GROUNDWATER FLOW AND PARTICLE TRACKING MODEL FOR NILESHWAR BASIN USING MODFLOW

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PROJECT REPORT

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DECLARATION

We hereby declare that this project entitled **“GROUNDWATER FLOW AND PARTICLE TRACKING MODEL FOR NILESHWAR BASIN USING MODFLOW”** 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 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 **“GROUNDWATER FLOW AND PARTICLE TRACKING MODEL FOR NILESHWAR BASIN USING MODFLOW”** is a record of project work done independently by **Joseph Sunny** and **Sumayya Roshan P 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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Above all we bow our head before **The Almighty,** whose blessings empowered us to complete this work successfully.

JOSEPH SUNNY

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Dedicated to the poor victims of Water Crisis

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SYMBOLS AND ABBREVIATIONS

MODFLOW	-	MODular finite-difference ground water FLOWmodel
FDM	-	Finite difference method
FEM	-	Finite element method
USGS	-	United States Geological Survey
PDE	-	Partial differential equations
FEFLOW	-	Finite Element subsurface FLOW system
GMS	-	groundwater modelling system
PMWIN	-	Pro-cessing MODFLOW for Window
3-D	-	Three dimensions
HFM	-	Hydogelogical Framework Model
NCP	-	North China Plan
CWRDM	-	Central Water Resource Development Management
BNCR	-	Beaver-North Canadian River
PBC	-	periodic boundary condition
MSL	-	Mean Sea Level
PC	-	Personal Computer

CHAPTER I

INTRODUCTION

1.1 GROUNDWATER

Groundwater is the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers. The world's total water resources is 1.378×10^8Mha-m. Out of this fresh water only 2.7% and the remaining 97.3% is as saline water. In this fresh water, about 77.2%is contributed from glaciers, 22.4% from groundwater and soil moisture, 0.35% from swamps and lakes, 0.04% from atmosphere and 0.01% from the streams. So one fifth of the total water used is obtained from groundwater resources and agriculture is one of the main user with about 80% of the entire consumption.

Groundwater is naturally replenished by various form of water and surface water from precipitation, streams, and rivers is one of them. The main source of groundwater is the precipitated water. The water gets infiltrated after meeting the soil moisture deficiency, which percolates downwards under the influence of gravity and becomes groundwater. In the subsurface, groundwater is occurring mainly in two zones, they are zone of saturations and zone of aeration. In the zone of saturation, under hydrostatic pressure, all the interstices are filled with water which is generally regarded as groundwater. The water table is the upper boundary of the zone of saturation. In the zone of aeration the interstices are partially occupied by air and partially by water.

Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supply. During the recent years the water level was reduced a lot in several parts of the country, and there is a chance of no availability of groundwater in future and our country will have to pay more to buy water. The failure of the monsoon and increase in extraction are the main reasons of the decrease in groundwater level. The rapidly rising population of our country and changing lifestyles has also increased need for water. The number of wells drilled is rapidly and indiscriminately increased.

Unfortunately, the groundwater, as other water supplies, is more and more exposed to pollution and gets depleted day by day and as a result demand for water increases. This results in the contamination of groundwater and soil that is in contact. Some of the groundwater contaminations are naturally occurring, but, a majority is the result of human activity. Groundwater pollution most often results from improper disposal of wastes on land. Major sources include underground storage tanks, abandoned waste sites, agricultural activities, septic tanks, surface impoundments and municipal landfills, since they are numerous and represent the major threat to groundwater. Underground storage tanks are used to store fuel, heating oil, chemicals, liquid hazardous wastes and other products. They represent a high source of groundwater contamination as they can leak through holes due to corrosion or cracks. Transport processes in subsurface water are the major pathways for contaminant spreading from contaminated areas to groundwater supplies, lakes or steams. Still, due to complex hydrogeological settings and to the high technical and scientific knowledge that are required, predictions of groundwater contaminant transport are rarely performed. Particle tracking is a widely applied tool to calibrate aquifer porosity values in groundwater flow models and to characterize water availability and quality at groundwater discharge points such as wells, springs, lakes, and streams.

The management of the sustainable water resources is one of the challenging issues. For identifying the remedial measures first objective is the development of techniques for investigating the occurrence and movement of groundwater. For this the mathematical modelling is a suitable tool which is frequently used in studying groundwater flow systems in recent years. The main achievement in the groundwater hydrology was the introduction of numerical groundwater models, which is a simplified representation of a more complex reality.

The main purpose of this project work was to study the groundwater resource flow modelling of the Nileswar basin and to set up a groundwater transport and particle tracking model for the area so that any contaminant transport in the area can be studied.

1.2 GROUNDWATER FLOW AND TRANSPORT PROCESSES

The process of groundwater flow is generally assumed to be governed by the relations expressed in Darcy's law and the conservation of mass. Darcy's law does have limits on its range of applicability

1.2.1 GOVERNING EQUATIONS

The development of mathematical equations that describe the groundwater flow and transport processes may be developed from the fundamental principle of conservation of mass of fluid or of solute. Given a representative volume of porous medium, a general equation for conservation of mass for the volume may be expressed as:

(rate of mass inflow) – (rate of mass outflow) + (rate of mass production/consumption) = (rate of mass accumulation)

This statement of conservation of mass (or continuity equation) may be combined with a mathematical expression of the relevant process to obtain a differential equation describing flow or transport

1.2.2 GROUNDWATER FLOW EQUATION

The rate of flow of water through a porous media is related to the properties of the water, the properties of the porous media, and the gradient of the hydraulic head, as represented by Darcy’s law, which can be written as

$$q_i = -K_{ij} \frac{\partial h}{\partial x_j}$$

where q_i is the specific discharge, K_{ij} is the hydraulic conductivity of the porous medium and h is the hydraulic head.

A general form of the equation describing the transient flow of a compressible fluid in a non-homogeneous anisotropic aquifer may be derived by combining Darcy's law with the continuity equation. A general groundwater flow equation may be written in

$$\frac{\partial}{\partial x_i}\left(K_{ij}\frac{\partial h}{\partial x_i}\right) = S_S\frac{\partial h}{\partial t} + W^*$$

where S_S is the specific storage, t is time, W* is the volumetric flux per unit volume (positive for outflow and negative for inflow and x_i are the Cartesian co-ordinates

1.2.3 NUMERICAL METHODS TO SOLVE EQUATIONS

The partial differential equations describing groundwater flow and transport can be solved mathematically using either analytical solutions or numerical solutions. The advantages of an analytical solution is that it usually provides an exact solution to the governing equation and is often relatively simple and efficient to obtain. Many analytical solutions have been developed for the flow equation;

In general, obtaining the exact analytical solution to the partial differential equation requires that the properties and boundaries of the flow system be highly and perhaps unrealistically idealised. For most field problems, the mathematical benefits of obtaining an exact analytical solution are probably outweighed by the errors introduced by the simplifying assumptions of the complex field environment that are required to apply the analytical model.

Alternatively, for problems where the simplified analytical models are inadequate, the partial differential equations can be approximated numerically.

In so doing, the continuous variables are replaced with discrete variables that are defined at nodes. Thus, the continuous differential equation, which defines hydraulic head or solute concentration everywhere in the system, is replaced by a finite number of algebraic equations that defines the hydraulic head or concentration at specific points. This system of algebraic equations generally is solved using matrix techniques. This approach constitutes a numerical model.

The equations describing groundwater flow and solute transport are second-order differential equations, which can be classified on the basis of their mathematical properties. There are basically three types of second-order differential equations, which are parabolic, elliptic, and hyperbolic. Such equations can be classified and distinguished based on the nature and magnitude of the coefficients of the equation. This is important because the numerical methods for the solution of each type have should be considered and developed separately for optimal accuracy and efficiency in the solution algorithm.

Two major classes of numerical methods have come to be well accepted for solving the groundwater flow equation. These are the finite-difference methods and the finite-element methods. Each of these two major classes of numerical methods includes a variety of subclasses and implementation alternatives. Both of these numerical approaches require that the area of interest be subdivided by a grid into a number of smaller subareas (cells or elements) that are associated with node points (either at the centre’s of peripheries of the subareas).

Finite-difference methods approximate the first derivatives in the partial differential equations as difference quotients (the differences between values of variables at adjacent nodes, both in space and time, with respect to the interval between those adjacent nodes). Finite-element methods use assumed functions of the dependent variables and parameters to evaluate equivalent integral formulations of the partial differential equations.

In both numerical approaches, the discretisation of the space and time dimensions allows the continuous boundary-value problem for the solution of the partial differential equation to be reduced to the simultaneous solution of a set of algebraic equations. These equations can then be solved using either iterative or direct matrix methods.

Each approach has advantages and disadvantages, but there are very few groundwater problems for which either is clearly superior. In general, the finite-difference methods are simpler conceptually and mathematically, and are easier to program for a computer. They are typically keyed to a relatively simple, rectangular grid, which also eases data entry tasks. Finite-element methods generally require the use of more sophisticated mathematics but, for some problems, may be more accurate numerically than standard finite-difference methods

1.2.4 BASICS OF FINITE-DIFFERENCE METHODS

The partial differential equations describing the flow and transport processes in groundwater include terms representing derivatives of continuous variables. Finite-difference methods are based on the approximation of these derivatives (or slopes of curves) by discrete linear changes over small discrete intervals of space or time. If the intervals are sufficiently small, then all of the linear increments will represent a good approximation of the true curvilinear surface.

Considering the observation wells in a confined aquifer, a reasonable approximation for the derivative of head, $\partial h/\partial x$, at a point (d) midway between wells 1 and 0 (Fig.1.1a) is:

$$\left(\frac{\partial h}{\partial x}\right)_d \approx \frac{h_0 - h_1}{\Delta x}$$

Note that the observation wells are spaced an equal distance apart. Similarly, a reasonable approximation for the second derivative, $\eth^2 h/\eth x^2$, at point 0 (the location of the centre well) can be given as:

$$\left(\frac{\partial^2 h}{\partial x^2}\right) \approx \frac{\left(\frac{\partial h}{\partial x}\right)_e - \left(\frac{\partial h}{\partial x}\right)_d}{\Delta x} = \frac{\frac{h_2 - h_0}{\Delta x} - \frac{h_0 - h_1}{\Delta x}}{\Delta x} = \frac{h_1 + h_2 - 2h_0}{(\Delta x)^2}$$

If we also consider wells 3 and 4 shown in Fig.1.1a , located on a line parallel to the y-axis, we can similarly approximate $\partial^2 h/\partial y^2$ at point 0

$$\left(\frac{\partial^2 h}{\partial y^2}\right) \approx \frac{h_3 + h_4 - 2h_0}{(\Delta y)^2}$$

If the spacing of the wells in Fig.1.1b is uniform (that is, $\Delta x = \Delta y = a$), then we can develop the following approximation:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} \approx \frac{h_1 + h_2 + h_3 + h_4 - 4h_0}{a^2}$$

These approximations can also be obtained through the use of Taylor series expansions. A certain error is involved in approximating the derivatives by finite-differences, but this error will generally decrease as a (or Δx and Δy) is given smaller and smaller values. This error is called a “truncation error” because the replacement of a derivative by a difference quotient is equivalent to using a truncated Taylor series, so that the exact solution of a difference equation differs from the solution of the corresponding differential equation. Also, it may not be possible to achieve an “exact” solution of the difference equation because of limits of precision in storing numbers in a digital computer. In solving a large set of difference equations, many arithmetic operations are performed, and round-off errors may sometimes accumulate.

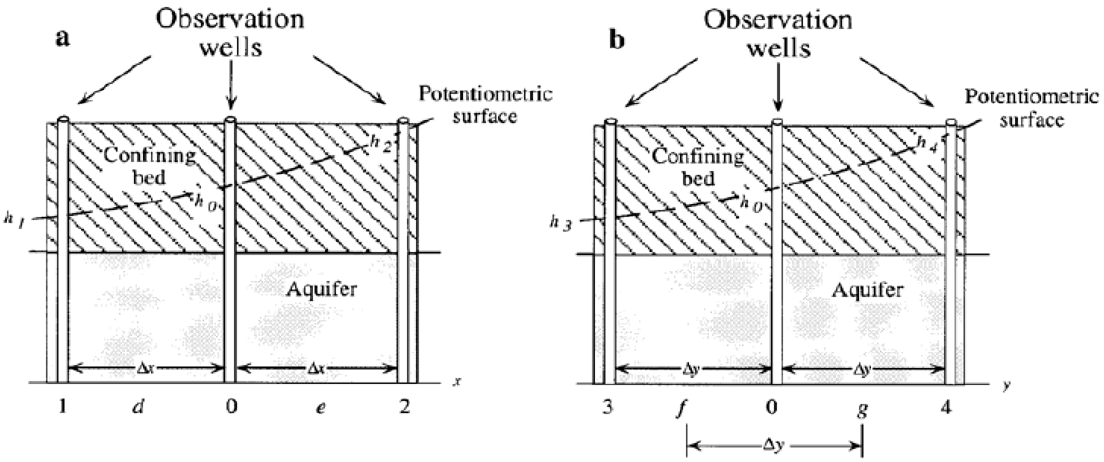


Fig. 1 .1 observation well

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

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

K_x, K_y, and K_z 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, S_s 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 groundwater flow model, MODFLOW

1.3 FLOW MODELS

Simply a model is defined as a representation of a real system or process. The hypothesis of how a system or process operates is the conceptual model and this hypothesis can be expressed as a mathematical model. In the mathematical model, the equations are a representation of processes in which physical properties as constants or coefficient and variables as measures of state or potential in the system. The mathematical models are mainly of two types, i.e, analytical and numerical. Analytical models are mathematical models that have a closed form solution, and the solution to the equations can be used to describe changes in a system which can be expressed as a mathematical analytic function. There are too many assumptions in an analytical solution whereas numerical models are mathematical models that use some sort of numerical time-stepping procedure to obtain the models behavior over time. The mathematical solution is represented by a generated table and/or graph. The advantages of an analytical solution, when it is possible to apply one, are that it usually provides an exact solution to the governing equation and is often relatively simple and efficient to obtain. Many analytical solutions have been developed for the flow equation.

The numerical models are a best fit for groundwater flow. For creating a numerical model, the first step is to understand how the system behaves, which is coming from the laws and concepts. Then it will be converted to mathematical expression usually as a partial differential equation with boundary and initial conditions. In case of groundwater flow equation there are two numerical approaches which are successfully applied, the finite difference method (FDM) and the finite element method (FEM). The finite element method is a computational method that subdivides a model into very small but finite-sized elements of geometrically simple shapes.

The system of field equations is mathematically represented by the partial differential equations (PDEs). The finite-difference method is typically defined on a regular grid and can be used for very efficient solution methods. The method is therefore not usually used for irregular geometries, but more often for rectangular or block-shaped models.

1.4 MODFLOW

MODFLOW, MODular finite-difference groundwater FLOW model, frequently referred to as MODFLOW, first used by McDonald and Harbaugh, 1988, is a groundwater flow modelling program, for simulating confined or unconfined, saturated flow in one, two or three dimensions. This programme is based on finite difference method and is the most commonly used groundwater flow model. The source code is free, is in public domain, the software first written in Fortran, and can compile and run on Microsoft Windows or Unix-like operating systems.

The USGS in 1970s had developed several hundred models, written in different dialects of FORTRAN. At the time, it was common practice to rewrite a new model to fit the need of a new groundwater scenario. The concept for MODFLOW was originally designed in 1981 to provide a common modular groundwater model. The original name of the code was "The USGS Modular Three-Dimensional Finite-Difference Ground-Water Flow Model", or informally as "The Modular Model." The name MODFLOW was coined several years after the initial code development, which started in 1981. The first version of MODFLOW was published on December 28, 1983, and was coded entirely in FORTRAN 66.

FEFLOW; Finite Element subsurface FLOW system (Diersch 2009), GMS;groundwater modelling system (Anon 2000), Visual MODFLOW ;Visual Modular three Dimensional Flow (Anon 2000), UNCERT ;uncertainty analysis and visualization soft-ware package (Wingle et al.1999) and Pro-cessing MODFLOW for Window (PMWIN, Chiang 2005 are all numerical groundwater modelling software. Of them, MODFLW (McDonald and Harbaugh1988) was broadly used because of its simple methods, modular program structure and ease of operation.

For the 3-D groundwater flow and contaminant transport modelling Visual MODFLOW is the proven standard software. It is specifically designed to increase modelling productivity and decrease the complexities associated with modelling. It consists of three modules, that is input module, run module and output module. Visual MODFLOW is an integrated environment and intuitive interface available with the latest versions of MODFLOW, MODPATH, Zone Budget and MT3D.

1.5 GROUNDWATER MODELLING - STEPS

- Concept development

  This is the first and most important part of modelling.
- Selection of computer code for simulation

  Code is selected such that it can most specifically designed to effectively simulate the concept and purpose of modelling and decrease complexity
- Generating a new model

  It includes the necessary steps to generate a new model. Conceptual mode for the study area to be developed based on the specific details of the area.
- Definition of cell types.

  Include selection of cell types, i.e., active, inactive, constant head cell etc.

- Refining the model grid

  The grid screen provides a complete assortment of graphical tools for delineating inactive zone, refining the model grid, importing layer surface elevations, optimizing (smoothing) the grid spacing and contouring the layer surface elevations.
- Adding wells

  Includes the steps necessary to assign pumping well and observation well to the model.
- Assigning model properties

  Includes the steps necessary to design a model, with layers of highly contrasting hydraulic conductivities (horizontal and vertical), storage properties and porosity assigned to each zone.
- Assigning model boundary conditions

  Describes some of the steps required to assign the various model boundary conditions like recharge, rivers, constant head, drains etc.
- Definition of initial head.

  MODFLOW requires an initial value for the head distribution for steady state simulation and a starting head distribution for a transient simulation.
- Definition of stresses acting upon system

  This includes areal recharge, well pumpage etc.
- Model run

  Include choosing a mathematical model for solving the system of algebraic equation, iteration criteria and acceptable error criteria for terminating the iteration process.
- Calibration and sensitivity analysis

  Includes model calibration using observed water level data collected, so that model is capable of producing field measured heads and flow probably the lengthiest and most demanding part of any modelling process.

- Verification of model validity

  Calibrated model is checked against another set of field data that was not used in model design.
- Prediction

  In most cases it is the purpose of model design. The validated model was used for predicting the flow head for the next years.
- Presentation of result

  Includes both the prediction result and relevant data documenting stages of model design.

1.6 OBJECTIVES OF THE STUDY

- Develop a model to simulate the groundwater flow in the study area.
- Interpret the regional flow system using the develop model.
- To prepare the water table contour map.
- To study about particle tracking for contaminant simulations

CHAPTER 2

REVIEW OF LITERATURE

MODFLOW is most popular numerical groundwater flow modelling code which is capable of simulating confined and unconfined, steady-state or transient groundwater flow in one, two or three dimensions. It is developed by USGS (United State Geological Survey) (McDonald and Harbaugh, 1988, HarbaughMcDonald, 1996a,b) which is Modular finite-difference groundwater FLOW model, frequently referred to as MODFLOW. It is 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 area vertically into units of common hydrogeologic properties

Faunt *et al*. (2004) constructed a 3D model which is a digital HFM (hydro geological framework model). It defines the physical geometry and materials of hydrogeological units and the hydrogeological structures. Identified hydrogeological units were represented in the form of HFM. These units are about twenty five. The HFM was discretized into numerical flow model input arrays using Hydrogeological Unit Flow package of MODFLOW-2000.

Kumar and Elango (2006) developed a MODFLOW model to simulate the groundwater flow. It was used to assess the effect of a subsurface barrier in the Palar river basin, Tamil Nadu on groundwater. To meet the ever-increasing demand for groundwater by the nearby nuclear power station, a subsurface barrier or 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.

Sivakumar *et al*. (2006) developed for South Chennai coastal aquifer, a numerical model to understand the behavior of systems with varying hydrological stresses. This study stimulated the effect of increase in pumping and changes in rainfall pattern. It was carried out to develop a numerical model for the area in order to understand the behavior of the system with changes in hydrological stresses. They used the finite difference computer code MODFLOW (Modular 3-D Finite Difference Flow) with Groundwater Modelling System (GMS) as pre and post processor.

Palma *et al.* (2007) presented a regional-scale groundwater flow model for the Leon-Chinandega aquifer in Nicaragua. Groundwater flow in the acquifer was simulated using transient and steady state numerical models. In the study Visual MODFLOW a numerical groundwater flow model was used to study the groundwater flow system and the effects of groundwater developments. Model results indicated that pumping induces a decrease in base flow, depleting river discharge. This becomes critical during dry periods, when irrigation is highest. Transient modelling indices that the response time of the aquifer is about one hydrologic year, which allows the development of management strategies within short time horizons.

Wang *et al*. (2007) developed the model for North China plain (NCP) for estimating water budget and recharge rate by using MODFLOW and geographic information system. The objective of the study was 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.

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%.

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, Model calibration involved changing input parameters within reasonable limits until acceptable matches were obtained between the observed and simulated water levels for all observed hydrographsAs 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 model for the North China Plain in order to assess groundwater development potential. The model covered an area of 139,000 km^2 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.

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. 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 indicated 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.. Dispersion influenced contaminant transport in the transverse direction, while advection was the dominant transport process in the direction of flow.

Post, (2011) presented a new package, periodic boundary condition (PBC) package into MODFLOW to overcome the difficulties encountered with tidalboundaries in modelling 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 Boundary conditions are assigned to the nodes at the sediment air or sediment water interface depending on a user-defined tidal signal.

Lachaal *et al.* (2012) constructed 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 showed that calculated water levels are close to the observed values

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 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.

CHAPTER 3

MATERIALS AND METHODS

Groundwater, under most conditions is safer and more reliable for use than surface water because the surface water is more readily exposed to pollutants than groundwater. Any chemicals that are easily soluble and penetrate the soil are prime candidates for groundwater pollutants. Once it is contaminated, it is extremely difficult and costly to remove the contaminants from groundwater (Gurganus, 1993). In order to know if, and to what extent groundwater is endangered, knowledge of the changes in groundwater quality is needed.

Nowadays, a number of commercial computer software's have been developed, and numerical groundwater modelling appears to be one of the most efficient methods for groundwater transport predictions, capable of realistic handling of complex hydrogeological conditions. The main purpose of this thesis work was to set up a groundwater transport model for Nileshwar basin. The modelling was carried out with visual MODFLOW software, which is one of the most sophisticated groundwater modelling tools available today. The process of groundwater modelling has a number of stages and needs combined skills and a general knowledge of hydrogeology and process of groundwater flow and methods for testing the reliability of the developed model. A river basin is a natural integrator of all hydrological processes, pertaining to its boundaries and may be considered as the physical unit for planning optimum development of land and water resources. Nileshwar river basin is taken as study area for this research work and the materials and methods adopted for the study are briefly discussed in this chapter.

3.1 GENERAL FEATURES OF THE STUDY AREA

The present study has been carried out in the northern part of Kerala state, India. Though Kozhikode, Malappuram, Wayanad, Kannur and Kasargod are the drought prone districts of northern Kerala, Kasargod is the worst hit district. Hence this district was considered for the study. It is a well known fact that the water resources studies should be carried out with drainage basins or watersheds as the unit for better understanding of the hydrologic system and for accurate quantitative estimation of the resources. It is in this context, this project has been carried out in a representative river basin namely Nileshwar of Kasargod District. The drainage area of Nileshwar is about 190 sq. kms. All the three physiographic regions, such as highland, midland and lowland of Kerala are represented in this drainage basins.

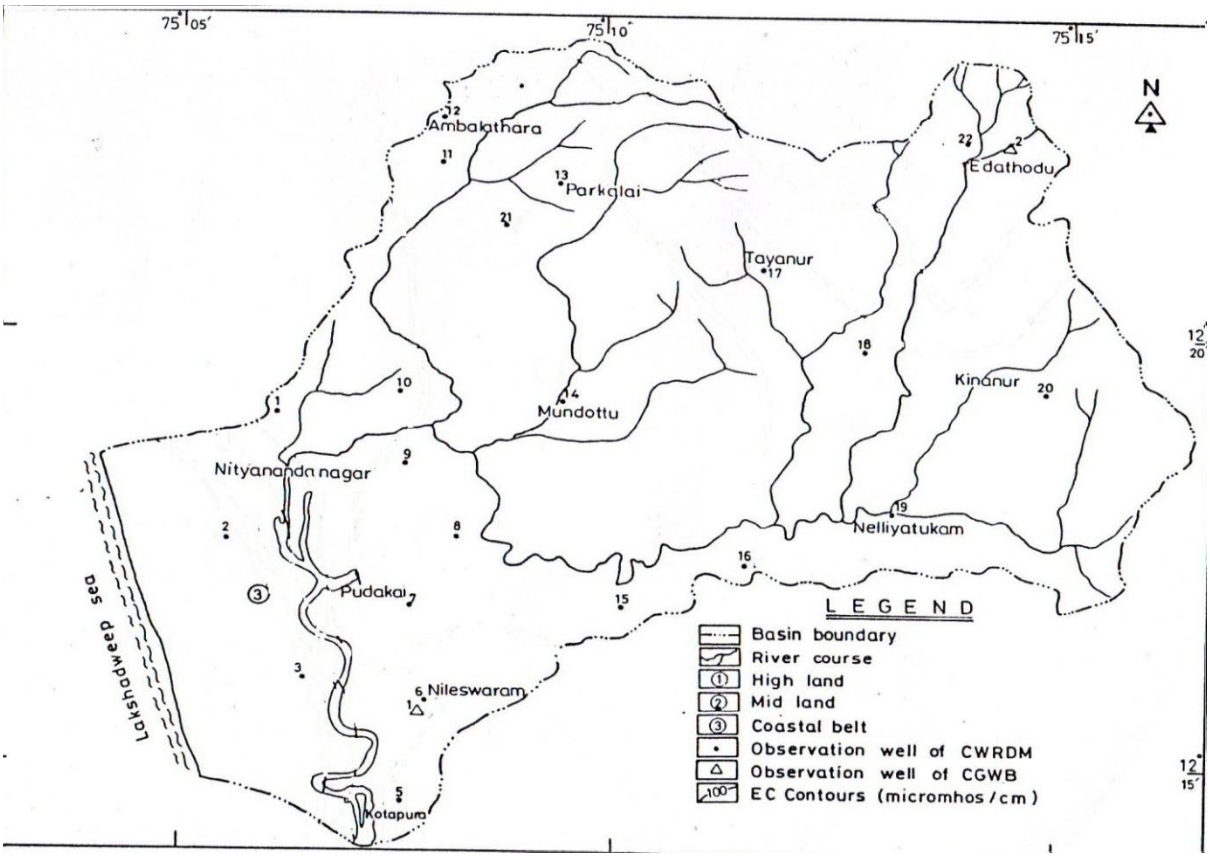


Fig. 3.1: Study area under Nileshwar river basin

3.1.1 GEOGRAPHICAL LOCATION

The Nileshwar river basin of Kerala state, India, has a drainage area of 190 sq. km. and lies between north latitudes 12˚ 13' and 12˚ 23' and east longitudes 75˚ 05' and 75˚ 17'. The river originates from Kinannur in Hosdurg Taluk at an elevation of 140 m above MSL. Though the origin of the river is at 140 m above MSL, the river bed falls rapidly to 15 m above MSL within a short distance of 8 km. The length of the river is 46 km in which the last 10 km experiences tidal effect (PWD, 1974). The Nileshwar river joins the Karingotte river which in turn joins the Lakshadweep sea. The entire basin area falls under the Kasargod district.

3.1.2 PHYSIOGRAPHY

Physiographically the basin has been divided into three units namely the coastal belt or lowland in the west (between MSL and 7.5 m above MSL), the midland region in the central portion (between 7.5 m and 75 m above MSL) and the highland in the east, comprising the foot hill and hill ranges of western ghats (more than 75 m above MSL).

3.1.3 RAINFALL

The average annual rainfall for the Nileshwar basin is 3,600 mm (CWRDM, 1995). The south-west monsoon (June- August) contributes 65% and the north-east monsoon (September-November) contributes 25% of the annual rainfall. During April-May, 10% of the annual rainfall is received as pre-monsoon showers. December and January- March are the almost rainless months. The normal (long term average) rainfall during monsoon (June- September) and non-monsoon (October- May) seasons for Nileshwar basin can be considered to be 2800mm and 800mm respectively.

Although the annual normal rainfall is very high, a major portion of it is confined to only 3-4 months in a year leaving the rest of the year particularly dry. Also, deflects of more than 20% from the normal values especially for the North-East monsoon, or its early cessation, or the late onset of the South-West monsoon do create very extended dry summer period during which drought conditions prevail. In areas where the predominant crops are annual in character, the effect of drought during a particular year is confined only to that year. However in case of perennial crops (as in the study area), the effect of drought in a particular year continues to be felt several years after it, although the rainfall in those years may be normal

3.1.4 STUDY BOUNDARIES

The study area is part of the Nileshwar river catchment. The study area is bounded by Lakshadweep sea in the west and all other sides by no distinct land feature topography or geological structure

3.1.5 TOPOGRAPHY

The Nileshwar basin exhibits undulating topography with steep slopes. The basin has been classified as lowland, midland and highland. however there are small hill rocks, 100 to 200 m above MSL are present in the midland region. In Nileshwar basin the ground elevation ranges between MSL to 400 m above MSL within the basin
length of 20 km. It has been determined that about 60% of the area in the basin falls within the ground elevation of 100 m above MSL

3.1.6 HYDROGEOLOGY OF THE STUDY AREA

The subsurface strata in the study area consist mainly of metamorphic origin. The principal formation of the Nileshwar basin includes red soil, lateritic soil, clay, weathered rock, hard rock and sandy soil. The thicknesses of the various layers vary spatially in different regions of the study area according to the topography and elevation of the area. The red soil and lateritic soils are present in the high elevation part only, whereas sandy soil is the only layer in the low lying coastal areas in the western part of the study area. The details of geology of the soil and its hydraulic conductivity used are given in Table 1

Table 1 Hydrogeology of the study area

layers	Soil type	Hydraulic conductivity
Layer1	Red soil	51.84 m/day
Layer2	Lateritic soil	3.25 m/day
Layer3	Clay	0.0000864 m/day
Layer4	Weathered rock	2.39 m/day
Layer5	Hard rock	0.0000001 m/day
Layer5	Sandy soil	4.32 m/day

3.1.8 SOILS

The different types of soils which occur in this river basin are Red soil, lateritic soil, Clay soil, sandy soil.

Red soil

Red soil is a type of soil that develops in a warm, temperate, moist climate under deciduous or mixed forests. That have thin organic and organic-mineral layers overlying a yellowish-brown leached layer resting on an illuvial (see illuviation) red layer. Red soils generally derived from crystalline rock. They are usually poor growing soils, low in nutrients and humus and difficult to cultivate because of its low water holding capacity. Red soils denote the third largest soil group of India covering an area of about 3.5 lakhs sq. km (10.6% of India's area.

Lateritic soil

The lateritic soil is a weathered product derived under humid tropical conditions. This soil is acidic and poor in nitrogen, phosphorous, potash and organic matter. It is well drained, widely cultivated and responds to agricultural management practices. The pH of the soil ranges from 5 to 6

Clay

Clay is a fine-grained natural rock or soil material that combines one or more clay minerals with traces of metal oxides and organic matter. Clays are plastic due to their water content and become hard, brittle and non–plastic upon drying or firing . Geologic clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure.

Sandy soils

Sandy soils are granular soils that contain small rock and mineral particles. The texture of sandy soils is usually gritty Sandy soils have a higher proportion of sand than clay, drain quickly, warm up faster in spring and are usually easier to work. The red color indicates the presence of iron. Sandy soils are often acidic and have fewer nutrients than clay, loam or peat soils.

3.2 DETAILED METHODOLOGY

The model was developed using VISUAL MODFLOW2.8. Microsoft Excel was 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
- Recharge
- Surface elevation
- Bottom elevation
- Grid
- River conductance
- River bottom and stage
- Groundwater pumping

3.3 CONCEPTUAL MODEL

A conceptual model is a hypothesis for how a system or process operates. This hypothesis can be expressed quantitatively as a mathematical model. Mathematical models are abstractions that represent processes as equations, physical properties as constants or coefficient in equation measures of state or potential in the system as variables.

Most groundwater models in use today are deterministic mathematical models. Deterministic models are based on conservation of mass, momentum, and energy and describe cause and effect relations. The underlying assumption is that given a high degree of understanding of the processes by which stresses on a system produce subsequent responses in that system, the system's response to any set of stresses can be predetermined, even if the magnitude of the new stresses falls outside of the range of historically observed stresses. Deterministic groundwater models generally require the solution of partial differential equations. Exact solutions can often be obtained analytically, but analytical models require that the parameters and boundaries be highly idealized.

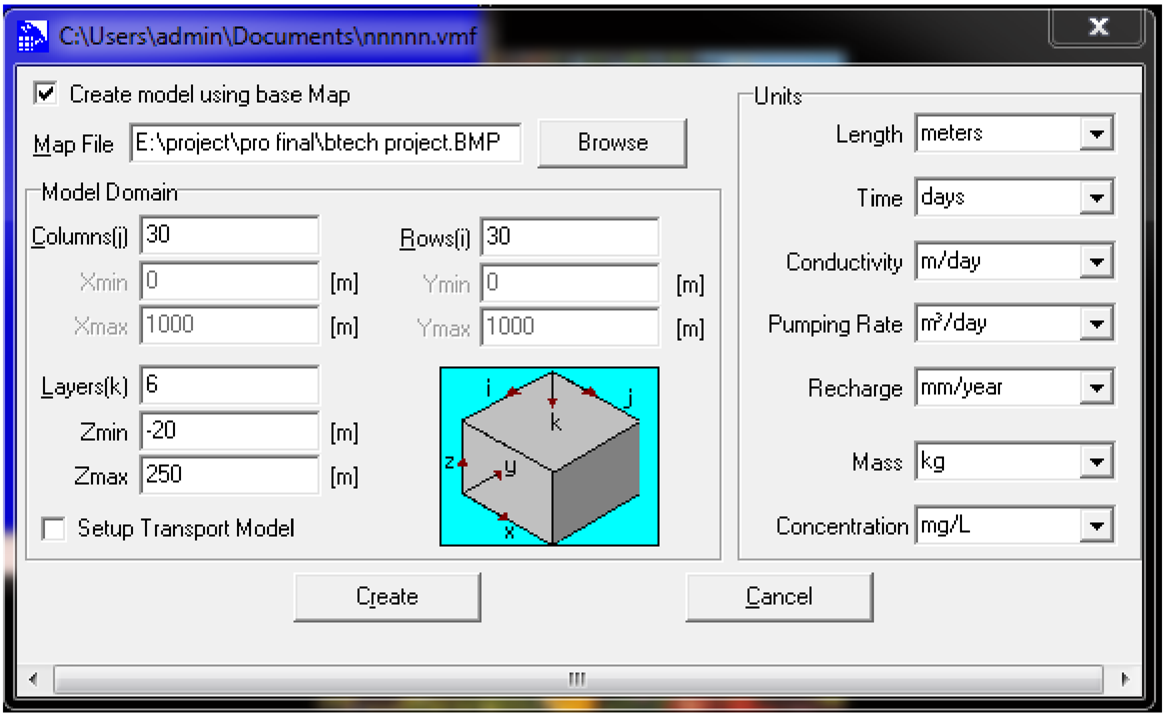
3.4 MODFLOW INPUT

3.4.1 CREATING THE MODEL

Visual MODFLOW supports the use of base maps in all modules of the program. Raster map of Nileswaram river basin obtained from CWRDM was used to prepare the base map and was converted into BMP format. Base map was imported into the model screen as shown in Fig.3.2 and it was georeferenced using georeferencing option of MODFLOW software. To construct the model the study area was divided into finite difference cells, which have constant size of 30m x 30m. In the vertical direction, 6 groundwater layers were represented. In Visual MODFLOW 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.

3.4.2 DISCRETIZATION OF THE BASIN

The model is based on a rectangular block-centred grid network covering the entire model domain. This cell size was chosen in order to avoid any type of interpolation when importing the topographic map. The study area was discretised by dividing it into 30 rows and 30 columns.



C:\Users\admin\Documents\nnnnn.vmf

☑ Create model using base Map

Map File: E:\project\pro final\btech project.BMP

Model Domain

Columns(j): 30
Rows(i): 30
Xmin: 0 [m]
Xmax: 1000 [m]
Ymin: 0 [m]
Ymax: 1000 [m]
Layers(k): 6
Zmin: -20 [m]
Zmax: 250 [m]

☐ Setup Transport Model

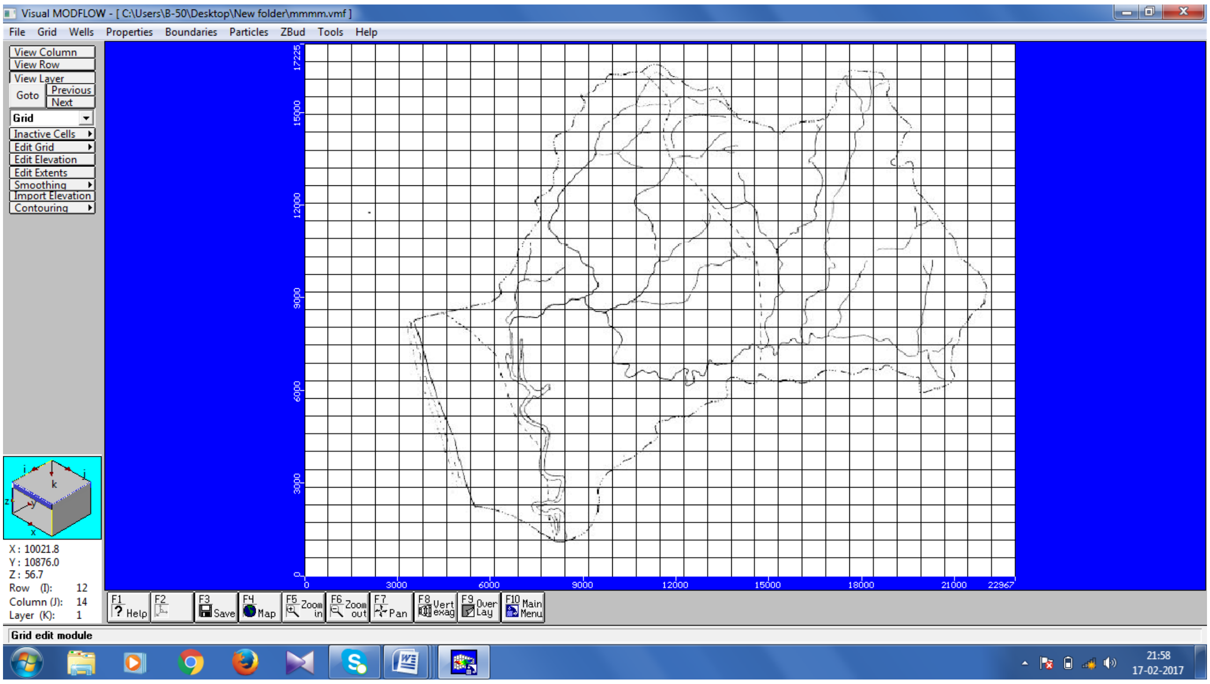
Units

Length: meters
Time: days
Conductivity: m/day
Pumping Rate: m^3/day
Recharge: mm/year
Mass: kg
Concentration: mg/L

Fig.3.2 Model creation

Table 2 Model configuration

CHARACTERISTICS	VALUE
Maximum model elevation	**250 m**
Minimum model elevation	**-20 m**
Layers	**6**
Rows	**30**
Columns	**30**

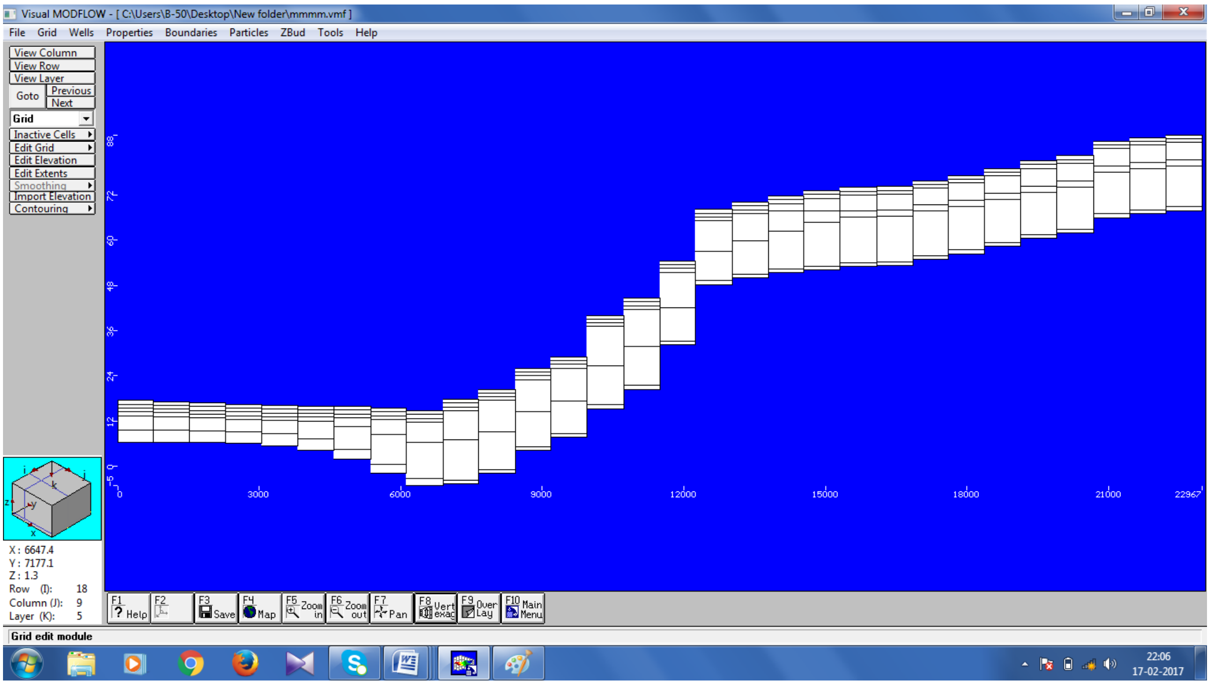


X : 10021.8
Y : 10876.0
Z : 56.7
Row (I): 12
Column (J): 14
Layer (K): 1

Fig. 3.3: Grid formations to the study area

3.4.3 IMPORTING ELEVATION

The model surface elevation values are imported as ASCII and is given in Appendix

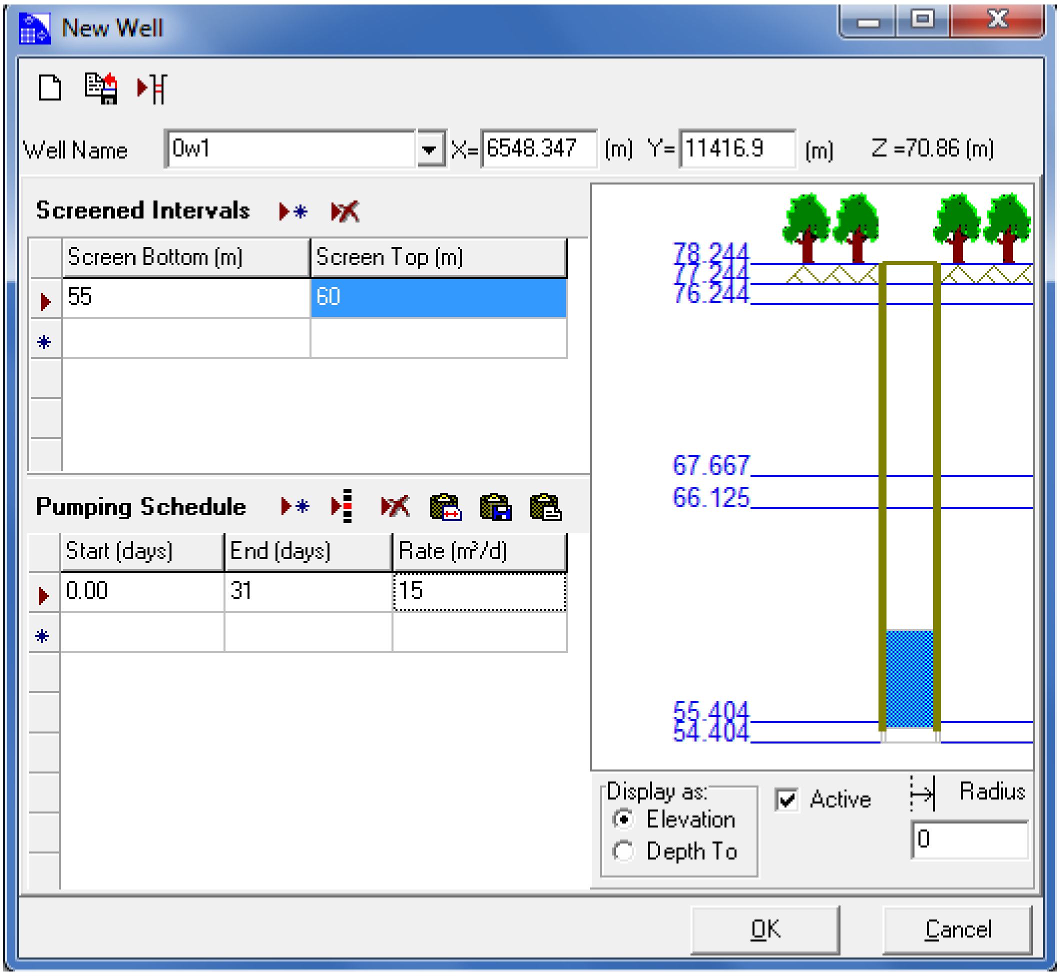


X : 6647.4
Y : 7177.1
Z : 1.3
Row (I): 18
Column (J): 9
Layer (K): 5

Fig. 3.4: Cross section of imported elevation

3.4.4 ADDING WELLS

Visual MODFLOW permits to input field observations of pumping rate and watertable observations from observation wells to get model output values. Thus, the coordinates and calculated groundwater potential were imported into MODFLOW. The observation well data are given as a table in Appendix II. . From the well drop-down menu of the software we can choose to graphically add, delete, move or edit pumping wells and head observation wells.



Well Name Ow1 X= 6548.347 (m) Y= 11416.9 (m) Z =70.86 (m)

Screen Bottom (m)	Screen Top (m)
55	60

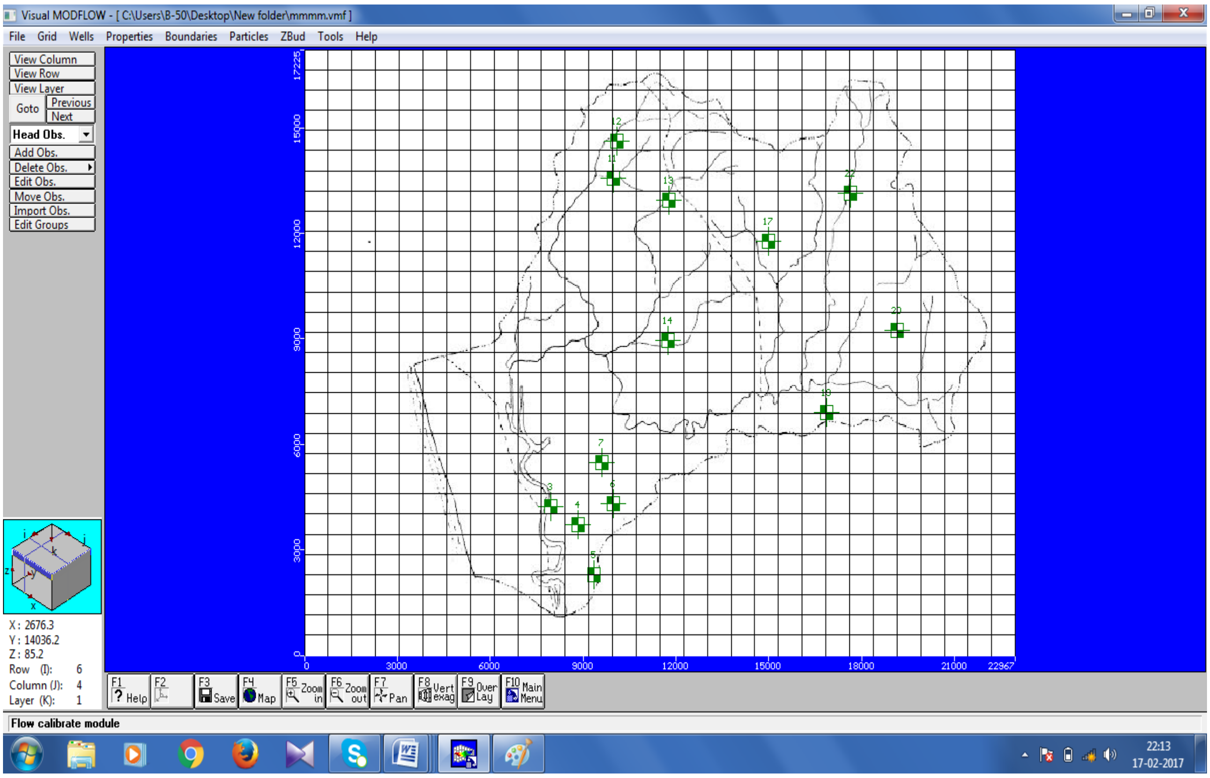
Start (days)	End (days)	Rate (m^3/d)
0.00	31	15

Display as: ● Elevation ○ Depth To

☑ Active

Radius 0

Fig.3.5 Observation well add module



Visual MODFLOW - [C:\Users\B-50\Desktop\New folder\mmmm.vmf]

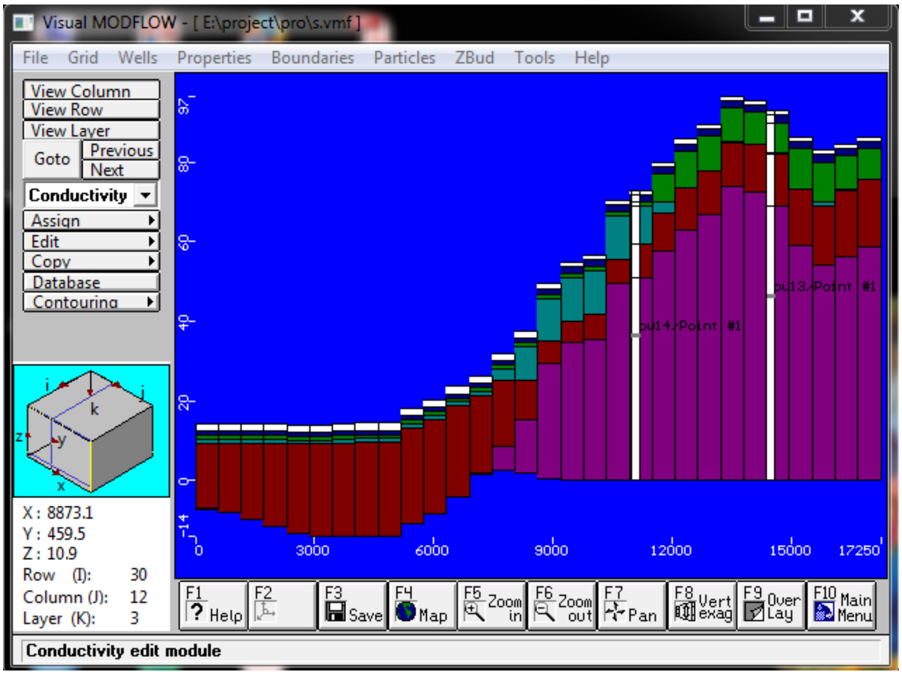
X: 2676.3
Y: 14036.2
Z: 85.2
Row (I): 6
Column (J): 4
Layer (K): 1

Flow calibrate module

Fig. 3.6 Adding wells

3.4.5 ADDING PROPERTIES

The hydraulic conductivity values for different layers are at different colours.



Visual MODFLOW - [E:\project\pro\s.vmf]

X: 8873.1
Y: 459.5
Z: 10.9
Row (I): 30
Column (J): 12
Layer (K): 3

Conductivity edit module

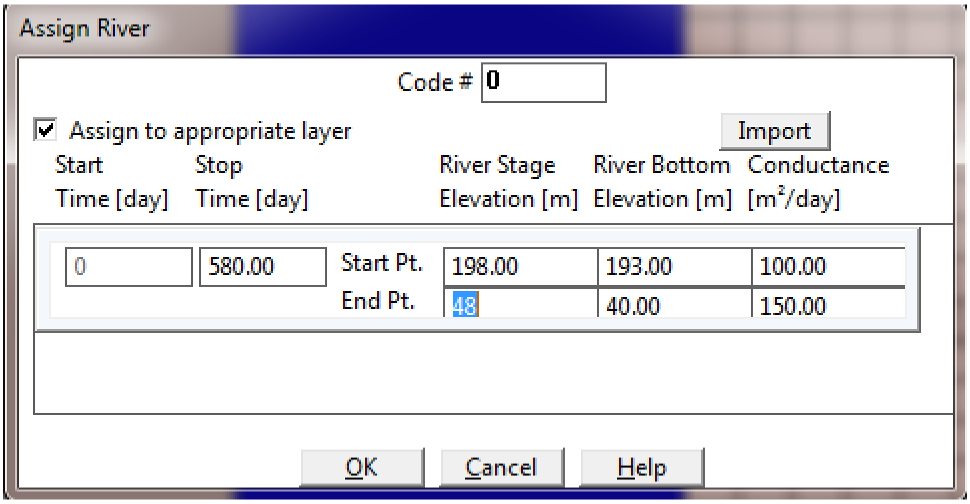
Fig.3.7Adding properties

3.4.6 ADDING BOUNDARIES

The boundary conditions of any model must represent the systems relationship with the surrounding areas. MODFLOW model needs boundary conditions of the model domain which includes constant head, rivers, drains and recharge boundary conditions.

- **Rivers**

The river boundary condition is used to simulate the influence of a surface water body on the groundwater flow. As our study area is large, we have selected locations having different river stage elevations. The river conductivity values for the different locations are entered in fig 3.8.



Assign River

Code # 0

☑ Assign to appropriate layer

Start Time [day]	Stop Time [day]		River Stage Elevation [m]	River Bottom Elevation [m]	Conductance [m^2/day]
0	580.00	Start Pt.	198.00	193.00	100.00
		End Pt.	48	40.00	150.00

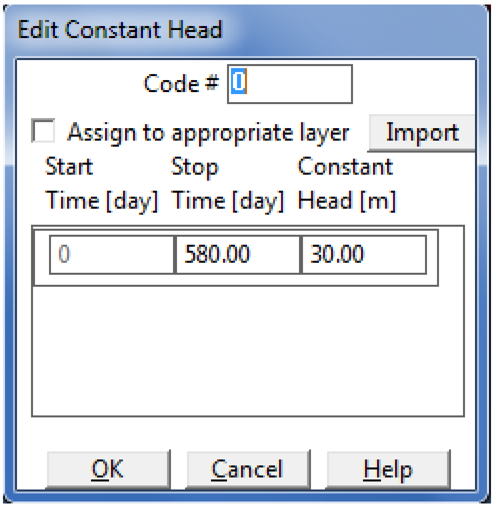
Fig.3.8 Assigning river boundaries

- **Drains**

Visual MODFLOW is designed to simulate the effects of agricultural drains which remove water from the aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or elevation of the drain.

- **Constant head**

The west boundary is considered as constant head boundary. While entering the data, the start point and the end point are given as 3.9



Code # 0

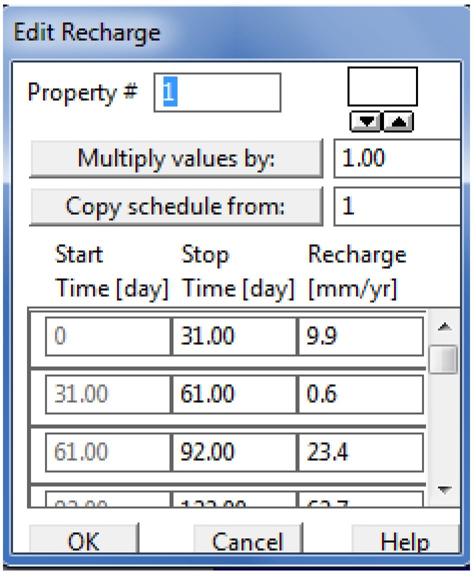
☐ Assign to appropriate layer

Start Time [day]	Stop Time [day]	Constant Head [m]
0	580.00	30.00

Fig.3.9 Assign constant head

- **Recharge**

The recharge package is designed to simulate aerial distributed recharge to the groundwater system. Most commonly, aerial recharge occurs as a result of precipitation that percolates into the groundwater system. Recharge can only be the input for the top layer, ie, layer 1. There is no need to allow recharge to occur simultaneously at multiple depths in the same vertical column because natural recharge enters the groundwater system at the ground surface. The recharge data are given in Appendix III.



Property # 1

Multiply values by: 1.00

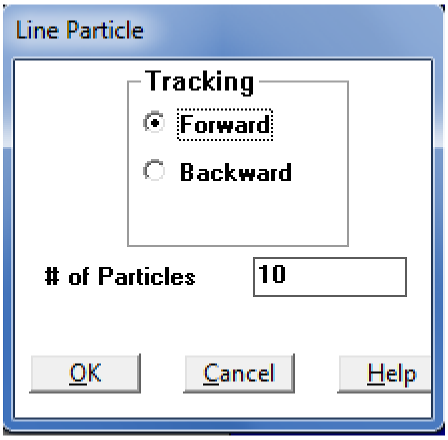
Copy schedule from: 1

Start Time [day]	Stop Time [day]	Recharge [mm/yr]
0	31.00	9.9
31.00	61.00	0.6
61.00	92.00	23.4

Fig. 3.10 Assign recharge

3.5.7 PARTICLE ASSIGNING

Assigning some forward tracking particle in the vicinity of well to determine the preferred migration pathway of groundwater plume



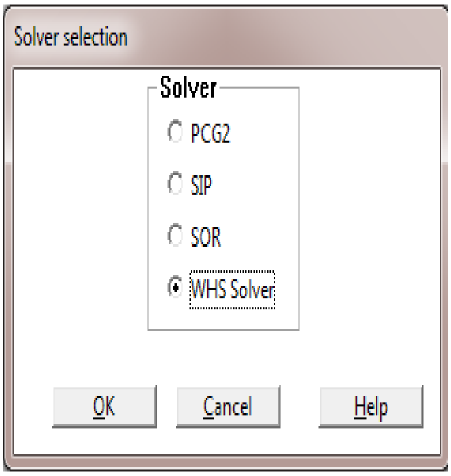
Tracking
● Forward
○ Backward

# of Particles 10

Fig.3.11 Assigning particles

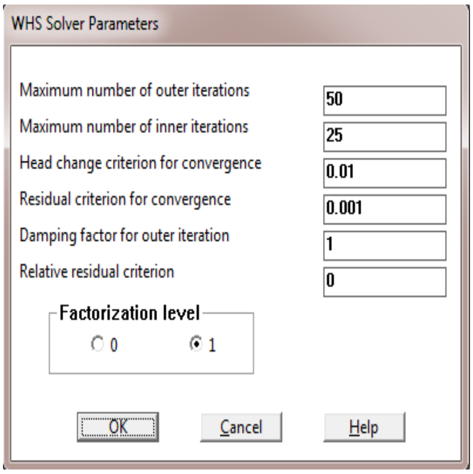
3.5.8. MODFLOW RUN

After completing the input parameters, model run is selected from the screen. By selecting [**Run**] in the Main Menu, Select Run Type dialog box appears. Steady state and transient state run types are available in the model. The model was run for steady state condition. WHS solver was selected. Initial head options, recharge options, WHS Solver parameters, anisotropic factor, layer type and rewetting options are shown below


Solver selection

Solver
- ○ PCG2
- ○ SIP
- ○ SOR
- ● WHS Solver

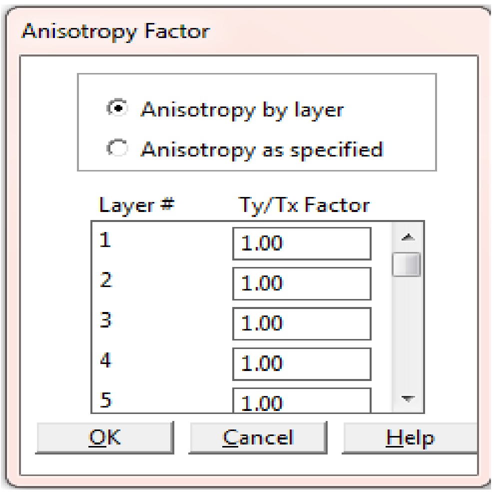
Fig 3.12: Solver selection


WHS Solver Parameters

Maximum number of outer iterations	50
Maximum number of inner iterations	25
Head change criterion for convergence	0.01
Residual criterion for convergence	0.001
Damping factor for outer iteration	1
Relative residual criterion	0

Factorization level: ○ 0 ● 1

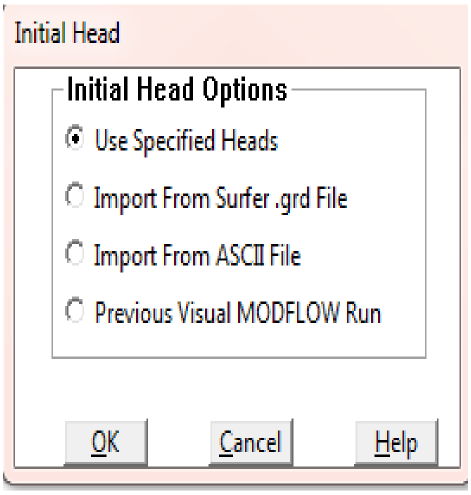
Fig 3.13: WHS Solver parameter


Anisotropy Factor

- ● Anisotropy by layer
- ○ Anisotropy as specified

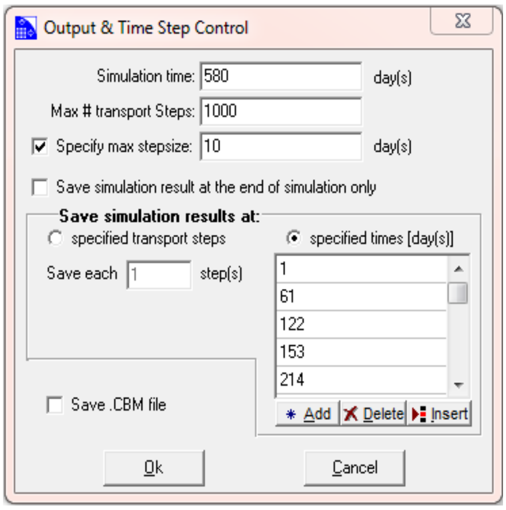
Layer #	Ty/Tx Factor
1	1.00
2	1.00
3	1.00
4	1.00
5	1.00

Fig. 3.14: Anisotropy factor


Initial Head

Initial Head Options
- ● Use Specified Heads
- ○ Import From Surfer .grd File
- ○ Import From ASCII File
- ○ Previous Visual MODFLOW Run

Fig.3.15: Initial head



Simulation time: 580 day(s)

Max # transport Steps: 1000

☑ Specify max stepsize: 10 day(s)

☐ Save simulation result at the end of simulation only

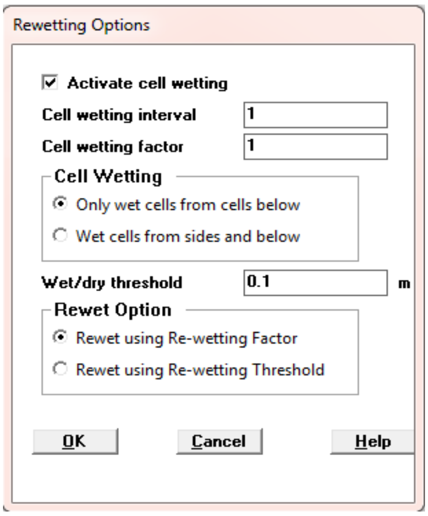
Save simulation results at:

○ specified transport steps ● specified times [day(s)]

Save each 1 step(s)

1
61
122
153
214

☐ Save .CBM file



☑ **Activate cell wetting**

Cell wetting interval 1

Cell wetting factor 1

Cell Wetting

● Only wet cells from cells below

○ Wet cells from sides and below

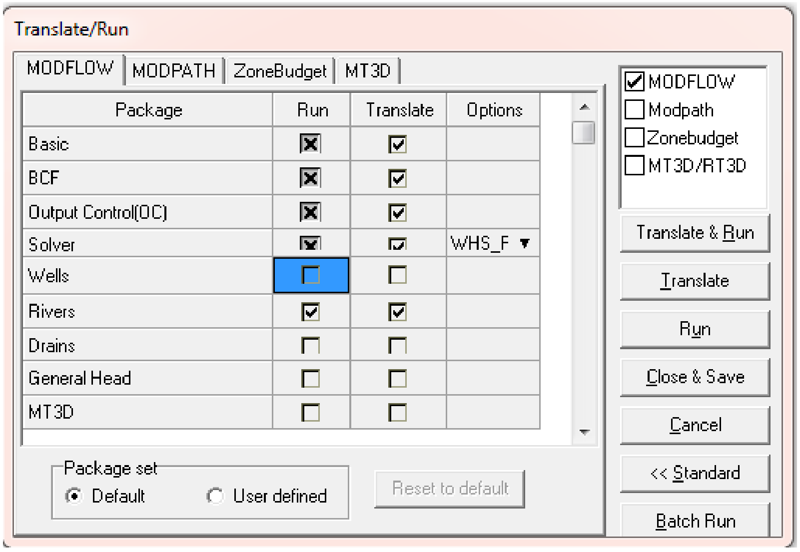
Wet/dry threshold 0.1 **m**

Rewet Option

● Rewet using Re-wetting Factor

○ Rewet using Re-wetting Threshold

Fig 3.16: Output & Time step control **Fig 3.17: Rewetting options**



Package	Run	Translate	Options
Basic	☒	☑	
BCF	☒	☑	
Output Control(OC)	☒	☑	
Solver	☒	☑	WHS_F ▼
Wells	☐	☐	
Rivers	☑	☑	
Drains	☐	☐	
General Head	☐	☐	
MT3D	☐	☐	

☑ MODFLOW
☐ Modpath
☐ Zonebudget
☐ MT3D/RT3D

Package set: ● Default ○ User defined

Fig 3.18: Translate and run MODFLOW

3.5.9. MODFLOW CALIBRATION

The model was then calibrated using the observation well data collected from CWRDM, Calicut, so that the model is capable of producing the observed heads and flow. The model was calibrated by systematically adjusting values of parameters like hydraulic conductivity, specific yield and specific storage of the geological formations and the river conductance to achieve an acceptable match between the computed and observed values of the water table.

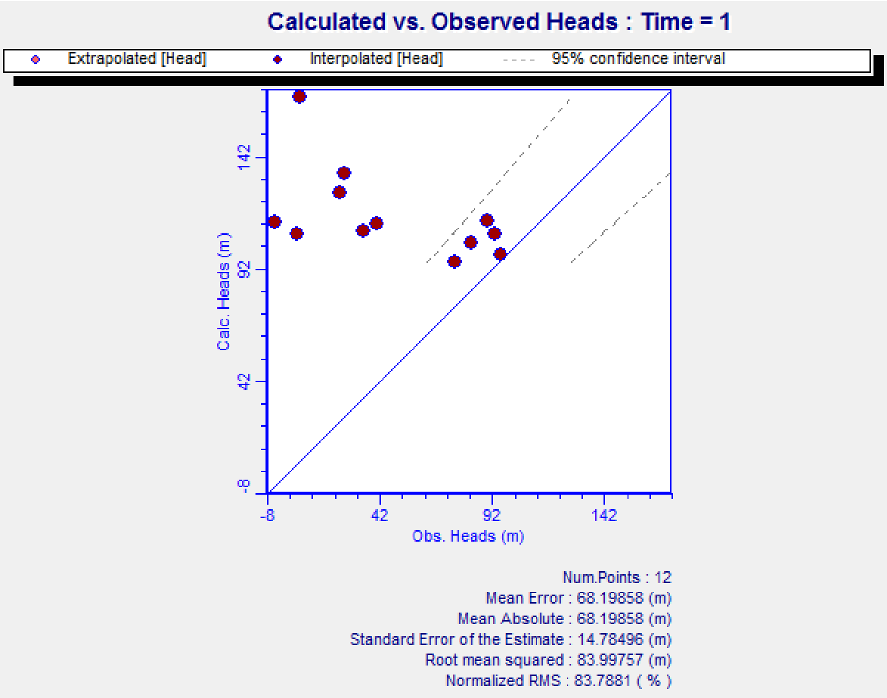
CHAPTER IV

RESULTS AND DISCUSSIONS

The study area, Nileshwar and its nearby locality, was found to be under the threat of an acute groundwater crisis. The study was mainly intended to identify the characteristics of groundwater fluctuations by groundwater modelling using MODFLOW 2.8.1 and also to develop a particle tracking model for the study area. 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.

4.1 FLOW MODELLING

MODFLOW output provides contours of head equipotentials, head difference, drawdown, elevation, net recharge and water table. It also provides graphs of calculated Vs observed heads, calibration of residual histogram etc. Model output also provides velocity vectors with direction of flow. The scatter plot for computed Vs observed head for selected 12 observation wells before calibration is shown in figure 4.1.

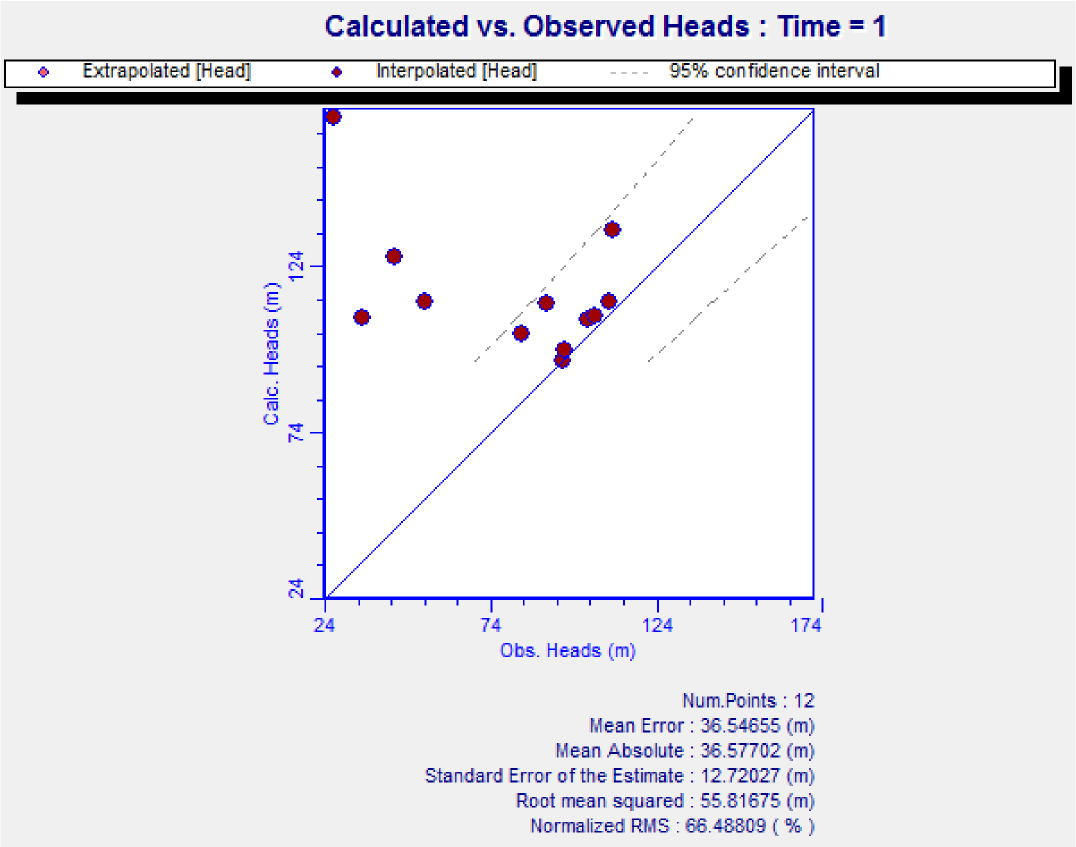


Num.Points : 12
Mean Error : 68.19858 (m)
Mean Absolute : 68.19858 (m)
Standard Error of the Estimate : 14.78496 (m)
Root mean squared : 83.99757 (m)
Normalized RMS : 83.7881 (%)

Fig.4.1 Model calculated Vs Observed water level

4.1.1 Calibration

The model was calibrated for steady state conditions. 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 parameter. 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 were adjusted in sequential model runs to match the simulated heads and measured heads. The scatter plot for computed Vs observed head for selected 12 observation wells are shown in figure 4.2. This figure indicated that there is a good agreement between the calculated and observed water levels in most of the wells. The error obtained during model run was minimized by calibration.



Num.Points : 12
Mean Error : 36.54655 (m)
Mean Absolute : 36.57702 (m)
Standard Error of the Estimate : 12.72027 (m)
Root mean squared : 55.81675 (m)
Normalized RMS : 66.48809 (%)

Fig.4.2 Calibration plot

4.1.2 Model Validation

Following calibration, the groundwater flow model needs to be validated. This is accomplished by testing the system with data, which are not used for calibration. For this study purpose 12wells were selected in the study area and water level data was collected for three seasons of the year 1997. The model is validated with the year 1997 water level data. The scatter plot for computed Vs observed head for selected 12 observation wells for the year 1997 is shown in figure 4.3. The water table contours and velocity vectors of groundwater flow after calibration is given in Fig 4.4 and Fig 4.5 respectively. In our study, we have observed that the water table values of the validated model were matching with the observed values (Fig. 4.4 and Table. 3). In the velocity vectors of groundwater flow (Fig. 4.5) we can observe a sink located almost at the centre of the southern boundary of the study area.

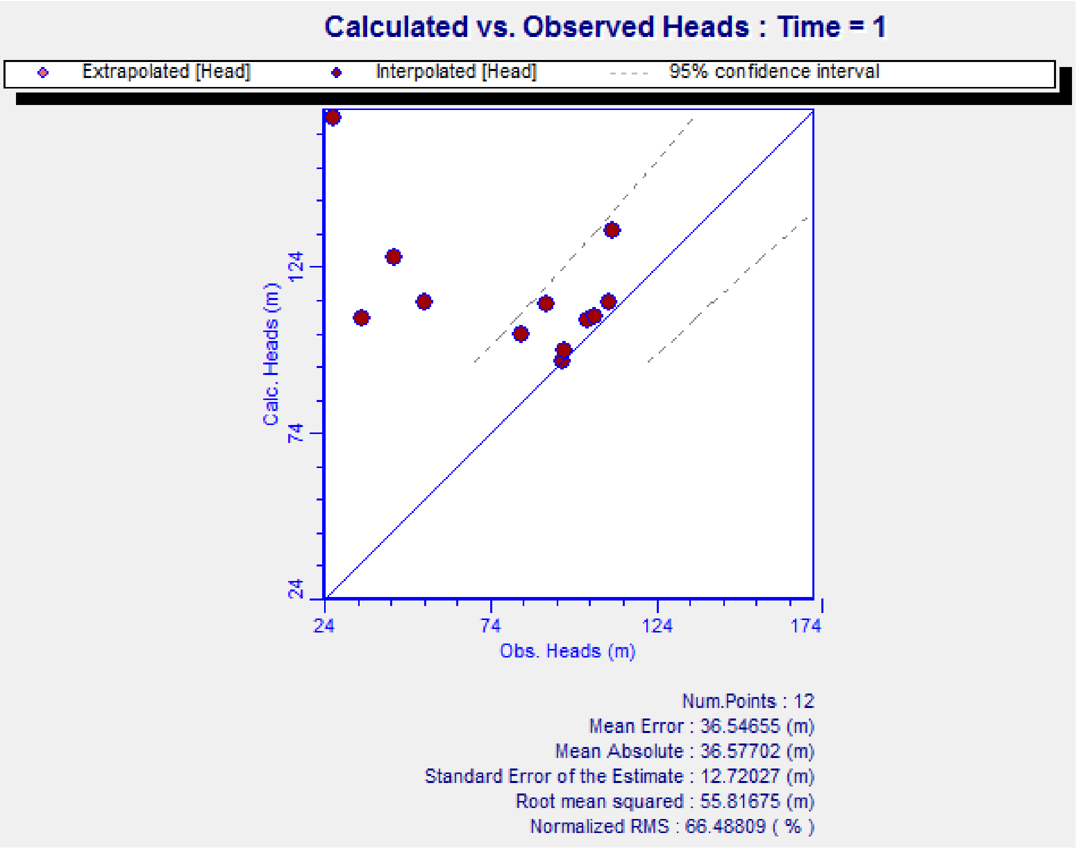


Fig.4.3 Calculated Vs observed head for the year 1997

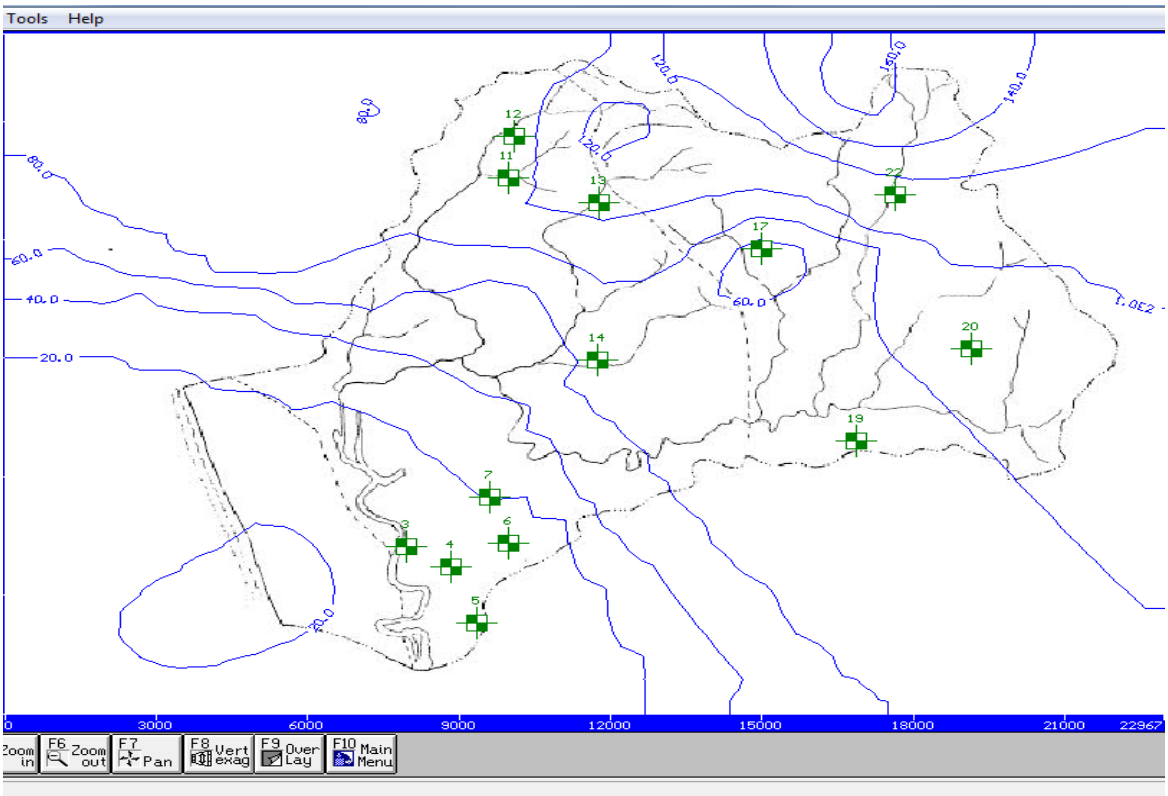
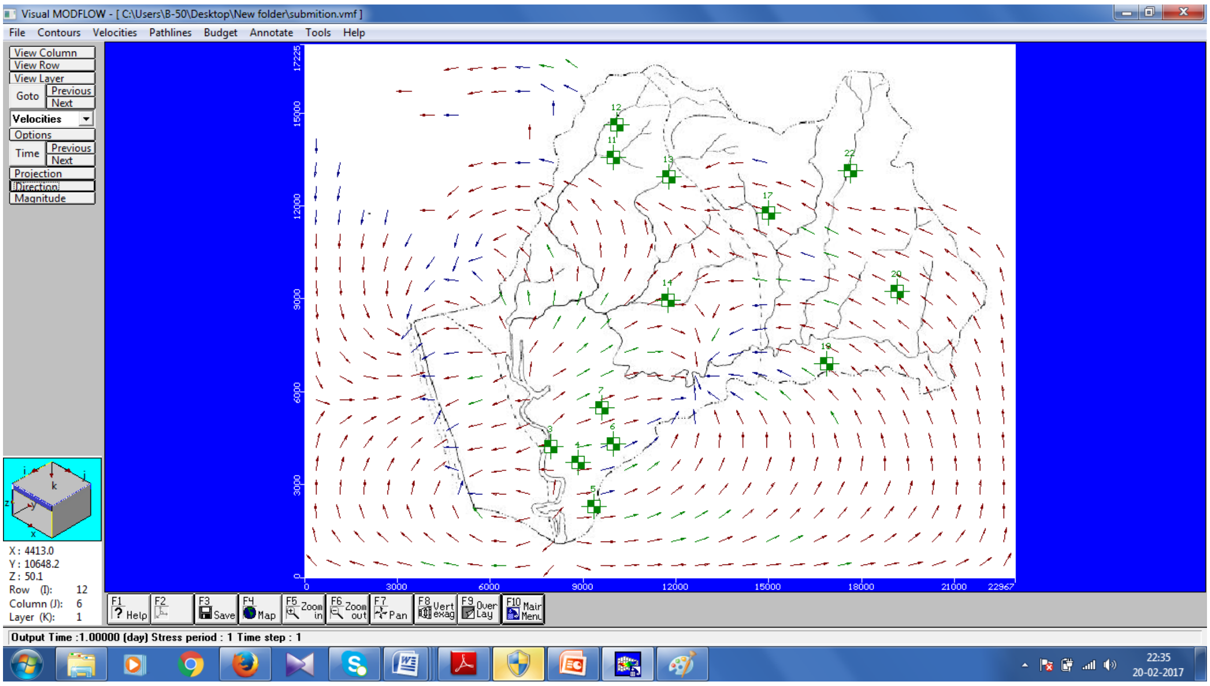


Fig.4.4 Location of observation well and water table contours


Visual MODFLOW - [C:\Users\B-50\Desktop\New folder\submition.vmf]

X : 4413.0
Y : 10648.2
Z : 50.1
Row (I): 12
Column (J): 6
Layer (K): 1

Output Time :1.00000 (day) Stress period : 1 Time step : 1

Fig.4.5 Velocity vector of groundwater flow

Table 3 Water level and location of observation well

Well name	X (m)	Y (m)	Water level (m)
Ow3	7971.9	4242.19	26.02
Ow4	8854.5	3729.71	25.31
Ow20	19161	9224.63	90.12

4.1.3 Model Prediction

The reliable prediction of the water table is possible only if a validated model is available. From the available validated model, we had predicted the water table values of the next two years by adding 730 more days in the output and time steps of **[Run].** From our study, we had observed that there is no appreciable change in the water table of the study area for the next two years.

4.2 PARTICLE TRACKING

MODPATH was used to conduct a forward particle tracking study. In forward particle tracking, the particles are released at the water source (e.g. point of groundwater recharge) and collected at cells such as drains. These sink cells could be either weak, meaning they can only discharge a portion of water entering the cell, or strong, meaning they discharge all groundwater reaching them. Migration pathway of groundwater plume was studied. As time increases the particle can travel more distance as shown in fig.4.6 and 4.7 along the direction of groundwater flow.

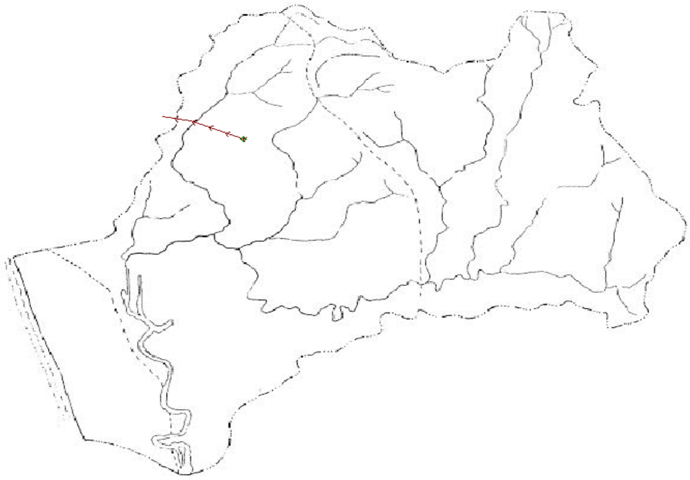


Fig.4.6 Location of particle after 400 days

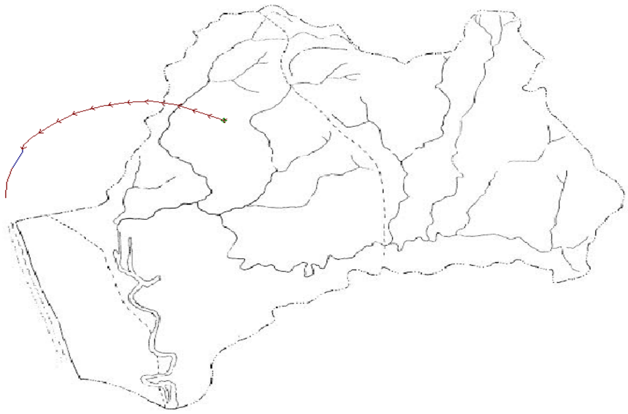


Fig 4.7Location of particle after 600 days

A source of contamination is assumed to be placed near to water supply well (ow 11) to study the effectiveness of using pumping wells to remove the contamination. First a pumping well (pw 1) is placed at the location shown in Fig. 4.8 and the particle tracking study is done. From Fig. 4.8 it can be seen that the pumping well has no effect in capturing the contaminated water and it flows in the direction of the supply well and reaches the well after 365 days. As a second trial a second pumping well (pw 2) was placed as shown in Fig. 4.9. It can be seen from Fig. 4.9, that, the flow from the source of contamination flows only up to the new pumping well, even after 365 days. So the pw 2 can be effectively used for the removal of the contaminants. So if the pumping well is placed in the direction of flow it will capture all the contaminants before it reaches the supply well within 365 days as shown in fig.4.9

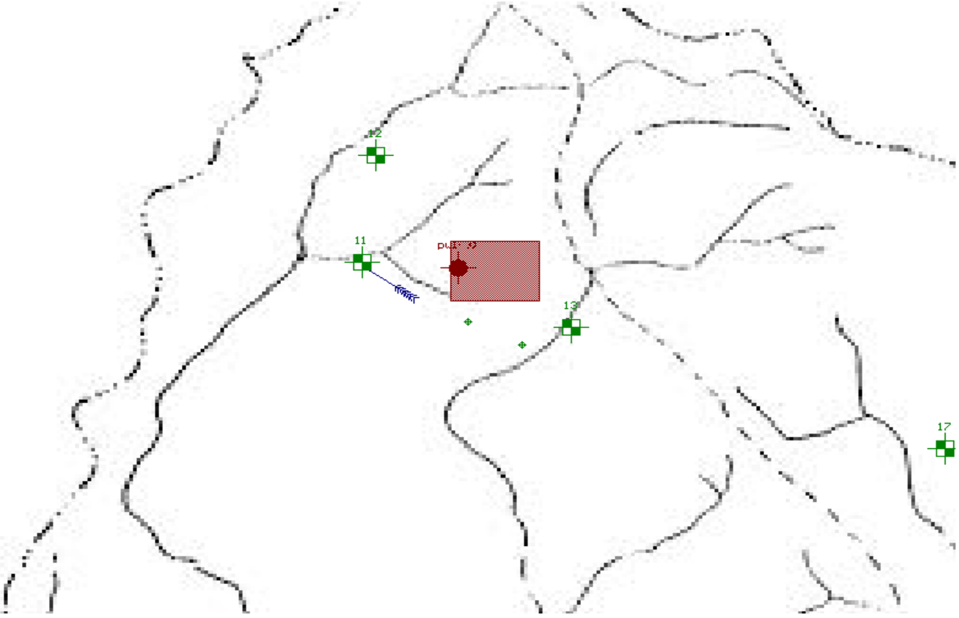


Fig.4.8 Effect of pumping well pw 1

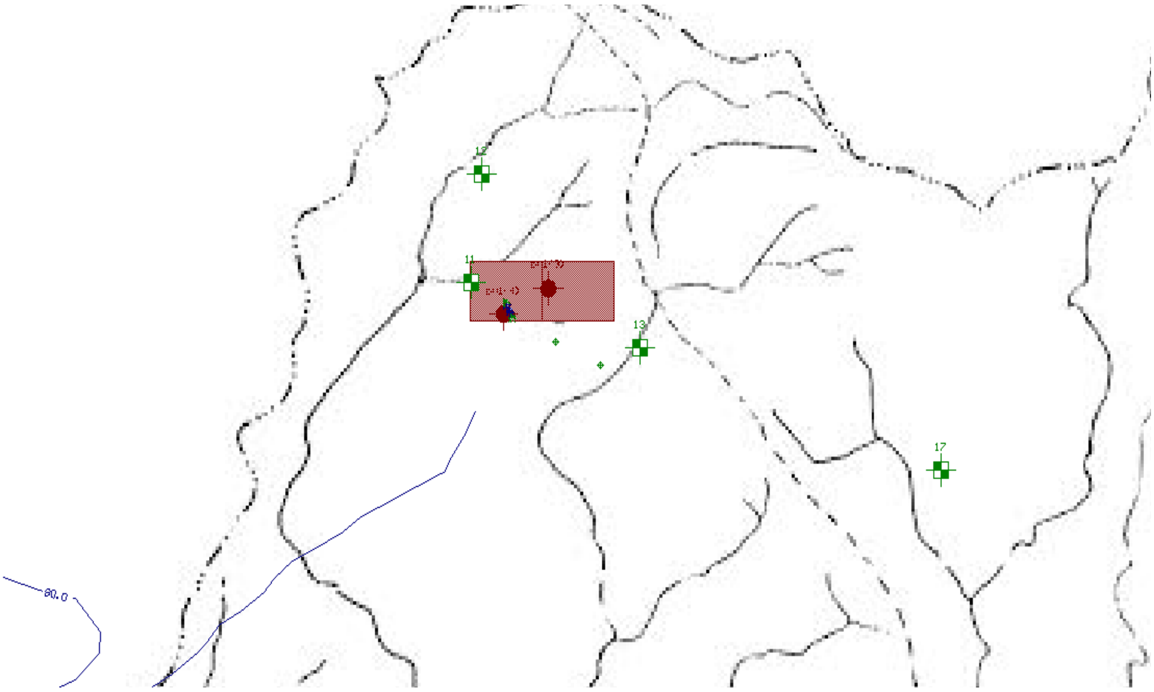


Fig.4.9 Effect of pw2 over pw1

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

Computer simulation modelling plays a vital role in water quality studies. Simulation models are capable of providing an objective evaluation of the consequences of future growth and pollution control measures. Therefore, simulation models are essential tools for water quality studies for urban, rural and industrial planning and decision making. As design of groundwater extraction system for mining, groundwater remediation etc. groundwater models have been used. 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. Models are also used for many engineering applications. Groundwater models are computer models of groundwater flow systems, and are used by hydro geologists. Groundwater models are used to simulate and predict aquifer conditions. It consists of two components, a conceptual model, and a graphical presentation of hydrogeological setting and the mathematical model. 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 six layers. The water table contour map and groundwater flow velocity, its direction and magnitudes were obtained by the simulation. The various wells under study are marked in the map. Three years (1995-1997) monthly rainfall and river flow have been used in the study. The particle tracking is analysed by this map also effect of pumping well to remove particle if any oil spill is occurred in a region.

5.2 CONCLUSIONS

A steady state groundwater model has been developed by using Visual MODFLOW 2.8.1. The model water balance was calculated. The input parameters were taken from previous studies done by CWRDM. In this approach, the distributed recharge, wells, vertical and horizontal hydraulic conductivity of the six layers, constant head and river boundary conditions were the inputs to the groundwater system.

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. In this study we had done the calibration, validation and prediction of the model and obtained the output. The output model can be used for further groundwater modelling studies.

By considering this map as base we study about the migration of particle,if an oil spill occurred in any location.we analyse that the particle migrate on the direction of groundwater flow as time increases it contaminate more groundwater. In this study we could understand appropriate location of pumping well to capture all the particle before it reach at the water sources.

From the study, it can be concluded that MODFLOW and MODPATH are very powerful and extensive groundwater modelling softwares. But they have to be adapted, which is not always obvious due to lack of information about different parameters. In the present study the results are satisfactory and a realistic groundwater flow model and particle tracking model was developed for the study area. A successful removal of the contaminants can be achieved by placing a pumping well at a suitable location. The results confirm that numerical groundwater modelling is much more effective for predicting groundwater transport than analytical calculations.

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ABSTRACT

Groundwater is an important source of drinking water and its availability is getting reduced as the population grows. Moreover, the groundwater, as other water supplies, is more and more exposed to pollution which results in the contamination of the groundwater. Transport path of subsurface water is the major pathways for contaminant spreading from contaminated areas. The study of this require information such as the average rate and direction of movement of ground water and contaminants The groundwater flow modelling is a vital tool for obtaining the information regarding the groundwater resources and contaminant transport in the study area. With rapid increases in computational ability and wide availability of computers and softwares, groundwater modelling has become a standard tool for effective groundwater management. The study proceeded with the development of the conceptual model of regional groundwater flow.

The main objective of the present study was to set up a groundwater and contaminant transport model for the Nileswar basin in Kasaragod district of Kerala. The study presented herein used visual MODFLOW to construct a groundwater flow model in the basin. The drainage area of Nileshwar is about 190 sq kms. All the three physiographic regions, such as highland, midland and lowland of Kerala are represented in the drainage basins. A conceptual model of the study area was created based on the available input data such as topographical, climatic and well data of the area. The recharge in the area was taken as 10% of the average rainfall of the area during the period of study. A study state model was developed on the basis of average groundwater heads for 3 year period. The calibration of the model parameters was conducted under steady-state flow conditions.

The model predicted the flow of the groundwater and velocity in magnitude and direction. The river, drain and constant head are taken as the boundary condition. The migration of the plume was also predicted by assigning some forward particle at different location and to remove the particle, the effect of the pumping well was studied. The model created during our study provides

a clear idea of groundwater characteristics of Nileshwar river basin and it will help in the future studies and development of the groundwater management in the area. The groundwater and particle tracking model developed can be used to get a good knowledge of the groundwater availability and the risks of contaminant transport and how to mitigate its effect in the study area. A good use of the modelling software visual MODFLOW was used in this study.