ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Development of Groundwater Flow Model Using Visual MODFLOW

G. N. Pradeep Kumar[1], P. Anil Kumar[2]

1Professor, Dept of Civil Engineering, S.V.U. College of Engineering, S.V. University, Tirupathi - 517502.
2P.G. Scholar, Dept of Civil Engineering, S.V.U. College of Engineering, S.V. University, Tirupathi – 517502.

Manuscript Info

Manuscript History:

Received: 15 April 2014
Final Accepted: 23 May 2014
Published Online: June 2014

Key words:

Corresponding Author

G. N. Pradeep Kumar

Abstract

A steady state finite difference model, MODFLOW, is developed to quantify groundwater in Choutuppal Mandal, Nalgonda (Dt) AP., using GW data from 19 observation wells. Well inventory and base map are used to assess surface features, GWL and direction. MODFLOW is conceptualized as two *layered* weathered and fractured aquifer system spread over 19215 m x 10366 m area. Result shows that the computed groundwater level contours are in good agreement with observed ones.

INTRODUCTION

Water demand for industrial, agricultural and domestic uses is continuously increasing and freshwater resources are shrinking. Against this backdrop, groundwater management has become critical issue for current and future generations. Groundwater models play an important role in the development and management of groundwater resources and in predicting effects of management measures. With rapid increases in computational ability and wide availability of computers and model softwares, groundwater modeling has become a standard tool for effective groundwater management. The study proceeded with the development of the conceptual model of regional groundwater flow. The study presented herein used processing MODFLOW to construct a groundwater flow model in the basin. The calibration of the model parameters was conducted under steady-state flow conditions. The numerical model was then used to simulate the groundwater flow under the current stress conditions. [5]

Details of the study area

The study area, consisting of 19 villages of Choutuppal Mandal, a drought prone mandal of Nalgonda district, lies between longitude 78°45' and 79°E and latitude 17°10'and 17°24'N (Fig.1). Of 25 villages of Choutuppal mandal, 19 observation wells are selected at random one well per village. The temperature in summer varies between 30°C and 46.5°C and in winter 16°C and 29 °C. The highest elevation in the study area is +447 m and the lowest elevation is +323 m. Cotton, Paddy, Red grams and Castor are the important crops grown. Since, surface water availability is less, high dependency on groundwater resulted in drop of water table. The toposheet maps (No: 56k/15 and 56k/16) collected from Survey of India are used in the present study.

Data collection

Data collection is another important component in the model development process. In the present study, data are collected from CGWB, Hyderabad, State PWD, Hyderabad, SOI, Hyderabad and NRSC, Hyderabad. The data include hydrological, hydrogeological, rainfall and well data.

After thorough study of the existing data and reports, a field reconnaissance survey was carried out to have a complete understanding of site hydrogeology and information on the watershed area.

Geology

The study area is generally covered with granite, gneisses and numerous dolerite dykes and quartz veins. Weathered granites occur in most parts of the study area. Granites in the area are medium to coarse grained, pink to grey, hard massive to foliated and well jointed. The granitic rocks are large in depth. The study area falls under semi-arid environment and is highly undulating.

In order to develop MODFLOW for the study area, it is first of all necessary to know the vertical stratification of the area. That is, types of rocks making up subsoil and their thickness and also the depth at which relatively hard rock is encountered. This objective can be achieved through VES (Vertical Electrical Sounding), a type of electrical resistivity survey.

In the present study, out of the two configurations (Venner and Schlumberger), the later one is used to conduct resistivity survey over the entire study area. From the results of this survey and also from observations of local wells, it is found that the geology of the sub stratum is as follows:

Top layer is made up weathered rock with thickness ranging from 19 m to 21 m over the study area. This is overlain by a fractured rock of almost same thickness. Below this layer, a relatively hard and impervious bed is encountered. Therefore, for the development of MODFLOW for the study area, a conceptual model of two layers of each of thickness being 20 m is used in the present study. While top layer is of weathered rock, the bottom layer is that of fractured one.

Hydrogeology

Groundwater is present in both the weathered and fractured zones. Since precipitation is the main source of groundwater recharge, rainfall data were collected from Agriculture office Choutuppal. Significant deformation has produced a network of intersecting fractures to facilitate hydraulic continuity between the two systems. The study area contains unconfined and confined aquifers.

Well inventory

The groundwater level data from 19 observation wells (Fig.2), recorded by using a water level indicator, indicated that, generally the GWL to lie between 40 m and 50 m (bgl). Using these data, hydraulic gradient and direction of flow are also determined. Further, a large number of hand pump-fitted bore wells, (Fig.3), in addition to observation wells, are included in the development of MODFLOW. These wells influence GWLs and quantity of withdrawal of groundwater in the villages.

Modflow software

MODFLOW is a computer program that numerically solves the ground-water flow equation for a porous medium by using a finite-difference method and is developed by U.S. Geological Survey. The software is used primarily by hydrogeologists to simulate groundwater flow and contaminant transport. MODFLOW was designed such that the user can select a series of modules to be used during a given simulation. Each module deals with a specific feature of the hydrologic system (e.g., wells, recharge and surface water bodies). The choice between analytical and numerical models is somewhat crucial and depends on the complexity of hydrogeologic conditions and the availability of field data. Keeping this in view, in the present study, a numerical model for the solution of groundwater flows is developed. [2], [3]

Groundwater flow processes - Governing equations

The subsurface environment constitutes a complex, three dimensional heterogeneous hydrogeologic setting. The variability strongly influences groundwater flow and such a reality can be described accurately only through careful hydrogeologic practice. Mathematical equations that describe groundwater flow may be developed from the fundamental principle of conservation of mass of fluid. Given a representative elementary volume (REV) of porous medium, a general equation for conservation of mass for the volume is expressed as:

Rate of inflow – Rate of outflow = Rate of change

Mathematically stated, it is , .

$$Q = -kiA \qquad (1)$$

where Q = discharge, K = hydraulic conductivity, i = hydraulic gradient and A = area of flow.

A general groundwater flow equation may be written in Cartesian form as:

$$\frac{\partial}{\partial x_i}\left(k_{ij}\frac{\partial h}{\partial x_i}\right) = S\frac{\partial h}{\partial t} + W \qquad (2)$$

where S is the specific storage, L^{-1}; W is the volumetric flux per unit volume (- for outflow and + for inflow), T^{-1}; and K is the hydraulic conductivity. [1]

Groundwater velocity

The rate of groundwater flow is affected by its velocity. Actual seepage velocity of groundwater is given by

$$V_s = V / n = - k\, i / n \quad (3)$$

where V_s is the seepage velocity, V is bulk velocity, n is the porosity, k is hydraulic conductivity and i is hydraulic gradient.

Flow model

The groundwater flow model in the present study is conceptualized as a two layered weathered and fractured aquifer system spread over 19215 m x 10366 m area. A number of trails is made to determine a reliable number of rows and columns into which the watershed has to be divided into. Finally, it is found to be 80 rows and 80 columns of rectangular cells of 240.18 m x 129.57 m. The simulated cross section has a total thickness of 40m. The vertical section along Row 29 indicates that the weathered zone has a thickness of about 30 m, which is underlain with a fracture zone of about 10 m thickness. The highest permeability, determined experimentally, is found in the valley fill zone with a value of 2.0 m/d and the same is assigned along the stream courses in the development of GW model. For the rest of the area, the field permeability values ranging from 1.6 to 1.8 m/day were assigned. (Fig 4). The vertical permeability is considered as one tenth of the horizontal permeability. [3]

Constant head boundary condition of +310 m (amsl), as determined from field observations, was simulated at the outflow region. The stream channels have been simulated with river boundary condition varying from +301 m to +310 m.

The groundwater recharge of 42 mm/year, as determined from experimentation on the field, was assigned to incorporate the influence of recharge in the study area, while developing the MODFLOW. However, effect of recharge is considered over the first layer in the watershed.

Pumping wells in the watershed, in addition to observation wells, are included to include the effect of withdrawal in the MODFLOW. Pumping rates, as determined from pump tests, varying from -20 m^3/day to -35 m^3/day are used in the present study. (-ve sign indicates withdrawal of groundwater)

Model calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within an acceptable criterion. Calibration is carried out by trial and error adjustment of parameters or by using an automated parameter estimation code. Model calibration requires that field conditions at a site be properly specified. Otherwise, model will not be a reliable representative of actual field conditions. After a number of trial runs, computed water levels were matched fairly reasonably with observed values. In the present study, during calibration, horizontal and vertical hydraulic conductivities and recharge values were adjusted in sequential model runs to match the simulated heads and measured heads. (Fig 5) [5]

Steady state calibration

In this model development, steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW. The calibration was made using 19 observation wells monitored during September 2013. By trial and error calibration, the conductivity values were increased during many sequential runs until the match between the observed and simulated water level contours were obtained.

The computed water level accuracy was judged by comparing the mean error, mean absolute and root mean square error calculated. Root mean square (RMS) error is the square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 7.507m (Fig 5). The correlation coefficient is 0.993. The absolute residual mean is similar to the residual mean except that it is a measure of the average absolute residual value. The absolute residual mean measures the average magnitude of the residuals, and therefore provides a better indication of calibration than the residual mean. It was ensured that the model water levels during September 2013 reasonably matched with the observed water levels during that period. The computed water level of September 2013 indicates a prevailing trend of groundwater flow in the inter stream region (Fig 6). The observed water levels for selected observation wells were used for the steady state calibration. [5]

ZONEBUDGET

Groundwater flow modelling programs typically produce water budgets for the model area, but some time it is useful to have a water budget for a specific region of the model area. Visual MODFLOW incorporates

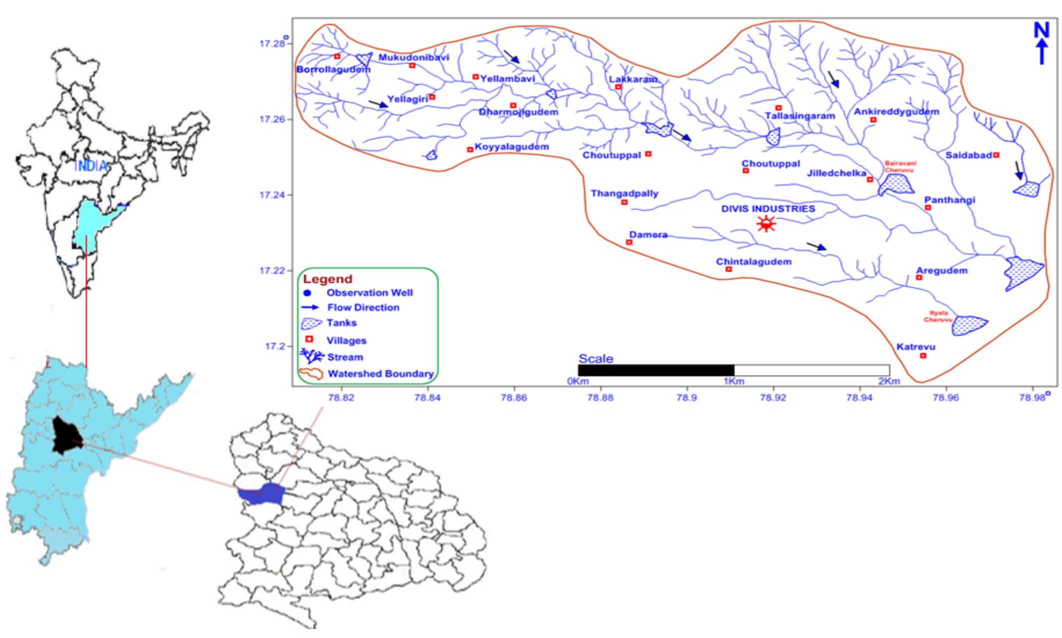
ZONEBUDGET. ZONEBUDGET software developed by USGS, calculates sub-regional water budgets using the results from the MODFLOW. It calculates budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. A sub region of a model for which it calculates a water budget is termed a zone and is indicated by a zone number. The user simply specifies the sub regions for which budgets are needed.

The groundwater budget was computed from the groundwater flow model for the entire watershed using zone budget. Here, recharge is from rainfall is 11417 m^3/day and from other inflows it is 268.15 m^3/day. Regarding outflows, an amount of 3068 m3/day leaves the watershed through constant head boundary and withdrawals from the wells it is 8610.4 m^3/day. Thus, the total volume of water entering the watershed is 11686 m^3/day and leaving the watershed is 11678 m^3/day. A sample page of MODFLOW output is presented Fig. 7. The output indicates that there is a very little amount ofstorage. This necessitates immediate arrangement for recharge of groundwater by all possible means to save the ground water for future usage.

Conclusions

Groundwater models are tools which are frequently used in studying groundwater flow systems. A ground water model is a simplified representation of a more complex reality. They have proven to be useful tools over several decades for addressing a range of ground water problems and supporting the decision-making process. In the present study, a MODFLOW model is developed to estimate water budget of a part of Chotuppal mandal with the known boundary conditions and field observations. The field monitoring is incorporated to verify model predictions. The best method of reducing modelling errors is to apply good Hydrogeological judgment. The model calibration has been performed based on the available data. The model results show that the computed values are in good-fitness of the measure data, which indicate the model is reliable. It is ascertained that groundwater enters from Borrollagudem and leaves at Aregudem and Katrevu through Choutuppal. Similar studies can be undertaken for other water stressed areas for reliable water resources estimation adopted in better and efficient water resources planning and management.

Fig. 1 Location map of study area.



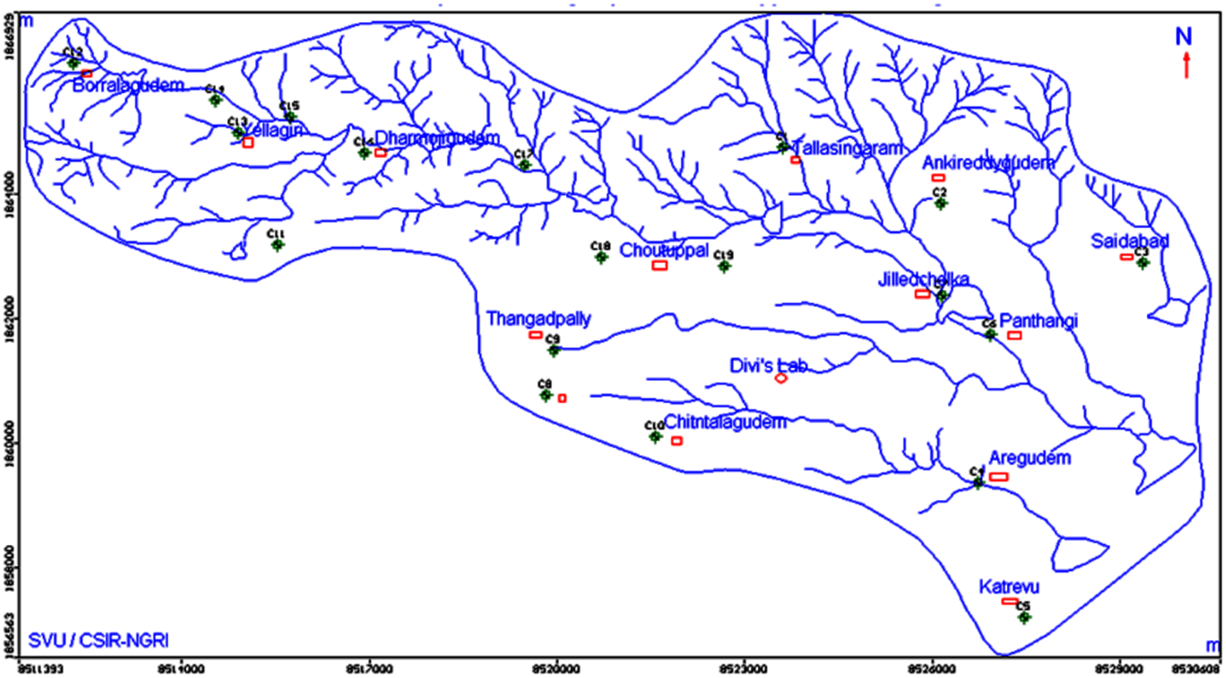


Fig. 2 Observation wells of the watershed area

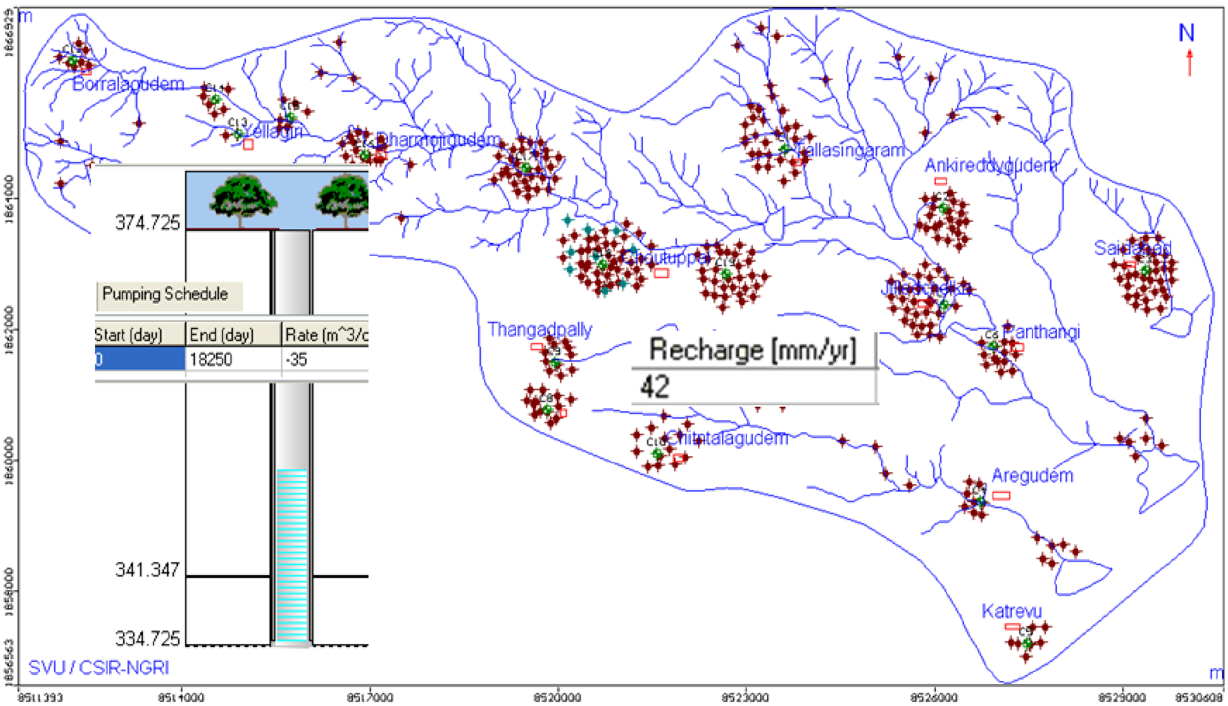


Fig. 3 Pumping wells in the watershed area

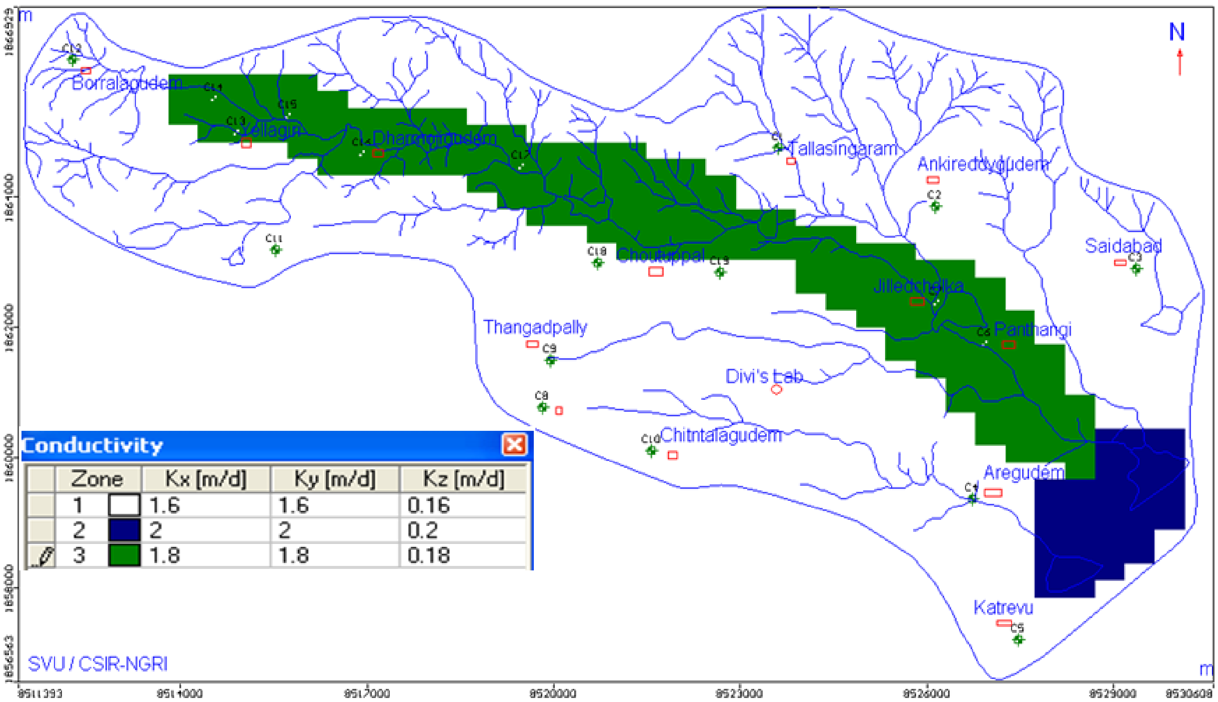


Fig. 4 Boundary conditions in the watershed area

Fig. 5 Computed vs. observed head for steady state model

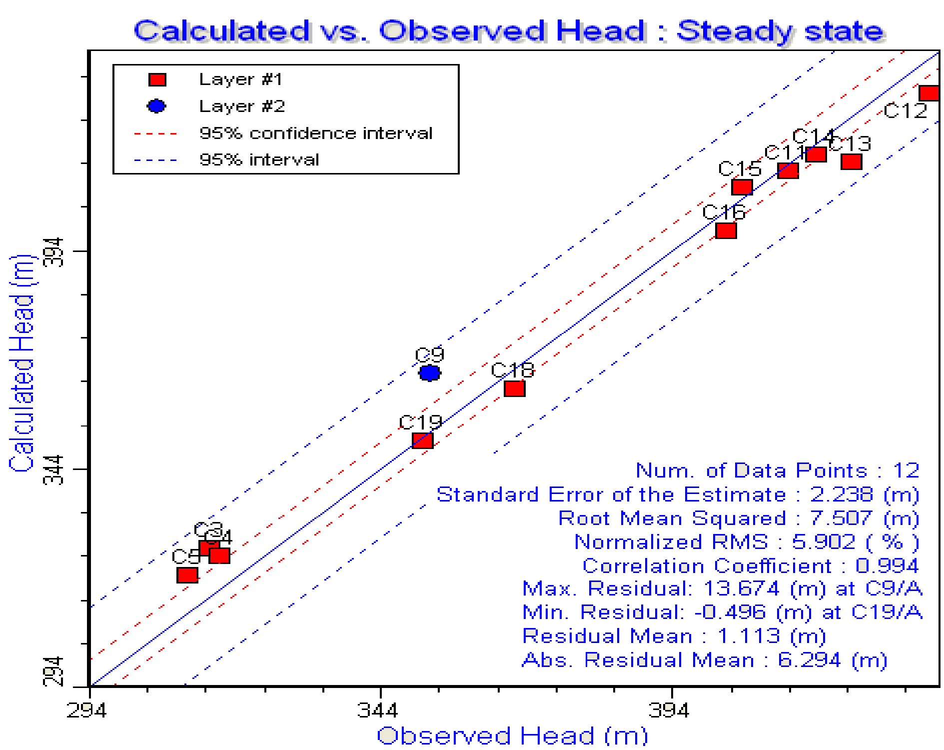


Fig. 6 Computed groundwater level contours in groundwater flow model

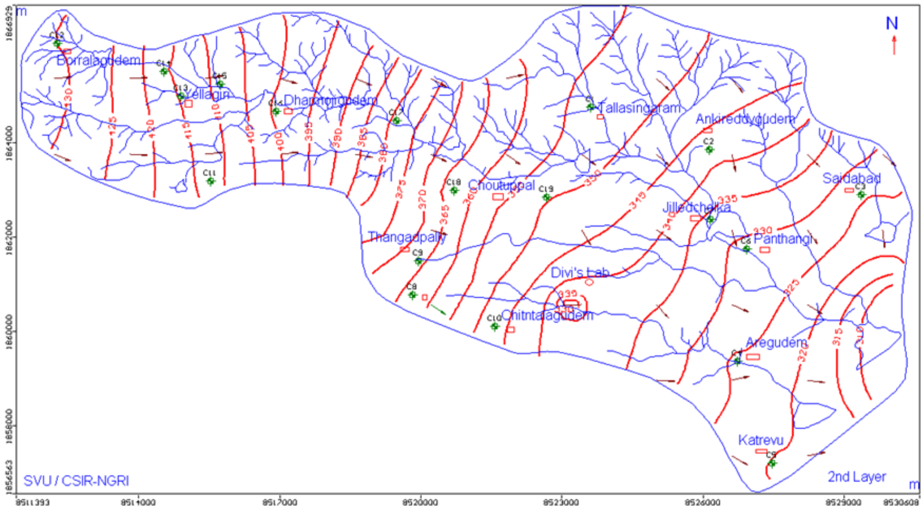


Fig.7 A sample page of output from MODFLOW

Groundwater Balance in the Choutuppal Watershed using Zone Budget

INFLOW	OUTFLOW
Recharge = 11417 m^3/day	Recharge = 0 m^3/day
Constant Head = 886.73 m^3/day	Constant Head = 886.73 m^3/day
Wells = 0 m^3/day	Wells = 8610.4 m^3/day
Total IN = 11686 m^3/day	Total OUT = 11678 m^3/day

Inflow	Outflow
Storage = 0.00 m^3/day	Storage = 0.00 m^3/day
Constant Head = 268.15 m^3/day	Constant Head = 3068.00 m^3/day
Wells = 0.00 m^3/day	Wells = 8610.40 m^3/day
Drains = 0.00 m^3/day	Drains = 0.00 m^3/day
MNW = 0.00 m^3/day	MNW = 0.00 m^3/day
Recharge = 11417.00 m^3/day	Recharge = 0.00 m^3/day
ET = 0.00 m^3/day	ET = 0.00 m^3/day
River Leakage = 0.00 m^3/day	River Leakage = 0.00 m^3/day
Stream Leakage = 0.00 m^3/day	Stream Leakage = 0.00 m^3/day
Surface Leakage = 0.00 m^3/day	Surface Leakage = 0.00 m^3/day
General-Head = 0.00 m^3/day	General-Head = 0.00 m^3/day
Total IN = 11686.00 m^3/day	Total OUT = 11678.00 m^3/day

Acknowledgments

The authors thank the Director and all the staff, NGRI, Hyderabad for their support and encouragement. The authors are specially thankful to V.V.S. Gurunadha Rao, DD (Retd), Environmental Hydrology Group and Dr.M.J.Nandan Principal Scientist, NGRI for their guidance during the work.

References

1. Fouepe Takounjou A., Gurunadha Rao V. V. S., Ndam Ngoupayou J., Sigha Nkamdjou L. and. Ekodeck G. E. (2009) "Groundwater flow modelling in the upper Anga'a river watershed, Yaounde, Cameroon". African Journal of Environmental Science and Technology.
2. Kumar CP. (2013) "Numerical modelling of Groundwater flow using MODFLOW". Indian Journal of Science, Volume 2, Number 4.
3. McDonald, J.M. and Harbaugh, A.W., (1988). "A modular three-dimensional finite difference groundwater flow model". Techniques of Water resources Investigations of the U.S. Geological Survey Book.6, pp.586.
4. Nasrin koohestani , Mehdi Meftah Halaghi and Amir Ahmad Dehghani. (2013) "Numerical simulation of Groundwater level using MODFLOW software" (A case study: Narmab watershed, Golestan province) International journal of Advanced Biological and Biomedical Research.
5. Tamma Rao G.,Gurunadha Rao V. V. S. , Surinaidu L. Mahesh J. and Padalu G. (2011). "Application of numerical modeling for groundwater flow and contaminant transport analysis in the basaltic terrain, Bagalkot, India". Saudi Society for Geosciences.

Notations

A = area of flow,
i = hydraulic gradient,
K = hydraulic conductivity,
n = porosity
Q = discharge,
. S = specific storage
V_s = seepage velocity
V = bulk velocity
W = volumetric flux per unit volume