

Evaluation of Hydraulic Conductivity for the Estimation of Artificial Groundwater Recharge Rate

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Abstract: Water resources are limited and are 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. Authors have discussed hydraulic conductivity affects drastically on recharge rate of recharge borewell. Results obtained from field constant head, falling head permeability tests and simulation model test authors have proved by suggesting correlation of recharge rate of well Q_r with radius of well r , hydraulic conductivity of aquifer k and pervious soil strata below ground water level H . Constant head permeability test gives approximately same value with original value of field test so constant head permeability test is preferable. Authors have highlighted From numerical equations, analytical approach, computer algorithm and field test that hydraulic conductivity is a prime and predominant geometrical design governing parameter for any recharging technique. If the hydraulic conductivity of the aquifer is not in permissible range prescribes in I.S. code of practice then purpose of artificial recharge to ground water will not fulfill.

Key words: Transmissibility • Radius of influence • Porosity • Recharge well • Roof top recharge system • Precast step well • Rainfall • Runoff

INTRODUCTION

Scarcity of water resources and climate change would be the major emerging issues in the next century. These issues would be followed by problems of desertification and deforestation, poor governance at the national and global levels, the loss of biodiversity and population growth.

In earlier days water was present in plenty and a demand was less, thus it was many times taken for granted that it is abundant. However with rapid increase in industrialization and development, an acute scarcity of water is felt. Despite of the fact that water is scarce, it is still being used recklessly further aggravating the water scarcity problem.

Water supply in urban areas is heavily dependent on ground-water resources. Industrial and population growth and increasing agricultural activities often lead to over-exploitation of local ground-water resources in order to meet the rising demand for water.

Lowered water tables can lead to many problems such as decrease in the water reserves and intrusion of contaminated water in bodies of potable water. The conservation of water can be efficiently made by adopting artificial recharging methods of soil aquifer by reuse of rainwater conjunction with storm water drainage system. Suitable recommendations for rooftop rain water harvesting have also been made for future benefits of society.

Water is one of the most essential natural resources for sustaining life and it is likely to become critically scarce in the coming decades, due to continuous increase in its demands, rapid increase in population and expanding economy of the country. There is a need for increasing the availability of water and reducing its demand. For increasing the availability of water resources, there is a need for better management of existing storages and creation of additional storages by constructing suitable artificial recharging structures. The availability of water resources may be further enhanced by rejuvenation of drying lakes, ponds, tanks, recharge well or bore and increasing the artificial means of groundwater.

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. More than 2000 million people would live under conditions of high water stress in year 2050.

Water is one of the renewable resources. India with an average rainfall of 1150mm 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. Around one-third of the world population now lives in countries with moderate to high water stress.

Necessity and Purpose: The demand of water is increasing day-by-day resulting in extraction of more and more groundwater and 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.

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 and surface rainwater harvesting is gaining wider importance to meet ever-increasing water demand and ground water depletion.

Everybody should ceaselessly prefer and follow the method of *Artificial Ground Water Recharging*. Depending upon the rainfall, one can take into account the availability of annual rainwater that falls on each and

everyone's roof tops, residential premises and property. Facts and figures say that 1 mm rain that falls on 1 Sq.m. Area amount to 1 liter of water. So 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 rain water that falls in our residential premises.

Artificial recharge is the planned engineered system human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction, also improves the quality of water like pH, hardness, alkalinity, turbidity. Artificial recharge also has application in wastewater disposal, waste treatment, secondary oil recovery, prevention of land subsidence and storage of freshwater within saline aquifers, crop development and stream flow augmentation.

Impacts of Ground Water Recharging: In urban areas, adequate space for surface storage is not available, water levels are deep enough to accommodate additional rainwater to recharge the aquifers, rooftop and runoff rainwater harvesting is ideal solution to solve the water supply problems for better tomorrow. Fred Lee recommended the evaluation of the potential water quality problems associated with a proposed groundwater recharge project along with quantification of the aquatic chemistry of the recharge operation. Contributing to that evaluation are a compilation and evaluation of existing water quality data, development of a monitoring program to collect reliable data to describe the chemical characteristics of the recharge and aquifer waters over time. To assure sustainability, studies must show that the hydrological, ecological and other impacts of groundwater utilization are minimal.

Hypothesis of Water Availability: In year 1970 - water was freely available. In year 1980 - 50 paisa / glass. In year 1999 - Rs. 12 / liter. In year 2050 - may be Rs. 100 / liter. Thus there is immediate need to conserve every source of usable water for the future generation. 10 years planning could post pone water crisis by few more years.

Ground Water Level in Past 20 Years (Refer Table 1)

- Withdrawal lowered G.W.L. 1 m /year for past 20 years.

Table 1: Statistics of location of water level

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

Table 2: Variable Permeability (k)

Aquifer permeabilityk (m/sec)	Rise of water level h_0 (m)	Draw down S_0 (m)	Detention time T (days)
Sandy silt (1.16×10^{-6})	34.850	14.850	109.00
Silty sand (5.36×10^{-5})	11.160	1.162	51.00
Fine sand (5.78×10^{-4})	10.110	0.110	48.88
Coarse sand (2.0×10^{-3})	10.030	0.030	48.68
Sandy Gravel (1.1×10^{-2})	10.006	0.006	48.60

Necessity of Determination of In-situ Permeability Test:

- Determination of the water permeability (hydraulic conductivity) is important for agricultural-as well as for environmental soil research. On the basis of the permeability factor (k-factor) irrigation and drainage systems are designed. Also with respect to the extend of the spreading of possible pollution the permeability factor of the soil is of great importance. The permeability of the soil can be determined in the laboratory as well as directly by field test.
- The hydraulic conductivity is defined as the proportionality constant k. The conductivity (k) is not a true constant but a rapidly changing function of water content. Even under conditions of constant water content, such as saturation, k may vary over time due to increased swelling of clay particles, change in pore size distribution due to classification of particles and change in the chemical nature of soil-water. However, for most purposes, saturated conductivity (k) can be considered constant for a given soil. The k value for flow in the vertical direction will not necessarily be equal to k in the horizontal direction.
- For alluvial deposit k_h / k_v can vary widely in layer stratification so it is important parameter for design of ground water recharge well system.
- In-situ Constant head permeability test gives reliable value which is confirmed by all other approaches. So In-situ constant head permeability test is preferred for evaluation of recharge rate of bore well system. This will incorporate influence of strainer and casing used well.
- For alluvial stratified deposits alternate layer of sand and silt in space average k value could vary in horizontal and vertical flow conditions. The field constant head test there fore gives appropriate value for adoption in design of recharge bore well system.

Effect of Permeability K from Analytical Approach:

Case 1: Rise of water level in recharge well for *unconfined aquifer* due to artificial recharge can be estimated from analytical quadratic form of this equation [1] with the variation of permeability (Refer Table 2). Other data are assumed as $P = 1.1653 \times 10^{-6}$ m/sec, $L = 70$ m, $q_0 = 5 \times 10^{-5}$ m³/sec, $p = 0.3$, $h_n = 10$ m.

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

Symbols used in analysis.

- h_0 = Rise of water level above aquifer base (m).
- H = Saturated thickness of aquifer (m)
- k = Co-efficient of permeability (m/sec)
- L = Influence zone or Radius of spread (m)
- p = Porosity of sand (dimensionless) = 0.3
- P = Amount of rainfall (m/sec)
- q_0 = Underground flow per unit aquifer - width (m³/sec)
- r = Radius of well (m)
- s_0 = Drawdown of water level (m) = ($h_0 - h_n$)
- t = Time (sec)
- q_r = Recharge rate (m³/sec) or (m³/sec) = (P x L)
- h_n = Height of natural G.W.T.
- T = Detention time = pHL / q_0

- Permeability of the soil aquifer increases, draw down decreases, also decreases detention time of water in aquifer. It shows the significant effect of permeability on design parameter of recharge system.

Case 2: Plotting recharge curve with variation of permeability (k) with other datas are assumed ($P = 0$, $h_n = 10$ m, $q_0 = 5 \times 10^{-5}$ m³/sec, $L = 0$ to 70 m) (Refer Figure 1).

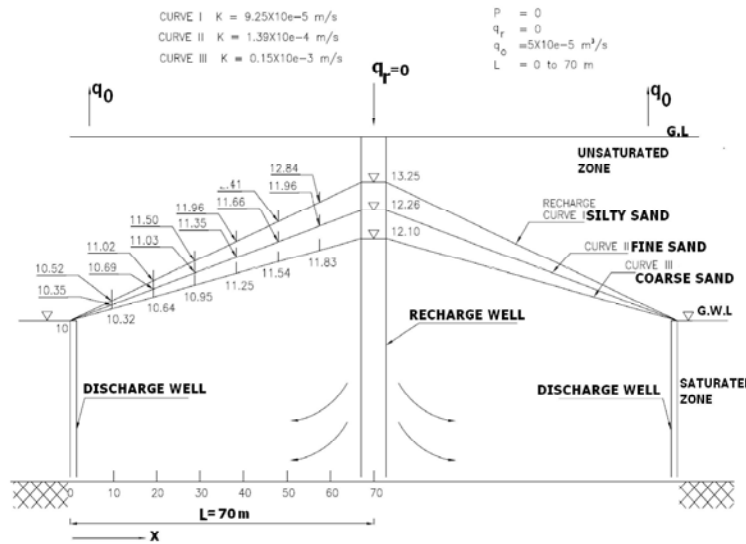


Fig. 1: Plotting of recharge mound with different values of k

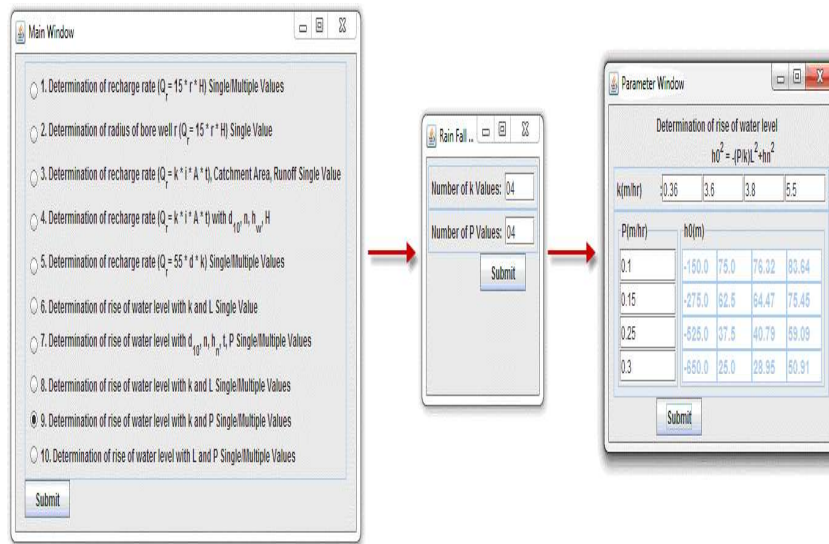


Fig. 2: Determination of rise of water level in bore well with k variable

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

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

k = 0.15x10 ⁻³ m/sec	h ₀ ² = 0.666L + 100	curve - III,	Coarse sand
k = 1.39x10 ⁻⁴ m/sec	h ₀ ² = 0.719L + 100	curve - II,	Gravel
k = 9.25x10 ⁻⁵ m/sec	h ₀ ² = 1.081L + 100	curve - I,	(Sand + silt)

Effect of Permeability K from Computer Algorithm: Determination of rise in bore well in equation 1 withdrawal of water from well q_0 is considered as zero and equation can be modified as: (Refer Figure 2, 3).

$$h_0^2 = -\frac{P}{k}L^2 + h_n^2 \quad (3)$$

Figure 3 shows that for the constant value of recharge rate, rise of water level in well is increases with permeability increases.

From Expermental Aspect (Field Tests)

In-Situ Falling Head Method: The soil stratum is homogeneous and isotropic in which the intake point is placed is of infinite thickness. The permeability by falling head method [2] in an uncased bore hole should be computed by the following relations (Refer Figure 4, Table 3).

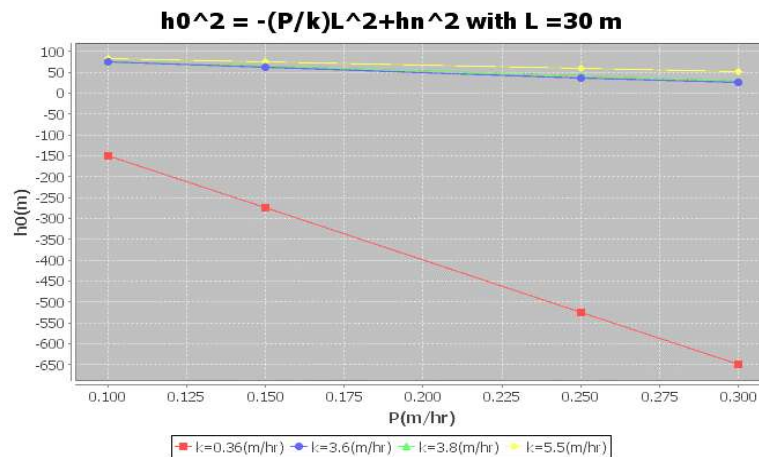


Fig. 3: Determination of rise of water level in well with k variable

Table 3: Observations from in-situ falling head test

Head (m)		Time (min.)		Permeability	Remark
h_1	H_2	t_1	t_2	k (m/sec.)	
10.65	10.30	5	10	3.85×10^{-7}	$k_{ave} = 4.45 \times 10^{-7}$ (m/sec.) SANDY SILT
10.65	9.88	5	15	4.33×10^{-7}	
10.30	9.40	10	15	1.05×10^{-7}	
10.65	9.40	5	20	8.57×10^{-7}	

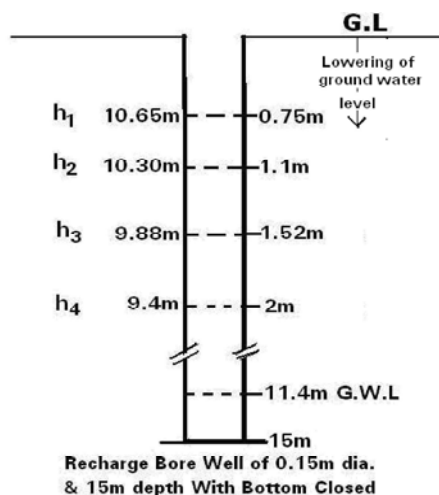


Fig. 4: In- situ Falling Head Permeability Test

$$k = \frac{d^2}{8L} \log_e \frac{L \log_e h_1/h_2}{R(t_2 - t_1)} \quad (4)$$

Where

- k = Coefficient of permeability (m/sec)
- d = Diameter of intake pipe (stand pipe) = 0.15 m
- L = Length of test zone = 3 m
- h_1 = Head of water in the stand pipe at time t_1 above piezometric surface,

h_2 = Head of water in the stand pipe at time t_2 above piezometric surface,

R = Radius of Bore hole = 0.15 m

In-Situ Constant Head (k_h or k_v) Derived Using Available Different

Approaches of Researchers (Refer Table 4)

Remarks:

- In-situ Falling head test does not give reliable value of permeability (k) so this test is not recommended for evaluation of recharge rate of well. Permeability obtained from constant head test will be preferred.
- Table 3 gives soil classification as sandy silt and Table 4 gives same soil classification as coarse sand. It means classification and value of permeability is interpreted from Table 4 preferable for recharge system than In-situ falling test.
- Value of permeability $k = 1 \times 10^{-3}$ m/sec (3.6 m/hr) is confirmed with Allen Hazen, U.S.B.R. Earth Manual formula, Darcy's, Rainfall Simulation Model test gives approximately same value of recharging capacity of bore well indicates the assumed value of k from constant head is preferable for determination of recharging capacity of design well.

Table 4: Calculated values of permeability by different approaches

Method	Formula	Value of km/sec	References
Emperical formulas (kv)	(a) $k = \frac{qr}{2.75 \times d \times h}$	1.1 x 10 ⁻³	U.S.B.R. Earth Manual [3] (541-46)
	(b) $k = C_1 \times \frac{Q}{H}$	3.9 x 10 ⁻³	
	(a) $k = \frac{qr}{5.5 \times r \times H}$	1.2 x 10 ⁻³	Alamsingh [4] IS 5529 Part I (1985) (6-14) [2]
	(b) $k = C_1 \times \frac{Q}{H}$	4.0x 10 ⁻³	
	$q_r = \frac{h^2 - h_w^2}{2L} \times k$	3.0 x 10 ⁻³	Manfred R Hausmann [5] (150-181)
	Jacob's Approximation $L = 1.5\sqrt{\frac{k \times m \times t}{S}}$	1.7 x 10 ⁻³	Manfred R Hausmann (150-181)
	Kozeny Time Dependent Expression $L = 1.5\sqrt{\frac{k \times h \times t}{n}}$	1.9 x 10-3	Manfred R. Hausmann (150-181)
Numerical Approach (kv)	$h_0^2 = -\frac{P}{k}L^2 + \frac{2q_0}{k}L + h_n^2$	2.1 x 10 ⁻³	Huisman and Olsthoorn (33-79) [1]
Analytical Approachd 10 and D20 Criteria (kave)	1. k _{D20} = 1.2 mm = 150,000 Ft / Year	1.5 x 10 ⁻³	Chart Given by[6] Creager, Justin & Hinds (158-178)
	2. k _{D10} = 0.8 mm = 400,000 Ft /Year	4.0 x 10 ⁻³	G. Leonard (291-295) Desai M.D (1-4)
	3. k = C (D ₁₀) ²	1.0 x 10 ⁻³ (3.6 m/hr)	Allen Hazen and U.S.B.R. Earth Manual
In-Situ Pumping-in			
Recharge Trial Test(kh)	$k_h = \frac{Q_r}{A \times i \times t}$	1.0 x 10 ⁻³ (3.6 m/hr)	Darcy's equation
Soil is classified as coarse sand having (k _{ave}) is 3.6 m/hr suitable for aquifer			

Soil is classified as coarse sand having (k_{ave}) is 3.6 m/hr suitable for aquifer

Table 5: Soil Stratification

Particlesize (mm)	Depth 11m	Depth 12.12 m	Depth 15 m	Depth 17m
4.75	88	99.0	94	96.0
2	60	70.3	48	54.5
0.6	7	9.9	15	17.2
0.425	3	8.9	10	11.1
0.212	0	1.0	3	3.0
0.075	0	0.0	1	1.0

Determination of Permeability of Soil (K) by Simulation

Technique [7, 8]: Referring field data experiment is carried out on *RAINFALL SIMULATION SYSTEM* for validation of the actual field permeability value which is determined by various approaches. Actual depth wise soil data and its particle size analysis is highlighted in Table 5 and Figure 5.

Recharge well is installed in unconfined aquifer. Experiment conducted on this model catchment's tank of size 2 m x 1 m x 0.2 m using soil strata mentioned in Figure 5 to confirm the value of permeability of aquifer with the determined value of project site.

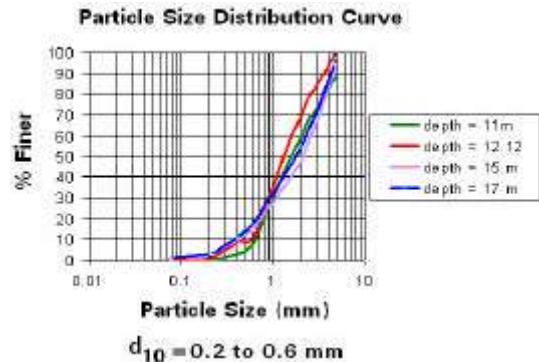


Fig. 5: Particle size distribution curve

Referring Dupuit's and Thiem Formula [9] and data obtained from prepared simulation model at Water Resource Laboratory.

$$k = \frac{Q_0}{2\pi h(s_1 - s_2)} \log_n \left(\frac{r_2}{r_1} \right) \quad (5)$$

Where

h = Thickness of aquifer = $2 - 0.5 = 1.5$ m

Q_0 = Discharge through V - notch with rainfall 3 lpm = 23.5 lpm = 3.9×10^{-4} m³/sec.

k = Permeability of aquifer

$s_1 = s_2$ = Piezometric level as draw down at radius r_1 and r_2 respectively measured on Multi bank Manometer.

$s_1 - s_2$ = 11 mm = 0.011 m at 0.112 m, 0.33 respectively

$$k = \frac{3.9 \times 10^{-4}}{0.011 \times 2 \times \pi \times 1.5} \times 1.0986 = 4 \times 10^{-3} \text{ m/sec.}$$

$$k_{\text{experimentally}} = 4 \times 10^{-3} \text{ m/sec.}$$

$$k_{\text{Analytical}} = C \times d_{10}^2$$

$$= 100 \times (0.04)^2$$

$$k_{\text{Analytical}} = 1.6 \times 10^{-3} \text{ m/sec.}$$

$$k_{\text{actual at project site}} = 1 \times 10^{-3} \text{ m/sec.}$$

$$k_{\text{fallin head}} = 4.45 \times 10^{-7}$$

- Value of permeability is confirmed with analytical, simulation model test and actual field test value. But falling head test gives different value of k and soil classification so it is not recommended for design of recharge system.

Evaluation of Recharge Capacity of Well Q_r with Diameter (D) and Permeability (k) ($Q_r = 55 \times d \times k$):

Recharging flow Q_r by constant head recharge in borehole can be calculated by using

$$Q_r = 2.75 \times d \times h \times k \quad [10]$$

Where

d = Diameter of bore (m)

H = Depth of pervious sand strata depth maximum 20m below G.W.L. (m)

k = Co-efficient of permeability (m/sec)

$$Q_r = 2.75 \times d \times 20 \times k$$

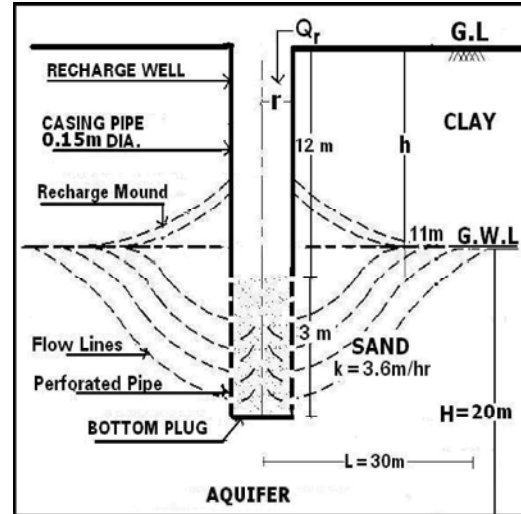


Fig. 6: Recharge Well With Bottom Plug

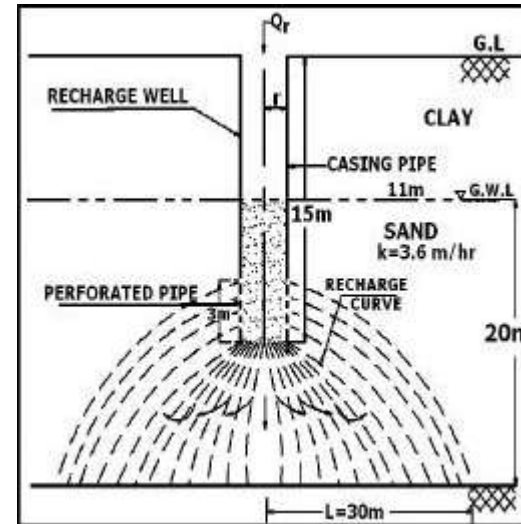


Fig. 7: Recharge Well With Open Bottom

$$Q_r = 55 \times d \times k \quad (6)$$

(Refer Figure 6, 7, 8 and Table 6)

- Decrease in permeability recharging capacity of well is reduces.
- If we required more designed recharge rate then provide larger diameter bore instead of installing two smaller diameter of bore.

Findings of the derived equation: (Refer table 7)

Table 7 shows permeability effects directly on recharge rate of well. With the same diameter of well (0.15m diameter), recharge rate of well is decreases with k decreases.

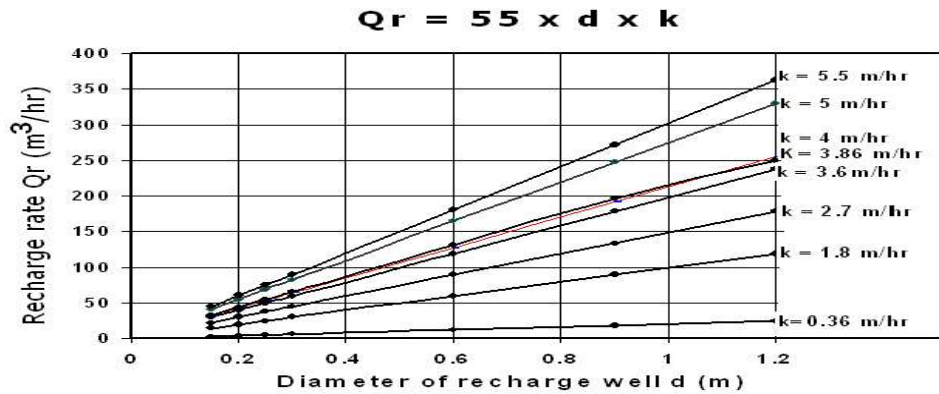


Fig. 8: Recharge capacity of borehole Q_r versus Diameter of recharge well (d) with variable permeability of aquifer (k)

Table 6: Calculated Values of $Q_r = 55 \times d \times k$

k m/hr	5.5	5	4	3.86	3.6	2.7	1.8	0.36
d (m)	Qr m³/hr							
0.15	45.37	41.25	32.67	31.84	29.7	22.28	14.85	2.97
0.2	60.50	55.00	44.00	42.46	39.6	29.70	19.80	3.96
0.25	75.62	68.70	54.45	53.08	49.5	37.13	24.75	4.95
0.3	90.00	82.50	65.34	63.69	59.4	44.55	29.70	5.94
0.6	181.15	165.00	130.68	127.38	118.8	89.10	59.40	11.88
0.9	272.00	247.00	196.02	191.07	178.2	133.65	89.10	17.82
1.2	363.00	330.00	250.22	254.76	237.6	178.20	118.80	23.76

Table 7: Out puts of derived equation $Q_r = 55 \times d \times k$ [11]

k m/sec	1.5×10^{-3}	1.4×10^{-3}	1.1×10^{-3}	1.07×10^{-3}	1×10^{-3}
k m/hr	5.5	5	4	3.86	3.6
d (m)	Qr m³/hr				
0.15	♦ 45.37	41.25	32.67	♣ 31.84	♥ 29.7
0.2	60.50	55.00	♠ 44.00	42.46	39.6
0.25	75.62	68.70	54.45	● 53.08	49.5
0.3	90.00	82.50	65.34	63.69	59.4
0.6	181.15	165.00	130.68	127.38	118.8
0.9	272.00	247.00	196.02	191.07	178.2

Case studies highlighted below where recharge system is installed:

♥ AMD, SVNIT ● SCIENCE CENTER ♠ PANAS ♣ RADHE KRISHNA ♦ GARDEN SILK MILL

Concluding Remarks:

- Based on results obtained from analytical approach, computer algorithm and experiments (field tests) one can justify that hydraulic conductivity k of aquifer is important and prime factor for design any type of recharge system.
- In-situ constant permeability test gives reliable value which is confirmed by all other researcher approaches, therefore In-situ constant permeability test is preferred for evaluation of recharge rate of bore well system.
- Equation 6 shows recharge rate of well directly varies with d and k . Table 6 shows that with small variation in aquifer permeability, the recharge rate is drastically changed. If permeability of the aquifer is known than proper diameter of well can be adopted from Table 6.
- Our derived work is justify by Equations 6 and Table 6 that for installation recharge bore / well system permeability of soil (k), diameter of well (d), depth of pervious strata (H) are design governing parameters. Besides that for a given recharge system Geology of aquifer, casing material (PVC, Concrete) and strainer/openings will also influence recharging capacity of bore and cost aspects (economics) of whole system.
- Uncertainties in the values of radius of influence L because it is difficult to determine L precisely because of the sensitivity of permeability factor k . For this reason and because of variability of natural soil deposits, field tests for permeability are highly recommended. Although it seems most desirable to determine k in-situ.

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