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Computational and Mathematical Aspect of Artificial Ground Water Recharging into Unconfined Aquifer

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Abstract

CARE FOR GROUND WATER BEFORE IT BECOMES RARE therefore CATCHES WATER IN EVERY POSSIBLE WAY AND EVERY POSSIBLE PLACE IT FALLS.

Mathematical aspect 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 discuss in the paper.

In this mathematical expression, inducing ground water mounding through artificial recharge using rainwater stored in specially designed basin. This technique can be implemented to an unconfined stratified aquifer with horizontal impervious base receiving vertical recharge. Authors have established various correlations for suitable recharge scheme.

Added would be the tremendous pressure to meet water requirements for other purposes such as for industrial use, environment and ecological management etc. emanating from population growth, the land use policies, degradation of water resources and depletion of aquifers in the country. Need for water conservation is deeply felt worldwide. Rooftop rainwater harvesting system is looked upon as one of the most feasible and economical ways of water conservation. With increasing problem of water scarcity, planning and designing rooftop rainwater harvesting is gaining wider importance to meet ever-increasing water demand and ground water depletion.

Facts and figures say that 1 mm rain that falls on 1 sq.m. Area amount to 1 liter of water. Therefore, we can very well guess the quantity of rainwater available in our area. Therefore, we should adhere to the practice of collecting and holding the rainwater that falls in our residential premises. We should learn the art of holding, deflecting and percolating the rainwater.

A long-term perspective planning of water resources is required to meet various competing demands on sustainable basis. Artificial Recharging of Ground water into soil aquifer is a Viable- Economical solution. An author have set up case studies for recharge scheme at site and gives satisfactory results, few are listed.

Keywords: Unconfined aquifer, artificial recharge, numerical modeling, permeability, radius of influences, draw down.

Water - Towards Vision 2050

The groundwater boom is turning to bust. 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 largely.

Hypothesis of Water Availability

In the year 1970 - Freely available, in the year 1980 - 50 paisa/glass, in the year 1999 – Rs.12 /liter and may be in the year 2050 – Rs.100 /liter.

Population and Water Needs

The population of India is estimated to reach a figure between 1.5 billion and 1.8 billion by the year 2050. The UN agencies have put the figure at 1.64 billion. It is now generally accepted that the countries with annual per-capita water availability of less than 1,700 (m^3) are water stressed and less than 1000 m^3 as water scarce. India would therefore need 2,788 billion cubic meters (b.c.m.) of water annually by 2050 to be above water stress zone and to avoid being water scarce country required 1,650 b.c.m.

Table 1 shows the demand of water is increasing day-by-day resulting in extraction of more and more groundwater, such extraction is in far excess of net average recharge from natural sources, and hence it necessitates artificially recharging the aquifers to balance the output.

Table 1: Per capita per year availability and utilizable surface water in India.

Sr. No.	Year	Population (in million)	Per-capita surface water availability m^3	Per-capita utilizable surface water m^3
1	1951	361	5410	1911
2	1955	395	4944	1746
3	1991	846	2309	816
4	2001	1027	1902	672
5	2025 (Projected)	a. 1286 (low growth) b.1333 (high growth)	1519 1465	495 ----
6	2050 (Projected)	a. 1346 (low growth) b. 1581 (high growth)	1451 1235	421 ----

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. Proper planning and management of 10 years could post pone water crisis by few more years.

Facts

Water Conserve or fight War by 2050 ? For Surat city : (Gujarat, India)

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 is the only answer for the water crisis.

Level of ground water during past 20 years.

Year	Water level
1970	10 m below G. L.
1999	30 m - 60 m below G. L.
2050	80 m - 200 m below G. L. **If not recharged now**

Research Work

The problem of ground-water mound formation below artificial recharge basins has been investigated by many researchers - Baumann (1952) Glover (1960) Hantush (1967) Hunt (1971). Warner et al. (1989 Basak (1982) has presented closed-form analytical solutions of the Boussinesq equation for mound build-up and depletion in an island aquifer in response to constant recharge and evaporation over the entire aquifer. The water table at the boundary of the aquifer is assumed invariant with time. Zomorodi (1991) has shown solutions For different one-dimensional and two dimensional flow models, Rai and Singh (1981, 1995) and Rai et al. (1994) have also shown that variations in the rate of recharge have significant effects on the growth of groundwater mounds.

Empirical Approach

Radial flows from recharge well penetrating in unconfined aquifer recharge rate of well can be estimated from empirical approach. Deep aquifers can be recharged by a *recharge well*. Its 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. if surface conditions permit. The recharge wells are just like ordinary production wells. In this recharge well injecting the water into boreholes, the water is therefore fed into recharge wells by gravity or may be pumped under pressure to increase recharge rate, if surface conditions permit. The recharge wells are just like ordinary production wells.

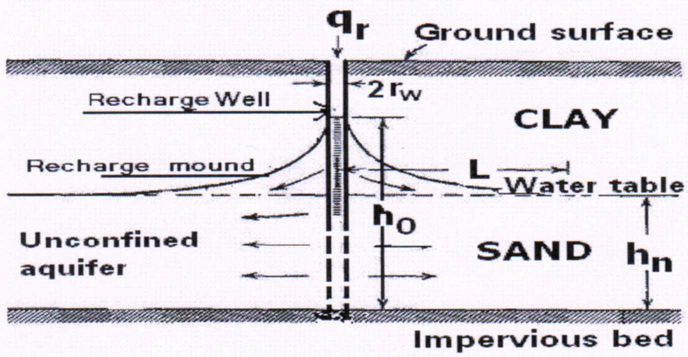

Figure 1: Aquifer and Recharge Well.

Radial flows from recharge well penetrating in unconfined aquifer, Recharge rate of well can be estimated from empirical formula as :

$$q_r = \frac{h_0^2 - h_n^2}{2L} \times k$$

Where,

h_o = Height of phreatic water table above aquifer base in well (m).
k = Co-efficient of permeability (m/sec)
L = Influence zone or Radius of spread (m)
r_w = Radius of well (m)
s_0 = Drawdown of water level (m) = **($h_0 - h_n$)**
q_r = Recharge rate (m^3/sec) or (m^3/m/sec) **(P x L)**
h_n = Height of G.W.T.

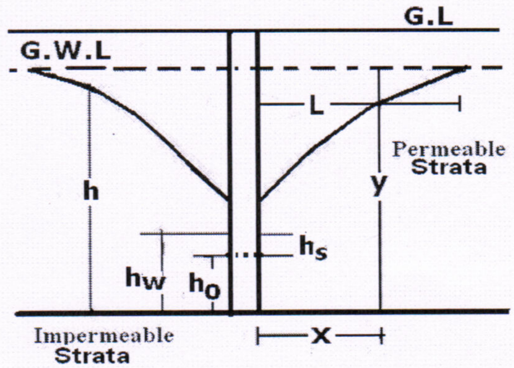

Figure 2: Fully Penetrating Recharge Well in Unconfined (Gravity flow) Aquifer.

(Manfred R. Hausmann (1990)

- Discharge (recharge) quantity $Q = \dfrac{\pi k(h^2 - h_w^2)}{\ln(L/r)}$
- The phreatic surface $y^2 - h_w^2 = \dfrac{Q}{\pi k}\ln\left(\dfrac{x}{r}\right)$
- Equation for drawdown (recharge) curve

$$h^2 - y^2 = \frac{L-x}{L}(h^2 - h_w^2)$$

- Estimating the free discharge height

$$h_S = \begin{cases} 0.5(h-h_0) & \text{(Boulton)} \\ \dfrac{(h-h_0)^2}{2h} & \text{(Ehrenberg)} \\ (h-h_0)e^{(-\alpha/\pi)} & \text{(Juhasz)} \end{cases}$$

$$Where\ \alpha = \frac{\sqrt{k}}{15}\ \frac{2\pi\, r\, h_0}{Q}$$

For design of pumping or recharge, well 'L' should know with reasonable accuracy, as it is indirectly proportional to 'q_o' or 'q_r'. In the well formula, 'L' appears in a logarithmic term and a good assessment of co-efficient of permeability (**k**) is much more important than the value of influence range (**L**).

Mathematics of Groundwater Flow --Unconfined Aquifer

Symbols Used in Mathematical Formation:

h = Height of phreatic water table above aquifer base (m).
H = Saturated thickness of aquifer (m)
k = Co-efficient of permeability (m/sec)

kH = Co-efficient of transmissivity (m^2/sec)
L = Radius of spread (m)
p = Porosity (dimensionless) = 0.3
P = Amount of rainfall (m/sec)
q = Underground flow per unit aquifer – width (m^3/m/sec)
Q = Total flow of well (m^3/m/sec)
r = Radius of well (m)
R = Effective radius of flow domain (m)
s = Drawdown of water level (m)
t = Time (sec)
v = Velocity (m/sec)
ϕ= Piezometric head (m)
q_r = Recharge rate (m^3/sec) or (m^3/m/sec) (P x L)

NUMERICAL APPROACH for an Unconfined Aquifer above an Impervious Soil

The flow of phreatic water in an unconfined aquifer above an impervious base is complicated by two factors: *a change in the saturated thickness accompanying the variation in Piezometric level and the presence of recharge by rainfall.*

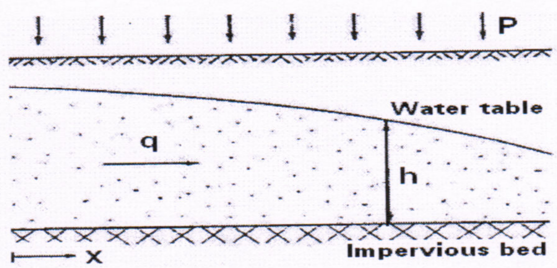

Figure 3: One-dimensional flow in an unconfined aquifer above an impervious base.

With the notation of Figure 1 the equations of flow becomes (Huisman L. and T. N. Olsthoorn (1983))

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

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

For the recharge scheme of Figure 3, 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

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

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

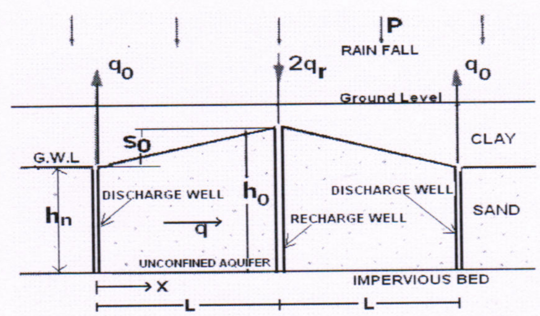

Figure 4: Artificial recharge by fully penetrating wells in an unconfined aquifer above an impervious base.

By the quadratic form of this equation, formula for the drawdown $s_0 = h_0 - h_n$ **(2)**

The design of an artificial recharge scheme is mainly governed by Detention time (T) : *The time, the water is meant to stay underground and the amount of water that can be stored in the aquifer.* $T_{days} = p\ H\ L\ /\ q_0$ .The natural recharge by rainfall can be calculated by, $q_r = P \times L$.

Mathematical Formulation Relevant to Ground Water Recharge Problem

For study 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).

- Variable: Rainfall (P): Others parameters are fixed ($q_0 = 5 \times 10^{-5}$ $m^3/m/sec$, k= 0.15×10^{-3} m/sec, L=70 m, h_n=10 m)

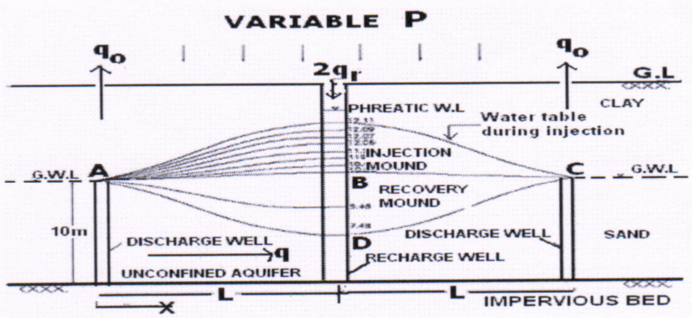

Figure 5: Schematic Cross Section Displaying Dynamic Water Table for Recharge (Injection) and Discharge (Recovery)

Fig. 5 shows that rainfall increases, height of water mound decreases. Drawdown also decreases. It means water percolates through aquifer and merges with ground water. Also indicates ABCD zone for SURAT city (GUJARAT, INDIA) maximum to minimum rainfall 10 mm/hr to 5 mm/hr respectively. The storage of water during recharges and water detent in aquifer is about 42 to 48 days.

- *Variables: permeability (k) and distance (L): Other data are fixed (P = 0, h_n = 10 m, $q_0 = 5x10^{-5}$ $m^3/m/sec$)*

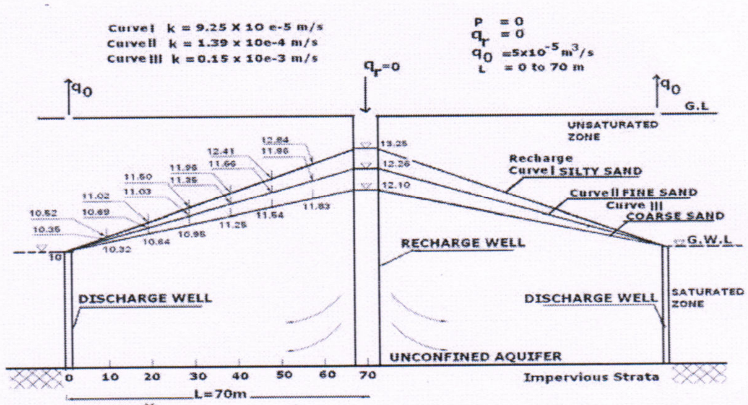

Figure 6: Schematic Plotting of Water Mound under Different Values of ‘k’ and ‘L’.

➢ *Variable: L (Distance between two wells): Other datas are fixed (P = 1.1653 x 10^{-6} m/sec, L = 70 m, q_o = 5 x 10^{-5} m3/m/sec, p = 0.3, h_n = 10 m, k = 0.15 x 10^{-3} m/sec)*

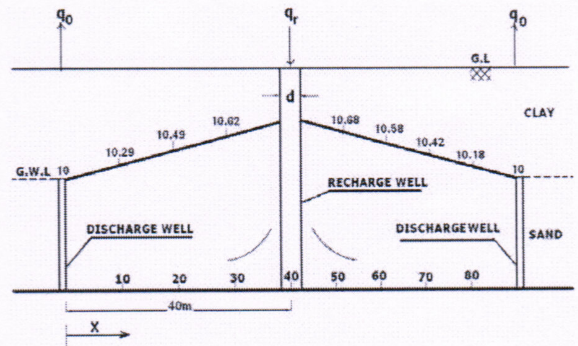

Figure 7: Schematic Plotting of Water Mound under Different Values of 'L'.

Findings of Installed Recharge Bore Well System

Correlation Between r, h and Qr.

➢ Correlations between radius of Recharge bore well (**r**) and Depth of pervious strata (aquifer) (**h**) with capacity of borehole (**Q_r**)

- Overall capacity of Borehole Q_r = k A i t
- Coarse sand permeability 10^{-3} m/sec (3.6 m/hr)
- Area of Borehole = 2πrh
- Hydraulic gradient i = h/L = 20/30
- Time = 1 hr
- Q_r = 3.6 x (2πrh) x h/L x 1 = 3.6 x (2πrh) x 0.67 x 1

Q_r = 15 r h

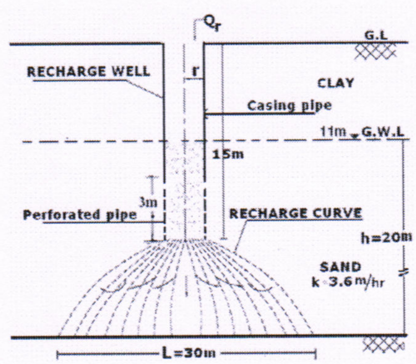

Figure 8: Recharge Bore Well With Open Bottom.

Table 2: $Q_r = 15 \times r \times h$.

h (m) / r (m)	4m	6m	8m	10m	20m
0.05 m	3 m^3/hr	4.5 m^3/hr	6 m^3/hr	7.5 m^3/hr	15 m^3/hr
0.075	4.5	6.7	9	11.25	22.5
0.1	6	9	12	15	30
0.15	9	13.5	18	22.5	45
0.45	27	40.5	54	67.5	135

Remark: Recharge capacity of borehole is directly varies with radius of bore well (r) and thickness of pervious strata (h).

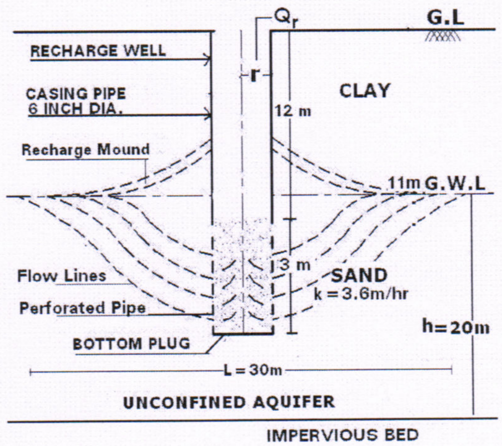

Figure 9: Installed Recharge Bore Well With Bottom Plug.

- Figure 9 shows due to bottom plug flow lines moves in upward direction and merge with G.W.L i.e. it form hump (recharge mound) above the G.W.L and hence it increases water table.

Case Studies

Authors have set up many case studies related to recharge systems, till date it gives satisfactory results. Few are listed below.

(1) Radhe Krishna Market, Surat, Gujarat, India

$q_r = \frac{(h^2 - h_w^2)}{2L} k$ (Assumed data = 10 m^3/hr, L = 30 m), $10 = \frac{[12.3^2 - 6.5^2]}{2x30} \cdot q_r\, k$

$k = \frac{10 \times 2 \times 30}{18.8 \times 5.8} = 5.5$ m/hr   Say 1.5×10^{-3} m/sec.

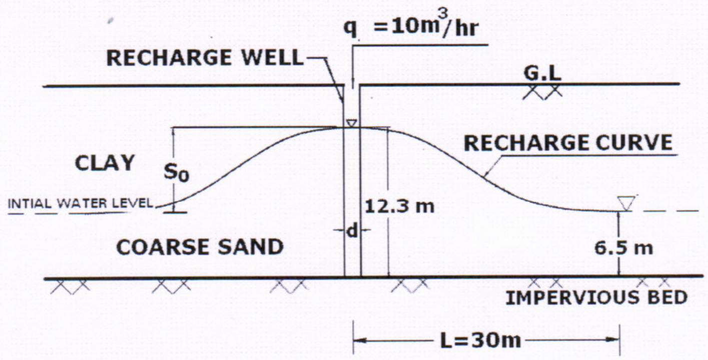

Figure 10: Recharge Well At Radhe Krishna Market, SURAT.

Author has suggested recharge well system at this site and observed that water level rises satisfactory and permeability of soil (k) is confirm (coarse sand) with original value given in soil investigation report..

Results of the numerical revealed in above casestudy that a reduction in the growth of the ground-water mound due to decrease in the recharge rate or due to reduction in the radius of recharge basin is most pronounced below and in the vicinity of recharge basin and its magnitude decreases with distance away from the center of the well.

(2) Panas Recharge Bore Well: S.M.C, Surat, Gujarat, India

Provide 1.5 m depth and 12 m wide tank, 100 mm radius of P. V. C. pipe, 12m to 20m sloughed pipe 20 to 22 cm Gravel pack.

Recharge rate $q_r = 5.5 \times r \times h \times k_{av} = 5.5 \times 0.1 \times 18 \times 10^{-3} = 35.6$ m^3/hr Say 30 m^3/hr.

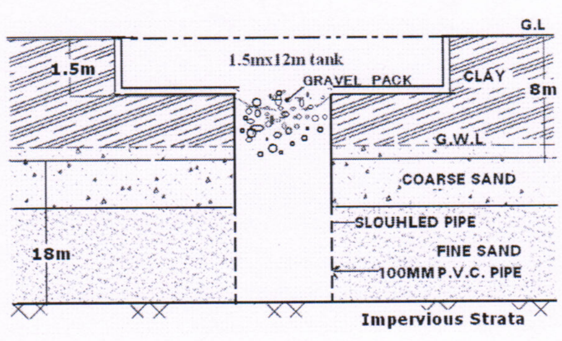

Figure 11: Recharge Borehole System at PANAS, Surat.

➢ *At this site author has adopted underground Tank & Bore-well type of recharge system and evaluated recharge rate of water is 30 m^3/hr. It gives satisfactory rise in water table level. Also, improve the quality of the water.*

Concluding Remarks

- From **Table 2 & Related equation** of recharge rate one can predict recharing capacity of well for its own site(with the known value of depth of pervious strata & diameter of well)
- You 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.
- 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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