Predicting Availability and Scarcity of Water Using Visual MODFLOW

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ABSTRACT— ***Due to ever increasing population, industrialization and demand in agricultural needs, the humanity is on the verge of experiencing the huge shortage of fresh water supply. Hence ground-water is a resource of global importance, particularly in areas where access to surface water is limited. Ground-water modelling can be done using commercially available softwares. This paper highlights ground-water flow pattern and velocity vectors using Visual MODFLOW v.2011.1 which predicts availability and scarcity of water along with necessity for commissioning new bore-wells or artificial supply schemes to meet increasing water demand provided average recharge remains constant. Such a study would be helpful in predicting the effective locations suitable for artificial water extraction systems such as bore-wells to obtain maximum yield of ground-water.***

Keywords— Ground water, modeling, flow pattern, velocity vectors, Visual MODFLOW 2011.1, bore-well.

1. INTRODUCTION

Ground water is a resource of global importance particularly in areas where access to surface water is limited and makes up about 95% of unfrozen fresh water available on earth. Groundwater resources include shallow and deep rechargeable aquifers that are connected to rivers; streams or seas while non-renewable aquifers or fossil water are those that may have been created by age. It serves as a major source of water for drinking in urban as well as rural areas. Besides this, ground water serves as a major role in agricultural and industrial sector. Millions of people in the developing world rely heavily on ground water, mostly through shallow dug wells. Municipal water supply in many cities is unreliable and many villages in the developing countries do not have potable water supply. Over exploitation of ground water being a natural resource must be checked. To provide sustainability, the traditional methods of water harvesting and usage methods need to be revived and if required, modified to suit the present day requirements. This demands the need to effectively model the ground water flow to analyze and predict the fate of the same. Numerical and mathematical modeling can be effectively used for this purpose. Moreover, using these techniques efficient and optimized water extraction points could be determined. Visual MODFLOW is said to be the complete, and user-friendly, modelling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulation. This paper highlights the need and usefulness of modeling techniques used in predicting the ground water flow.

2. LOCATION OF STUDY

Location of the study is Karukutty, a village in Ernakulam district, Kerala state. The area was found to have acute water scarcity during summer season. Also artificial water supply systems such as municipal water supply were not effective in this region. So the people dwelling was forced to rely on bore-wells dug in the region. The area was occupied by an Engineering College along with their work-shops, and three hostels. Parameters necessary for analysis were obtained conducting various experiments and surveys. Three Geo-reference points were obtained using the Google Earth. Average annual rainfall of this study area is 2903.4 mm as obtained from meteorological department of Government of India. Average depth of rock strata is 10.5m from ground surface as obtained from the bore-log data collected from site. Soil profile of the area is shown in figure 1. Water demand existing in the area under consideration was preliminarily obtained by surveys and then modified using National Building Code standards with necessary factor of safety. There are four wells; viz-a-viz, 3 bore-wells and 1 open well in the locality. Among these, two bore-wells are commissioned and open-well is used as rainwater harvesting pit. The area had an irrigation canal fed by Ezhattumugham Power project running along its southern boundary.

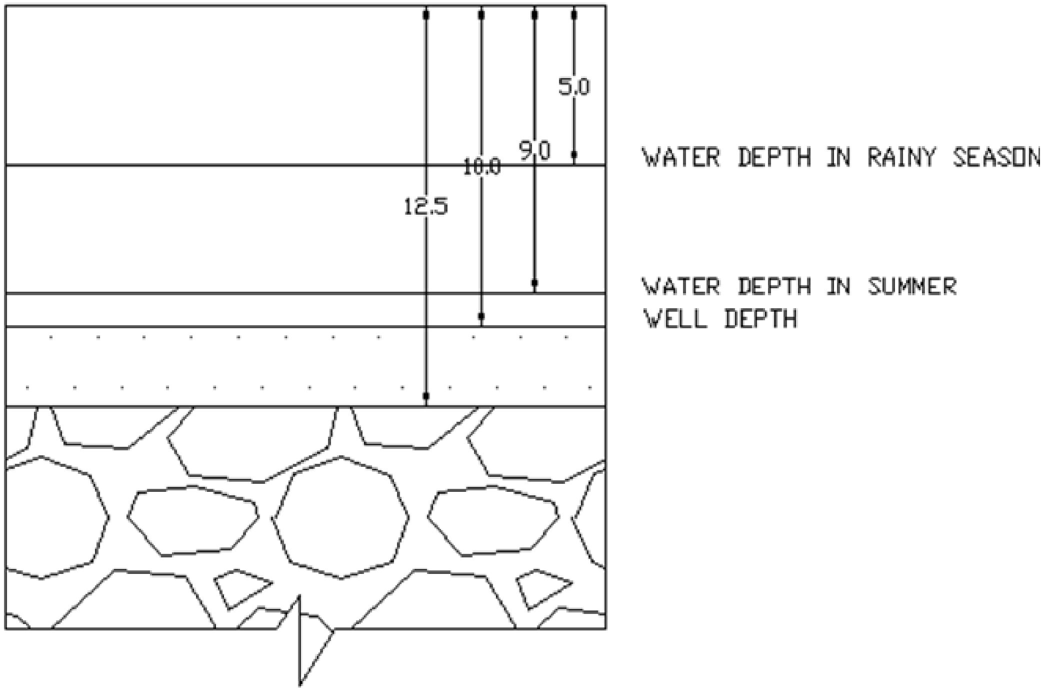

Figure 1: Soil Profile

3. GROUND WATER FLOW MODELLING

The use of groundwater models can be applied to investigate a wide variety of hydro- geologic conditions. These models are just conceptual descriptions that can describe physical systems using mathematical equations. By mathematically representing a simplified version of a hydro geological system, reasonable alternative scenarios can be predicted, tested, and compared. Groundwater models describe the groundwater flow using mathematical equations based on certain assumptions involving the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock.

Finite-difference based software MODFLOW (Visual MODFLOW v.2011.1) [8] was used to simulate the ground-water flow in the present study. Visual MODFLOW software in groundwater modeling has been universally accepted and well documented in many research journals such as [1] [2] [3] [4] [5] [6] [7]. The interface of Visual MODFLOW has been specifically designed to reduce complexities and increase productivity of three-dimensional models associated with groundwater flow and contaminant transport models. The interface of the software has three sections namely the Input module, the Run module and the Output module. The Input section is used to graphically assign all of the necessary input parameters for building a three-dimensional groundwater flow and contaminant transport model. The input menus represent the basic "model building blocks" and are displayed in a logical order to guide the modeller through the steps necessary to design a groundwater flow and contaminant transport model. The Run section is used to modify the various run-time options for each numeric engine. These include selecting initial head estimates, setting solver parameters, selecting the layer types, activating the re-wetting package, specifying the output controls, etc. Each of these menu selections has default settings, which are capable of running most simulations. The Output section is used to display all of the modelling and calibration results for the groundwater flow, particle tracking, and contaminant transport simulations. The output menus allow you to select, customize, and overlay the various display options for presenting the modelling results. In each of the three sections, the Visual MODFLOW 3D-Explorer can be used for three-dimensional visualization of the groundwater flow and contaminant transport model.

Finite- difference modeling was done for prototype conditions, such as inflow and outflow rates, drawdown, head contours and velocity vectors in an area of 0.12 km_2 for 7300 days. When a new model is created, it consists of a rectangular model domain with uniformly spaced grid cells, uniform property values, and initial boundary conditions.

Per capita demand was obtained using National Building Code (2013) [9] which is 480 m^3/day. Area of the study is 0.12 km^2. There is an unlined canal marking the south boundary of the area under consideration. Average depth of flow in the canal is 0.8 m. Hydraulic gradient is 0.003. Velocity of flow is 0.00316 m/sec. North, East and West boundaries are considered to be in dry state and hence a constant head is assumed. Eighty two reference points were selected randomly to input their elevations with respect to their Northing and Easting coordinates. The model was generated by inputting necessary parameters as shown in figure 2.

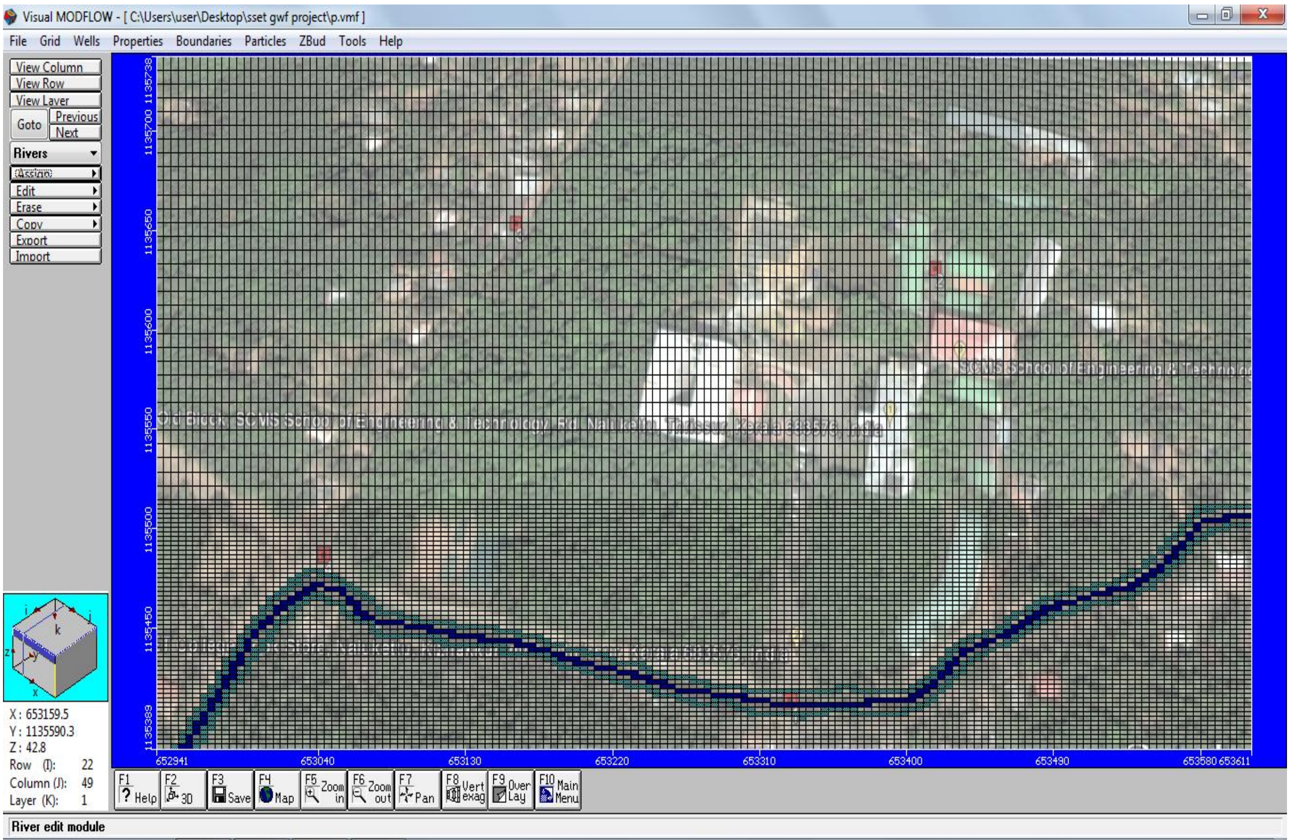

Figure 2: Input Module

Input parameters based on soil strata, permeability, storativity, conductivity, specific yield, total and effective porosity were selected as shown in table 1. Elevations were imported into the model and kringing method of interpolation was adopted. Recharge and drawdown from the area was also marked by plotting pumping wells at existing locations. The details of bore wells are depicted in table 2. The canal on Southern boundary is a lined during its half way run and hence cells surrounding these areas were inactivated.

Table 1: Input Parameters

***Model* Properties**		***Zone* 1 Laterite**	***Zone* 2 Weathered Rock**	***Zone* 3 Hard Rock**
Specific storage, S_s (l/m)		$1x10^{-5}$	$1x10^{-5}$	$1x10^{-5}$
Specific yield, S_y		0.2	0.2	0.2
Effective porosity		0.15	0.15	0.15
Total porosity		0.3	0.3	0.3
Hydraulic conductivity (m/sec)	k_x	$2x10^{-5}$	$5x10^{-6}$	$5x10^{-7}$
	k_y	$2x10^{-5}$	$5x10\text{-}^{6}$	$5x10^{-7}$
	k_z	$2x10^{-6}$	$5x10^{-7}$	$5x10^{-8}$

Table 2: Bore-well Specifications

Well	***Bore-well* 1**	***Bore-well* 2**
Diameter (mm)	150	150
Depth (m)	73.5	85

Flow direction along with properties of canal was assigned. Built-in automatic mesh generation algorithms enabled a well-behaved, numerically robust discretization. As such, a finite-element model was developed and is depicted in figure 3. A detailed explanation about the modeling can be found in the user's manual for MODFLOW [8]. Inflow and outflow rates were predicted using zone budget and drawdown, head contours and velocity vectors were obtained using MODFLOW 2005 numeric engine [8].

4. RESULTS AND DISCUSSIONS

Ground-water flow modeling was done using prototype conditions and the output file is shown in figure 3. The data related to meteorological, geological and water demands were collected. These data collected were given as inputs to the Visual MODFLOW software and flow pattern and drawdown and velocity vectors were predicted for another 20 years provided the average rainfall remains constant throughout these years. The results obtained from this study predict the availability and scarcity of water and necessity for commissioning new bore-wells or artificial supply schemes to meet the increasing demand in water consumption. Also this study suggests the places were bore-wells could be scientifically dug in order to obtain maximum yield of ground-water. The dry patched obtained near bore-well 1 indicates that it turned dry because of water extraction by persisting demand in the location.

From the figure 3, the Drawdown shading obtained indicates the degree of availability of water in the considered region. In the figure, the blue colour indicates regions of water scarcity. It means that water is available only at a higher depth beneath the mean sea level. Therefore, more wells can be suggested in areas facing the road approaching towards Nalukettu region from entrance of the study location under consideration, where the drawdown is orange-yellowish colored.

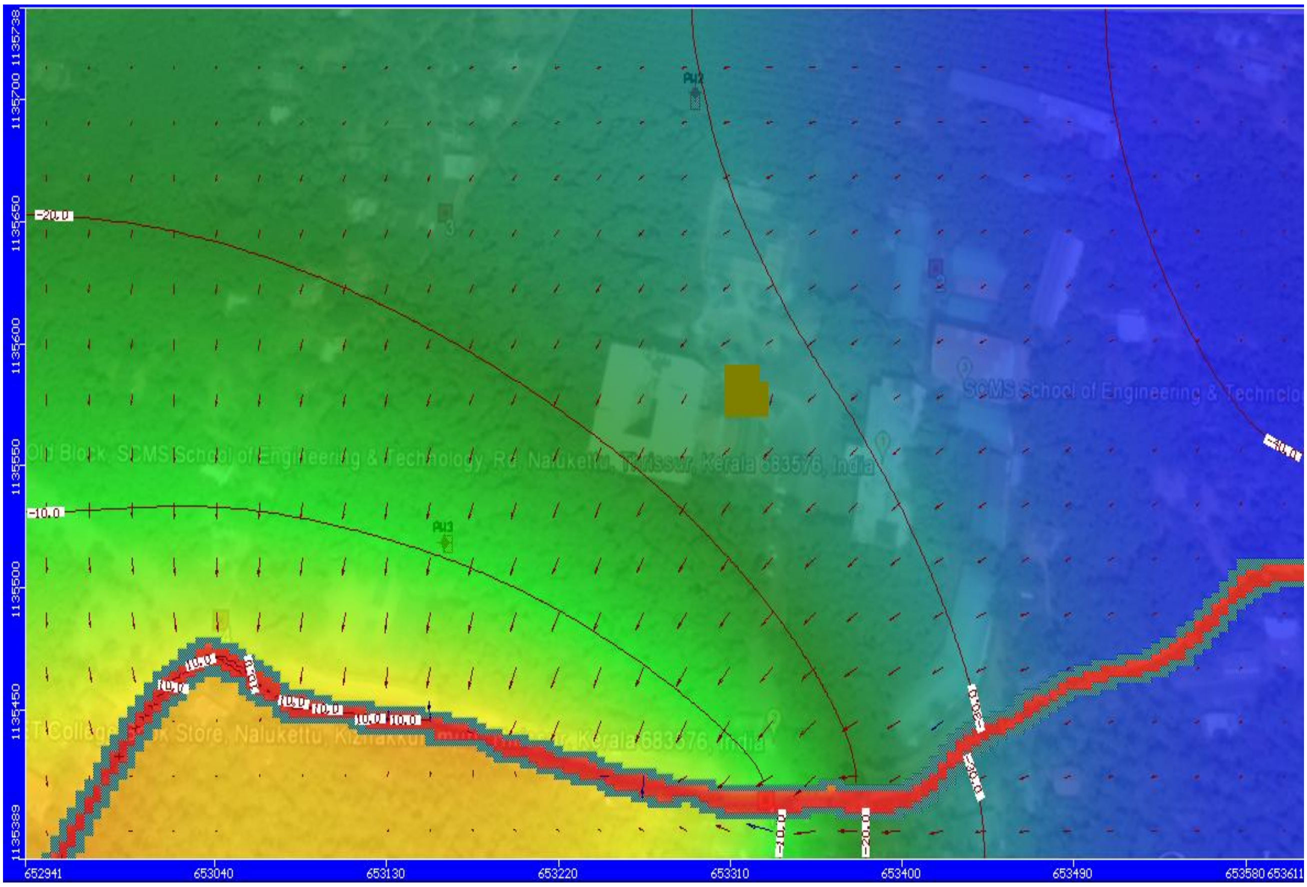

Figure 3: Draw-down Pattern and Head Contours

5. CONCLUDING REMARKS

Following concluding remarks can be drawn the present study:

- Visual MODFLOW v.2011.1 is an effective tool for ground-water flow modelling.
- Ground-water flow modelling was done for the study location for a period of 20 years.
- Modelling proved that existing groundwater extraction sources are not sufficient to meet existing needs of the location.
- Modelling predicted that more wells can be effectively dug in the study location.
- Study gives result on net draw-down occurring in the area under consideration. This shows that under current conditions, if there is a heavy increase in water demand, new bore-wells should be commissioned at the South-Western regions of the area under consideration.

6. ACKNOWLEDGEMENT

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