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NUMERICAL MODELING RELEVANT TO GROUND WATER RECHARGE PROBLEM—UNCONFINED AQUIFER

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ABSTRACT: Numerical modeling of ground water flow related to unconfined aquifer and a change in saturated thickness with variation in piezometric level so, permeability *k*, radius of influences *L*, distance between two recharge wells and presence of recharge by rainfall *P* is discussed in the paper. In this numerical expression inducing ground water mounding through artificial recharge using rain water stored in specially designed basin. This technique is implemented to an unconfined homogeneous aquifer with horizontal impervious base receiving vertical recharge. Various correlations are established for suitable recharge scheme.

Empirical estimate of the influence range L can therefore be viewed as being associated with the development of drawdown of an undercharged aquifer at a particular point in time. Since most natural aquifers are recharged either underground or through rain-fall.

Authors have calculated drawdown $s_0 = h_0 - h_n$ by using quadratic equation of $h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2$. The design of an artificial recharge scheme is mainly governed by: the natural recharge by rainfall can be calculated by $q_r = P \times L$ and design value of detention time of the water in the aquifer is calculated by $T_{days} = p\,H\,L / q_0$.

Authors have verifying dimension (shape) of water mound below recharge area, by varying all the variables rainfall *P*, permeability *k*, distance between two recharge well (radius of influence) *L*, thickness of saturated soil strata *H* in above quadratic equation and framed Numerical modelling and drawn significant conclusion in this paper.

Authors have set up various case studies for recharge scheme which are adopted at site and gives satisfactory results, few are highlighted.

1. INTRODUCTION

Care for ground water before it becomes rare therefore catches water in every possible way and every possible place it falls.

It is said that in the city of Frankfurt, Germany, every drop of water is recycled eight times.

Rainwater is the primary source for all and is one of the purest forms of water. Water resources are limited and water is becoming a scarce commodity everyday due to ever-increasing demand in proportion to the rapidly increasing population. Now it is high time we must conserve this natural resource. For conservation of water resources, rain-water harvesting from roof-top catchments should be done in the form of ground water recharging be made mandatory in the urban areas.

Water is one of the renewable resources. India with an average rainfall of 1150 mm is the second wettest country in the world with good water resources. But the water resources are not evenly distributed over the country due to varied hydro geological conditions and high variations in precipitation both in time and space.

The development of water resources in the country is at cross roads. This sustainability of water resources has been endangered by vagaries of rainfall and unplanned development. An optimum development can be achieved by the conjunctive use of surface and ground water. Artificial Recharge of the ground water resources is the most commonly adopted and cost effective method of replenishing the ground water reserves. Artificial recharge of the ground water resources is the most commonly adopted cost effective and viable—economical solution to ensure Sustainable Land and Ground Water Management.

2. WATER CRISIS

About one-fifth of the world's population lacks access to safe drinking water and with the present consumption patterns;

two out of every three persons on the earth would live in water-stressed conditions by 2025.

Water scarcity is serious problem throughout the world for both urban & rural community. Nearly 44 million people in India are affected by water quality problems either due to pollution, prevalence of fluoride, arsenic, and iron deposits in groundwater or saline water intrusion in coastal areas. At the dawn of 21st century numerous countries including India are facing a growing water crisis.

3. NECESSITY

As large quantities of rainfall are going to sea as runoff, it is better to harness this wasteful runoff by adopting proper scientific conservation measures and constructing suitable recharging structures at appropriate locations and artificially recharge the depleted aquifers through sub-surface recharge bore wells.

Ground water recharging is essential because surface water is inadequate to meet our demand and we have to depend on ground water. Due to rapid urbanization, infiltration of rain water into the subsoil has decreased drastically and recharging of ground water has diminished.

Artificial ground water recharging needs to be implemented due to paucity of water resources. Nature has showered enough potential to recharge our existing water bodies and also to store water for years to come and to meet the present/ future demands.

India has more than 250 city dwellers even though the rate of urbanization is among the lowest in the world. So it is necessary to recharge rainwater every year to fulfil our requirements.

4. WATER CONSERVE OR FIGHT WAR BY 2050? FOR SURAT CITY (GUJARAT)

Year	*Population*	*Water need*	*Available*
2000	25 lakh	450 MLD	300 MLD
2050	50 lakh	900 MLD	? ? ?

Source of River will give maximum 700 MLD. Then shortage of 150-200 MLD will be standing demand in 2050. With the growing demand of water, artificial ground water recharging of aquifer by storm water reuse or surface water is the only answer for this water crisis.

5. MATHEMATICS OF GROUNDWATER FLOW–UNCONFINED AQUIFER

The flow of phreatic water in an unconfined aquifer above an impervious base is complicated by two factors: 1. a change in the saturated thickness accompanying the variation in piezometric level (h) and 2. The presence of recharge by rainfall (P).

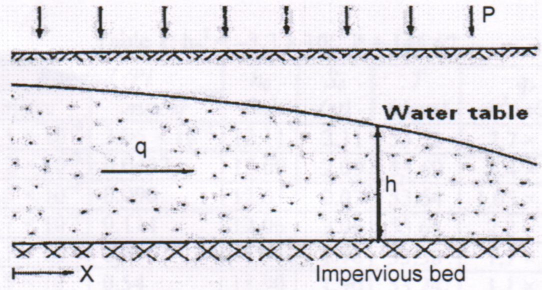

Fig. 1: One-dimensional Flow in an Unconfined Aquifer above an Impervious Base.

With the notation of Figure1 the equations of flow becomes

Darcy $q = -kh\dfrac{dh}{dx}$ and Continuity $\dfrac{dq}{dx} = P$

Integrated $q = Px + C_1$ (i)

Put value of q in Eq. (i) $kh\,dh/dx = Px + C_1$

Combined $hdh = -\left(\dfrac{Px + C_1}{k}\right)dx$ and

Integrated $h^2 = -\dfrac{P}{k}x^2 - \dfrac{2C_1}{k}x + C_2$ (ii)

In which the integration constants must be calculated from the boundary conditions.

For the recharge scheme of Figure 2, again consisting of three wells fully penetrating the saturated thickness of the aquifer these boundary conditions $x = 0$, $h^2 = h_n^2 = C_2$. It means that height of water table (h_n) and water mound (h_o) is at same level. Put $x = 0$ in Eq. (i) then $q = -q_0 = C_1$

Put x = maximum L, and values of C_1, C_2, in Eq. (ii) we get

$$h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2 \quad (1)$$

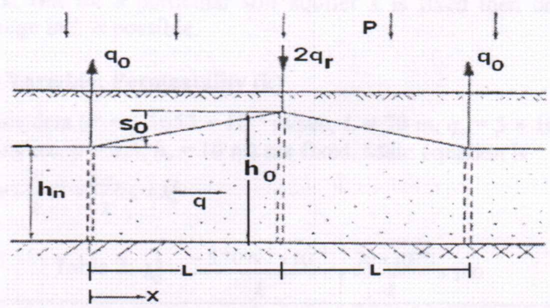

Fig. 2: Artificial Recharge by Fully Penetrating Wells in an Unconfined Aquifer above an Impervious Base

It means that height of water table (h_n) and water mound (h_o) is at same level. Put $x = 0$ in Eq. (i) then

By the quadratic form of this equation, formula for the drawdown $s_0 = h_0 - h_n$

Detention time (T) of the water in the aquifer can be calculated by, $T_{days} = p\,H\,L/\,q_0$

The natural recharge by rainfall can be calculated by, $q_r = P \times L$

As per above recharge scheme equation for recharge rate Q_r into a completely penetrating well for unconfined aquifer (Figure 3)

$$Q_r = \frac{\pi\, k\,(h_w^2 - h_0^2)}{\ln(r_0 / r_w)}$$

Though the equations are similar to discharge equations but the recharge rates are seldom equal to pumping rates .In this recharge well injecting the water (from roof top or storm water reuse) into bore holes. Water flow is the reverse of the pumping well but its construction may or may not be the same. If water is passed into a recharge well, a cone of recharge will be formed which is reverse of a cone of depression for a pumping well.

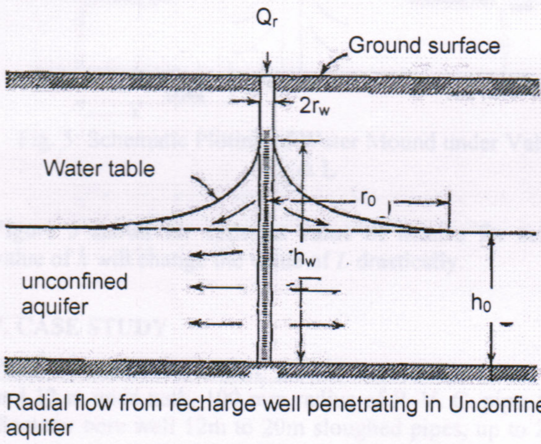

Fig. 3: Aquifer and Recharge Well

6. MATHEMATICAL FORMULATION RELEVANT TO GROUND WATER RECHARGE PROBLEM

For verifying dimension (shape) of water mound below recharge area, by trial & error varying all the variables like rainfall (P), permeability (k), distance between two recharge well (L), thickness of saturated soil strata (H) in Equation : 1

6.1 Variable: Rainfall (P)

Others parameters ($q_0 = 5 \times 10^{-5}$ m^3/m/sec, k = 0.15 × 10^{-3} m/sec, L = 70 m, h_n = 10 m) are fixed. Main equation is

$$h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2$$

Table 1: $h_0^2 = -3.3 \times 10^{-7}\,P + 146.67$

Rainfall (P)		h_0	S_0	T	q_r
m/sec	*mm/hr*	*(m)*	*(m)*	*(days)*	*m^3/m/sec*
1.1×10^{-9}	3.96×10^{-3}	12.11	2.11	53.72	7.7×10^{-8}
1.2×10^{-8}	0.0432	12.09	2.09	53.69	8.4×10^{-7}
2.5×10^{-8}	0.090	12.07	2.07	53.64	1.05×10^{-6}
3.17×10^{-8}	0.114	12.06	2.06	53.61	2.2×10^{-6}
1.1×10^{-7}	0.396	11.96	1.96	53.38	7.7×10^{-6}
1.5×10^{-7}	0.54	11.90	1.90	53.24	1.1×10^{-5}
1.2×10^{-6}	4.16	10.43	0.43	49.64	8.4×10^{-5}
1.3×10^{-6}	5.00	10.06	0.06	48.00	9.1×10^{-5}
1.7×10^{-6}	6.25	9.48	–0.52	47.34	1.19×10^{-4}
2.8×10^{-6}	10.00	7.48	–2.52	42.00	1.96×10^{-4}

Table 1 shows that rainfall increases, height of water mound decreases, drawdown also decreases. It means water percolates through aquifer and merges with ground water.

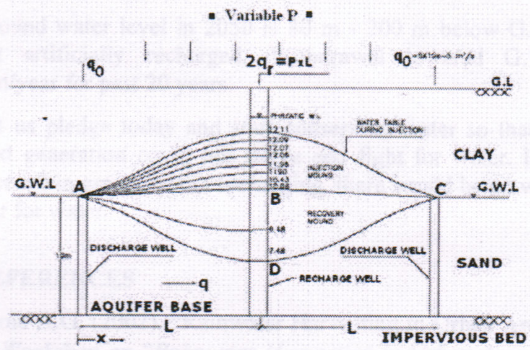

Fig. 4: Schematic Diagram Displaying Dynamic Water Table for Recharge (Injection) and Discharge (Recovery)

Remark: Figure 4 indicates ABCD zone for Surat city (Gujarat) maximum to minimum rainfall 10 mm/hr –5 mm/hr respectively. Also shows that ABCD Zone is the storage of water during recharges and water detent in aquifer about 42 to 48 days. Highlighted given value of k and L, rainfall more than 10 mm/hr, ho become negative. Then either modified L or k. But for a particular soil aquifer k is fixed then only change in L is possible.

6.2 Variable: Permeability (k)

Other data ($P = 1.1653 \times 10^{-6}$ m/sec, L = 70 m, $q_o = 5 \times 10^{-5}$ m^3/m/sec, p = 0.3, h_n = 10 m) are fixed. Main equation is

$$h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2$$

Table 2: $h_0^2 = \dfrac{-5.70997 \times 10^{-3}}{k} + \dfrac{70 \times 10^{-4}}{k} + 100$

K (m/sec)	h_0 (m)	S_0 (m)	T (days)
Clay (1.16×10^{-6})	34.85	14.85	109
Sand + silt (5.36×10^{-5})	11.16	1.162	51
Gravel (5.78×10^{-4})	10.11	0.11	48.88
Coarse sand (1.74×10^{-3})	10.03	0.03	48.68
Sand + Gravel (1.1×10^{-2})	10.006	0.006	48.60

Table 2 shows that Permeability of the soil aquifer increases, draw down decreases, also decreases detention time of water in aquifer.

6.3 Variables: Permeability (k) and Distance (L)

Other datas ($P = 0$, $h_n = 10$ m, $q_0 = 5 \times 10^{-5}$ m^3/m/sec, $L = 0$ to 70 m) are fixed. Main Equation is

$$h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2$$

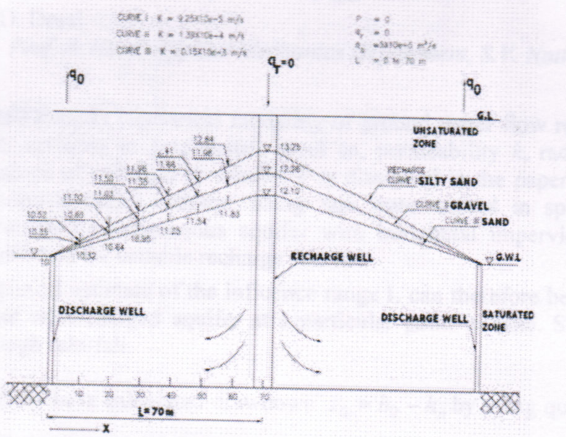

Fig. 5: Schematic Ploting of Water Mound under Values of k & L

Figure 5 shows for constant value of head s for selected value of k will change the value of L drastically.

7. CASE STUDY

Panas Recharge Bore Well: S.M.C (year 2000) 1.5 m depth and 12 m wide tank, 100 mm radius of P. V. C. pipe, 0.2 m diameter bore well 12m to 20m sloughed pipes, up to 20–22 cm Gravel pack. Recharge rate $qr = 5.5 \times r \times h \times k_{av}$

$$= 5.5 \times 0.1 \times 18 \times 10^{-3}$$

$$= 35.6 \text{ m}^3\text{/hr Say } 30 \text{ m}^3\text{/hr.}$$

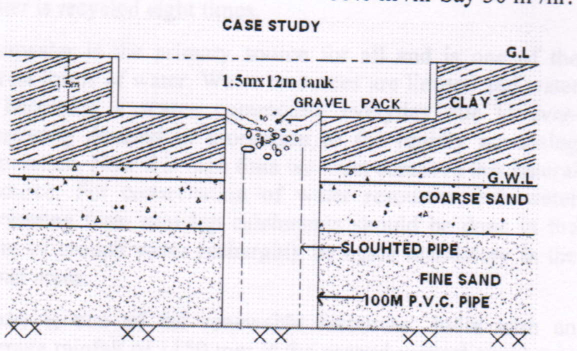

Fig. 6: Recharge Borehole System at Panas

Remark: Adopting underground tank of 1.5 m × 12 m & Bore well type of recharge system, water is recharged at the rate of 30 m^3/hr. It gives satisfactory rise in water table level.

8. CONCLUSIONS

We can capture and recharge 65,000 litters of rain water from a 100 sq. m. size roof-top and meet drinking and domestic water requirements of a family of 4 for 160 days. The rain water collected in a 2 m^3 sump could be sufficient for 5 members of a family for direct use for a period of 4 to 5 days.

Since water is a community resource and hence needs community participation unless we join hands to recharge ground water through water harvesting methods, the water scarcity will be havoc and damaging the environment to a large extent.

Ground water level in 2050 is 80 m - 200 m below G.L. If not artificially recharged, Withdrawal lowered G.W.L. 1 m/year for past 20 years.

Let us pledge today and start conserving water so that our next generation could not starve and fight for water. If we succeed in ground water recharging, there would be no world war for water.

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