GROUND WATER FLOW MODELLING OF K.C.A.E.T CAMPUS USING VISUAL MODFLOW

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PROJECT REPORT

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DECLARATION

We hereby declare that this project entitled **“”** is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us” **GROUND WATER FLOW MODELLING OF K.C.A.E.T CAMPUS USING VISUAL MODFLOW”** for any degree, diploma, associateship, fellowship or other similar title of any other university society.

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CERTIFICATE

Certified that this project report entitled **“GROUND WATER FLOW MODELLING OF K.C.A.E.T CAMPUS USING VISUAL MODFLOW”** is a record of project work done independently by **Ramla.T.T, Saranya.S, and Salsan.K.** Under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

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Ramla.T.T.

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SYMBOLS AND ABBREVIATIONS

,	Minute
o	Degree
,,	Second
%	Percent
<	Less than
>	Greater than
oC	Degree Celsius
3D	Three dimensional
BMP	Base Map
Dept.	Department
et al.	and others
etc.	et cetra
Fig.	Figure
GIS	Geographic Information System
H	Hour, potentiometric head
Hp	Horse power
HFM	Hydro geological frame work
K	Hydraulic conductivity
K.C.A.E.T	Kelappaji College of Agricultural Engineering and Technology
Km2	Square kilometer
m3	Cubic meter
M	Meter
Mm	Millimeter
NE	North East
NCP	North China Plain
Ss	Specific storage
S	Second

SW	South West
SN	South North
T	Time
USGS	United States Geology Survey
W	Volumetric flux per unit volume
WE	West East

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CHAPTER 1

INTRODUCTION

1.1 GENERAL OVERVIEW

Groundwater accounts for over 20% of the daily water usage in the world. In the present scenario groundwater is an important resource to meet our needs. Groundwater is the major source of drinking water in both urban and rural area. Besides, it is an important source of water for the agricultural and the industrial sector. Being an important and integral part of the hydrological cycle, its availability depends on the rainfall and recharge conditions. An uncontrolled use of the bore well technology has led to the extraction of groundwater at such a high rate that often recharge is not sufficient. The availability of groundwater gets reduced if more water is withdrawn by pumping (discharge) than is fed by recharge from the surface.

When groundwater gets depleted day by day and as the demand for water increases, the management of the sustainable water resources is one of the challenging issues. For identifying the remedial measures studies should have to be conducted on groundwater. Warnings of a groundwater crisis (with falling groundwater tables and polluted aquifers) have led to calls for urgent management responses. Also the availability of ground water influenced by numerous factors including the weather patterns. Thus, as the use of groundwater sources increases, understanding of the water cycle and contamination processes are critical to ensure adequate supplies are always available. Also, for any remediation technique to be successful, knowledge and understanding of the particular groundwater flow patterns of the area are required. This can be attained by using mathematical predictive groundwater models. Various numerical methods like finite difference method and finite element method are used for numerical modelling of engineering problems.

Groundwater models have been widely used as an important tool for engineering applications such as design of groundwater extraction system for mining, groundwater remediation etc. There is a growing demand to develop an accurate groundwater model to meet the requirements from various engineering applications. The model is affected by complex geological and hydro geological flow conditions and a well representative groundwater model is a key to success of an engineering implementation

MODFLOW developed by USGS is capable of simulating steady-state or transient groundwater flow in one, two or three dimensions. MODFLOW is based on the finite difference method, which leads to a numerical approximation which can be solved to get solutions of complex ground water flow problems. A rectangular grid is superimposed over the study area to divide the area horizontally into a number of rectangular cells. Layers are used to subdivide the study area vertically into units of common hydro geologic properties.

1.2 VISUAL MODFLOW

The modular finite-difference groundwater flow model, frequently referred to as MODFLOW (McDonald and Harbaugh, 1988; Harbaugh andMcDonald, 1996 a, b) is a program for simulating confined or unconfined, saturated flow in one, two, or three dimensions. MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a set of computer programs that solves the groundwater flow equation (Harbaugh, 2005). The program is used by hydro geologists to simulate the flow of groundwater through aquifers. The code of this software is written primarily in FORTRAN and can compile and run on Microsoft Windows or Unix-like operating systems. It allows both steady-state and transient simulations. Groundwater flow modelling is an important tool to study the dynamic behavior of groundwater system.

Visual MODFLOW is the most complete and easy-to-use modeling environment for practical applications in three – dimensional groundwater flow and contaminant transport simulations. This fully- integrated package combines MODFLOW, MODPATH, zone budget, and MT3Dxx/RT3D with graphical interface. Visual MODFLOW is designed with a modular structure each dealing with a specified feature of the hydrologic system. Visual MODFLOW provides professional 3D groundwater flow and contaminant transport modeling using MODFLOW 2.8, MODPATH, MT3DMS and RT3D.

This fully-integrated groundwater modeling environment allows to:

- Graphically design the model grid, properties and boundary conditions,
- Visualize the model input parameters in two or three dimensions,
- Run the groundwater flow, path line and contaminant transport simulations,

1.3 STEPS IN GROUND WATER FLOW MODELLING

Every ground water flow modelling consists of the following stages;

1. Concept development - It is the most important part of modelling and basis for all further activities.

2. Selection of computer code for simulation**.** - Code is selected such that it can most effectively simulate the concept and purpose of modelling

3. Definition of model geometry. - It include lateral and vertical extent of area to be modelled defined by boundaries, grid layout, position and number of layers.

4. Definition of cell types. (Active, inactive, constant head cell)

5. Input of hydro-geologic parameters for each cell - Hydraulic conductivity (horizontal and vertical), storage properties and porosity are assigned to each zone.

6. Definition of boundary conditions (boundaries with known head)

7. Definition of initial head. (Distribution of hydraulic head)

8. Definition of stresses acting upon system (areal recharge, well pump age)

9. Model run - It includes choosing a mathematical model for solving the system of algebraic equation, iteration criteria and acceptable error criteria for terminating the iteration process.

10. Calibration and sensitivity analysis - This is probably the lengthiest and most demanding part of any modelling process.

11. Verification of model validity. - The calibrated model is checked against another set of field data that was not used in model design

12. Prediction - In most cases it is the purpose of model design

13. Presentation of result - This includes both the prediction result and relevant data documenting stages of model design.

1.4 NEED FOR THE STUDY

Even though the study area is located very near to the Bharathapuzha river, the area is facing acute water shortage in a few weeks after the offset of monsoon. The depletion of ground water is a major concern in the campus for the irrigation and civic requirements. So in the present work a ground water flow modelling using MODFLOW is taken up to study the ground water trends in the campus and to predict the future

1.5 THE SPECIFIC OBJECTIVES OF STUDY ARE TO:

- Develop a model to simulate the groundwater flow in the study area
- Interpret the regional flow systems using the developed model
- Prepare the water table contour map.
- Predict ground water heads
- Understand the ground water flow velocity
- Study the path lines and equipotential lines

1.6 STRUCTURE OF THE PROJECT WORK

This work is organized into three major parts: literature review, materials and methods and results and discussions. Chapter 1 is the introductory part which deals mainly with the importance of the topic. Chapter 2 deals with literature review on past and existing knowledge about this topic. Chapter 3 focuses on a detailed description of the study area and available data for modeling work and also discuss the modeling tools and procedure. The results and discussion presented in chapter 4 and the conclusions and recommendations in the last chapter.

CHAPTER 2

REVIEW OF LITERATURE

2.1 VISUAL MODFLOW

MODFLOW, developed by the U. S. Geology Survey (USGS), is capable of simulating steady-state or transient groundwater flow in one, two, or three dimensions. MODFLOW is based on the finite-difference method; a method leading to a numerical approximation that allows for a description and solution of complex groundwater flow problems. A rectangular grid is superimposed over the study area to horizontally subdivide the region of interest into a number of rectangular cells. Layers are used to subdivide the study are vertically into units of common hydro geologic properties

Groundwater flow is formulated as a differential water balance for every model cell and hydraulic head is solved for at the centre of every model cell. MODFLOW allows for the specification of flows associated with wells, areal groundwater recharge, rivers, drains, streams, flow barriers and other groundwater sources/sinks. When properly conceptualized and constructed, MODFLOW model can simulate groundwater flow with a fast, good convergence and an accurate solution for most complex groundwater flow systems which is especially useful for mining and groundwater remediation engineering applications.

Richard and Ken, (1995), studied the area catchment of the Victoria Nile basin in central Uganda, the timing and magnitude of recharge determined by soil moisture balance approach supported by stable isotope data and groundwater flow modelling. The soil moisture balance study reveals that the average recharge is 20 mm/yr. and is more dependent upon heavy rainfall than total annual volume of rainfall. Stable isotope data suggested that Simulation of Groundwater and Lake water Interaction using PMWIN

The recharge occurred during the heaviest rainfall of the monsoon and further established that recharge stems entirely from direct infiltration of rainfall. Aquifer flow modelling supports the recharge estimates but demonstrates that vast majority (about 99 %) of recharging water must be transmitted by the aquifer in the regolith rather than underlying bed rock fractures, which has traditionally being developed for rural water supplies

Faunt *et al.* (2004). Developed a 3D digital hydrogeological framework model (HFM) which defines the physical geometry and materials of hydrogeological units and the hydrogeological structures .Twenty five hydrogeological units were identified and represented in the HFM. The hydrogeological framework model was discretized into numerical flow model input arrays using Hydrogeological Unit Flow package of MODFLOW-2000.

Kumar and Elango, (2006) developed a groundwater model MODFLOW to assess the effect of a subsurface barrier on ground water flow in the Palar river basin, Tamil Nadu. In order to meet the ever-increasing demand for groundwater since the nearby nuclear power station is using significant quantity of groundwater therefore a subsurface barrier/dam was proposed across Palar river to improve the groundwater potential. It predicted the groundwater levels would increase by 0.1-0.3 m at a distance of about 1.5 – 2 km from upstream side and a decline of 0.1 -0.2 m on the downstream side.

Sivakumar *et al.* (2006) developed a numerical model for South Chennai coastal aquifer to understand the behavior of systems with changes in hydrological stresses. It simulated the effect of increase in pumping and changes in rainfall pattern. This study was carried out to develop a numerical model for the area in order to understand the behavior of the system with the changes in hydrological stresses. The conceptual model of the hydro geologic system was derived from geology, borehole lithology and water level fluctuations in wells. Groundwater of the study area was found to occur in both alluvial formations and in the underlying weathered rocks was conceptualized as an unconfined single layered system. The finite difference computer code MODFLOW (Modular 3-d finite difference flow) with Groundwater Modeling System (GMS) as pre and post processor was used to simulate the groundwater flow in this study. Simulation was carried out from the year 2000 assuming the initial groundwater level measured from about 28 wells located in the area. Aquifer parameters were estimated from about five pumping tests carried out by the government agencies. The K and S values determined from these tests ranged from 25 to 75m/day and 0.17 to 0.23 respectively. The model developed was initially calibrated with steady state run and later by transient state. The model input parameters namely the K and S values were varied by about 10% during calibration. The simulated groundwater head values compare reasonably with the observed trends. The model was later used to simulate the effect of increase in pumping and the changes in the rainfall pattern.

Wang *et al.* (2007) carried out study at North China plain (NCP) for estimating water budget and recharge rate by using MODFLOW and geographic information system. The aim of the study is to check the groundwater usage pattern based on recharge and discharge quantity. Therefore study area was generalized to a conceptual hydrologic model which was three layers, heterogeneous, horizontal isotropy, and three dimensional, transient. On the basis of the conception model, a numeric model was set up. The model was calibrated through fitting calculated value with observed value. The results of model were in accordance with the practical hydro geologic conditions. And the water budgets of North China Plain showed that the total recharge was 49,374 x 106 m3, and the total discharge was 56,530 x 106 m3 during the simulation period, the difference was -7,156 9 106 m3. This verified that the groundwater in the NCP was over-exploited and the water crisis is serious. For the shallow aquifer of the NCP the precipitation recharge was the main recharge source and it was 34,220 x 106 m3 accounting for 75.15% of all recharge in 2002 and 2003. And the evaporation is the main discharge of shallow aquifer accounting for 24.71% of all discharge in 2002 and 2003. For the deep aquifers of the NCP artificial pumping is the major discharge. That was the main reason led to series of water environment problems.

Zume and Tarhule, (2007) used a visual MODFLOW, numerical groundwater flow model to evaluate the impacts of groundwater exploitation on stream flow depletion in the Alluvium and Terrace aquifer of the Beaver-North Canadian River (BNCR) in Oklahoma, USA. Using MODFLOW‘s stream flow routing package, pumping-induced changes in base flow and stream leakage were analysed to estimate stream flow depletion in the BNCR system. Simulation results indicates that groundwater pumping has reduced base flow to streams by approximately 29% and has also increased stream leakage into the aquifer by 18% for a net stream flow loss of 47%. The magnitude and intensity of stream flow depletion, however, varies for different stream segments, ranging from 0 to 20,804 m3/d.

Arshad *et al.* (2008) carried out a study to measure and assesses the recharge contribution of a distributary of canal in Pakistan for crop irrigation using groundwater flow model. This study was carried out because of increasing groundwater demand by various crops specially Wheat and rice, which consume the maximum quantity of water. With the increase in consumption of these crops and to cater the necessity of water by these crops heavy pumping is being carried out. Therefore assessment of recharge through distributary was carried out using a groundwater flow ―MODFLOW‖ model, which utilized the observed water table, climatic, crop and soil for a period of about 1 year in addition to hydraulic conductivity, evapotranspiration and aquifer characteristics data. The requisite primary data for ―MODFLOW‖ were collected from field and secondary data from public sector organizations dealing with water. Model calibration involved changing input parameters within reasonable limits until acceptable matches were obtained between the observed and simulated water levels for all observed hydrographs. The external inputs such as, recharge through irrigation, precipitation, stresses due to evaporation, lateral flow and stream were simulated to calculate the monthly water budget of aquifer. As concluded, recharge contribution was 16.5% of the inflow rate of the distributary. Using predicted results of the model a relationship between recharge (R) and discharge (Q) was also developed.

Shao *et al.* (2009) constructed a regional groundwater models for the North China Plain in order to assess groundwater development potential. The model covers an area of 139,000 km2 with a uniform grid of 4 km by 4 km. The thickness of the aquifer system ranges from 550 m to 650 m and was simulated with 3 model layers. The model was calibrated with data from 2002 to 2003, with monthly stress periods

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Nimmer *et al.,* (2010) worked on contaminant transport beneath an infiltration basin by using MT3D model simulation of tracer transport. This simulation model showed mound formation to cause more rapid tracer movement away from the basin compared to the natural gradient, and advection was shown to be the dominant transport process in the flow direction. This study used a combination of the numerical one-dimensional HYDRUS model and the three-dimensional MODFLOW model to predict water table mound formation, and the numerical model MT3D to assess the potential for contaminant transport beneath a storm-water infiltration basin. Results from this study indicate that although the unsaturated zone was thin and comprised of coarse material, an attenuation of recharge by approximately two hours justified the need to couple an unsaturated model HYDRUS-1D with MODFLOW. Mounding caused more rapid spreading of contamination added to the basin. Mounding decreased the arrival time of peak contaminant concentration by approximately 14 and 7.5 h at 10 and 20 m, respectively, down gradient of the basin center, and by approximately 158 h at 20-m side gradient of the basin. Dispersion influenced contaminant transport in the transverse direction, while advection was the dominant transport process I the direction of flow.

Post, (2011) presented a new package, periodic boundary condition (PBC) package into MODFLOW to overcome the difficulties encountered with tidal boundaries in modeling coastal groundwater system. It highlights the boundary condition for head and concentration during simulations and allows for development of seepage face. This new package was developed for MODFLOW and SEAWAT (United States Geological Survey code). This package is primarily designed for handling dynamic boundary conditions due to tides, but other types of water-level fluctuations, for example, sea-level rise, can also be incorporated. Boundary conditions are assigned to the nodes at the sediment air or sediment water interface depending on a user-defined tidal signal. Any number of tidal constituents can be included.

Lachaal *et al.* (2012) developed an integral methodology to investigate hydrological and groundwater properties, in Zeramdine Beni Hassan Miocene aquifer system in East-central Tunisia in a semi-arid region, from geological, geophysical and hydro chemical studies in the region using MODFLOW 2000 with GIS tools. A 3D groundwater flow model was developed using available geological and hydrological data. The model was calibrated and validated with data sets of 1980–2007 periods. Results of the groundwater dynamics simulation of the study aquifer show that calculated water levels are close to the observed values. The hydraulic conductivity and the aquifer water balance are deduced from the steady state. The porosity, specific storage, and groundwater reserve evolution are deduced from the transient simulations. The used methodology allowed completing and finalizing the groundwater hydro geological comprehension in totality.

Malik *et al.* (2012) carried out a study in Gurgaon district which is about 32 km from New Delhi, the national capital of India. The study area is divided into 102 column and 66 rows wherein each grid has 570.03 m in length and 570.03 m in width. Using the information of 75 observation wells and input of model parameters viz. storage coefficient (0.011) and effective porosity (0.16) were given and transmissivity was specified as the model calculated value. Then results were obtained for aquifer parameters viz. storage coefficient, and transmissivity using pump tests and average value of Theis‘ Method, Cooper-Jacob Method, Chow‘s

Method solutions and recovery test. MODFLOW model was calibrated to match the observed drawdowns with model calculated drawdowns using different values of aquifer parameters. Using this calibrated model and water balance inputs of 35 years averaged over five year period, recharge, pumping, balanced water as well as horizontal exchange at various time developmental stages and potential were estimated. Calibrated and validated model was used to find out 1974 to 2008 period as well as for future predictions at 2025 and 2050. Existing water was analysed to understand different component of water pumping, recharge and change in water levels. Various scenarios viz. normal rainfall and no-pumping, roof top water harvesting with recharge and water conservation structure recharge were formulated for sustainable planning and management.

CHAPTER-3

MATERIAL AND METHODS

Any useful groundwater model for groundwater resources assessment and management should simulate the whole groundwater basin and, therefore, has to be at basin-scale. Such a large regional model must include characteristics of groundwater discharge and recharge and the aerial distribution of multiple aquifer systems. Distinct features of basin-scale groundwater flow and flow models include differences in topographic elevation which provide the principle driving force for regional flow, leakage through aquitards which forms an essential element of regional flow systems and groundwater and surface water as a single resource. The intensive river and groundwater interactions should be simulated as line sources/sinks; discharge and flow-through lakes should be simulated as head-dependent discharge or constant head (especially useful for a steady state model). In this project the software MODFLOW is used to simulate the groundwater resources in K.C.A.E.T Campus with the data available and to prepare water table contour maps.

3.1 THE GROUNDWATER FLOW MATHEMATICAL MODEL

Groundwater models are computer programs of groundwater flow systems for calculation of groundwater flux and head. A model is only an approximation of the field conditions because of the simplifying assumptions made in the mathematical equations and uncertainties in the values of data required by the model. But groundwater models are useful investigation tools in spite of the various simplifying assumptions made. For the calculations one needs hydrological inputs, hydraulic parameters, initial and boundary conditions. The input is usually the inflow into the aquifer or the recharge, which varies temporally and spatially. Important parameters are topography, thickness of soil and aquifer layers and their horizontal and vertical hydraulic conductivity, porosity and storage coefficient etc. Initial conditions and boundary conditions can be related to water levels, pressures and hydraulic heads on the one hand (head conditions), or to recharge, discharge, inflow and outflow on the other hand (flow conditions)

In general, groundwater models are conceptual descriptions or approximations that describe the given flow system using mathematical equations, i.e., they are an approximate description of the physical system. By mathematically representing a simplified version of a hydrogeological system, reasonable alternatives can be predicted, tested and compared. The usefulness of the model depends on how closely the mathematical equations approximate the physical system being modelled.

Groundwater modelling begins with conceptual understanding of the physical problem. The next step is translating the physical system to mathematical terms. Most models solve the general form of the three- dimensional groundwater flow equation which is a combination of water balance equation and Darcy's law, given by

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right)\pm W = S_s \frac{\partial h}{\partial t}$$

Where,

Kx, *Ky*, and *Kz* are the values of hydraulic conductivity along the *x*, *y* and *z* coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity

h is the potentiometric aquifer head

W: is the volumetric flux per unit volume representing sources and/or sinks of water, with $W<0.0$ for flow out of the groundwater system, and $W>0.0$ for flow in

Ss is the specific storage of the porous material and

t is time.

This equation, when combined with boundary and initial conditions, describes transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions. McDonald and Harbaugh (1988) used a finite difference version of this equation in MODFLOW, where the groundwater flow system is divided into a grid of cells. For each cell there is a single point called node at which the head is calculated. The equation is solved in MGO using the modular three dimensional finite difference ground water flow model, MODFLOW

3.1.1 Model development

A groundwater model development consists of two distinct processes, namely model development resulting in software product and application of that product for a specific purpose.

3.1.2 Hydrogeological characterization

Proper characterization of the hydro geological conditions at site is necessary to understand the importance of relevant flow processes. Without proper site characterization, it is not possible to select an appropriate model to develop a calibrated model.

3.1.3 Model conceptualization

In this process the data describing field conditions are assembled in a systematic way to describe groundwater flow. This aids in determining the modeling approach and which modeling software to use.

In the simulation zone, the east and west boundaries are conceptualized as constant head boundaries, in the north the boundary is a river and the west boundary is conceptualized as drain boundary as it forms the top of a hilly area. Water exchanges occur in the top surface which is in contact with atmosphere, such as precipitation recharge, agricultural irrigation, phreatic water evaporation and so on. (The lower surface constitutes lateritic rock which is pervious and so flow takes place)

3.1.4 Model design

To transform a conceptual model to a mathematical model, a database that provide information to apply the equations is necessary. For this one needs to to know the physical configuration of the aquifer. This include the location, areal extent and thickness of all aquifers and confining layers, location of water bodies and boundary conditions of aquifers.

Important hydraulic properties include the variation of transmissivity or permeability and storage coefficient of the aquifers, the variations of permeability and specific storage of the confining layers etc. To model the stress on groundwater flow system, one must know the locations, types and amounts through time, of any artificial recharge as well as amounts and locations through time of groundwater withdrawals from wells. Changes in quantity of water flowing in streams and changes in water levels should also be known.

3.1.5 Model calibration

Calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. Model calibration requires the field conditions to be properly characterized.

3.1.6 Model verification

A calibrated model uses values of hydro geologic parameters, sources and sinks and boundary conditions to match historical field conditions, which result in further calibration or refinement of the model. After the model has been successfully reproduced measured changes in field conditions, it is ready for predictive simulations.

3.2 METHODOLOGY

The model construction is done using Visual MODFLOW 2.8 interface. To construct the model the study area was divided into finite difference cells, which have constant size of 25m x 25m. In the vertical direction, 5 groundwater layers were represented. Parameters representing physical characteristics and flow conditions were attributed to each cell. Visual MODFLOW stores all of the data in a set of files. Most of the input files are stored in ASCII text format. So the input files can be manipulated using a text editor. Visual MODFLOW translates these data files to the required format prior to running the model. By constructing the model, Visual MODFLOW creates the modules and the program code needed by the numeric engine.

3.2.1 Description of the study area

3.2.1.1 Geographical location

The study area is KCAET campus located at Tavanur in Malapuram district,Kerala.It is situated at 10° 53’30’’ North latitude and 76° East longitude and lie adjoing to the Bharathapuzha river. The region under consideration consists of laterite rock, lateritic soil and sandy soil.

3.2.1.2 Study boundaries

The study area is a rectangular area with dimensions 1.03 km in the north-south direction and 0.879 km in the east-west direction. The study area is bounded by the river Bharathapuzha in the north and Kuttippuram - Ponnani road in the south. Along the east and west boundaries the ground is slopping uniformly towards the Bharathapuzha river with an elevation difference of 24 m.

3.2.1.3 Topography

Figure shows the contour of the topographic elevations in the area. The highest points are found at the south western part and reach 30 meters while the lowest elevation point along the northern boundary of the study area and reach 8 meters above datum of the model.

3.2.1.4 Hydrogeology of the study area

The subsurface strata in the study area consist mainly of metamorphic origin. The principal formation of KCAET campus includes lateritic rock, lateritic soil and sandy soil. The thicknesses of the various layers vary spatially in the campus. The layer1, i.e., lateritic rock is present in the high elevation part of the campus only, whereas sandy soil is the top layer in the low lying paddy fields in the north. The details of geology of the soil and its hydraulic conductivity used is given in table

Layer No.	**Soil type**	**Hydraulic conductivity**
Layer-1	**Lateritic rock**	**K=3.76X10-5m/s**
Layer-2	**Lateritic soil**	**K=6X10-4m/s**
Layer-3	**Sandy soil**	**K=5X10-5m/s**
Layer-4	**Lateritic soil**	**K=6X10-4m/s**
Layer-5	**Lateritic rock**	**K=3.76X10-5m/s**

Table1. Geological cross section of study area

3.2.1.5 Ground water

The regional aquifer underlying the area is mainly of lateritic origin. The dominant sources of recharge to the study area are precipitation and river leakage.

Dominant mechanisms of discharge from the ground water are drains and pumping wells.

3.2.1.6 Recharge

Spatially distributed recharge over the entire first layer of the study area (in mm/y) was taken as one in tenth of the average precipitation for the purpose of the study.

3.2.1.7 Land use and soil

In general, the texture of the soil can be described as lateritic in the high elevations and sand and sandy loam in the low lying areas of the study area. The main land use type of the area are agriculture, built up (3%), barren.

3.2.1.8 Rainfall and climate

The study area has more or less the same climatic conditions viz. dry season from December to February and hot season from March to May, the South-West monsoon from June to September and the North East monsoon from October to December. The normal rainfall is 2793.3 mm. Out of this, major rainfall contribution is from SW monsoon followed by the NE. The South West monsoon is usually very heavy and nearly 73.5% of the rainfall is received during this season. NE monsoon contributes nearly 16.4% and March to May summer rain contributes nearly 9.9% and the balance 0.2% is accounted for January and February months.

The climate is generally hot and humid. March and April months are the hottest and January and February months are the coldest. The maximum temperatures ranges from 28.9 to 36.2°C and the minimum temperatures range from 17.0 to 23.4°C. The temperature starts rising from January and reaches the peak in the month of March and April and then decreases during the monsoon month and again rising from September onwards.

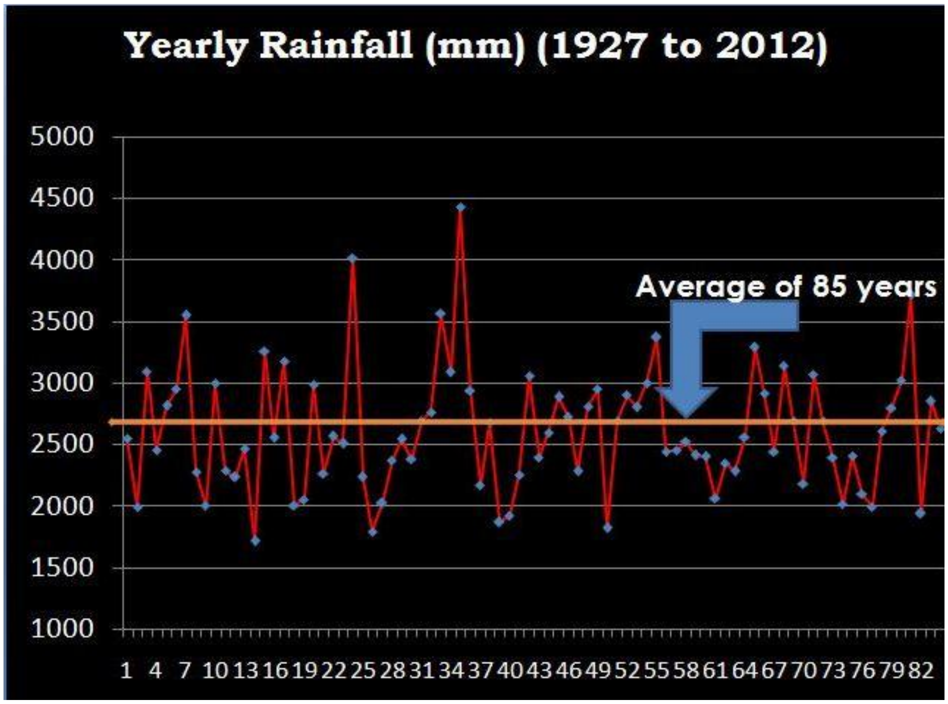


Fig1. Rainfall data

3.2.2 Available data

The following data are available for the study area

1. Digital elevation model with 30m by 30m grid size covering the whole study area was created by digitising the topographic map of the area.
2. The basic meteorological data required for running the model, recharge was collected from the precipitation data.
3. Hydro geologic and geologic characteristics and parameters of the study area including the hydraulic conductivity and bottom elevations of layers were collected from previous work.

4. Well data collected from three pumping wells and two observation wells in the area. Their location, average pumping rate and depth of filter is available from previous studies and recent measurements from the study area.

3.3 DETAILED METHODOLOGY

The model was developed using VISUAL MODFLOW 2.8. Microsoft Excel was also used for input data preparation. The final model design follows several model runs to best match field data with model results. The conceptual model information is inserted into mathematical model and model choices are made to suit the data entered and output required. Visual MODFLOW requires model data to be entered in consistent units. Selected units are meters and day, except for recharge where m/y is used.

Model needs include:

- Layers
- Elevation limits
- Grid
- Recharge
- Surface elevation
- Bottom elevation
- Groundwater pumping
- Aquifer characteristics
- River conductance
- River bottom and stage

3.3.1 Model dimensions

The model domain was selected so that the whole K.C.A.E.T.Campus and surrounding area lies within it. The model area has a rectangular geometry and is 735 m from East to West and 833 m from North to South.

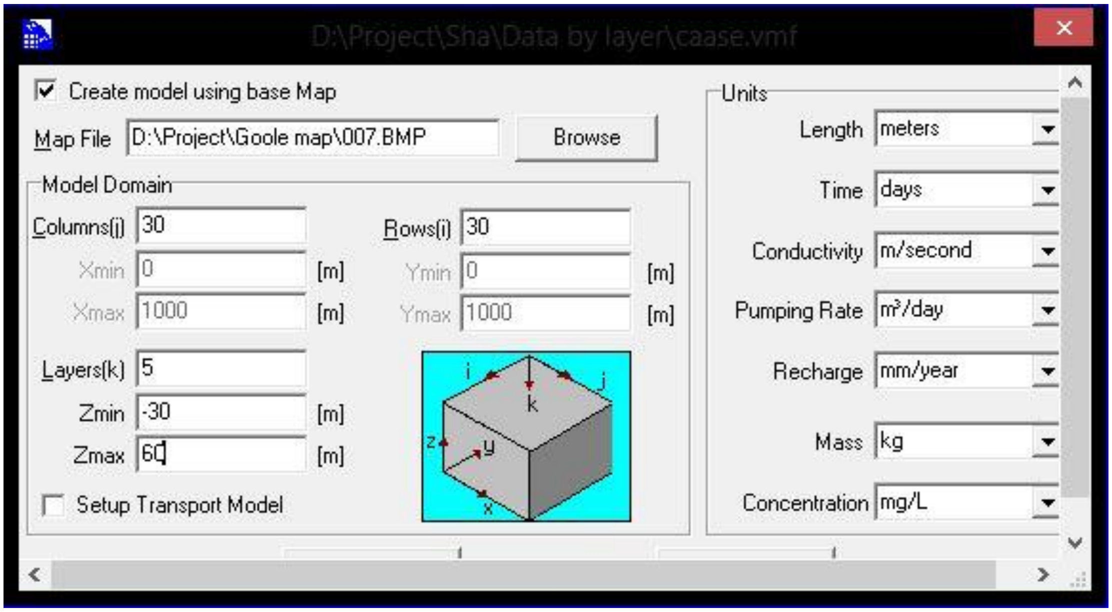


Fig 2. Model domain and units of measurement

CHARACTERISTICS	VALUE
Maximum model elevation	60 m
Minimum model elevation	-30 m
Layers	5
Grid cell size	25
Rows	30
Columns	30

Table 2. Model configuration

3.3.2 Layers

There are five layers labelled 1 – 5 from top to bottom. Layer 1 is composed of lateritic rock, Layer 2 composed of lateritic soil layer 3 sandy soil, layer 4 lateritic soil and layer 5 lateritic rock.

3.3.3 Elevation data

Surface elevation and bottom elevation data of the five layers were exported from Microsoft Excel and imported to Visual MODFLOW. The model surface elevation values prepared as a Microsoft excel file.

3.3.4 Aquifer characteristic data

The hydro geologic layers of the model are bounded by lateritic rock in the top and bottom in higher elevations and bounded by sandy soil at top and lateritic rock at bottom in the paddy fields near the Bharathapuzha river. The steady state model requires the hydraulic conductivity of each model layer. The hydraulic conductivity zone vary widely in the area and the hydraulic conductivity of various layers given in table 1. The horizontal hydraulic (Kx and Ky) conductivity used as initial input corresponds to the value obtained from the pumping test carried out in the campus by Biju and Ambili. The vertical hydraulic conductivity (Kz) was taken ten times smaller than the horizontal one as it is usual in groundwater modelling

Soil type	Horizontal hydraulic conductivity (Kx,Ky)
Lateritic rock	3.768×10^{-5}m/s
Laterite soil	6×10^{-4}m/s
Sandy soil	5×10^{-5}m/s

Table 3..Horizontal hydraulic conductivity

3.3.5 River

The river in the model domain flow from east to west and has a bottom elevation of 3 m and river stage elevation 6m. The conductance of the river was assumed to be 1000 as the infiltration rate of the river is very high.

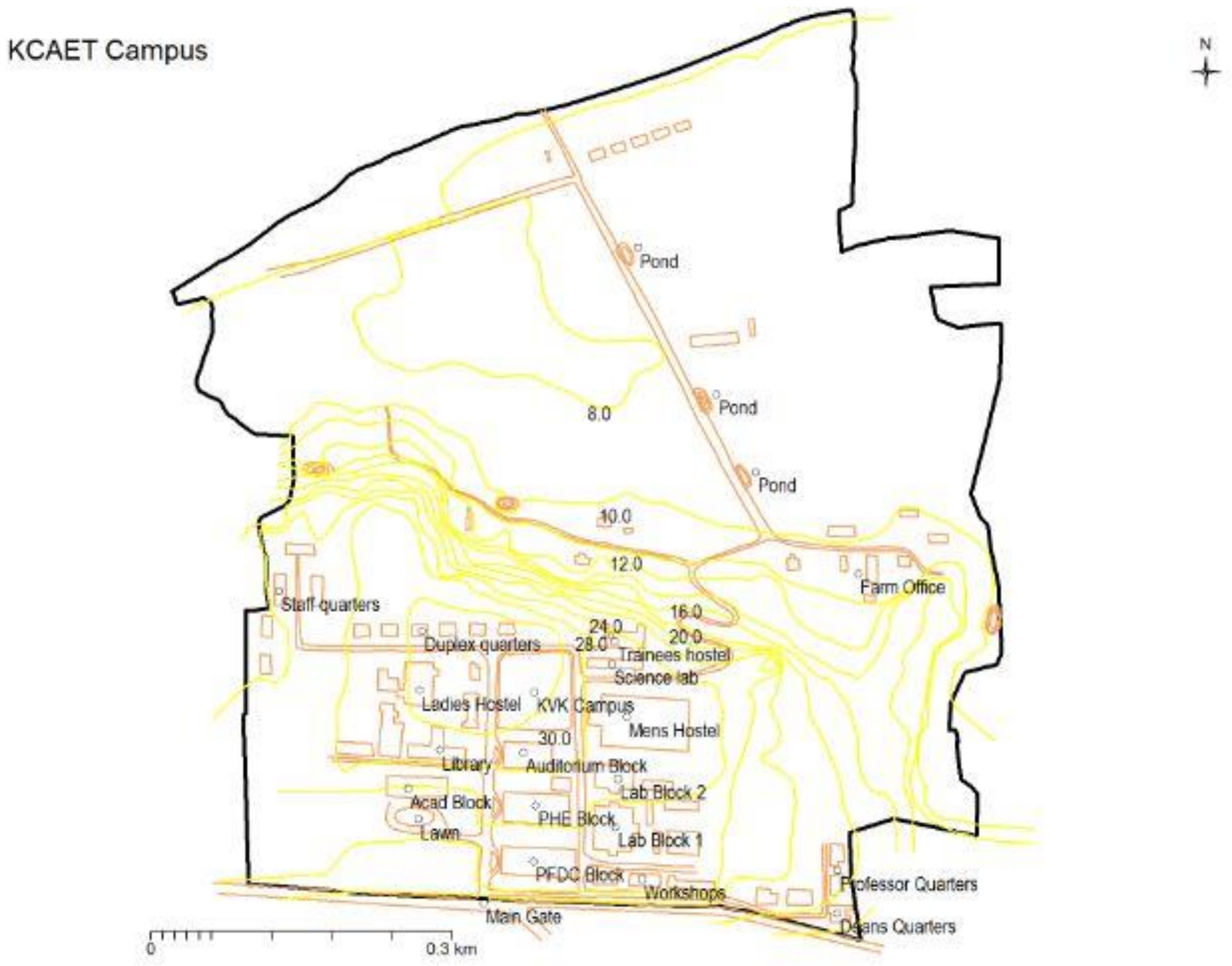


Fig 3.study area

BMP Map of K.C.A.E.T Campus

3.4 MODEL CONSTRUCTION AND INPUT DATA

3.4.1 Grid discretization

The model is based on a rectangular block-centred grid network covering the entire model domain. The grid dimensions are 30 m width and 30 m long while the number of cells is 900 with a cell size of 25 m by 25 m all over the domain. This cell size was chosen in order to avoid any type of interpolation when importing the topographic map.

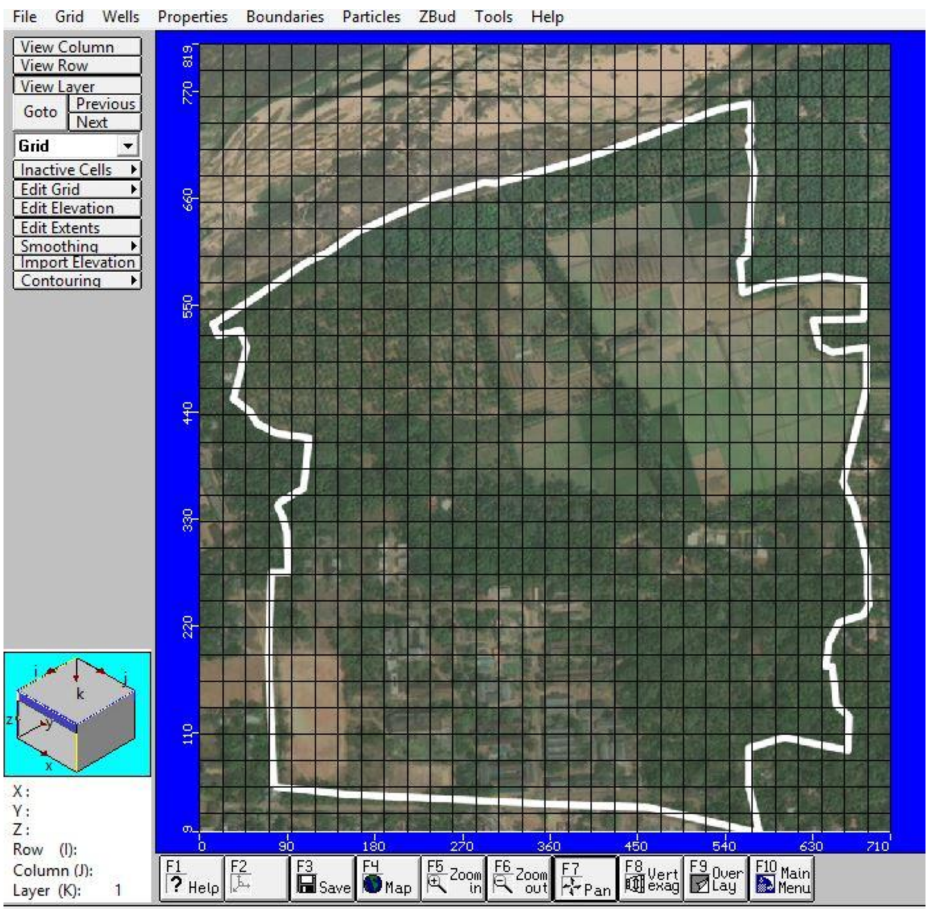


Fig 4.Model domain showing grid

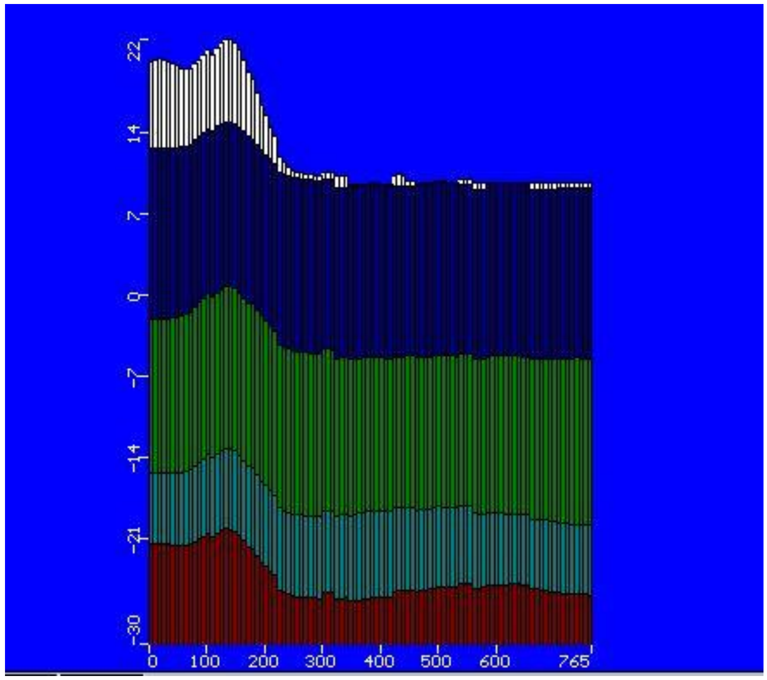


Fig 5.Cross section of layer elevation

3.4.2 Groundwater recharge

Groundwater recharge is that amount of surface which reaches the permanent water table either by direct contact in the riparian zone or by downward percolation through the overlying zone of aeration. The methods for the estimation of recharge are generally based on the following parameters: intensity and duration of rainfall, evaporation, soil moisture, runoff, infiltration capacities of soils, and storage characteristics of aquifers, water level fluctuations and movement of groundwater.The recharge values employed in this model were extracted from the collection of climatological data from Pattambi Research station. The average recharge was found to be and this is the value assigned as a single zone to the whole model domain.

3.4.3 Boundary conditions

The boundary conditions of any model must represent the system's relationship with the surrounding areas. Model results depend on the quality of these data. For the study area three types of boundaries supported by MODFLOW were chosen: River, Constant head and Drain.

3.4.3.1 Constant head

This boundary was placed in the WE direction of the study area. This type of boundary is selected to fix the head value in those cells regardless of the conditions in the surrounding cells and acting as an infinite source of water entering the system.

3.4.3.2 Drain

This boundary was placed in the SN direction in the both sides of the study area which having a sloppy surface towards the river.

3.4.3.3 River

Northern part is the Bharathapuzha river having high conductance value.

3.4.4 Pumping wells and observation wells

The necessary observation points for latter calibration of the model were taken from the inventory. Thus, the coordinates and calculated groundwater potential were imported into MODFLOW .In addition, the hand-dug wells which were pumping groundwater at a known rate were introduced in the model as pumping wells

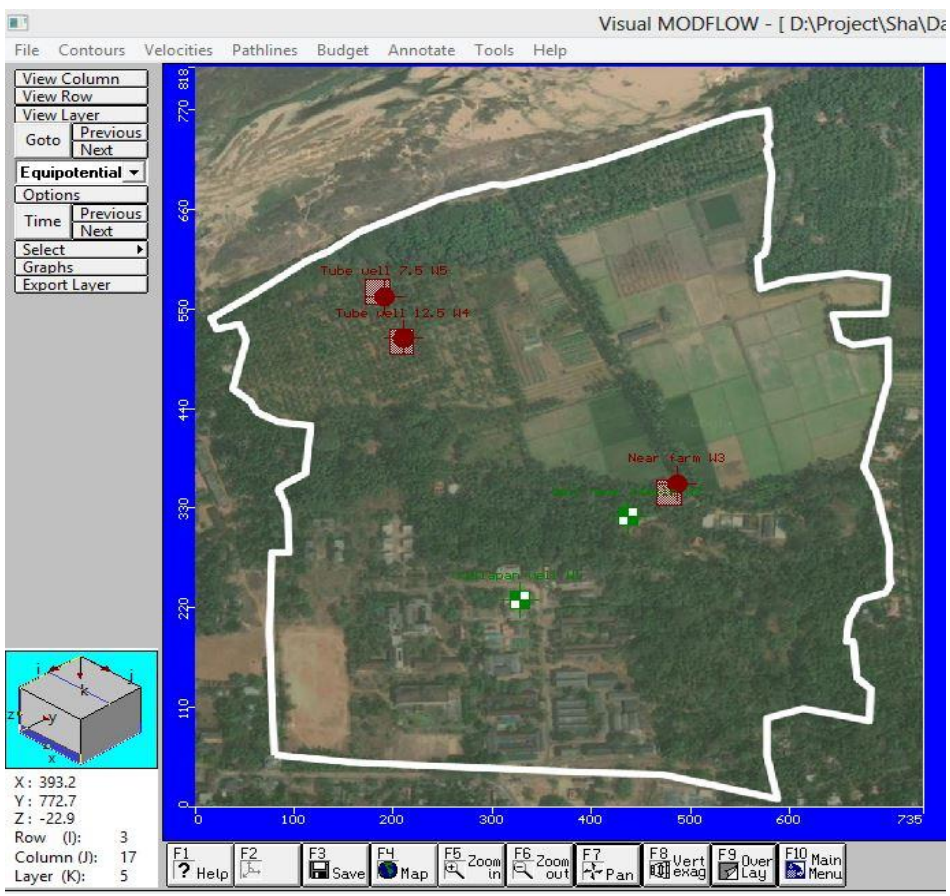


Fig 6. Wells under study area

Description of well	Well NO:	Well type	Pump specification (Hp)	static water table Level (m)	Average discharge in 1 yr. (m^3/day)
Near kelappan's home	W1	Open well	-	17.8	-
Open well near temple	W2	Open well	-	3.5	-
Near farm office	W3	Pumping open well	15	4.3	135
Tube well1	W4	Pumping open well	12.5	-	225
Tube well2	W5	Pumping well	7.5	-	337.5

Table.4.Well data

3.4.5 Simulation

The solver was used to solve the simulation equations. The maximum number of outer iterations applied was 50, while for the inner iterations it was 25 and the change criterion for convergence was set to 0.01. The residual applied was 0.001 as well.

CHAPTER 4

RESULTS AND DISSCUSSION

4.1 RESULTS

In this chapter the results or the model output are discussed and their interpretation is presented. The study area K.C.A.E.T and its nearby locality were found to be under the threat of an acute groundwater crisis. The study was mainly intended to identify the characteristics of groundwater by ground water modelling using MODFLOW 2.8. Rainfall is found to contribute a major share of the groundwater. The undulating topography of the study area had a tremendous influence on the groundwater resources. Throughout the study period behaviour of the groundwater was precisely studied and the following results were obtained.

4.2 OUTPUT FROM THE MODEL

Groundwater leaves the system through river leakage, pumping wells, constant head and drains. Figure show the zone budget and mass balance of the steady state model.

4.2.1 Zone budget

Zone budget calculates sub regional water budget using results from steady-state or transient MODFLOW simulations. Zone Budget calculates budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. The user simply specifies the sub-regions for which budgets will be calculated. These sub-regions are entered as 'zones' analogous to the way that properties, such as hydraulic conductivity, are entered. The water balance in the zone calculated shown in Figure

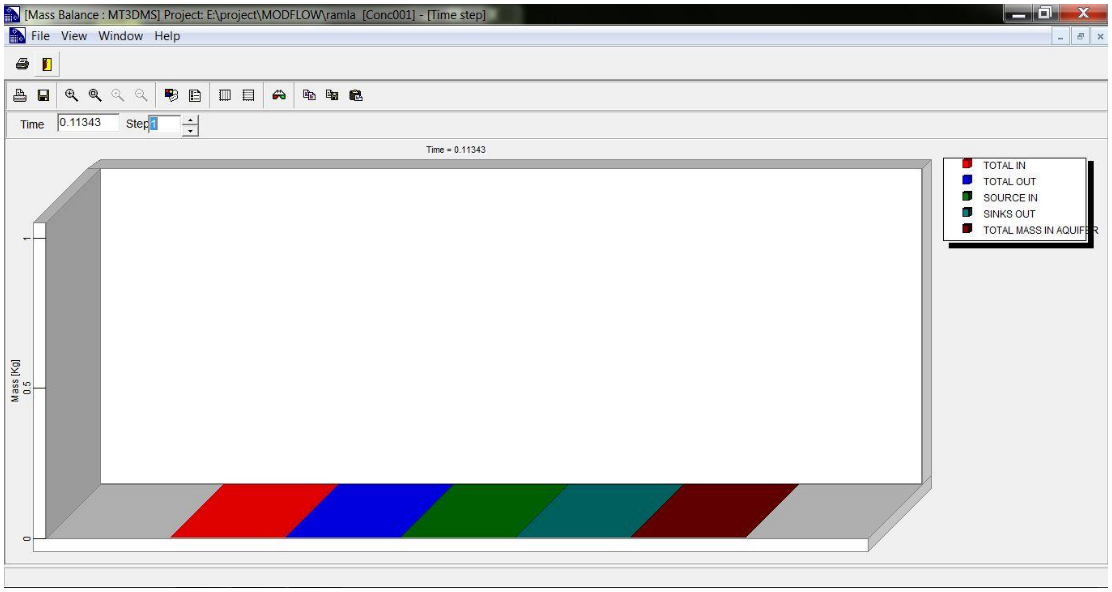


Fig 7. The volumetric water balance of the model at steady state condition.

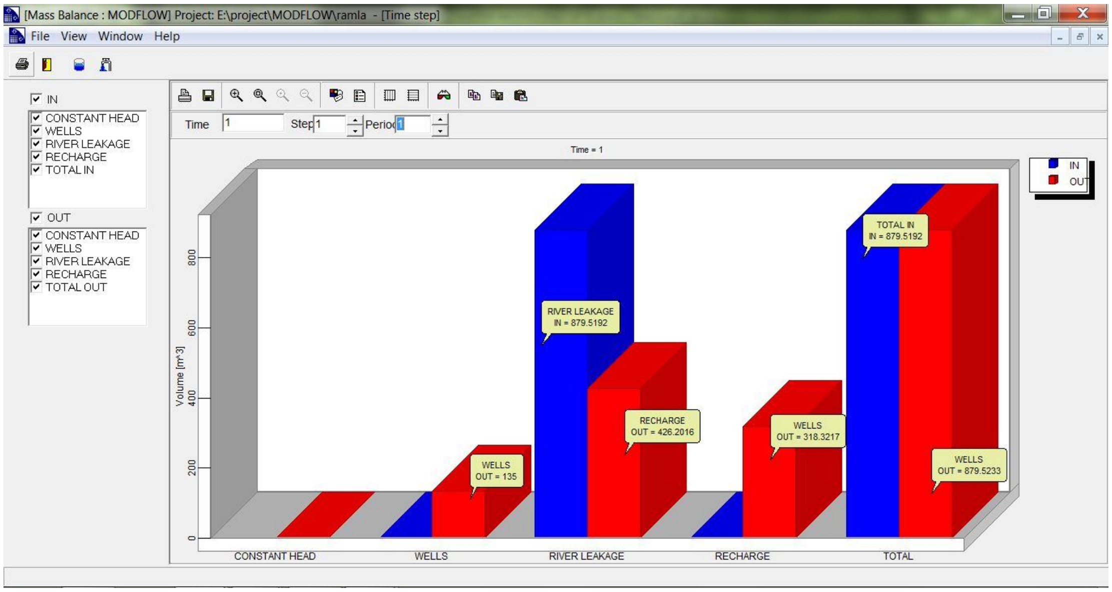


Fig 8. The Volumetric water balance of the model at transient state.

4.2.2 Groundwater head

The head distribution output of the model is considered as an important hydrological parameter to characterize the flow system, in that it measures the energy of flow, and can also be used to calculate the direction and rate of movement of the groundwater. Figure 9, 10 indicates the groundwater head and flow direction 1. From this figure it can be observed that flow is from higher heads which are on the Southern parts of the model to lower heads which are mainly located around the river.

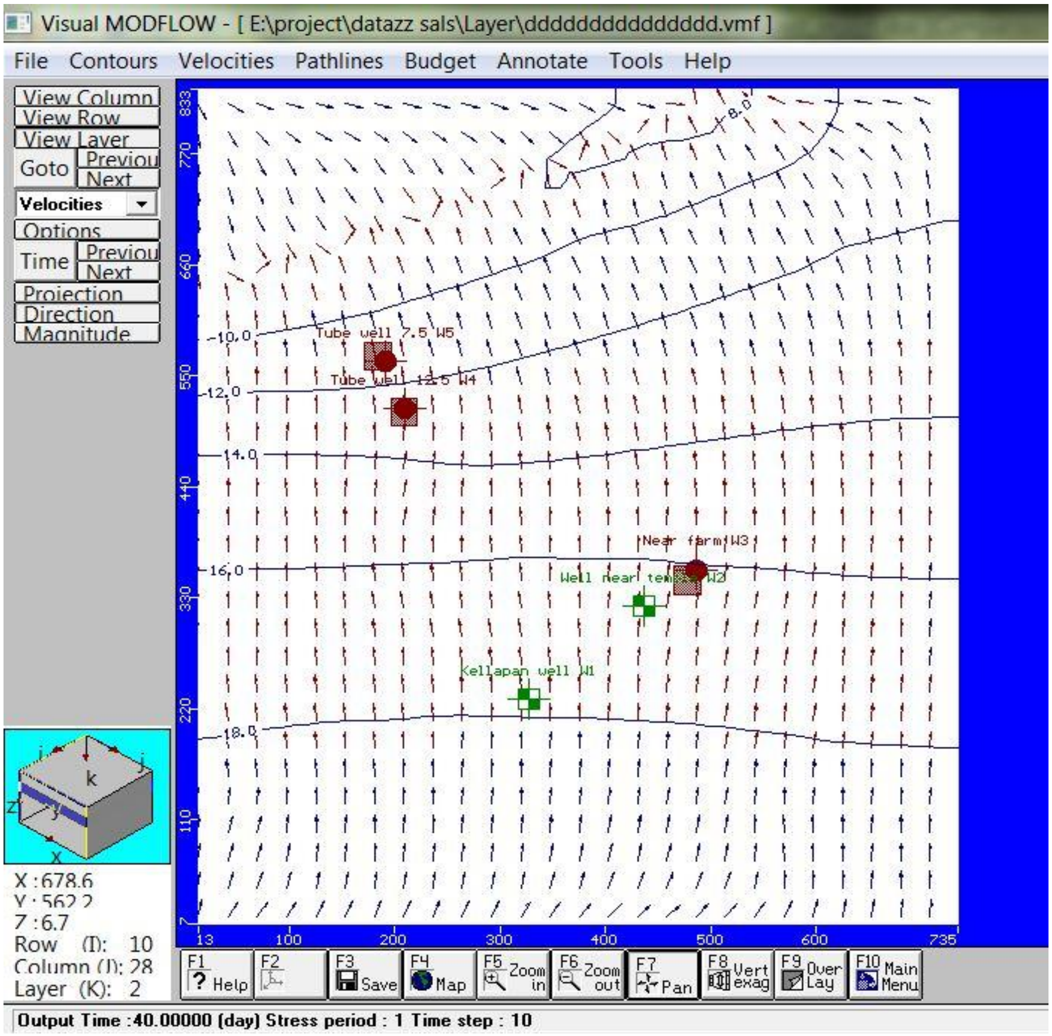


Fig 9.Equipotential head distribution of layer2

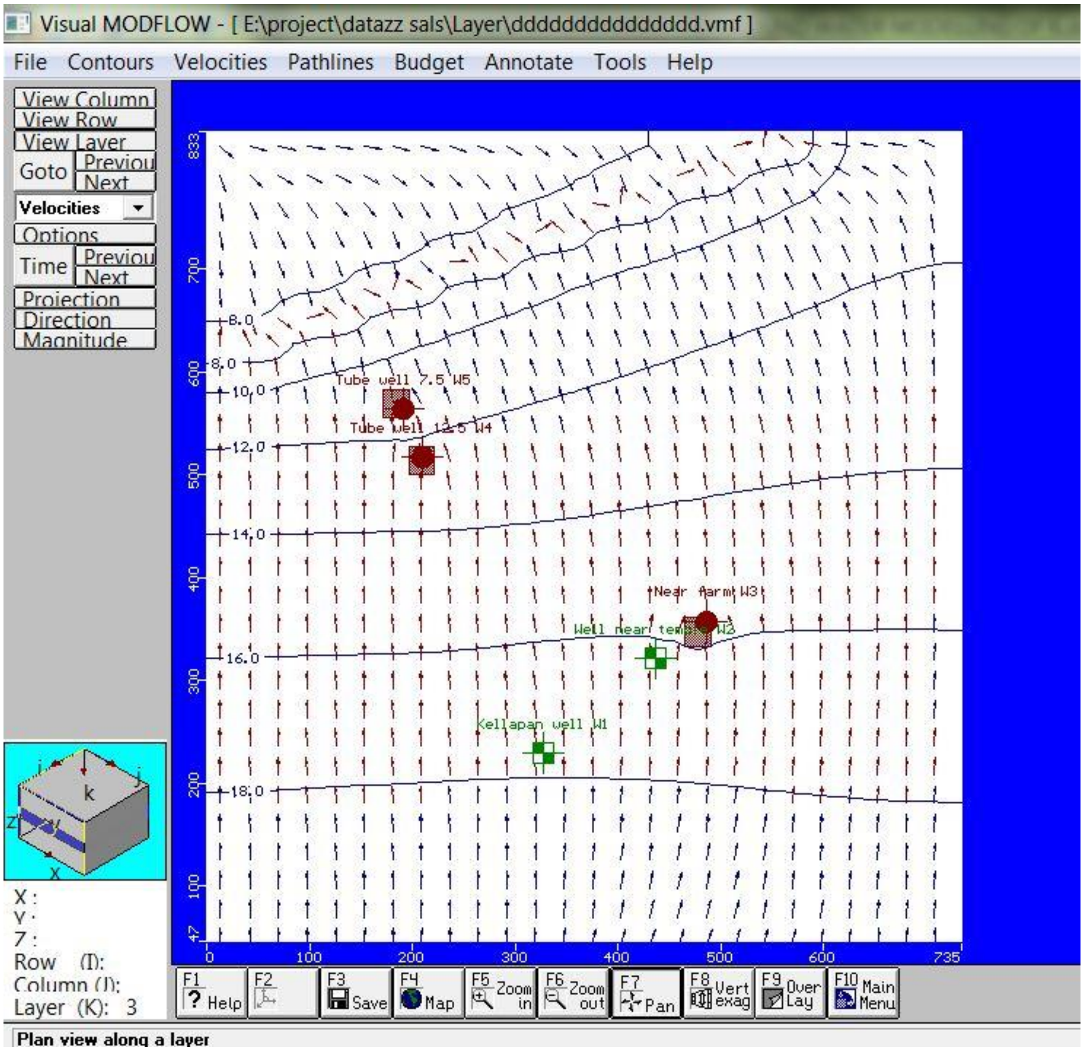


Fig 10.Equipotential head distribution of layer3

Fig 9 to Fig 10 show the equipotential head distribution and flow direction of groundwater across the layers of the model.

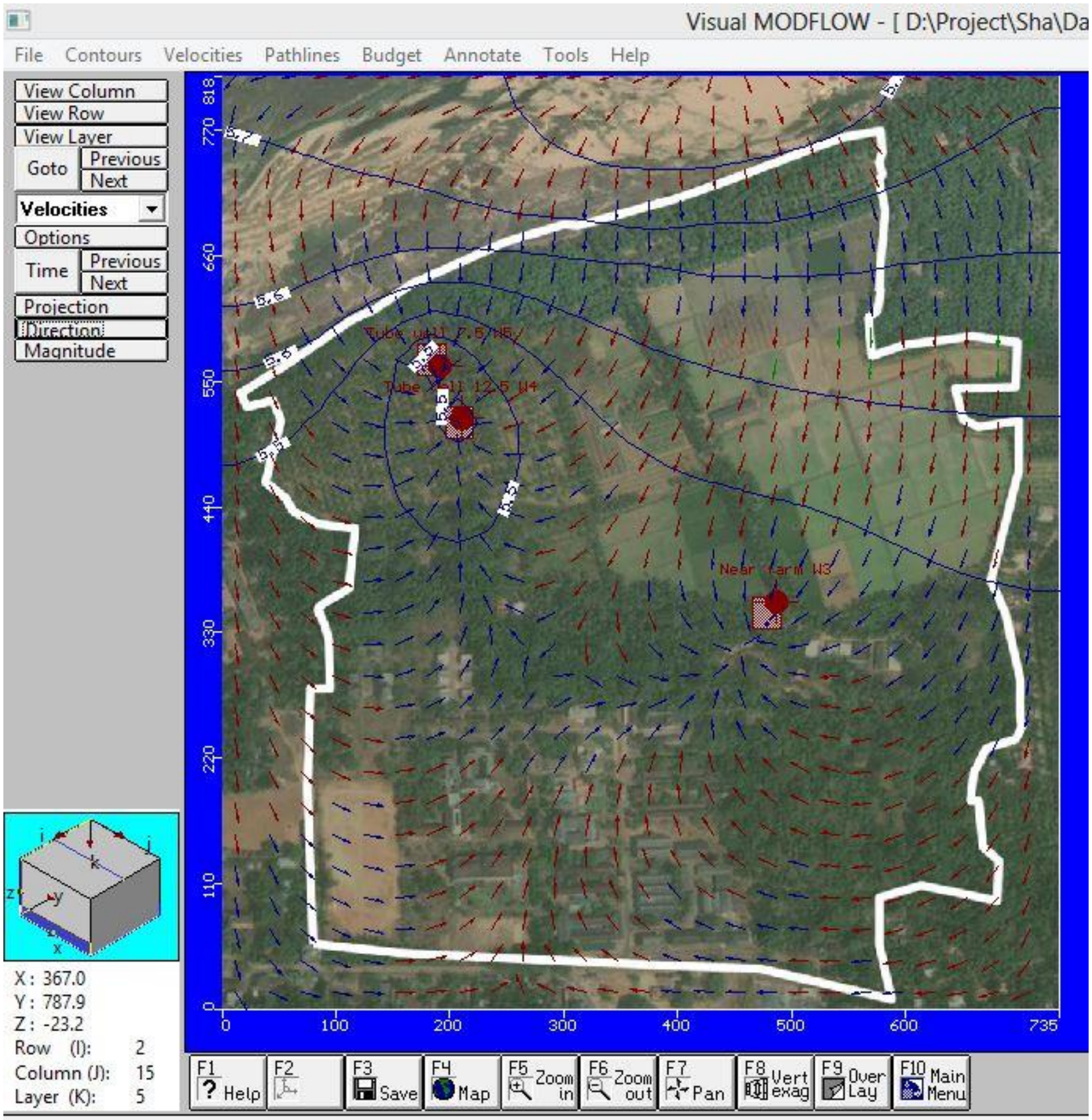


Fig 11. Velocity of flow to the wells without drain condition

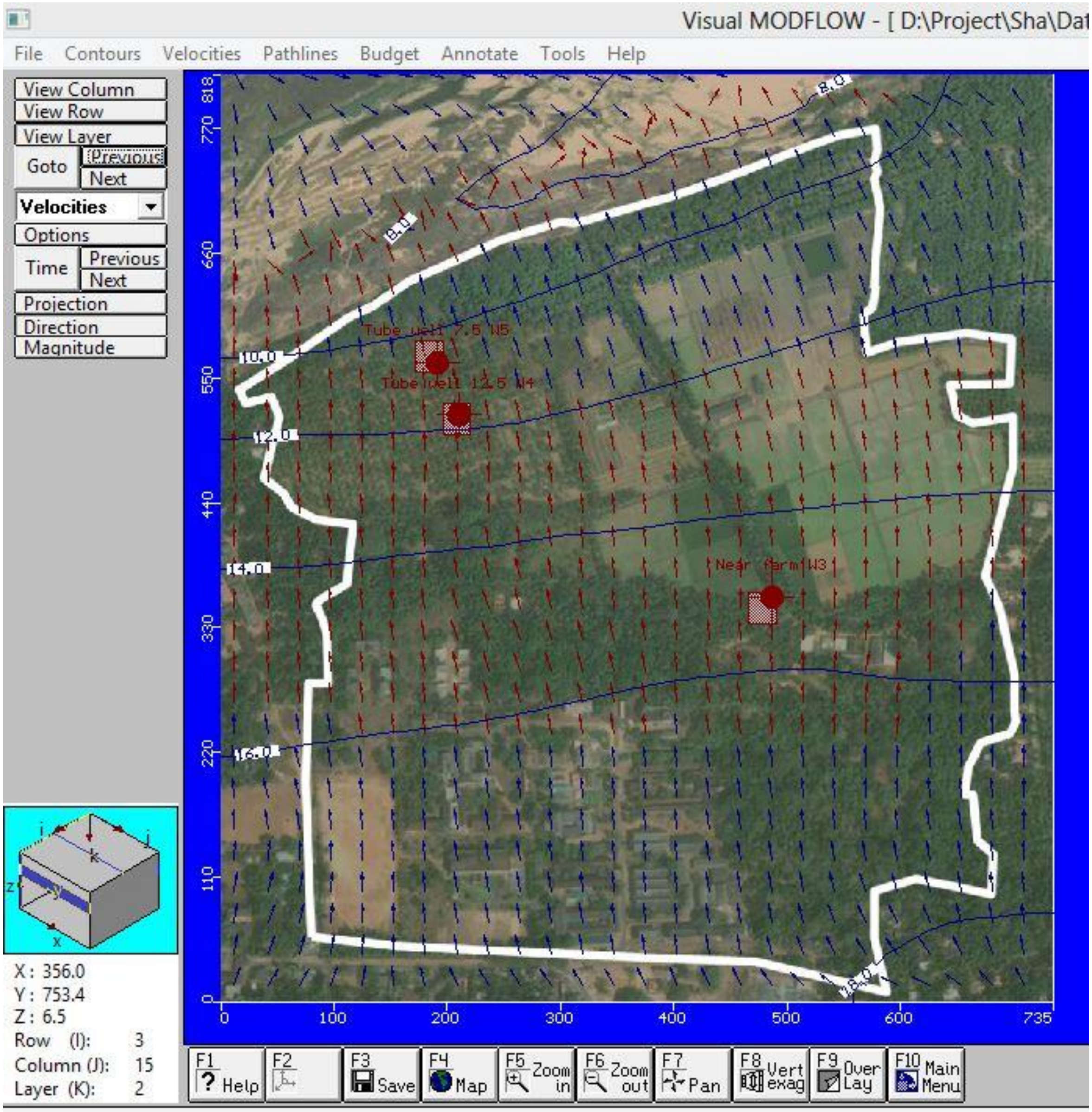


Figure 12. Velocity of flow to river with drain condition

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

Groundwater model has become a commonly used tool for hydro geologists to perform various tasks. The rapid increase of computing power of PCs and availability of user friendly modelling systems has made it possible to simulate large scale regional groundwater systems. Geological, hydrogeological and geophysical surveys are necessary to get data for constructing 3D hydrogeological framework models. The model should be used to simulate impacts of human activities on groundwater flow systems, to formulate sustainable groundwater resources development scenarios, and to communicate the results to public and decision-makers. The paragraphs below give a brief definition and background information regarding groundwater modelling. In the most abstracted words, groundwater model is a unification of the concepts of an aquifer that allow hydro geologists to make conceptual prediction of the aquifer future conditions. It's usually a computer based representation on the different aspects of a natural hydrogeological system. It consists of two components, a conceptual model, and a graphical presentation of hydrogeological setting and the mathematical model. A valid model should approximate the behaviour of the aquifer and provide a tool for prediction and quantification of impacts due to groundwater extraction. Groundwater models are often taken as an integral part of the decision support tools for water resources management. They are increasingly used to predict the impacts of proposed developments and policies concerning water management. The modelling process consists of the initial proposal, the modelling plan, the construction and calibration of the model, the design of the scenario presentation of results and achieving the model. MODFLOW is a finite-difference modelling program, which simulates groundwater flow in three dimensions.

MODFLOW model has been simulated on annual and monthly basis and the model gives very promising results. The study area has been divided into five layers.

The water table contour map and ground water flow velocity, its direction and magnitudes were obtained by the simulation. The various wells under study are marked in the map. Fifteen years (2000-2014) daily rainfall and river flow have been used in the study

5.2 CONCLUSIONS

A steady state groundwater model has been developed by using Visual MODFLOW. The model water balance was calculated. The input parameters were taken from previous studies. In this approach, the distributed recharge, wells, vertical and horizontal hydraulic conductivity of the three layers, constant head, river, and drain boundary conditions were the inputs to the groundwater system. The groundwater level and the flow budget were calculated as outputs of the model. The general flow direction was towards the river when drain boundary condition was applied and without the drain boundary condition the flow was found to be towards the pumping wells.

Uncertainty of parameter estimates and boundary conditions may be the most significant limitation. Slight alterations in parameters such as hydraulic conductivity and recharge can lead to dramatic differences in model output. Similarly, boundary conditions strongly control the flow regime, and so a poor representation can result in an inaccurate model.

REFERENCES

Arshad, M., Ahmed, N., Cheema, J.M. 2007. Modelling approach for the assessment of recharge contribution to groundwater from surface irrigation conveyance system. *Irrig Drainage Syst: Vol.22*, pp.67–77.

Batelaan, O. and De Smedt, F. 2001. Wetspass: A flexible, GIS based, distributed recharge methodology for groundwater modelling.

Batelaan, O. and De Smedt, F. 2004. Seepage, a new MODFLOW DRAIN Package, *Groundwater*. 42 (4): 576-88

Bingguo, W., Menggui, J., John N.R., Lei, Y., and Wenfeng, W. 2008. Estimating groundwater recharge in Hebei Plain, China under varying land use practices using tritium and bromide tracers. *Journal of Hydrology*: *Vol.*356: 209– 222.

Borah, D.K., Arnold, J.G., Bera, M., Krug, E.C., and Liang, X. 2007. Storm event and continuous hydrologic modelling for comprehensive and efficient watershed simulations. *Journal of Hydrologic Engineering*. 12(6): 605-616.

Conan, C., de Marsily, G., Bouraoui, F., and Bidoglio G. 2003. A long-term hydrological modelling of the Upper Guadiana river basin (Spain). *Physics and Chemistry of the Earth*. 28(4-5): 193-200.

Di Luzio, M., Arnold, J.G., and Srinivasan, R. 2005. Effect of GIS data quality on small watershed stream flow and sediment simulations. *Hydrological Processes*.19 (3): 629-650.

Don, N.C., Araki, H., Yamanishi, H., Koga, K. 2004. Simulation of groundwater flow and environmental effects resulting from pumping. *Environmental Geology: Vol* 47, pp.361–374.

Eric Marshall and Timothy Randhir.2008. Effect of climate change on watershed system: a regional analysis. *Journal of Climatic Change*.89: 263-280.

Faunt, C.C., Blainey, J.B., Hill, M.C., D'Agnese, F.A., O'Brien, G.M., 2004. *Transient Numerical Model*, Chapter F of Death Valley Regional Groundwater Flow System, Nevada and California-Hydrogeological Framework and Transient Groundwater Flow Model. U.S. Geological Survey. Scientific Investigation Report

Garbrecht, J.D., Schneider, J.M., and Van Liew M.W. 2006. Monthly runoff predictions based on rainfall forecasts in a small Oklahoma watershed. *Journal of the American Water Resources Association*. 42(5): 1285-1295.

Gassman, P.W., Reyes, M.R., Green, C.H., and Arnold, J.G. 2007. The Soil and Water Assessment Tool: historical development, applications, and future research directions. *Transactions of the ASABE*.50 (4): 1211-1250.

Hao FangHua., Zhang XueSong., Cheng HongGuang., Liu Chang Ming., and Yang ZhiFeng. 2004. Runoff and sediment yield simulation in a large basin using GIS and a distributed hydrological model, *International Conference of GIS and Remote Sensing in Hydrology, Water Resources and Environment*; 16-19 September-2003, ICGRSHWE, Three Gorges Dam, China.

Immerzeel, W.W., Gaur, A., and Zwart, S. J. 2008. Integrating remote sensing and a Process-based hydrological model to evaluate water use and productivity in a south Indian catchment. *Agricultural Water Management*. 95(1): 11-24.

Jensen, S.K., Dominigue, J.O .1988 Extracting topographic structure from digital elevation data for geographical information system analysis. *Photogramm Eng Rem S.* 54(11):1593-1600.

Jobson, H.E. 1989 *User's manual for an open-channel stream flow model based on the diffusion analogy*. US Geological Survey, Techniques of Water Resources Investigations,pp. 89-4133.

Jon, E., Hortness, Peter Vidmar. 2005. Surface-Water/Ground-Water Interaction along reaches of the Snake River and Henrys Fork, Idaho. USGS, Report 2004 – 5115

Julie Anne Ahern. 2005. Ground-water capture-zone delineation: method comparison in synthetic case studies and a field example on fort wainwright, Alaska.

Kim, N. W., Chung, I.M., Won, Y.S., and Arnold, J. G. 2008. Development and application of the integrated SWAT-MODFLOW MODEL. *Journal of Hydrology*.

Kollet, S.J., Maxwell. R.M. 2005. Integrated surface – groundwater flow modeling-A free surface overland flow boundary condition in a parallel groundwater flow model.

Konikow, L.F. and Reilly, T.E., 1999. Groundwater Modeling. *The Handbook of Groundwater Engineering*. Boca Raton, CRC Press,pp. 201-204.

Kresic, N. 1997. *Quantitative Solution in Hydrogeology and Groundwater Modeling*. Lewis Publishers, Boca Raton, Florida, 461 pp.

Kumar, D.2009. Groundwater Recharge Simulator, M. Tech. Thesis,Indian Institute of Technology, Bombay, pp: 3-11.

Lachaal,F.,Mlayah, A.,Bedir, M.,Tarhouni, J., Leduc, C. 2012. Implementation of a 3-D groundwater flow model in a semi-arid region using MODFLOW and GIS tools: The Zeramdine–BeniHassen Miocene aquifer system (east-central Tunisia), *Computers &Geosciences: Vol.48*, pp: 187–198.

Malik, V.S., Singh, R.K., Singh, S.K.2012. Groundwater modelling with processing MODFLOW for windows (PMWIN) for water balance study and suitable recharge site: Case of Gurgaon district, Haryana, India. *International journal of application or innovation in Engineering and management: Vol.1*, pp: 72-84.

Nimmer, M., Thompson, A.,Mishra, D. 2010, Modelling water table Moulding and contaminant transport beneath Strom water Infiltration Basins, *Journal of Hydrologic Engineering @ASCE*, December 2010, pp: 963-972.

[Online; accessed]. www.clas.ufl.edu/users/screaton/06fall/ Unsaturated Zone.doc.

Post, V.E.A. 2011. A new package for simulating periodic boundary conditions in MODFLOW and SEAWAT, *Computers &Geosciences: Vol.37*, pp: 1843–1849.

Rejani, R., Jha, M.K., Panda, S. N., Mull, R. 2006. Simulation Modeling for Efficient Groundwater Management in Balasore Coastal Basin, India. *Water Resour Manage*: *Vol.22*, pp: 23–50.

Reta, G.L. 2011. Groundwater and lake water balance of Lake Naivasha using 3-D transient groundwater model. M S Thesis, Geo- Information Science and Earth observation, University of Twente.

Richard, G.T. and Ken W. F.H. 1995. Groundwater recharge in the Victoria Nile basin of East Africa: Support for the soil Moisture balance approach using stable isotope tracers and flow modelling. *Journal of Hydrology: Vol.180*, pp: 31-53.

Rustogi, A. K. 2007. *Numerical Groundwater Hydrology*.

Senthilkumar, M., Elango, L. 2006. Modelling the impact of a subsurface barrier on groundwater flow in the lower Pala river basin, southern India, *Hydrogeology Journal*, pp.10-107.

Sivakumar, C., Elango, L., Ganasundar, D. 2006. *Numerical modelling of groundwater flow in south Chennai coastal aquifer*. In: Poeter, Hill, &Zheng (Eds.), MODFLOW and More: Managing Ground-Water Systems, pp: 506-510.

Shao, J.L., Zhao, Z.Z., Cui, Y.L., Wang, R., Li, C.Q., Yang, Q.Q. 2009. Application of groundwater modelling system to the evaluation of groundwater resources in North China plain. *Resources Science* 313.

Sophocleous, M. Groundwater recharge Encyclopedia of Life Support System (EOLSS), *Groundwater*: *Vol.1*. Simulation of Groundwater and Lake water Interaction using PMWIN

Todd, D .K. 1980. *Groundwater hydrology*.

Wang, S., Shao, J., Song, X., Zhang, Y., Huo, Z., Zhou, X. 2007. Application of MODFLOW and geographic information system to groundwater flow simulation in North China Plain, China. *Environ Geol: Vol.55*, pp: 1449–1462.

Waterloo hydrologic, 2002. Visual MODFLOW v.3.0.0 User's Manual, Ontario, Canada

Winter, T.C., Harvey, J.W., Frank, O.L., Alley, W.M. 1998. Groundwater and Surface water a single resource, US geological Survey Circular .1139.

Winter, T.C. 1999. Relation of streams, lakes, and wetlands to groundwater flow systems. *Hydrogeology Journal 71*, pp. 28-45.

Woesner WW, 2000. Stream and fluvial plain groundwater interactions: Rescaling hydrogeologic thought. *Groundwater* 38(3): 423-429.

World Atlas, http://www.worldatlas.com/webimage/countrys/europe/be.html

Zheng and Bennet. 2002. *Applied Contaminant Transport modelling* (Second edition)

Zume, J., Tarhule, A. 2008. Simulating the impacts of groundwater pumping on stream aquifer dynamics in semi-arid north western Oklahoma, USA. *Hydrogeology journal*, *Vol 16*, pp: 797-810.

APPENDIX I

Table 1. First layer elevation data.

X Co- ordinate	Y Coordinate	Z Co ordinate
120	0	24
240	0	24
360	0	25
480	0	20
600	0	18
720	0	18
120	120	26
240	120	27
360	120	26
480	120	21
600	120	10
720	120	10
120	240	29
240	240	30
360	240	25
480	240	16
600	240	10
720	240	10
120	360	26
240	360	10
360	360	10
480	360	10
600	360	10
720	360	10
120	480	8
240	480	8
360	480	8
480	480	9
600	480	9
720	480	9
120	600	8
240	600	8
360	600	8
480	600	8
600	600	8
720	600	8
120	720	8
240	720	8
360	720	8
480	720	8

600	720	8
720	720	8
0	0	24
0	120	25
0	240	25
0	360	22
0	480	9
0	600	8
0	720	8

APPENDIX II

Table 2. Layer 2 elevation data

X Co ordinate	Y Co ordinate	Z Co ordinate
120	0	16
240	0	16
360	0	17
480	0	12
600	0	10
720	0	10
120	120	15
240	120	17
360	120	0
480	120	1
600	120	2
720	120	2
120	240	19
240	240	20
360	240	7
480	240	8
600	240	0
720	240	0
120	360	17

240	360	10
360	360	10
480	360	10
600	360	10
720	360	10
120	480	8
240	480	8
360	480	8
480	480	9
600	480	9
720	480	9
120	600	8
240	600	8
360	600	8
480	600	8
600	600	8
720	600	8
120	720	8
240	720	8
360	720	8
480	720	8
600	720	8
720	720	8
0	0	16
0	120	25
0	240	16
0	360	13
0	480	9
0	600	8
0	720	8

APPENDIX III

Table 3. Layer 3 elevation data.

X Co ordinate	Y Co ordinate	Z Co ordinate
120	0	-4
240	0	1
360	0	8
480	0	3
600	0	1
720	0	1
120	0	0
240	120	5
360	120	-9
480	120	-10
600	120	-11
720	120	-11
120	240	9
240	240	11
360	240	-2
480	240	-1
600	240	-9
720	360	-9
120	360	3
240	360	-5
360	360	-5
480	360	-5
600	360	-5
720	360	-5
120	480	-7

240	480	-7
360	480	-7
480	480	-6
600	480	-6
720	600	-6
120	600	-10
240	600	-18
360	600	-18
480	600	-18
600	600	-18
720	600	-18
120	720	8
360	720	8
480	720	8
600	720	8
720	720	8
0	0	4
0	120	16
0	240	6
0	360	-2
0	480	-6
0	600	-10
0	720	-10

APPENDIX IV

Table 4. Layer 4 elevation data

X Co ordinates	Y Co ordinates	Z Co ordinates
120	0	-19
240	0	-14
360	0	-22
480	0	-15
600	0	-16
720	0	-13
120	120	-13
240	120	-18
360	120	-21
480	120	-22
600	120	-24
720	120	-25
120	240	-6
240	240	-3
360	240	-13
480	240	-14
600	240	-24
720	240	-23
120	360	-11
240	360	-19
360	360	-18
480	360	-18
600	360	-19
720	360	-20
120	480	-21

240	480	-22
360	480	-21
480	480	-19
600	480	-18
720	480	-19
120	600	-23
240	600	-31
360	600	-31
480	600	-32
600	600	-33
720	600	-32
120	720	-6
240	720	-7
360	720	-6
480	720	-6
600	720	-7
720	720	-7
0	0	-10
0	120	1
0	240	-9
0	360	-15
0	480	-20
0	600	-21
0	720	-22

APPENDIX V

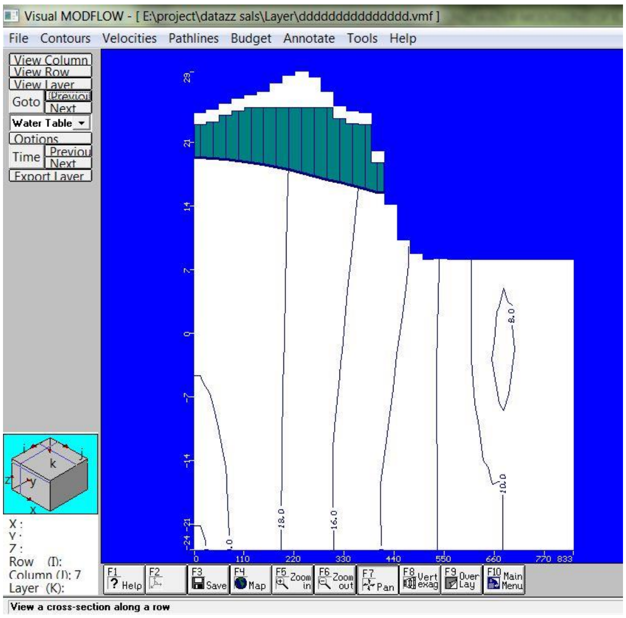
Table 5. Layer 5 elevation data

X Co ordinates	Y Co ordinates	Z Co ordinates
120	0	-25
240	0	-20
360	0	-29
480	0	-22
600	0	-22
720	0	-20
120	120	-19
240	120	-19
360	120	-27
480	120	-28
600	120	-30
720	120	-32
120	240	-13
240	240	-9
360	240	-19
480	240	-21
600	240	-30
720	240	-30
120	360	-18
240	360	-26
360	360	-26
480	360	-25
600	360	-25
720	360	-26
120	480	-28

240	480	-29
360	480	-27
480	480	-26
600	480	-24
720	480	-25
120	600	-30
240	600	-37
360	600	-37
480	600	-38
600	600	-39
720	600	-39
120	720	-14
240	720	-13
360	720	-13
480	720	-14
600	720	-14
720	720	-14
0	0	-17
0	120	-6
0	240	-15
0	360	-21
0	480	-26
0	600	-27
0	720	-28

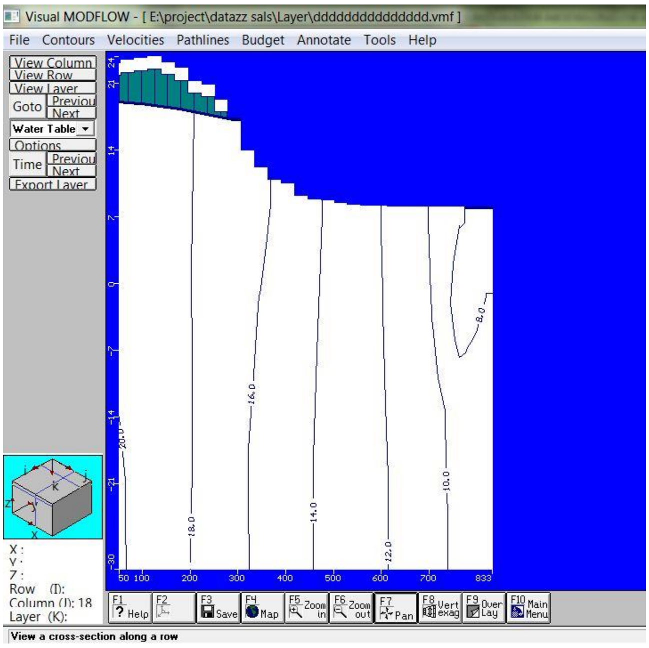
APPENDIX V1

Water table cross section along column 7



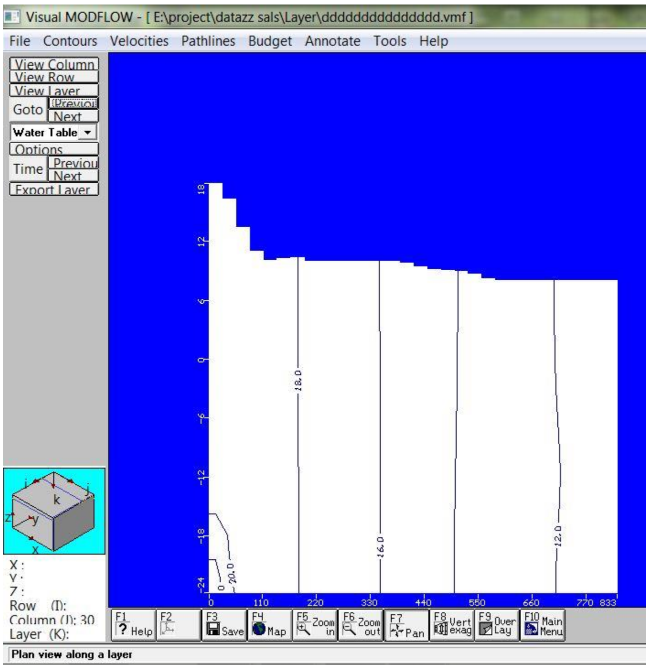
APPENDIX V1I

Water table cross section along column 18



APPENDIX V1II

Water table cross section along column 30



ABSTRACT

Groundwater models are increasingly used in modelling of groundwater flow problems to develop useful information about groundwater resources. In this study the MODFLOW model is applied to evaluate the groundwater availability in K.C.A.T. campus and predict water levels in response to increased pumping .A conceptual model was constructed based on the topographical and climatic data of the study area along with the field observation data including pumping data and geological data of the area. The area. The recharge in the area was taken to be 10% of the rainfall. Rainfall. A steady state model was developed on the basis of average groundwater heads for a 15 period (2000 to 2014).The simulations were conducted using monthly average for recharge and discharge from pumping wells.

Despite the data scarcity for observation wells in the area, the developed groundwater model will provide more insight in understanding the hydrological behavior of the system. This study revealed that the model could be predict the flow of groundwater and its velocity in magnitude and direction with direction with good accuracy. The Bharathapuzha river at the northern boundary taken as the boundary condition and the southern part is assumed as constant head condition. Drain condition. Drain boundary condition is assumed over the eastern and western boundary. This boundary. This model provides a clear idea of groundwater characteristics in K.C.A.E.T campus and it will helps in future studies and development of groundwater management in this campus and also it will help to get an idea about the groundwater modeling using MODFLOW software