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Research Article

Estimating Time for Formation of Recharge Mound and Rate of Recharge from Percolation Tank Using a Mathematical Model

ANJU BALA[1*], MUKESH KUMAR[2], KISHAN SINGH RAWAT[3] AND DALIP SINGH TANEJA[4]

[1]*Department of Civil Engineering, WCTM, Gurgaon, Haryana*

[2]*School of Agriculture, IGNOU, New Delhi*

[3]*Division of Agricultural Physics, IARI, New Delhi*

[4]*RIMT-Maharaja Aggarasen College, Mandi Gobindgarh, Punjab*

ABSTRACT

The withdrawal of groundwater has been far in excess of natural recharge, which has led to the progressive decline of water table. An effective way of bridging the gap is artificial groundwater recharge. Artificial recharge provides groundwater users an opportunity to increase the amount of water available during periods of high demand-typically summer months. Prior to artificial recharge through percolation tank if we know that how much time will be taken by recharge mound to develop, it will save cost and energy. It can be done by use of a mathematical model from which time taken for development of mound can be calculated. Thus, a mathematical model was developed at Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, India, to predict time taken for formation of recharge mound due to recharge through percolation tank and its validation. Various parameters required to calibrate and validate this model were measured by conducting an experiment. There was not much difference found between observed and calculated time for development of recharge mound. The mathematical model, therefore, could be successfully used to predict the time taken for formation of recharge mound due to recharge through percolation tank.

Key words: Ground water recharge, Percolation tank, Arificial ground recharge, Recharge mound

Introduction

There has been over exploitation of groundwater in the state of Punjab due to increase in cropping intensity as well as growing of high water consuming crop such as rice. The annual withdrawal of groundwater has been far in excess of annual natural recharge, which has led to the progressive decline of water table. An effective way of bridging the gap between groundwater withdrawal and natural recharge is augmentation of groundwater by artificial recharge. Out of various methods, recharge by percolation tank is an effective method. As water percolates, the recharge mound forms below the percolation tank. Prior to artificial recharge through percolation tank if we know that how much time will be taken by recharge mound to develop, it will save cost and energy. It can be done by use of mathematical model from which time taken for development of mound can be calculated.

Various scientists have developed mathematical models to predict recharge from

*Corresponding author,
Email: anjukathuria@yahoo.com

rectangular areas. Bittinger and Trealease (1960) developed an equation, which described the variation with time and the shape of groundwater mound that formed after an instantaneous release of deep percolation from a circular spreading basin. Glover (1961) and Hauntush (1963) estimated the growth of groundwater ridge in an infinite aquifer in response to uniform deep percolation from a spreading area that was in the form of an infinitely long strip using mathematical models. Marino (1974) developed a model for the growth of groundwater mound in an unconfined aquifer receiving uniform vertical percolation. Using Boussineq equation Rao and Sharma (1981) developed an analytical solution for the growth of groundwater mound in finite aquifers bounded by open water bodies in response to recharge from rectangular area, assuming that the level of these open water bodies are not affected by recharge operation and remain always equal to initial static water level in the aquifer and the aquifer parameters remain constant throughout the aquifer at all times and the rate of recharge is very small as compared to hydraulic conductivity of the aquifer. Rai And Singh (1995) also developed a model to predict the spatio-temporal variation of water table in a finite aquifer system in response to a transient recharge from an overlying rectangular basin. This model also had similar assumptions as that of Rao and Sharma (1981). Manglik and Rai (2000) developed an analytical solution to predict the water table fluctuation in an unconfined aquifer due to time varying recharge and withdrawal of multiple wells and basins respectively. Ritesh Vijay *et al.* (2007) analysed spatio-temporal analysis of groundwater recharge and mound dynamics in an unconfined aquifer and found that the effect of long-term groundwater mounding in the aquifer depends on soil, aquifer geometry and the area contributing to recharge. The significance of the study is to assess the effectiveness of the basin in terms of its hydrologic and hydraulic properties for sustainable management of groundwater recharge. Pratima Patel *et al.* (2011) studied impact on artificial groundwater recharge mound and derived analytical equation for predicting growth as well as decline of the ground-water mound depending on the recharge rate with different value of permeability, depth of pervious strata and diameter of well, besides studying the effects of variation in the geotechnical parameters on water-table fluctuations. But there is a need to develop mathematical model to calculate time taken for development of mound. Thus, in present study a mathematical model has been developed to predict time taken for formation of recharge mound due to recharge through percolation tank and this model also has been validated by the data collected from the field.

Model Development

A mathematical model was developed at Department of Soil and Water Engineering, Punjab Agriculture University, Ludhiana, India to predict time taken for formation of recharge mound due to recharge through percolation tank and its validation.

A percolation tank of length '2L1' is made and water is filled up to some height. Let 'H'is the depth of impermeable layer below the water table. As water percolates, it meets the water table and formation of recharge mound takes place below the percolation tank. The recharge mound is highest in the centre and fades away with distance from percolation tank.

Let '2L' be the total length of mound and has unit width. Let P be the percolation rate and 'p' is the porosity of aquifer.

Thus dynamic storage (V_d) is

$$V_d = 2\int_0^L phdx \tag{1}$$

By Darcy's Law;

$$Q = -K\left(h + H\right)\frac{dh}{dx} \tag{2}$$

By equation of continuity

$$\frac{dq}{dx} = P$$

$$\text{Or } Px + C_1 \tag{3}$$

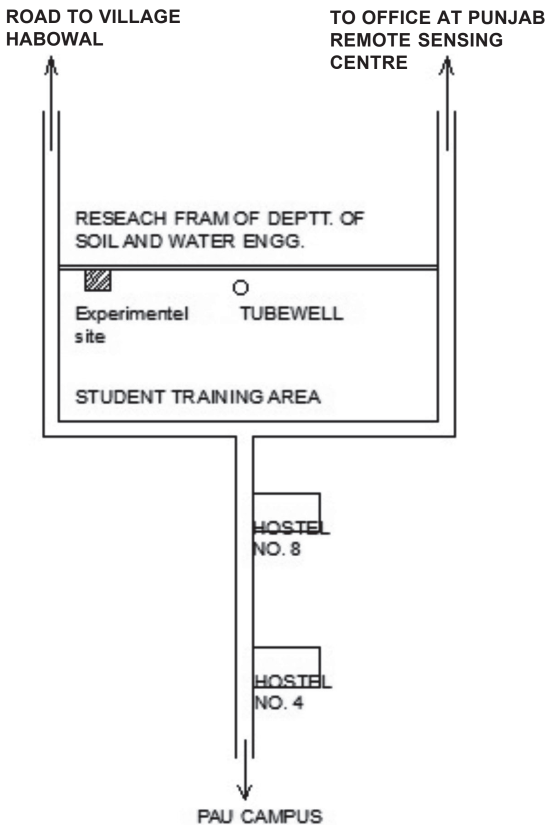

Fig. 1. Location map of the Experimental Site

The boundary conditions are

$x = 0$ q = 0 (i)

$x = L$ h = 0 (ii)

Using boundary conditions (i) in equation (3)

$C_1 = 0$

From equation (2) and (3)

$$-K\left(h+H\right)\frac{dh}{dx} = Px$$

Or

$$\left(h+H\right)dh = -Px\frac{dx}{K}$$

Integrating

$$h^2/2 + hH = -Px^2/2K + C_2$$

$$h^2 + hH = -Px^2/K + 2C_2$$

Or

$$h^2 + 2hH = -Px^2/K + C_3 \tag{4}$$

Using boundary conditions (ii) in equation (4)

$$C_3 = PL^2/k$$

So, $h^2 + 2hH = \frac{P}{K}\left(L^2 - x^2\right)$

Or

$$h^2 + 2hH - \frac{P}{K}\left(L^2 - x^2\right) = 0$$

Or

$$h = -H \pm \sqrt{H^2 + \frac{P}{K}\left(L^2 - x^2\right)} \tag{5}$$

In case H>>h

$$h = -H + H\sqrt{1 + \frac{P}{KH^2}\left(L^2 - x^2\right)}$$

$$h = -H + H\left[1 + \frac{P}{KH^2}\left(L^2 - x^2\right)\right]^{-\frac{1}{2}}$$

Using Binomial theorem

$$h = -H + H\left[1 + \frac{P}{2KH^2}\left(L^2 - x^2\right) + \ldots\ldots\ldots\ldots\right]$$

Neglecting higher order terms

$$h = -H\left|H\right|\frac{P}{2KH^2}\left(L^2 - x^2\right)$$

$$h = \frac{P}{2KH^2}\left(L^2 - x^2\right) \tag{6}$$

Substituting value of (h) in equation (1)

$$V_d = 2p\int_0^L p/2KH\left(L^2 - x^2\right)dx$$

$$V_d = \frac{pP}{KH}\left|L^2x - \frac{x^3}{3}\right|$$

$$V_d = \frac{2pPL^3}{3KH} \quad (7)$$

Let ΔT is the time taken for development of recharge of mound

$$\Delta T = \frac{V_d}{2PL_1} = \frac{2pPL^3}{3KH \times 2PL_1}$$

$$\Delta T = \frac{pL^3}{3KHL_1}$$

Field Study

The study was conducted on the research farm of Department of Soil and Water Engineering, Punjab Agriculture University, Ludhiana, India to validate the developed mathematical model with the actual data collected during the study. A percolation tank of dimensions of 8.0m x 8.0 m x 0.6 m was constructed. Five observation wells in one line at 0, 4, 10, 20, 50m, and three others at 4, 10 and 20 m in second line at right angle to the first line were installed from the center of percolation tank to see the actual rise of groundwater level due to recharge through percolation tank. And water was added to percolation tank from nearby tube well and constant depth of water level i.e. 50cm was maintained for a long period even after steady state was reached to obtain the data of time taken for development of mound due to recharge through percolation tank.

To calculate the time taken for development of recharge mound by this model various parameters are required. These parameters are porosity (p) of aquifer, hydraulic conductivity (K) of aquifer, depth of impervious layer (H), length of mound (L) from the centre of percolation tank. Thus, porosity of aquifer was measured by taking a sample of aquifer material while installing the tube well in unconfined aquifer. Hydraulic conductivity and depth of impervious layer were also determined while installing a tube well and two observation wells in unconfined aquifer. Length of mound was measured by observing rise in groundwater level in respected observation wells from the center of percolation tank.

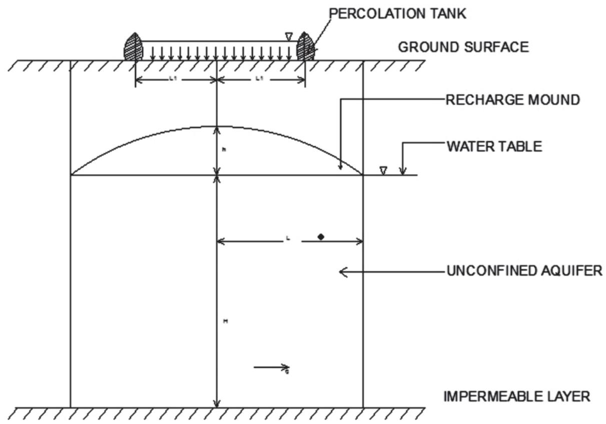

Fig. 2. Recharge by Percolation Tank

Results and Discussion

Observed rise in groundwater level with time at various observation wells

The rise in groundwater level with time at various observation wells was drawn. It is clear from fig. 3 that the steady state in rise of groundwater level was reached after 36 hours at the central observation well (0 m), after 28 hours at 4 m observation well and after 20 hours at 10 m observation well. However there was no rise in observation well at 20m. The rise and rate of rise in various observation wells are given in Table 1. From fig 2 and Table 1 it can also be seen that the rate of rise of groundwater level in any observation well is maximum in initial hours and then it decreases and finally becomes zero. Also the rate of rise is maximum in central observation well and goes on decreasing in other wells with respect to distance. At the steady state the rise in

Table 1. Time and rate of rise in groundwater level in various observation wells due to recharge through percolation tank

Distance of observation	Rate of rise		Rise in groundwater level	
well (m)	Rate(mm/hr)	Time (hr)	Rise(m)	Time (hr)
0	3.75	0<t<4	0.015	t = 4
	1.25	4<t<36	$1.25*10^{-3}t+0.01$	4<t<36
	0.0	t>36	0.055	t > 36
4	2.50	0<t<4	0.01	t = 4
	0.833	4<t<28	$0.86*10^{-3}t+0.06$	4<t<28
	0.0	t>28	0.030	t > 28
10	0.0	0<t<4	0.0	td"16
	2.50	4<t<36	$2.5*10^{-3}t-0.04$	16<t<20
	0.0	t>36	0.01	t > 20
20	0.00	For all 't'	0.00	For all 't'

groundwater in observation well at 0m, 4m and 10m was observed to be 0.055m, 0.030 m and 0.01m, respectively.

Observed rise in groundwater level with distance from center of percolation tank

The rise in groundwater level was recorded at different locations away from the center of percolation tank at different time intervals and are presented in Fig. 3. The fig. 3 shows that rise in groundwater level was more at the centre of percolation tank and it goes on decreasing with distance. The rise increases with time upto 36 hours but after that steady state reaches and there is no spatial variation in rise. It can also be seen that the rise in groundwater level is upto a distance of 20 m only. The variation in rise in groundwater level is comparatively more in 0-4 meters i.e. within boundary of percolation tank.

Model Verification

Porosity (p) of aquifer was found to be 0.403. Hydraulic conductivity (K) was calculated by pump test and was found to be 60 cm/hr. Depth of impervious layer (H) from the initial water level was found to be 12.10m. The value of length was measured by observing rise in observation wells was found to be 20m. By incorporating all

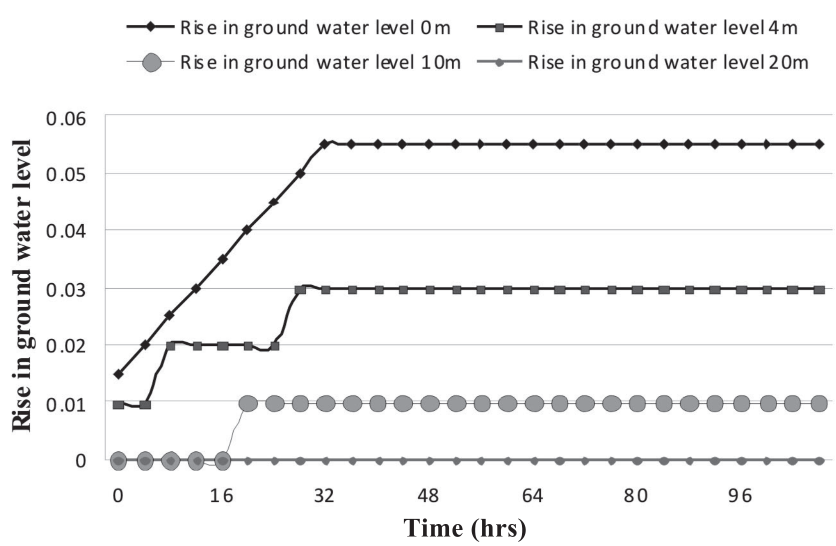

Fig. 3. Rise in groundwater level with time at different observation wells

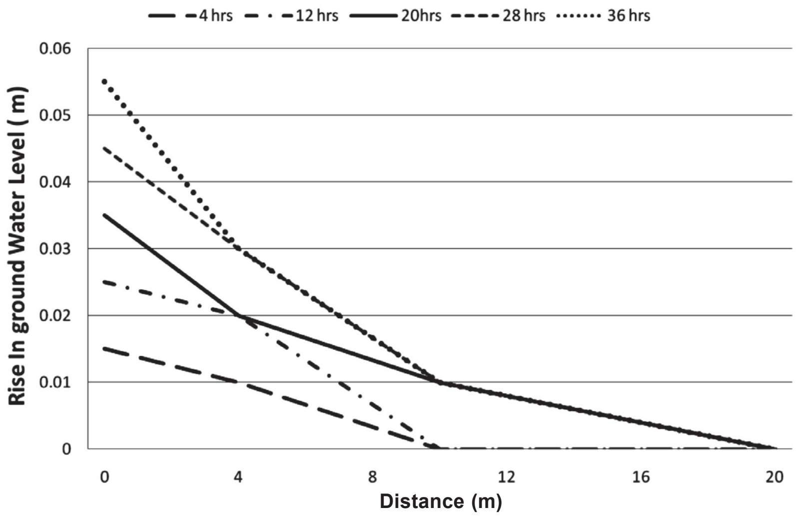

Fig. 4. Rise in groundwater level with distance from centre of percolation tank at various observation wells

these values of various parameters the time for the recharge mound at steady state condition was calculated as 37 hours. Observed time is seen by observing rise in observation wells with respect to time and also drawn in fig 4. The fig 4 clearly shows the observed time i.e. 36 hours. It shows there is no significant difference between observed time and calculated time through mathematical model.

Therefore, it can be concluded that above model can be used for calculation of time taken for development of recharge mound.

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