Determining the recharging capacity of an injection well in a semi-confined alluvial aquifer

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Artificial recharge to groundwater is steadily assuming importance in the wake of the decline in water level in several parts of the country. Recharge through an injection well is the most suitable option of artificial recharge for semi-confined and confined aquifers, especially in urban and industrial areas as it requires little space. Recharging capacity of a well is an important criterion in deciding the number of recharge structures required for large-scale planning of artificial recharge. The present work focuses on determining the recharging capacity of a well in a semi-confined alluvial aquifer in the middle Ganga Plain, wherein it has been found that the actual recharging capacity is lesser than the product of the well-specific capacity and available pressure head.

Keywords: Alluvial aquifer, groundwater, injection well, pressure head, recharging capacity.

A RECHARGE well is an essential structure for recharging a confined or semi-confined aquifer. The recharge well is also referred to as an inverted well because the movement of water in it is in the reverse direction to that of a pumping well. Artificial recharge through recharge well is well suited for urban and industrial areas, as it requires little space. Experience from different parts of the world reveals that aquifers can be recharged successfully over long periods through this technique and areas with existing large-yield production wells are better suited for well injection[1]. Recharge capacity of a well is the maximum rate at which it can take in and dispose off water admitted at or near its upper end, and can be approximated by the product of the specific capacity and the available pressure head[2]. Available pressure head of a recharge well is the vertical distance between the ground surface and water level in the well. Recharge through a well takes place by forced injection. This is generally viewed as a mirror image of pumping from a well[3]. However, it has been demonstrated through field experiments that the quantum that could be injected is much less than that which could be pumped out owing to the exponential decrease in the recharge rate with time against the possible constant rate of pumping[3,4]. Decrease in the recharge rate with time is attributable to several factors like clogging of the well screens, air binding in the pores of the aquifer, incrustations of screen opening, obstruction by bacterial slime and algae, and base-exchange and other chemical reactions between source water, formation water and formation material[5]. Recharge rates have been found to vary widely from 0.2 to 2 million litres/day. Case studies documenting the actual recharge rate determined through field studies are limited from India. Artificial recharge through wells in India was attempted in 1976, where an experiment was conducted at Hansol, near Ahmedabad, to study the feasibility of adopting siphon principle to recharge over-exploited, deep confined aquifers from phreatic aquifers[4].

The present study documents the experimental findings of a forced recharge experiment conducted on a semi-confined aquifer in Patna urban area representing a typical alluvial environment from middle Ganga Plain in Bihar, eastern India. Hydrogeological set-up of Patna urban area has been discussed in detail in the literature[6,7]. Here, the top sequence consists of an aquitard layer underlain by two aquifers (the shallower one is semi-confined in nature and the deeper one is a confined aquifer). The first semi-confined aquifer occurs between the depth of 55 and 150 m below ground level (bgl) and is separated from the deeper confined aquifers occurring beyond 160 m by a clay layer of 5–8 m thickness. The top aquitard consists of an admixture of clay, silt, caliche nodules (kanker) and fine sand with thickness varying between 20 and 60 m. This aquitard supports the dug wells and shallow hand-pumps. The thickness of the aquitard is more towards the eastern and central parts of the city. Exploration by the Central Ground Water Board (CGWB) has confirmed the continuance of the deeper aquifer up to over 220 m depth. At depths between 220 and 260 m, a clay layer has been encountered at few locations, the lateral continuity of which could not be ascertained throughout the urban area as the depth of drilling at other locations is within 220 m. The deeper aquifer consisting of medium to coarse-grained sand becomes gravelly towards the bottom.

The test was conducted on a well tapping the first semi-confined aquifer, hereafter referred to as the test well. Figure 1 provides the hydrogeological details of the experimental set-up and the electrical geophysical log (resistivity log and self-potential, i.e. SP). The resistivity of the top aquitard varies between 13 and 21 ohm-m for short normal, and 15 and 17 ohm-m for long normal indicating predominantly clayey nature of the formation up to 52 m depth. The SP variation in the aquitard layer has been recorded between –6 and 0 mV with respect to the shale baseline. For the semi-confined aquifer (aquifer I), the short normal resistivity varies between 41 and 61 ohm-m and the long normal resistivity varies between 45 and 69 ohm-m, indicating medium to coarse-grained sand. For the confined aquifer (Aquifer II), the short normal resistivity varies between 50 and 67 ohm-m and

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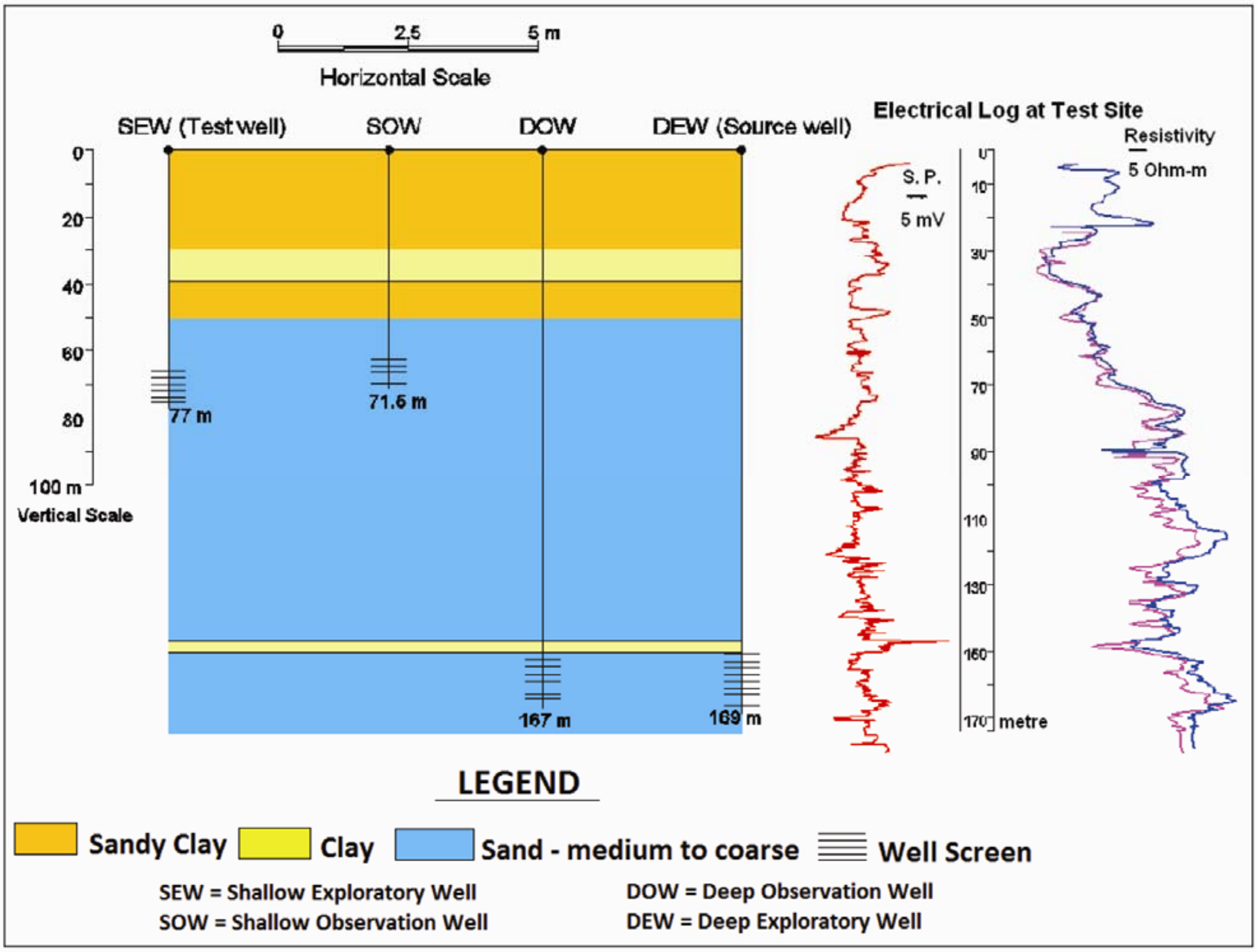

Figure 1. Schematic diagram showing the experimental set-up and electrical geophysical log at the test site.

the long normal resistivity varies between 57 and 71 ohm-m, thereby indicating coarse-grained sand. The geophysical logs match well with the drill cut samples.

During the experiment, water from a source well tapping the second confined aquifer was injected into the test well. Figure 1 also shows the horizontal distance between the source well and the test well along with the zones tapped in these. The depth of the test well (dia 0.254 m), marked as a shallow exploratory well (SEW), is 72 m with well screen length of 6 m placed between 63 and 69 m bgl. The source well (dia 0.305 m), marked as a deep exploratory well (DEW), is 172 m deep with screen length of 6 m placed between 163 and 169 m bgl. Preliminary yield test of 7 h duration was conducted individually on both DEW and SEW. For DEW, the drawdown at constant discharge of 158 m^3/h was recorded as 3.9 m, while for SEW the drawdown at constant discharge of 33 m^3/h was recorded as 3.71 m. The specific capacity of DEW and SEW is 40.5 and 9 m^3/h/m respectively. Marked variation in the specific capacity of the two wells is attributable to the difference in the diameter of the wells and the difference in the granularity of the formation tapped in both the wells.

The injection test was conducted in two cycles keeping the supply rate constant in each cycle. During each cycle, the change in hydraulic head with time was recorded for both the injection period and after stoppage of injection. Water levels were recorded in all the four wells shown in Figure 1. It was found that there was no effect of pumping of water from DEW on the water levels in SEW and the shallow observation well (SOW).

The discharge from the pumped well was measured by orifice–weir method[5]. In this method, a circular orifice centred in a circular metal plate is fixed at the outlet end of the discharge pipe which is provided with a transparent piezometer for recording the head in the piezometer. The ratio of the orifice to the discharge pipe diameter is pre-determined to ensure full flow through the orifice. The discharge rate is calculated according to the formula[8]

$$Q = 1.23\, Cd^2 \sqrt{gh}, \quad (1)$$

Table 1. Recorded data during the injection period and after stoppage of injection during the two cycles of the experiment

Injection phase		After stoppage of injection	
Time (sec)	Water level (m bgl)	Time (sec)	Water level (m bgl)
First cycle with constant supply rate of 5 litre/sec; initial water level (available pressure head): 7.39 m bgl			
30	4.66	100	5.46
100	3.84	160	6.3
115	3.36	220	6.4
120	2.72	275	6.84
140	2.14	290	6.99
155	1.73	300	7.02
165	1.27	315	7.08
		330	7.12
		350	7.17
		360	7.19
		410	7.29
		420	7.31
		435	7.33
		450	7.34
Second cycle with constant supply rate of 3 litre/sec; initial water level (available pressure head): 7.39 m bgl			
60	5.89	20	4.31
110	5.55	50	5.8
130	4.55	60	5.97
175	4.68	130	6.2
205	4.66	140	6.3
250	4.65	160	6.34
315	4.52	175	6.5
410	4.49	180	6.59
480	4.42	184	6.64
540	4.42	190	6.69
630	4.4	192	6.74
715	4.3	195	6.72
840	4.18	200	6.8
900	4.1	202	6.83
960	4.02	204	6.86
1020	4.02	206	6.88
1080	3.95	208	6.9
1140	3.9	209	6.93
1200	3.885	210	6.96
1260	3.815	220	6.98
1320	3.75	230	7
1380	3.74	235	7.3
1440	3.67		
1500	3.595		
1560	3.59		
1620	3.61		
1680	3.57		
1740	3.525		
1800	3.51		
1860	3.48		
1920	3.495		
1980	3.48		
2040	3.45		
2340	3.42		
2640	3.44		
2940	3.4		
3240	3.38		
3540	3.41		
3840	3.45		
4110	3.43		

Table 2. Ratio of change in head/available pressure head and recharge rate during the two cycles of the experiment

First cycle	Constant supply rate = 5 litre/sec	Second cycle	Constant supply rate = 3 litre/sec
Change in head/available pressure head	Recharge rate (litre/sec)	Change in head/available pressure head	Recharge rate (litre/sec)
0.015	0.653	0.007	0.826
0.016	0.663	0.008	0.853
0.019	0.671	0.011	0.881
0.022	0.691	0.014	0.900
0.024	0.713	0.027	1.011
0.030	0.762	0.030	1.037
0.035	0.760	0.037	1.093
0.039	0.763	0.042	1.138
0.055	0.786	0.050	1.185
0.058	0.817	0.054	1.221
0.061	0.851	0.074	1.260
0.065	0.848	0.134	1.473
0.069	0.845	0.147	1.530
0.072	0.848	0.261	1.870
0.074	0.851	0.388	2.539
0.078	0.852	0.392	2.642
0.082	0.853	0.402	2.687
0.090	0.873	0.402	2.721
0.093	0.854	0.405	2.760
0.097	0.869	0.418	2.781
0.104	0.883	0.434	2.806
0.111	0.889	0.445	2.815
0.123	0.888	0.456	2.822
0.144	0.921	0.456	2.833
0.150	1.038	0.465	2.839
0.163	1.079	0.472	2.845
0.194	1.360	0.474	2.852
0.217	1.480	0.484	2.856
0.418	2.228	0.493	2.860
0.480	3.202	0.494	2.866
0.545	3.225	0.503	2.869
0.632	3.029	0.512	2.882
0.710	3.101	0.514	2.872
0.766	3.151	0.514	2.877
0.828	3.122	0.517	2.885
		0.523	2.888
		0.525	2.891
		0.527	2.897
		0.529	2.894
		0.529	2.900
		0.533	2.902
		0.533	2.948
		0.535	2.924
		0.536	2.951
		0.537	2.914
		0.539	2.943
		0.540	2.931
		0.543	2.937

where Q is the discharge (m^3/s), d the diameter of orifice (m), h the height of water in the piezometer above the centre of the pipe (m), g the acceleration due to gravity (m/s^2) and C is a constant determined graphically, which depends on the ratio of orifice diameter to pipe diameter. This method stipulates that the discharge pipe should be horizontal; hence discharge during the experiment was measured after completion of every cycle of the experiment after removing the pipe attached to the discharge pipe for conveying the water from the pumping well to the test well.

The injection rate during the first and second experimental cycles was kept constant at 5 litres/sec and 3 litres/sec respectively. The variation of head with time was recorded during the injection period and after stoppage of injection. The volume of water injected into the well has been worked out as the difference between the total volume of water injected into the well (product of rate of injection and time) and the volume of water added as well storage (product of rise in head up to a given time and the cross-sectional area of the well). Recharge rate was obtained by dividing the volume injected during injection with the duration of injection. Table 1 shows the variation of water level with time recorded during the injection period and after stoppage of injection. Table 2 gives the ratio of the rise in head and the available pressure head for different recharge rates during the two cycles of the experiment.

Figure 2 is a bivariate plot of the ratio of the change in head and the available pressure head as abscissa and the recharge rate as ordinate. The curves obtained during both the cycles exhibit remarkable similarity for the head pressure ratio greater than 0.5, i.e. above this value the recharge rate plateaus off, indicating that the ratio of rise in head and the available pressure head is an important factor governing the recharging capacity of a well. Further increase in the ratio of rise in head and the available pressure head does not have any significant impact on recharge rate. For head pressure ratio <0.2, the recharge rate during the second cycle of experiment was higher than that during the first cycle. This may be due to the effect akin to well development process induced in the immediate vicinity of the test well during the first cycle of experiment. For head pressure ratio >0.2 and <0.5, there is general correspondence in the recharge rates observed during both the experimental cycles. The results also corroborate the earlier findings that recharge rate is much lesser that the pumping rate. The specific capacity of the test well has been determined as 9 m^3/h/m. As the available pressure head is 7 m in the present case, the approximate recharging capacity according to Meinzer's[2] approximation would be 63 m^3/h. However, in the present experiment, the recharging capacity has been determined as 11.52 m^3/h, which significantly differs from Meinzer's approximation.

The findings of the study can help in planning the desired number of recharge wells required for augmenting the groundwater resource through artificial recharge by adopting the technique of recharge pit with recharge well. It will thus be of immense interest for planning the artificial recharge projects in areas witnessing decline in

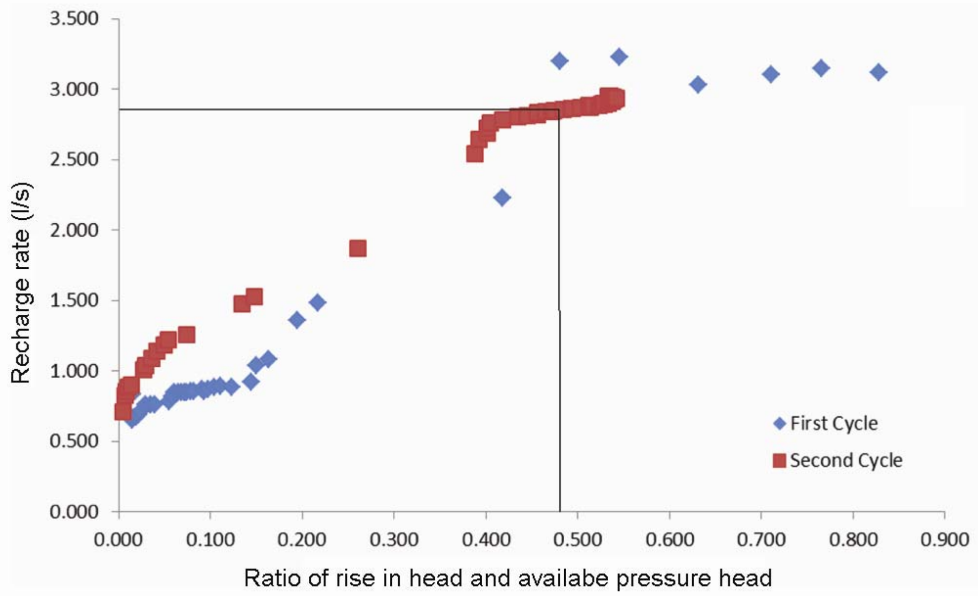

Figure 2. Plot showing the ratio of the change in head and available pressure head versus recharge rate.

hydraulic head. Similar investigations may be conducted in areas with deeper water levels to have an insight into the behaviour of the recharging capacity of wells in such areas.

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