Jour. Agric. Physics, Vol. 2, No. 1, pp. 13-17 (2002)

Effect of Recharge Head and Particle Size Distribution of Soil Formation on Injection Rate of Recharge Well

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ABSTRACT

This study was conducted to determine the effect of recharge head and particle size distribution of the soil near the strainers of the injection wells on ground water recharge rate. Potential surface runoff available for ground water recharge from an area of 2.95 ha was estimated using Curve Number method. Total estimated surface runoff for four months of monsoon season was 5333 m^3 day^{-1} The mean injection rate at site-1, where injection well was installed below ground water table (saturated zone), was 21.2 $m^3 day^{-1}$ and at site-2, where injection well was installed above water table (vadose zone), it was 8.04 m^3 day^{-1}. The results from the present study have shown that recharge rate increased with increase in recharge head and the incremental increase (increase in injection rate per meter increase in recharge head) was 20 $m^3 day^{-1} m^{-1}$ and 8.66 $m^3 day^{-1} m^{-1}$ for the well installed in the saturated and the vadose zone respectively. It was also found that injection rate was more for the well constructed in the saturated zone than for the injection well that was installed in the vadose zone as, soil formation of the former case consisted of higher proportion of coarse sand mixed with gravel.

Key words: ground water recharge, injection well, surface runoff, Curve Numbers

Introduction

Over exploitation of ground water in several parts of the country has resulted in declining ground water table, a reduction in supply, saline water intrusion, increased cost of water lifting and even local land subsidence in some places. Some of the states/union territories facing a severe problem of water table decline are Tamil Nadu, Madhya Pradesh, Uttar Pradesh, Maharastra, Rajasthan, Gujarat, Punjab, Haryana, Karnataka, National Capital Region of Delhi, Chandigarh and Pondicheri. According to State of Arts Report on Consumptive use of Surface and Groundwater (Saxena, 2000), in the last 40-50 years, ground water table has depleted by 10-50 meter in some districts of Tamilnadu. In some districts of western Uttar Pradesh, the rate of decline of water table is as high as 0.66 meter per year and at least 20 per cent of the area in Uttar Pradesh located out side the canal commands has shown a decline in the water table of about 7 meters during the period 1972-85. Similarly, in Madhya Pradesh, the long-term decline of the ground water table has been as high as 13.05 meters.

Based on the norms of Central Ground Water Board (CGWB, 2000), about 3.53 % and 2.53 % of the 7063 blocks/talukas/mandals/watersheds of the country have been classified as over exploited and dark blocks, respectively. Dark or critical blocks increased at a continuous rate of 5.5 per cent per year over the period of 1984-85 to 1992-93. At this rate, it is estimated that roughly 36 per cent of the blocks in the country would be either dark or critical by A.D. 2017-18 (Moench, 2000).

Artificial ground water recharge has been recognized as one of the important strategies of ground water management to counter over exploitation. It reduces or even reverses the declining levels of ground water, protects fresh water in coastal aquifers against saline water intrusion and stores monsoon runoff for future use. Artificial ground water recharge is accomplished mainly through harvesting of surface runoff or imported water from other sources. Since long distance transport of water for recharge is difficult and expensive, emphasis is given to in-situ rain water harvesting and recharge. In India this method is feasible because most of the annual rainfall is received in some 100 hours of heavy downpour, providing little time for natural recharging of aquifer.

Materials and Methods

Selection of sites

Surface runoff generated from an area of 2.95 hectares of the Division of Agricultural Engineering, IARI, New Delhi was for used artificial groundwater recharge. The climate of the area is subtropical and semiarid with hot dry summer and cold winter. The mean annual temperature is 24^{0}C. Mean annual rainfall is 710 mm of which, as much as 75 per cent occur during the monsoon season. Soils of the study area represent a typical alluvial profile of Jamuna origin. According to USDA classification, the soil belongs to sandy loam textural class.

Estimation of surface runoff

Potential surface runoff for ground water recharge was estimated using Soil Conservation Service (1972) method also known as Curve Number (CN) method. Weighted CNs under different Antecedent Moisture Conditions (AMC) were determined based on land use pattern, hydrologic soil group and antecedent moisture content (5 consecutive day rainfall total). The land use pattern of the area is consists of buildings and roads (52%) and lawns (48%). The hydrologic soil group of the area is B. The weighted CNs under AMC-I, AMC-II and AMC-III were found to 69, 84 and 92 respectively. The daily runoff from the 10 years daily rainfall data (1992-2001) was estimated for the monsoon season. The daily runoffs obtained in each month were summed to get monthly runoff (Table 1).

One day and two and three consecutive days maximum runoff were determined for different return periods using Plotting Position formula to design the storage capacity of tank for recharge and is given in Table 2. However, the actual design of storage tank was not done using the values of Table 2 due to lack of adequate space at the selected site.

Table 1. Mean monthly rainfall and runoff

Month	Rainfall (mm)	Runoff (mm)	Runoff (m^3)
June	98.27	18.75 (19.08)*	553.13
July	197.62	52.50 (26.56)	1548.75
August	210.81	71.93 (34.13)	2121.94
September	111.65	37.60 (33.67)	1109. 20
Total	618.35	180.78 (29.24)	5333.01

*Figures in parenthesis indicates runoff in %

Drilling and installation of injection wells

Two injection wells were installed at the selected sites. At site-1, a bore of diameter 152.4 mm was drilled till the depth of 13.72 m from the bottom of storage tank. In this bore a strainer (slotted pipe) of length 4.57 m and diameter 102 mm was installed below the water table (i.e. in saturated zone) and the rest upper portion was joined by casing pipe of length 6.10 m and diameter 102 mm (Fig. 1a, b). Water table was 8.60 m below ground level. At site-2, a bore of diameter 152.4 mm was drilled till the depth of 7.32 m from the bottom of water storage cum intake tank. A strainer of length 4.57 m and diameter 102 mm was installed above the water table (i.e. in Vadose zone) and kept in position with the help of clamps (Fig. 2a, b). The annular space between the bore and the strainer was filled with gravel to enhance the recharge rate and to prevent clogging of the strainer in both the cases.

Table 2. 1 day, 2 days and 3 days consecutive max. runoff for different return period

Return period (years)	1 day max. runoff (m^3)	2 days max. runoff (m^3)	3 days max. runoff (m^3)
1	708	708	708
5	1578	2208	2212
10	2456	3304	3487

Two storage cum intake tanks were constructed at site-1 and site-2 to store surface runoff for ground water recharge. Their dimensions are given in Table 3. These tanks were provided with suitable inlet for runoff water. A filter made of very fine net of synthetic material was used to prevent the entry of sediments, debris and other foreign material into the injection well.

Table 3. Dimension of storage cum intake tanks

Location	Dimensions
Site-1	1.60 m × 1.60 m ×1.0 m
Site-2	1.20 m × 1.20 m × 0.90 m

Recharge head

At site-1, where the injection well was penetrating beyond the ground water table, the distance between the water level in storage tank and groundwater table was taken as head for recharge.

At site-2, where the injection well was installed above the ground water table, the depth of water in

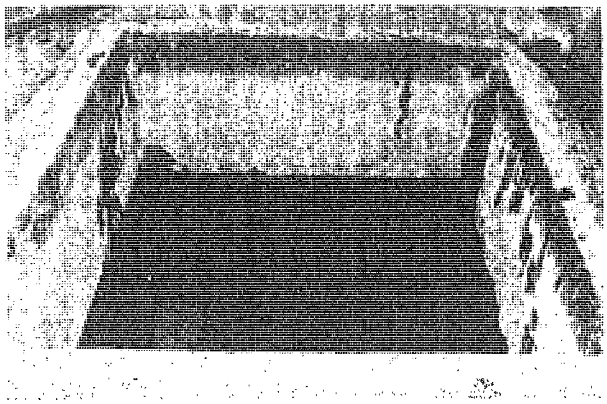

Fig.1a. Injection well at site-1

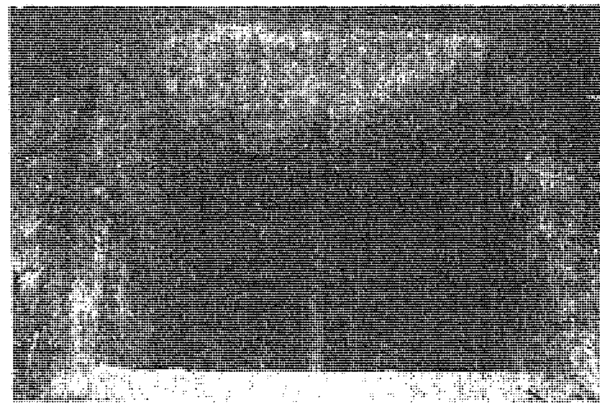

Fig.2a. Injection well at site-2

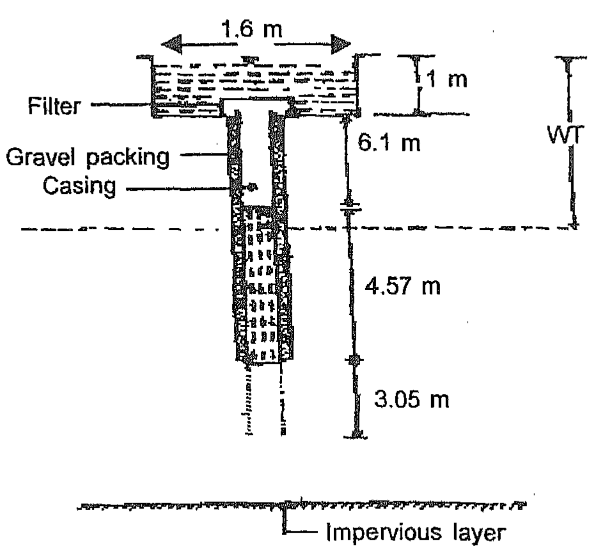

Fig.1b. Sectional view of injection well at site-1

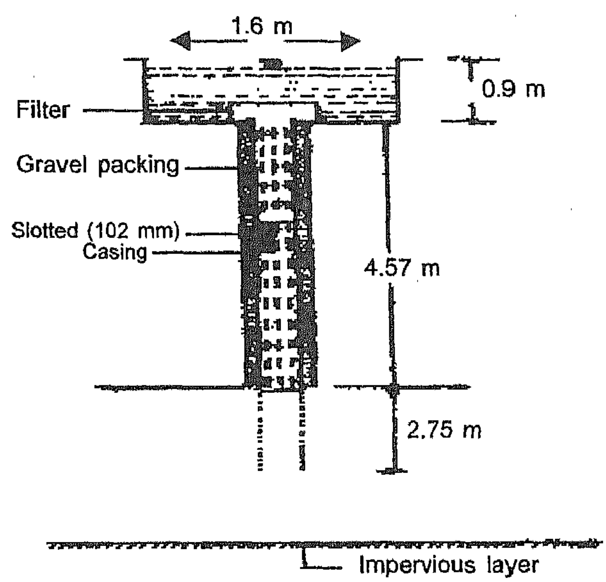

Fig.2b. Sectional view of injection well at site-2

the storage tank and half of the depth of the injection well was taken as the recharge head for groundwater recharge. In other words it is depth of water column above the center of the strainer to the water level in the storage tank.

Recording of depth of recharge

The depth of water injected by well in one hour were observed and recorded from the corresponding decline in the water level in the storage tanks for different depths of water column (recharge heads) for recharge. At site-1 observations were taken for four different heads (7.85 m, 8.10 m, 8.35 m and 8.60 m) and at site-2, for three heads (2.50 m, 2.75 m and 3.0 m). Recharge rates for different heads were calculated by multiplying the depth of recharge and the surface area of the storage tank and dividing by the time taken for the water level decline.

Result and discussion

Performance evaluation of the injection wells installed in the saturated and the vadose zones was done in terms of variation of injection rate with recharge heads and particle size distribution of the recharge zone.

At site-1, where the injection well was installed in saturated zone (below water table), mean injection rate was 21.2 m^3 day^{-1}. It was observed that for every 0.25 m increase in recharge head, the injection rate was increased by 5 m^3 day^{-1} from the preceding rate (Table 4). Similarly at site-2, the mean injection rate was observed to be 8.04 m^3

Table 4. Injection rate for the well installed in saturated zone under different heads

Recharge head (m)	Injection Rate (m^3 day^{-1})
7.85	13.20
8.10	18.14
8.35	23.33
8.60	29.38

day^{-1}. In this case the increase in injection rate varied between 1.73 m^3 day^{-1} and 2.60 m^3 day^{-1} (mean 2.165 m^3 day^{-1}) for every 0.25 m increase in head (Table 5). It was also observed that for every increase of 0.25 m in head, the injection rate was increased by about 1.30 times from its preceding injection rate for both the saturated and the vadose zone conditions.

Table 5. Injection rate for the well installed in vadose zone under different heads

Recharge head (m)	Injection Rate (m^3 day^{-1})
2.50	6.05
2.75	7.78
3.00	10.37

The maximum recharge rate for the injection well constructed in the saturated zone at site-1 was 29.4 m^3 day^{-1} at a head of 8.60 meter (Table 4). At site-2, the maximum recharge rate at a head of 3.0 meters was 10.4 m^3 day^{-1} (Table 5). The Maximum combined capacity of both the injection wells was about 40 m^3 day^{-1}, which is far less than the annually expected one-day maximum runoff of 708 m^3 of 1-year return period and hence more injection wells are needed to handle the available runoff in one day or additional storage tank should be constructed to store excess runoff for gradual recharge.

The incremental increase in the injection rate (increase in injection rate per meter increase in recharge head) for the well constructed in the saturated zone was 20 m^3 day^{-1} m^{-1} whereas, for the well installed in the vadose zone, it was about 8.66 m^3 day^{-1} m^{-1}. The variation of injection rate with head is shown in Fig. 3 & 4. This difference in the incremental increase as well as in the absolute values are attributed to the difference in particle size distribution of the soil near the strainer. The sieve analysis of the soil samples taken from the zone of installation of the strainer for both the cases showed a marked difference in their composition. Particle size distribution of soil sample taken from saturated zone at site-1 consisted of about 50 per cent coarse sand (mean diameter > 0.60 mm) mixed with gravel (Fig. 5) whereas, for the soil sample taken from the vadose zone at site-2, 30 per cent was the coarse sand and 70 per cent was the fine sand (Fig. 6). The uniformity coefficient (d60/d10) for soil taken from the saturated zone was found to be about 10 (d10 = 0.08 mm and d60 = 0.8 mm). However, it could not be determined from the particle size grading curve of vadose zone soil sample taken from site-2 because the d10 value was just zero. It can be safely said that the soil samples taken from the saturated zone at site-are more uniform than the soil samples taken from vadose zone of site-2 since uniformly graded sand has higher porosity than a less uniform, fine and coarse mixture. Thus from the above discussion it is revealed that both, the particle size distribution of soil of the zone of installation of the strainer and recharge head affect the recharge rate significantly.

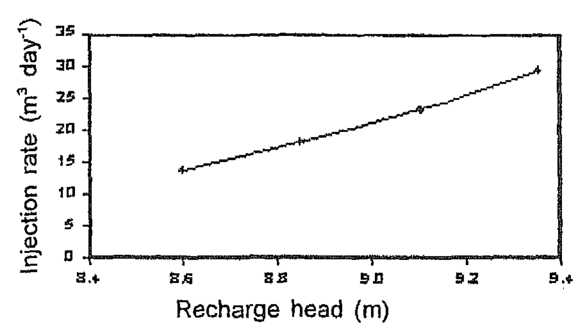

Fig. 3. Variation of injection rate with head for the well constructed in saturated zone

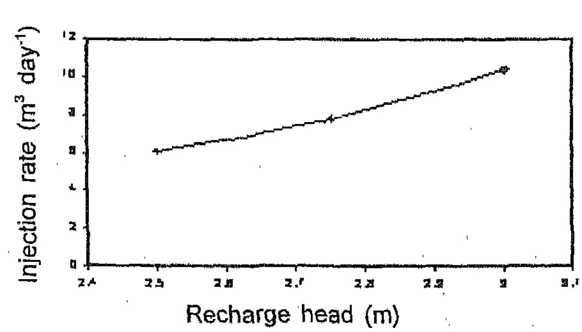

Fig. 4. Variation of injection rate with head for the well constructed in vadose zone

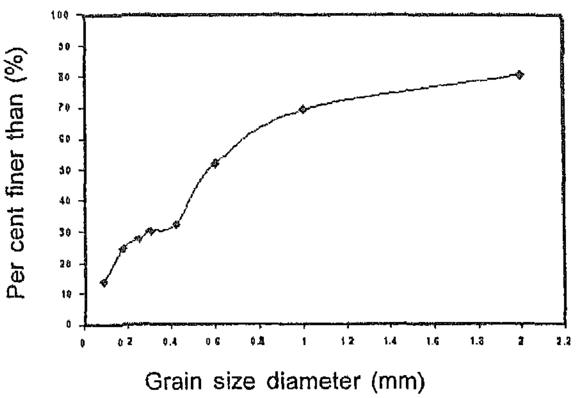

Fig. 5. Grading curve of the soil formation of the saturated zone at site-1

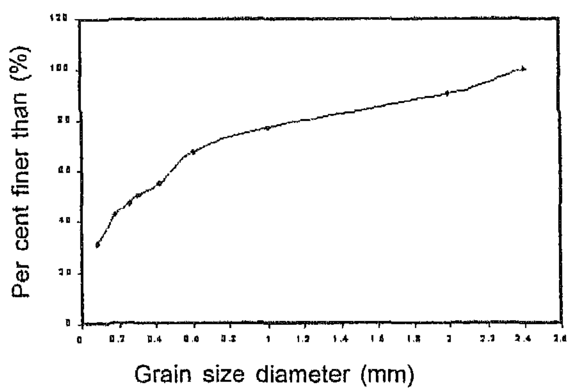

Fig. 6. Grading curve of the soil formation of the vadose zone at site-2

Conclusion

The mean injection rate at site-1 under saturated condition, was 21.2 m^3 day^{-1} and at site-2 under unsaturated condition, it was 8.04 m^3 day^{-1}. The Maximum combined capacity of the two injection wells was about 40 m^3 day^{-1} which was far less to recharge the 1-day maximum runoff of 708 m^3 of 1-year return period and hence, more injection wells are needed to handle the available runoff in one day or additional storage tank should be constructed to store the excess runoff. Injection rate was higher for the well penetrating the saturated zone as compared to the well terminating in the unsaturated zone because in the former case the soil in the vicinity of strainer was coarser and more uniform in comparison to the latter. Injection rate increased with increase in the recharge head and incremental increase in injection rate was found to 20 m^3 day^{-1} m^{-1} and 8.66 m^3 day^{-1} m^{-1} for well installed in the saturated and the vadose, zone respectively.

Acknowledgement

The authors are thankful to Director, Director (R) IARI, New Delhi for approving the project. The authors are thankful to other staffs for providing all type of support to carry out the different experiments.

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