ANALYSIS OF FLOW PATTERN BETWEEN HILL AND LAKE

Devatha Chella[1] and Arun Kumar Thalla[2]
[1]Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India
[2]Department of Environmental Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India
E-Mail: revacp@gmail.com

ABSTRACT

The demand for water is increasing rapidly with the increased population, industries and irrigation which lead to the scarcity of water. In order to avoid such a scarcity, which will hamper the development of the country, water resources projects should be planned and managed effectively. The south part of the Chennai metropolitan in India consists of hills and lakes. Due to the rapid urbanization, all the lakes in this zone are being encroached thus hindering the contribution of lake for ground water resulting in the depletion of ground water. For this enhancing situation, a microlevel study has been carried out on the surface water estimation and analysis of sub-surface flow pattern. This paper mainly emphasize on ground water modeling using VISUAL MODFLOW. Groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers. Estimation of surface runoff using Soil Conservation Service (SCS) shows that only in the year 2004, there is a high runoff which leads to over flow from the lakes and for the other years (2001-2003) average runoff contribution to the lakes is from 17% to 45%. The ground water analysis was done for six years (2001 to 2006) and the results indicate that for the monsoon period the velocity ranges from 0.02 to 0.05m/sec and for the non-monsoon period it ranges from $3.21*10^{-2}$m/sec to $8.75*10^{-2}$m/sec. which implies that there is a rapid increase in the radius of influence due to urbanization.

Keywords: model, ground water, flow pattern, modflow.

INTRODUCTION

The demand for water is increasing with the population, industries and irrigation leads to scarcity of water. In order to avoid such a scarcity it is important to improve the efficiency of the planning and management of water resources. Depletion of groundwater in areas where excessive withdrawals have occurred emphasizes the need for the analysis of the flow conditions.

Just below the hill side groundwater mainly occurs in the unconsolidated weathered mantle, underlying fractures, fissures, joints etc. and are termed as hard rock regions. The weathered mantle is usually poorly permeable but has water storage capacity. The fractured zones have high transmissibility values depending on the course, upon the apertures and the interconnections of the fractures. Generally fractures are interconnected with weathered zone as a result groundwater in the weathered mantle may recharge the fractures. This shallow groundwater zone ends in a lake. Kirby (1988) defined the process of movement of water on the hill slope and its contribution to ground water as Hill slope Hydrology and classified the flow pattern in the hilly slopes as Hortonian overland flow, saturation overland flow and return flow. At any point on or below ground in a hilly terrain, water shall be moving under a combination of potential gradients viz by gravity and water pressure or tension. For a hill slope with uniform net rainfall, flow vectors are typically vertical through the soil. However, vertical flows are critical in a hill slope hydrology as they control the diversion of flow on the slopes that finally results in lateral flow. Reddi (1990) relates the fluctuation of the ground water on a hilly terrain as a function of rainfall intensity, evapotranspiration, flow in the unsaturated zone and drainage by gravity. Further, he developed a mathematical model for assessing the ground water level on hillside slopes by using two-dimensional finite differences method. Gupta and Singh (1985, 1988) did a comparative study between finite difference and mass balance model associated with partially penetrating well in a hard rock terrain for the simulation of flow regime and they concluded that Finite difference gives better results than a mass balance model.

Kacimov (2000) describes the behavior of the lake, mainly its regime from gaining to losing, or flow through, as a function of the varying incident groundwater flow velocity, evaporation, precipitation runoff rates in the lakes and their hydrological characteristics. Yang *et al* (2002) proposed a flow-interval hill slope discretization scheme for catchment hydrological modeling. By this scheme, a two-dimensional catchment is simplified into a one-dimensional cascade of flow intervals linked by the main stream. This model performed well on simulating the overall water balance, general flow pattern, and daily and hourly hydrographs of a whole catchment, as well as simultaneous simulation in different sub catchments. Though many researchers have studied the surface and ground water balances, there has been limited study on the complex interaction of surface and ground water mass balances on a hilly slope.

Generally more than 95% of water in the stream flow passes to into the ground before reaching the channel network. The fluctuation of groundwater levels depends upon many related process such as rainfall, evapotranspiration, flow in the unsaturated zone and drainage by gravity.

With this as back ground, this paper mainly aims in (i) estimation of surface runoff of the study area using Soil Conservation Service (SCS) method (ii) analysis of subsurface flow pattern using visual MODFLOW package, which will lead to the evolution of the management strategies for the conservation of water.

Description of the study area

The area lies between 120^{0}55'N - 130^{0}N Latitudes and 80^{0}05'E-80^{0}10'E Longitude with an areal extent of 400 hectare. It lies between pachamalai hillock to chitlapakkam village in Chennai City, India and the lake is located in the centre of the village. The pachamalai hill used to serve as a source for the Chitlapakkam Lake. This lake water was used for irrigation purpose before urbanization. After the conversion of agricultural farms into residential areas, the water from the lake is not used for irrigation. There are three channels at the foot of the hill, which have been connected to the Chitlapakkam Lake. The map of study area is shown in Figure-1.

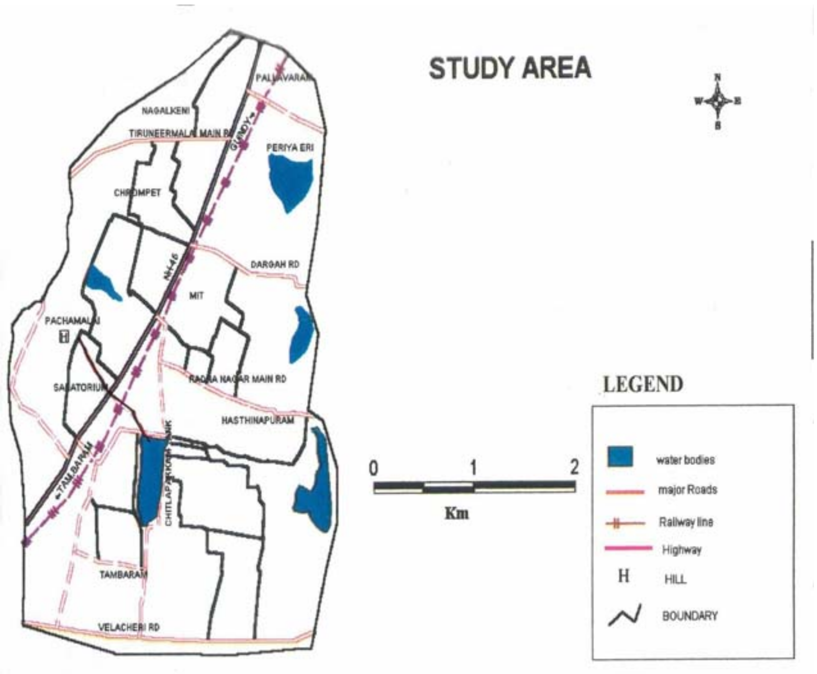

Figure-1. Map of study area.

The study area consists of crystalline hard rock like archean age gneiss and charnockite. The layers consist of weathered zone, fractured zone and hard rock. The soil profile comprises of kankar, weathered charnockite and recent formation deposited over the ancient archean age.

The elevation of the hillock is 110m and that of the lake is 24m above MSL. Therefore the gradient is decreasing towards the lake. The distance between the hillock and the lake is 2700m. There are three channels at the foot of the hill, which drains water into the lake. The radial drainage pattern of flow occurs from the pachamalai hill resulting in about twenty five lakes along its periphery. However, the flow pattern from the pachamalai hill to Chitlapakkam Lake is only considered and analysed. The land use pattern, village details and chitlapakkam tank details are given in the Tables 1, 2 and 3, respectively.

Table-1. Area description and classification.

Description of the area	Percentage classification
Settlements	30
Water body	15
Grazing/pasture	33.5
Paved area	10.5
Others	11

Table-2. Chitlapakkam tank details.

Tank name	Chitlapakkam tank
Location	East of chitlapakkam 2nd main road
Type	Non-system
Free Catchment area	34.01ha
Capacity	0.31Mcm
Bund length	1400m
Water depth	3.5m
NE rainfall	720mm
SW rainfall	477mm
Non-Monsoon rainfall	118.96mm

Table-3. Village details.

Area	**2.95 sq. km**
Population	25232
Total roads	315
Wells	10
Overhead tanks	2
Water storage tanks	3
Hand pumps	33
Small culverts	80

METHODOLOGY

Soil Conservation Service (SCS) method is the most widely used method that calculates peak discharge volume for one or more recurrence intervals and also can be used to develop runoff hydrographs for sub basin in watershed and to combine them as they move through the stream system.

The data required for this method are land use, soil group, rainfall data, hydrological cover, land treatment and antecedent moisture conditions. From the above data curve number can be found out. A Computer Code has been developed for SCS method in C Language for the present study.

MODFLOW is a finite difference ground water model used to simulate two-dimensional areal or cross-sectional, and quasi or fully three-dimensional, transient flow in anisotropic, heterogeneous, layered aquifer systems. The model is based on a block centered finite difference approach, using variable grid spacing in x, y and z directions. Layers may be simulated as confined, unconfined or convertible between these two conditions
The required input data are the base map of the area, water levels, recharge rate, porosity, specific yield and pumping rate of wells.

The base map for the present study has been prepared using ArcView GIS Version 3.1 software. The ground water level data for the period 2001 to 2006 was collected from Institute for Water Studies Taramani, Chennai, India. Evapotranspiration was calculated by Blaney-criddle method (Dilip Kumar, 1998).

$$E_{TO} = C\,(0.46T+8.13) \quad (1)$$

Where, T = mean monthly temperature; C = adjustment factor
Recharge was calculated by mass balance equation on the control volume, control volume being the study area in the present case (Raghunath, 1987).

$$R+I_q = Q_q + E_t + DGW \quad (2)$$

Where, R = recharge into the ground water due to other sources; I_Q = rainfall (mm); Q_q = runoff; E_T = evapotranspiration
DGW = Gross ground water draft
Porosity values vary between 30 to 40 percent for weathered granite, gneiss and rock formation. For the present study, an average value of 35 % is considered.

RESULTS AND DISCUSSIONS

The rainfall-runoff values along with the percentage contribution obtained using SCS method as shown in Table-4.

Table-4. Runoff percentage contribution.

Year	Rainfall	Runoff	%Contribution to lake
2001	1293.9	0.191	61.3
2002	933.9	0.126	40.64
2003	1042.7	0.055	17.74
2004	1522.9	0.37	119 (surplus)
2005	1693.2	0.093	30

In the year 2004, rainfall accounted is 1522.9mm and the runoff is $0.37Mm^3$ which shows that the rainfall is above average therefore runoff is also more and hence the contribution to lake is also excess. But for the year 2005, rainfall is 1693.2mm and the runoff is $0.093Mm^3$ here it shows that more rainfall accounts for less runoff and percentage contribution to the lake is less. Due to urbanization effects, inlets have been closed and therefore more runoff is lost through evaporation.

Data of the study area was analyzed by MODFLOW software and the output is shown in Figures 2 and 3.

The sub-surface flow pattern for the non-monsoon condition was obtained corresponding to a depth of 6m of ground water from a given input value of 20m. The observed monthly ground water levels corresponding to each year was taken as a base to deduce the area contributing to the ground water flow as shown in the Table-5. The overall area is determined during the non-monsoon season and ranges from a minimum of $30x10^4m^2$ to a maximum of $55x10^4m^2$. The highest observed water level ranges from a minimum of 2.5m to a maximum of 8m occurs in the recent years 2004 to 2006, however its contributing area is very large ranges from $30x10^4m^2$ to $21x10^4m^2$, respectively from 2004 onwards. The years 2004 to 2006 shows increased contributing area which can be attributed to the effect of urbanization.

Similarly for monsoon period, the overall area is determined and ranges from $1.6x10^5m^2$ to $6.9x10^5m^2$. However for the year 2002, the contributing area is very large and its value is $6.9x10^5m^2$ respectively. After 2002, water level ranges from 3m to 10.3m and for this the contributing area ranges from $1.6x10^5m^2$ to $4.5x10^5m^2$. It shows an increased contributing area.

The results show that with the rapid urbanization, the porosity of the soil in the study area decreased to a considerable amount which makes the soil compact and obstructs the percolation of water into the soil from that area thus increasing the radius of influence. Therefore in the recent years during monsoon/non-monsoon periods the contributing area is increasing. In addition to the reduction in porosity of soil, this could also be attributed to the closing of inlets of the channels and streams that lead to the lake.

Table-5. Subsurface area calculations.

Year	**Area of contribution during Non-monsoon period** (m^2)	**Area of contribution during Monsoon period** (m^2)
2001	$23x10^5$	$3.6x10^5$
2002	$26x10^5$	$6.9x10^5$
2003	$24x10^5$	$1.6x10^5$
2004	$40x10^5$	$3.85x10^5$
2005	$21x10^4$	$4.9x10^5$
2006	$30x10^4$	$2.8x10^5$

CONCLUSIONS

Estimation of surface runoff using SCS method gives the amount of runoff contribution to the lake. Based on the pressure surface contour values pumping can done according to the needs and also it gives an idea about increase as well as decrease in the ground water levels. The subsurface flow velocity for the non-monsoon period ranges from $.02x10^{-2}$m/sec to $.05x10^{-2}$m/sec and that for the monsoon period, it ranges from $3.21x10^{-2}$ m/sec to $8.75x10^{-2}$m/sec. This shows that there is a rapid increase in the radius of influence due to urbanization. Further, the study reveals that Flow net analysis can be done based on the above results. This analysis will leads to the evolution of the management strategies for the conservation of water and microlevel planning of the area.

REFERENCES

Chitlapakkam village details from Chitlapakkam Town Panchayat, Chitlapakkam, Chennai Municipal Corporation.

Dilip Kumar. 1998. Irrigation Water Management: Principles and Practice, Prentice-Hall of India, Delhi.
Ground water Level Data from Institute for Water Studies. Taramani.

Kacimov A. R. 2000. Three Dimensional Ground Water flow to a Lake: An Explicit Analytical Solution Journal of Hydrology. Vol. 240, Issues 1-2. pp. 80-89

Meteorological data from Indian Meteorological Department, Nungambakkam, Chennai.

Raghunath, H. M. 1987. Groundwater, Wiley Eastern, New Delhi.

Gupta C. P. and Singh, V. S. 1985. Effect of incomplete recovery prior to a pump test in a large diameter well Journal of Hydrology. 79(1-2): 141-144.

Gupta C. P. and Singh V. S. 1988. Flow Regime associated with partially penetrating large diameter wells in hard rocks Journal of Hydrology. 103(3-4): 209-217.

Singh V. S., and Gupta C. P. 1988. Analysis of pump test data for a large diameter well near a Hydro geological Boundary Journal of Hydrology. 113(1-4): 380-383

Reddi L. N. and Teie H. W. U. 1990. A Comparison of models predicting ground water levels on hillside slopes. American water works association.

Kriby M. 1988. Hill Slope Runoff Processes and models Journal of Hydrology. 100: 315-339.

Yang D. Herath, S and Musiake K. 2002. A hillslope-based hydrological model using catchment's area and width functions Journal-des Sciences Hydrologiques. 47(1): 49-65.

VOL. 4, NO. 3, MAY 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

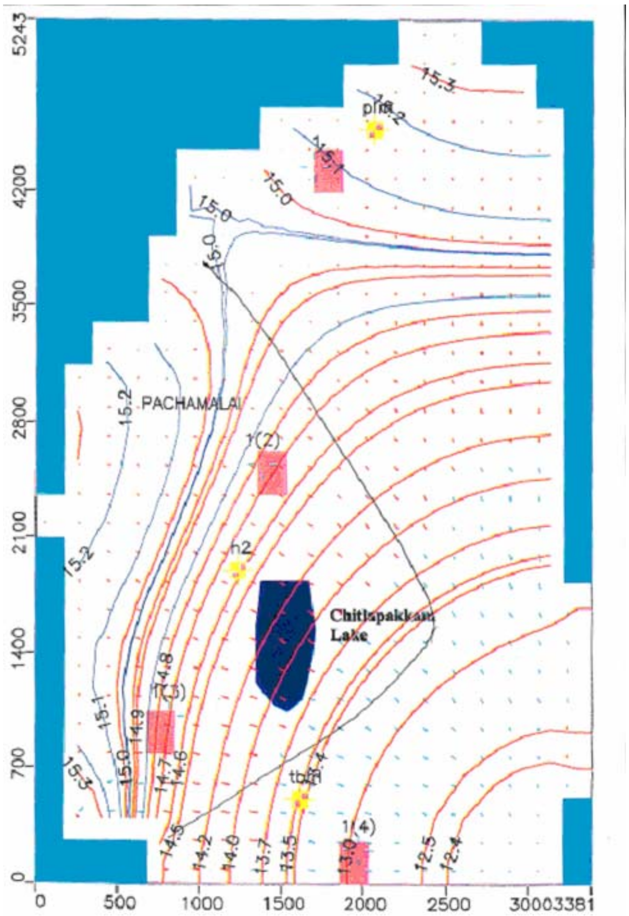

Figure-2. Subsurface flow pattern: monsoon period (2005).

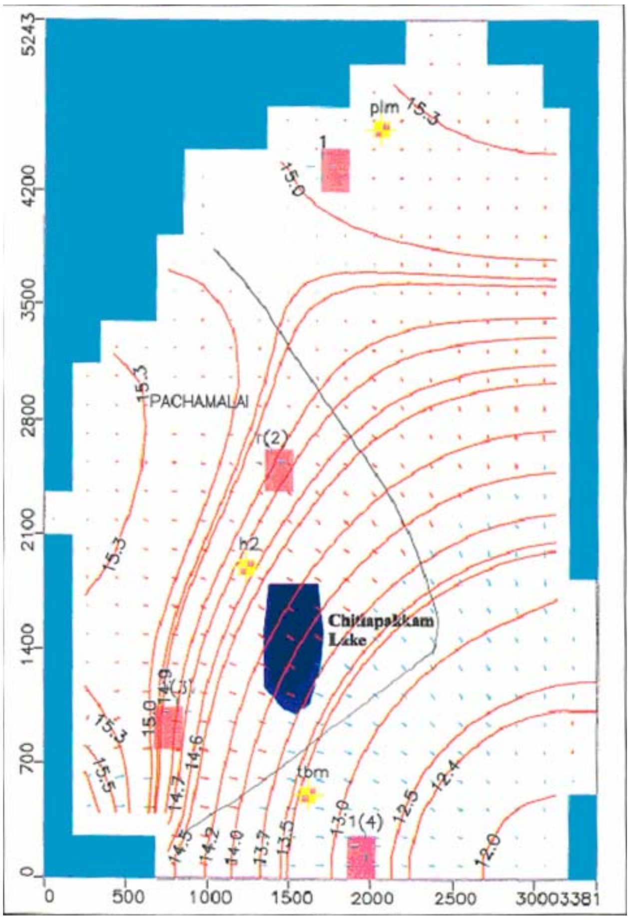

Figure-3. Subsurface flow pattern: non-monsoon period (2005).