac{K''W''}{B''}$ can be termed as conductance and the flow into the aquifer system under consideration depends on this term.

For transient flow problems, initial conditions are specified as

$$h = h_o\ (x,y,t) \text{ at } t = t_o \qquad \ldots(8)$$

where,

t_o is the starting time and h_o is the head at the starting time.

3.3 Model Formulation

The governing differential equation is solved for discritized aquifer domain by knowing the boundary conditions. Thus, in the numerical methods, the continuous function described by equation 1 is replaced by piecewise approximation.

The AQUIFEM-1 model uses the Galerkin approach. This approximation for head leads to (Wilson et al.,1979).

$$\underline{\underline{M}}\,\dot{\underline{h}} + \underline{\underline{K}}\,\underline{h} = \underline{f} - (\underline{\underline{M}}^*\,\dot{\underline{g}} + \underline{\underline{K}}^*\underline{g}) = \underline{f}^* \qquad \ldots(9)$$

where,

$\underline{h}$ is a vector of unknown piezometric heads,

$\dot{\underline{h}} = \frac{d}{dt}(\underline{h})$

$\underline{g}$ is a vector of specified model values of head on Γ_1

$\dot{\underline{g}} = \frac{d}{dt}(\underline{g})$

$\underline{\underline{M}} = \underline{\underline{M}}^*$ is the capacity or storage matrix representing storage effects,

$\underline{\underline{K}} = \underline{\underline{K}}^*$ is the conductivity or stiffness matrix representing transmissive effects and some effects of leakage

$\underline{f}$ is the flux vector representing the effects of 2nd-type boundaries, sources/sinks, and part of the contribution of leakage

$\underline{f}^*$ is the right-hand side vector in Equation 9 which includes the flux vector $\underline{f}$ and the effect of Ist-type boundaries.

In the expressions above, a single underline represents a vector and a double underline represents a matrix(which is not necessarily square).

This model uses triangular elements with linear interpolation functions, with the basic assumption that the properties like S,T_{xx}, T_{yy} and K'/B' and distributed sources/sinks. Q are constant over an element. Equation-9 is modified suitably dependening upon whether the case is steady state or transient state.

Thus, the number of equations are equal to the number of node points. Equation-9 is solved by Crout's method for steady state problems. For unsteady problems an implicit finite difference scheme is used for handling the time derivative. The implicit method ensures convergence at each time step. For changing status aquifer a fully implicit(backward differ-

difference) formula is used. The weighting coefficient and time integration parameter are prescribed according to necessity

3.4 Programming Aspects

The formulation is the previous section indicates that the solution accuracy depends upon and is roughly proportional to the number of node points. However, the computational cost is approximately related to square of the number of node points The rounding off errors also increase with increasing node points. Hence, it is desirable to use a minimum number of node points that give satisfactory accuracy. Thus an optimal grid design depends upon a close understanding and working experience with the model '

The aquifer area is discretized into basic elements with node points on the vertices of the triangle. Nodal coordinates are read in with appropriate scaling factors to convert those to the adapted length units. The rapidity of convergence and degree of accuracy are minimized when the triangles are more or less equilateral. Anisotropic hydraulic properties also induce a distortion effect that may be counteracted by corresponding distortion of the shapes of elements. Convergence may be adversely affected when the ratio of areas of adjacent elements lies outside the range of 1/5 to 5.

Internal zones of no-flow are assigned very low but non-zero conductivity values. The element connectivity data i.e. node points for each element) are given in counterclockwise order. If these data are not given as input in proper order the programme writes out negative areas which are indicative of this error. Several diagnostic error and warning messages are built in the program which can be printed, if necessary during programme execution. Output from a production run is obtained after an integral number of time steps and/or at specified times. In the later case extra solutions are computed at the given times if they do not coincide with the time steps. Print-plots of the grid and nodal heads can also be obtained for data checking and for visualization of the aquifer condition.

Any consistent set of units can be used in the model. The programme also provides dynamic storage allocation for economizing storage space.

3.5 Modelling Capabilities

The finite element formulation allows for the inclusion of various aquifer features in the mathematical analysis. In the case of a confined aquifer either transmissivities or hydraulic conductivities can be read in as aquifer properties, the aquifer thickness being necessary in the later case. The thickness data are also useful in checking for confined conditions. Since the aquifer property and thickness data do not vary in time, the conductivity matrix is computed only once while the system matrix is updated at every time step for a linear solution.

Phreatic aquifers can also be solved by linearizing the equations if there is no significant variation of the saturated thickness spatially. However, as a general rule a non-linear algorithm used, necessarily gives a more accurate solution. In such a case, it is appropriate to feed hydraulic conductivity data rather than transmissivity. The solutions for nonlinear equations can be obtained by using iterative procedures. The conductivity matrix is reformed at very iteration using values of piezometric head of the previous iteration.

A changing status aquifer is highly complicated due to variation in storage coefficient. In such cases, it is necessary to set the time integration parameter to 1.0 resulting in a fully implicit finite difference scheme. During execution, the programme checks for completely confined conditions, if this condition is invalidated a linear combination of the confined and phreatic values is used to compute the storage coefficient matrix for the next time step. A special storage weighting algorithm is used to find the new solution at each time step.

For transient and/or nonlinear problems the initial nodal piezometric heads must be known. These values may be either supplied, or computed by the programme. In the later case a linearized solution is computed based on the prescribed initial heads at head fixed boundary nodes.

Aquifer properties may be specified as nodal values or by elements. The properties include hydraulic conductivity or transmissivity, storage coefficient or specific yield, leakage parameter, aquifer thickness, bottom and top elevations of the aquifer. Assigning aquifer properties by elements is useful when sharp discontinuties exist within the aquifer domain. However, sharp discontinuties exist within the aquifer domain. However, natural basins with horizontal flow involve only gradual changes in properties.

3.6 Implementation of Boundary Conditions

Proper delineation of the aquifer domain is essential to the successful application of any numerical method. Hence, the physical limits of the aquifer must be known in addition to quantifiable hydraulic conditions at the boundary as well as elsewhere within the aquifer. The boundary conditions used in aquifer are as follows :-

1. Prescribed piezometric head
2. Prescribed lateral fluxes
3. Prescribed mathematical relation between the head and the flux.

The first of these conditions may be implemented with relative ease and accuracy, wherever possible. The second condition can also be determined with accuracy at times, as in the case of a no-flow ground water divide. The third condition is more difficult to ascertain and is used only when the first two conditions cannot be applied, e.g. when there is semi-permeable boundary. These three types of boundary conditions suitably account for various hydraulic conditions in the aquifer. Boundary conditions if changing with time, may be specified at diffierent times, but these times should coincide with an integral number of time steps since only step-function boundary values are incorporated in the model.

3.6.1 Prescribed head condition

The first type of boundary condtion head fixed node assumes that the piezometric head is prescribed at that node over the entire aquifer depth. Such points when located on streams, lakes, etc., imply in effect, that these surface water bodies penetrate the aquifer completely. Within the aquifer a sequence of head-fixed nodes represent a channel of relatively narrow width with respect to the areal dimension of adjoining elements. A cluster of head-specified nodes occupying a sub-region within the aquifer represents large reservoir or lake.

The programme computes inflow (or outflow) to or from the aquifer at the first type boundary nodes.

In phreatic aquifers the water table may rise to the ground surface as a result of recharge. In such cases, if the nodal ground levels be specified, the code imposes this level as the maximum elevation upto which the water level can rise. At all subsequent times after reaching this level the node is treated as a first boundary node. However, such rising water table nodes do not penetrate the aquifer.

3.6.2 Prescribed flux condition

If lateral flow of a known magnitude occurs across a boundary, flux rate per unit boundary length (L^2/T) is specified. A typical case is that of a no-flow boundary such as an aquiclude, geologic fault, or an artificial ground water divide. For non-zero flow, the flow across an element side is equally distributed by the code to the two nodes of the side.

Specified vertical fluxes may occur at nodes or over elements. Nodal fluxes represent point sources/sinks such as pumping, recharge etc. Element values represent distributed fluxes such as natural recharge, evapotranspiration, irrigation recharge, recharge ponds and spreading basins, network of distributed wells etc. Element fluxes are used to compute the total flux (L^3/T) over the entire element, and assign equally to its three node points. The choice of specifying either element or nodal fluxes depends primarily on the areal extent of the aquifer and the flux region. For regional modelling problems, small surface water bodies can be appropriately represented by nodal fluxes.

3.6.3 Mixed boundary condition

The third (or mixed) boundary condition relates flux to known head at the boundary. It can be used, for instance, to represent interaction between a phreatic aquifer and a stream mutually separated by a semi pervious barrier. In this case a leakage parameter is computed for the semipervious layer, and the flux is related to the stream-head and the leakage parameter. Mixed boundary condtions may also be used to represent partially penetrating surface water bodies. However, the method adopted in Aquifem is appropriate and requires the computation of a hypothetical leakage parameter. Hence, it is resorted to when the saturated aquifer thickness is much greater than the depth of penetration of the water body, and in the absence of reliable information on the flux into or out of the aquifer.

Both phreatic and confined aquifers may be subjected to leakage flux through a semi-permeable layer from a vertically adjacent aquifer. The head in the adjacent aquifer must be known, and a leakage parameter computed from the hydraulic conductivity and thickness of the aquifer. The rate of leakage into the aquifer is determined from the difference in heads between the aquifers and the leakage parameter.

Fully penetrating flowing wells with varying discharge but constant drawdown can be modelled using first type condition by suitably specifying the ground levels at those locations. Partially penetrating flowing wells are presented as third-type nodes and equivalent leakage parameters are used to examine their effect of partial penetration.

Direct evapotranspiration from a phreatic aquifer depends on the depth of the water table below the ground surface. Based on an estimate of the depth of the phreatic surface below ground level upto which it affects evapotranspiration, a simple computational scheme is provided for possible inclusion in the programme. Other hydraulic features such as springs, land drainage and dewatering can also be accommodated.

3.7 Data Requirement

The input data is broadly classified into five groups. The first type of input describes the nature of the problem-like, aquifer status, steady or unsteady state etc. If it is not an initial value problem the specification of initial conditions (piezometric heads) is optional. Several other aspects of the problem are also required in this group like the total number of elements and node points, specification of aquifer properties, whether by node or by element, the types and number of boundary conditions supplied, computational parameters and output control parameters.

The second input set describes the space discretization, the nodal coordinates and element connectivity data.

The third input group consists of aquifer properties which include aquifer thickness, permeability, transmissivity, specific yield/storativity, bottom and top elevations of the aquifer and leakage parameter for any underlying or over lying leaky layer. Initially default properties can be specified for the entire aquifer followed by specification of properties for individual element/nodes or groups of elements/ nodes.

The fourth type of input data consists of boundary and initial conditions, which are discussed earlier. The data needed in this category are piezometric heads for head fixed boundary nodes, ground elevations, areal fluxes, elementwise lateral fluxes across element sides, nodal fluxes, and leakage conditions for mixed boundary condition and nodal heads in a vertically adjacent aquifer separated from the aquifer under study by a semi-pervious zone etc.

All these boundary conditions are specified for given time intervals which should match with an integral mulitple of time step . It is to be noted that for an unsteady problem at least one nodal head fixed boundary condition must be specified at any given time to ensure a solution. Moreover, head fixed boundary conditions, over the initial conditions, if any specified earlier at those nodes. Initial piezometric head need to be specified at all nodes. However, this is optional for the case of steady state problem.

The fifth set of data are output controls. The specific types and extent of results that are desired as output are specified in this set. These also include print plots of nodal heads in the aquifer to appropriate scale. The output times are also required to be specified here.

Each of the above types of input data are read in different sub-routines. All input devices are assigned a logical value of five as is customary for card reader input. However, the data for the problem under consideration was directly created through an interactive terminal. All data variates are of text, logical integer and real types.

3.8 Information Output

Output listing is printed out without carriage control. All major input data are output for verification. Nodal coordinates, element connectivities, integration parameters and element areas can be printed out optionally. The maximum deviation between nodal head during the last two iterations is output as error (in convergence). A phreatic nodal condition is represented by 'PHR' whereas, piezometric head touching the aquifer bottom is indicated by a 'DRY' node. A vector ID with values 1, 2 and 3 represents nodes on 1st type, 2nd type and 3rd type boundary condtions. Areally distributed element fluxes are converted to and summed up with nodal fluxes, and represented as 'source/sink inflows', where a negative value indicates outflow. For unsteady problems, there may be significant inflow and storage in the aquifer. The volume rates of flow per unit time are printed out separately for nodal fluxes, leakage fluxes and lateral fluxes for each node and the net flow rate into or out of the aquifer is computed.

A number of warning and/or error messages may be printed during and at the end of an execution. If the final solution has converged despite (or in the absence of) such messages 'NORMAL ENDING' is indicated at the end of the run.

3.9 Modifications for Adoption

The AQUIFEM model was suitably modified to suit to the requirement. The file identification statements were introduced. The programme was tested using the given test data, keeping all the subroutines intact. After satisfactory implementation, some of the subroutines which are not essential for the case study were deactivated, without affecting the functional use of the programmes. The restructured programme which was tested on VAX-11/780 was used for a case study. The flow chart is given in figure 3. The input formats and typical test problems were given in the users' manual prepared by L.R. Townley and J.L. Wilson (1980) for AQUIFEM-1.

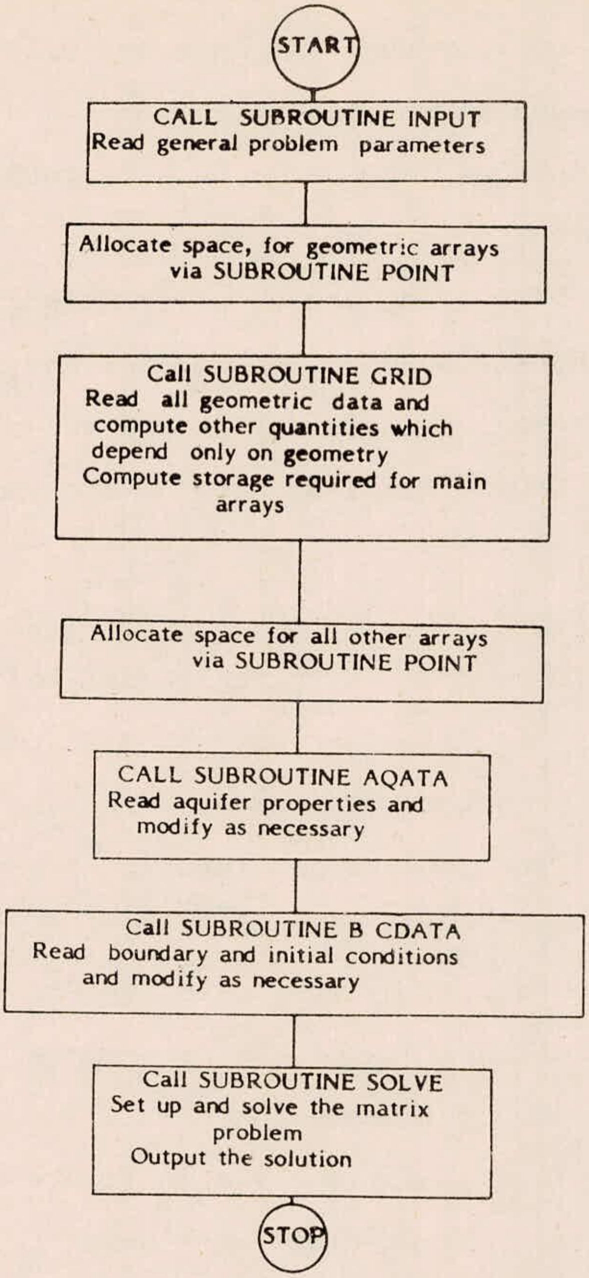

FIGURE 3 - FLOW CHART OF AQUIFEM PROGRAMME

REFERENCES

1. Seethapathi, P.V., "Tyson Weber Groundwater Flow Model", UM-1, 1984-85.
2. Seethapathi, P.V., and Gautam Roy, "Finite Element Groundwater Flow Model (Aquifem) - Upper Ganga Command Area", TN-3, 1983-84.
3. Townley, Lloyd R., and John L. Wilson, "Description of and User's Manual for a Finite Element Aquifer Flow Model Aquifem-1", Report No.252, Feb., 1980.
4. Wilson, John L., Lloyd R. Townley, and Antonia Sa da Costa, "Mathematical Development and Verification of a Finite Element Aquifer Flow Model Aquifem-1", Report No.248, June, 1979.

APPENDIX -I

Data file for Recharge/Abstraction Programme

File Name : GEOMR. DAT

Card Type	Variable Name	Description	Format	When required
I	NN	No. of internal triangles	3I5	Always
	NWELL	Indicator for the presence of wells in the area = no wells		
	NCANAL	Indicator for the presence of canals = 0 No canals		
II	AREA	Areas of triangular elements	8F 10.2	Always

Data file for subroutine SURCON

File Name : CON.DAT

Card Type	Variable Name	Description	Format	When required
I	TNCC	Total no. of command areas in the basin	I5	Always
II	CCAREA	Canal command areas	8F10.2	Always
	NC	Command area/Number	I5	
III	CNAME	Command area Name	A15	
	NNPC	No.of polygon in each command area	I5	
IV	PNCC	Polygon number	16I5	if NNPC > 0
	NAREAC	% of polygon area covered		
V	VOLC	Volume of water flowing in each distributory on monthly basis(Nov.onwards)	12I6	Always
VI	RUN	Corresponding running days for each distributory	12F6.2	Always
VII	NMWP	No. of different wetted perimeters for each distributory	16I5	Always
VIII	AREAIN	Seepage area for each wetted perimeter type in each distributory	8F10.2	Always
IX	DISLOS	Distributory loss coeff. each distributory in ft/day	8F10.2	Always
X	GULLOS	Gul loss coeff.for Guls in each distributory (dimensionless)	8F10.2	Always

Data file for subroutine WELL

Name of file : ABSWEL.DAT

Card type	Name of Variable	Description	Format	When required
I	TNB	Total no. of blocks in the area	I5	Always
II	NB	Block Number	I5	
	BNAME	Name of block	A15	Always
	NNPB	No. of polygons in each block	I5	
III	PNB	Polygon number		
	NAREB	% of the polygon area covered	16I5	if NNPB >0
IV	BLAREA	Area of blocks	8F10.2	Always
V*	NB	Block Number	I5	
	ANAME	Block Name	A15	
	PUMPR	Pumping rate for each type of lifting devices (there are five types)	5F 8.5	Always
VI	NB	Block Number	I5	
	ANAME	Block Name	A15	Always
	TLIFT	No. of lifting devices for each type (There are five types)	5F10.5	

*Card type V is to be provided for monsoon and nonmonsoon seasons.

Data file for subroutine RAIN

Name of file : RAIN.DAT

Card type	Name of Variable	Description	Format	When required
I	IRAIN	Indicator for the formula to be used for calculating the rainfall recharge = 1 Barbar-Carr formula = 2 Chaturvedi's formula = 3 CGWB formula	I5	Always
II	NRAINP	Polygonal rainfall values for each season	16I5	Always
III	NFOR	No. of polygons having forests	I5	Always
IV	NODFOR	Nodal numbers having forests	16I5	if NFOR > 0
V	AREAFO	Areas of forests in respective polygons NODFOR	10F8.2	if NFOR > 0

APPENDIX II

Name	Description of Contents	Comments
A	Main storage array equivalenced with IA (only used in main program)	
A	Coefficients of X in equations of element interpolation functions	
AQELPR	Array of element aquifer properties	
AQNOPR	Array of nodal aquifer properties	
AQPROP	Array of aquifer properties	
AREA	Element areas	
ARN	Areas associated with nodes	
B	Coefficients of Y in equations of element interpolation functions	
BEDLVL	Array of nodal bed levels on 3rd-type boundary	
BOT	Element average bottom elevation(AQELPR, subroutine AQDATA)	Alternative name
BOTN	Nodal bottom elevation (AQNOPR, subroutine aqdata)	Alternative name
CORRK	Effect of previous solution on sysv in iterative solutions	
FLXBC1	Fluxes through ist-type boundary with extraneous storage terms	
FLXLKY	Terms related to both types of leakage fluxes	
FLXSID	Known side fluxes	
FLXTOP	Nodal equivalents of point/distributed source/sink fluxes	
G	Effect of fixed heads on SYSV	
GK	Global conductivity matrix, sometimes modified by lumped storage terms	Alternative name
GKL	Lumped global areal leakage matrix (aqnopr, subroutine aqdata)	

GKLEAK	Lumped global leaky matrix-both types of leakage	
GKL3	Lumped global 3rd-type leakage matrix	
GM	Lumped global storage matrix,sometimes scaled by ADTINV	
GRD	Array of ground levels	
H	Piezometric heads	
HADJ	Array of heads in adjacent aquifer	
HBC3	Array of Nodal heads on 3rd-type boundary	
HL	Element average heads	
HNODE	Array of fixed heads	
HPRED	Predictor of head at this time step	
HZERO	Array of initial conditions/ Guesses or heads at previous time step	
I	Array of starting addresses	
IA	Main storage array, equivalenced with a (only used in main program)	
ICON	Array of element connectivities	
ID	Array indicating whether or not nodes are on boundaries(Status)	
IPT	Array of starting addresses of dynamically allocated arrays(I. MAIN)	Alternative name
ISTAT	Indicates status at nodes : 1/0/-1 means confined/phreatic/Dry	
KDIAG	Array of addresses of diagonal terms in comapcted global arrays	
LEXT	External element identification numbers	
LINT	Internal element identification numbers	
NADJ	Identification numbers of nodes where adjacent heads are given	
NAQREG	Number of elements in each of the NAQR aquifer property regions	Temporary Storage
NBHN	Identification numbers of fixed heads nodes (Status)	
NEXT	External node identification numbers	
NINT	Internal node identification numbers (equation numbers)	

NN	Array for sorting nodes for print-plot	
NN3	Identification numbers of nodes on 3rd-type boundary	
NODFIX	Identification numbers of nodes where heads are fixed to ground level	
NODGRD	Identification numbers of nodes where levels are given	
NQE	Identification numbers of elements with distributed fluxes	
NQN	Identification numbers of nodes with fluxes	
NQS	Identification numbers of nodes definingsides with fluxes	Temporary storage
NS3	Identification numbers of nodes defining 3rd-type side	Temprary storage
NUM	Array of identification numbers of nodes/ elements in AQ.property region	
NX	Line printer X-coordinates	
NY	Line printer Y-coordinates	
PLTIME	Special plotted output times	
PREDM	Effect of hapred on STSV in unsteady problems	
PRTIME	Special printed output tines	
QE	Array of element fluxes	
QN	Array of nodal fluxes	
QREG	Array of element fluxes for a region with uniform fluxes	Temprary storate
QS	Array of side fluxes	
QX	Flux per unit horizontal width in X-direction	
QY	Flux per unit horizontal width in Y-direction	
RADJ	Coefficients for modifying leaky fluxes if necessary (status)	
RBC3	Coefficients for modifying 3rd-type fluxes if necessary (Status)	
RKXX	Element average permeability in X-direction AQEKPR ,subroutine aqdata)	Alterantive name
RKYY	Element average permeability in Y-direction AQELPR ,subroutine aqdata)	Alternative name

S	Element are elastic storage coeft(AQELPR, subroutine AQDATA) (not used)	Alternative name
SN	Nodal elastic storage coefficient(AQNOPR, subroutine, AQDATA)	Alternative name
STO	Nodal storativities	
SY	Element average specific yield (AQELPR, subroutine AQDATA) (not used)	Alternative name
SYN	Nodal specific yield(AQNOPR ,subroutine AQDATA)	Alternative Name
SYSM	Left hand side system matrix	
SYSV	Right hand side vector in system of equations, or solution (EQSOLV)	
TBC3	Time associated with 3rd-type boundary heads	
TBH	Times associated with fixed heads	
TFLEXE	Times associated with element fluxes	
TFLEXN	Times associated with nodal fluxes	
TFLXS	Times associated with side fluxes	
TGRD	Times associated with ground levels	
THADJ	Times associated with heads in adjacent aquifer	
THIK	Element average aquifer thickness (AQELPR, subroutine AQDATA)	Alternative name
THIKN	Nodal aquifer thickness(AQNOPR, subroutine AQDATA)	Alternative name
TITLE	Alphanumeric character string as a run title	Real array
TXX	Element average transmissivities in X-direction	
TYY	Element average transmissivities in Y-direction	
V	Rate of change of piezometric head D/DT	
XORD	X-coordinates of nodes in finite element grid	
YORD	Y-coordinates of nodes in finite element grid	

ADT	Alpha* DT	
ADTINV	Inverse of ADT	
ALPHA	Parameter for time integration scheme	
AMIDT	(1.0 - ALPHA)*DT	
ATTOP	Indicates whether or not adj.Aquifer is at top of aquifer under study	Logical variable
BALANC	Net flow into aquifer at this time	
BEDBC3	Indicates whether or not bed levels on 3rd-type boundary are given	
BYNODE	Indicateswhether or not aquifer properties are given by node/element	Logical variable
CHCOND	Indicates when conductivity terms in GK are to be changed(Status)	Logical variable
CHECK	Indicates whether or not run is only for a data checking purposes	Logical Variable
CHGKL	Indicates when ordinary leakage terms in GK are to be changed (Status)	Logical Variable
CHGKL3	Indicates when 3rd-type leakage terms in GK are to be changed(Status)	Logical Variable
CHSTAT	Indicates a change of status since last check	Logical Variable
CONFIN	Indicates whether or not all Nodes are confined (Status)	Logical Variable
DHDT	Indicates when initial rate of change of read is being computed	Logical variable
DRAWDN	Drawdown from initial conditions at a node	
DT	Initial time step for unsteady computations	
DTPARN	Parameters for changing time step as computations proceeds	
DTPRV	Size of time step before modifing IDT to 3	
ENDTIN	Ending time for computations	
ERR	A measure of the difference between solutions is required (solve)	
FINAL	Indicates whether or not final steady staff solution is required (solve)	Logical Variable

FLEAKY	Leaky inflow at a node	
FLXBND	Flux through Ist or 2nd-type boundary at a node	
HAVARY	Indicates whether or not heads in adjacent aquifer very spatially	Logical variable
HZ	Initial head	
ICVARY	Indicates whether or not given initial conditions/guesses vary spatially	Logical variable
IDT	Indicates method for changing time step as computation Proceeds	
IDTPRV	Value of IDT before it was set to 3	
IERR	Error indicator	
INAQ	Input device number in subroutine AQDATA	
INBCS	Input device number in subroutine BCDATA	
INGRD	Input device number in subroutine grid	
INITIAL	Indicates whether initial conditions/ guesses are computed/given (Solve)	Logical variable
INP	Input device number in subroutine input	
INSOL	Input device number in subroutine solve	
IOUT	Indicates currently appropriate special printed output time (output)	
IPLT	Indicates currently appropriate special plotted output time	
IPP	counts the number of times subroutine prplot has been called (PRPLOT)	
IPREC	Single/double precision indicator	
IPRT	Output device number	
IRD	Input device number	
ISET	Causes ISTAT to be reset if ISET=0	
ISTPLT	First time step when plotted output is required	
ISTRIPRT	First time step when printed output is required	
ISIS	Number of iterations since sysm was last reformed	
ITBC3	Indicates which 3rd-type heads are currently appropriate (BCVALS)	
ITBH	indicates which fixed heads are currently appropriate (BCVALS)	

ITER	Interation counter	
ITFLEX	Indicates which element fluxes are currently appropriate (BCVALS)	
ITFLXN	Indicates which nodal fluxes are currently appropriate (BCVALS)	
ITFLXS	Indicates which side fluxes are currently appropriate (BCVALS)	
ITGRD	Indicates which ground levels are currently appropriate (BCVALS)	
ITHADJ	Indicates which adjacent heads are currently appropriate (BCVALS)	
ITOL	Indicates type of measure of the error between Iterations	
IWARN	Number of warning meassages	
LINEAR	Indicates whether analysis is linear(IZED) or nonlinear	Logical variable
MAXELT	Largest element identification number	
MAXIT	Maximum allowable number of iterations	
MAXNOD	Largest nodal identification number	
MAXUSE	Length of storage actually used in main storage arrays A and IA	
MSIZE	Length in words of main storage arrays A and IA	
NAQR	Number of aquifer regions with regionally defined aquifer properties	
NBAND	Bandwidth of global matrices in full form	
NBC3	Number of sides on 3rd-type boundary	
NBOUND	Number of of ROWS/COLS between plotted extrema and axes	
NDP	Number of digits printed after decimal point	
NDT	Number of constant length time steps before changing according to idt	
NDTPLT	Number of time steps between plotted outputs	
NDTPRT	Number of time steps between printed outputs	
NEFR	Number of regions with uniform element fluxes	
NEWADJ	Indicates new adjacent heads or leakage modification (BCVALS,BUILDF)	Logical Variable

NEBNCE	Indicates new element fluxes (BCVALS, BUILDF)	Logical Variable
NEWBCE	Indicates new element fluxes (BCVALS, BUILDF)	Logical Variable
NEWBCS	Indicates new side fluxes (BCVALS, BUILDF)	Logical Variable
NEWBC1	Indicates new fixed reads (BCVALS, BUILDF)	Logical Variable
NEWBC3	Indicates new 3rd-type boundary heads or modification (BCVALS,BUILDF)	Logical Variable
NEWDT	Indicates when magnitude of time step changes	Logical Variable
NEWK	Indicates when new conductivity matrix needed	Logical Variable
NEWM	Indicates when new storage matrix GM is needed (BUILDF)	Logical Variable
NEWSYS	Indicates when left hand side matrix sysm is to be rebuilt (BUILDF)	Logical Variable
NEWTIM	Indicates the start of a new time step (BUILDF)	Logical Variable
NFIX	Number of nodes where heads are fixed to ground level (Status)	
NFIXED	Number of heads fixed at ground level at previous time step/iteration	
NFLXE	Number of elements with distributed element fluxes	
NFLXN	Number of nodes with given nodal fluxes	
NFLXS	Number of sides with given 2nd-type side fluxes	
NGRD	Number of nodes where ground levels are given	
NGADJ	Number of nodes where heads in adjacent leaky aquifer are given	
NHNODE	Number of fixed head nodes	
NK	Number of terms in compacted global arrays	
NNOD3	Number of nodes on 3rd-type boundary	
NOUT	Number of special times when printed output is required	
NPLT	Number of special times when plotted output is required	
NQREG	Number of elements in an element flux region	
NRFLAG	Indicates whether or not rotation of plot axes is allowed	

NSPEC	Number of nodes/elements with individually defined aquifer properties	
NSYS	Number of iterations before reforming left hand side matrix sysm	
NTBC3	Number of times when nodal heads on 3rd-type boundary are given	
NTBH	Number of times when fixed heads are given	
NTFLXE	Number of times when element fluxes are given	
NTFLXN	Number of times when nodal fluxes are given	
NTFLXS	Number of times when side fluxes are given	
NTGRD	Number of times when ground levels are given	
NTHADJ	Number of times when adjacent heads are given	
NTIME	Time step number	
NUNEL	Number of finite elements'	
NUMNP	Number of nodal points in finite element grid	
OUTTIM	Next special output time either printed or plotted	
PDEALTA	User-supplied increment for labelling axes (order)	
PERM	Indicates whether permeabilities on transmissivitieis are given	Logical Variable
PERM3	K"/B" coefficient for a side link on 3rd type boundary	
PLGEOM	Indicates whether or not geometrix data should be plotted	Logical Variable
PLOT	Next special time at which plotted output is required	
PRGEOM	Indicates whether or not geometrix parameters should be printed	Logical Variable
PRINT	Next special time at which printed output is required	
PSCALE	Plotting scale (order)	
RESET	Indicates whether or not GM should be rebuilt next time step	Logical Variable
STEADT	Indicates whether or not problem is steady state (solve)	Logical Variable
STRTIM	Starting time for computations	
TIME	Time at which solution is currently being obtained	
TIMPRV	Time at previous time step	
TOL	Tolerance for convergence of iterative solutions	
TOTBNO	Total flux through ist and 2nd type boundaries at this time	

TOTIN	Total source/sink inflow at this time
TOTLEK	Total Leaky inflow from all sources at this time
WIDTH	W" for A side link on 3rd-type boundary
XSCALE	Scaling factor applied to all X-coordinates
YSCALE	Scaling factor applied to all Y-coordinates