Optimum design of injection rates and spacing of recharge wells in MAR region, South Korea

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Introduction

- Managed artificial recharge (MAR) of groundwater is a widely used technology that stores water in the underground layer by injecting extra water such as stream water or reused water. Such artificial recharge of groundwater has advantages such as water quality improvement, evaporation prevention, and pollution prevention effect due to the self-purification action in the aquifer.
- Such artificial replenishment of groundwater can be injected using facilities such as waterways and wells in the recharge basin.
- Therefore, in this study, in the case of injection using a vertical injection well among the artificial recharge injection methods, the optimal arrangement method was derived by considering the arrangement and number of injection wells.

Study area

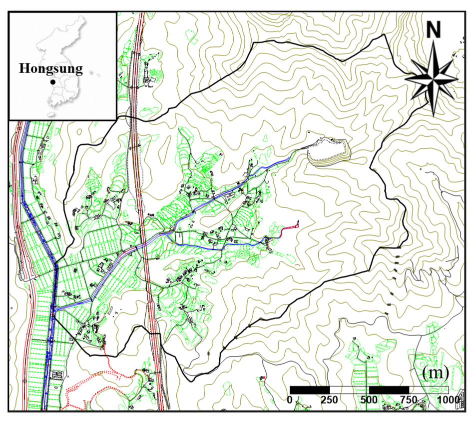

Fig. 1. Location map of research area.

- The area of this study is Ungok-ri (Singok Village), Galsan-myeon, Hongseong-gun, Chungcheongnam-do, Republic of Korea, with mountainous terrain in the northeast and lowlands in the southwest, and the 5~15 m wide Singok and Ungok Streams flow (Fig. 1).
- The geology of the study area consists of Cenozoic Quaternary alluvial and granite gneiss, and most of the land in the study area consists of field agriculture and paddy agriculture.

Contents of research

1. Preliminary evaluation of injection rate of artificial recharge injection facility

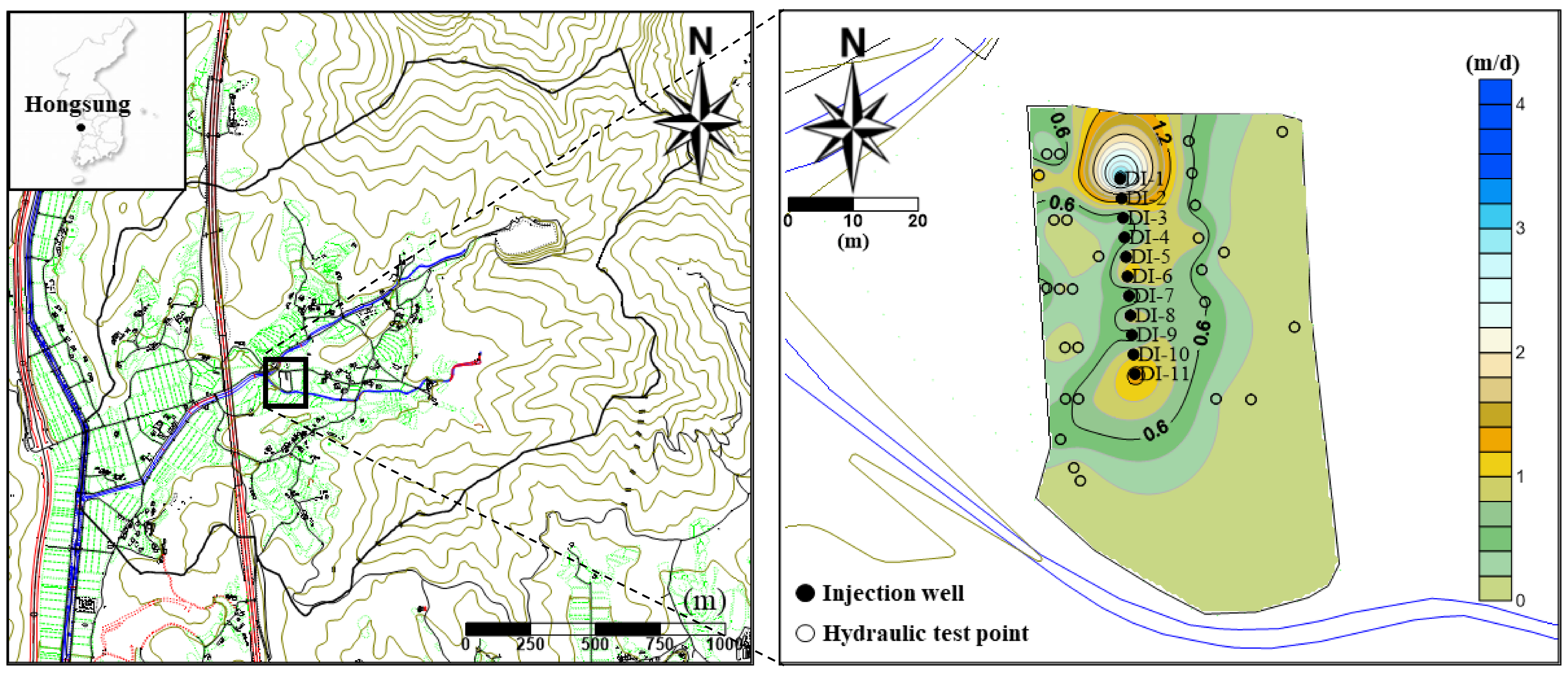

Fig. 2. Topographical and recharge basin map of the study area.

- 11 injection wells in the study area (DI-1, DI-2, DI-3, DI-4, DI-5, DI-6, DI-7, DI-8, DI-9, DI-10, DI- 11) was installed and a natural injection test was conducted, and the injection rate was about 0.49~38.13 m^3/d (Fig. 2).
- As a result of recalculating the injection rate using the existing empirical equation (Eq.1) and Kusakin's well radius equation (Eq.2) to calculate the average injection rate of the aquifer, the uncertainty of the hydraulic conductivity of the aquifer is about 2.71~12.98 m^3/d, calculated to be lower than the actual injection rate due to anisotropic effect.

$$Q = \frac{\pi K(h_w^2 - h_0^2)}{\ln(\frac{r_0}{r_w})} \qquad \text{(Eq.1)}$$

$$r_0 = 575 s_w (BK)^{0.5} \qquad \text{(Eq.2)}$$

- As a result of comparing single well and multi-well injection tests of 11 injection wells, it was found that the injection effect decreased due to the interference effect of adjacent injection wells during the multi-well injection. At this time, the injection rate for a single well injection is 0.49~38.13 m^3/d, and the injection rate for multi-well injection is 0.04~11.48 m^3/d (Table 1, Fig. 3).
- The injection efficiency was 4.4~95.4% compared to single well injection during multi-well injection (Table 1, Fig. 3).

Table 1. Comparison of actual injection rate and calculated injection rate.

No.	Injection rate for single well (m^3/d)	Injection rate for all wells (m^3/d)	Injection efficiency (%)	Calculated injection rate (m^3/d)
DI-1	4.23	1.87	44.17	12.98
DI-2	20.43	11.48	56.20	8.98
DI-3	1.37	1.30	95.35	2.71
DI-4	6.04	0.73	12.03	5.54
DI-5	5.67	3.90	68.81	10.05
DI-6	18.52	8.98	48.46	11.81
DI-7	0.49	0.04	7.52	2.84
DI-8	9.39	2.91	31.01	11.23
DI-9	5.23	0.23	4.41	4.15
DI-10	25.43	5.29	20.80	10.06
DI-11	38.13	9.50	24.92	12.74
Total injection rate (m^3/d)	134.93	46.23	-	93.09

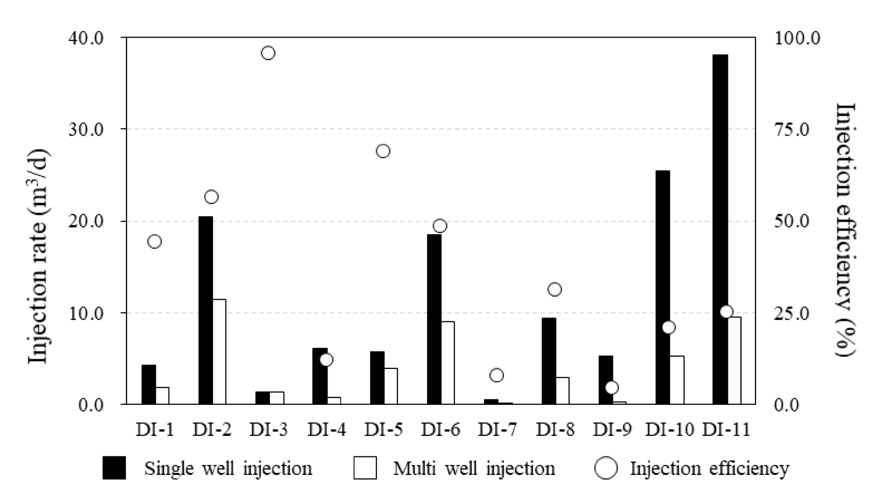

Fig. 3. Comparison of injection rate and injection efficiency according to single well and multi wells.

2. Estimation of injection amount considering interference effect

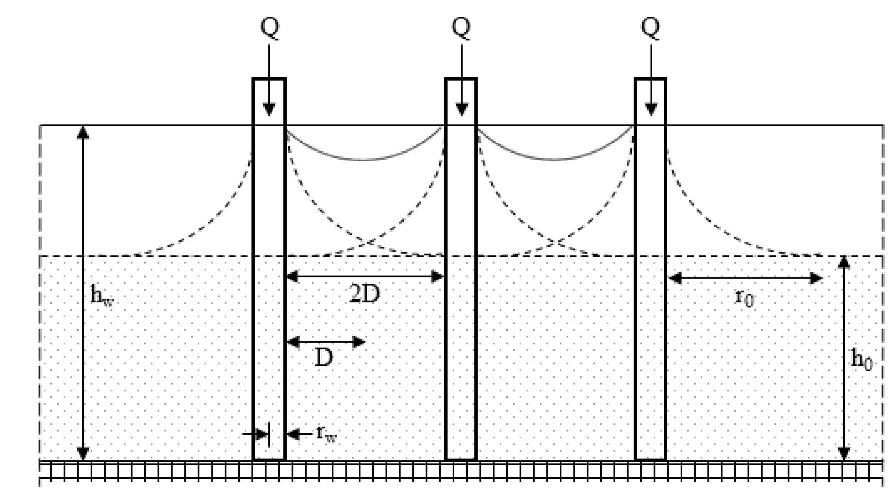

Fig. 4. The effect of increasing the water level according to the interference effect when injecting in the injection well(modified from Mohamned and Ahmed 2013).

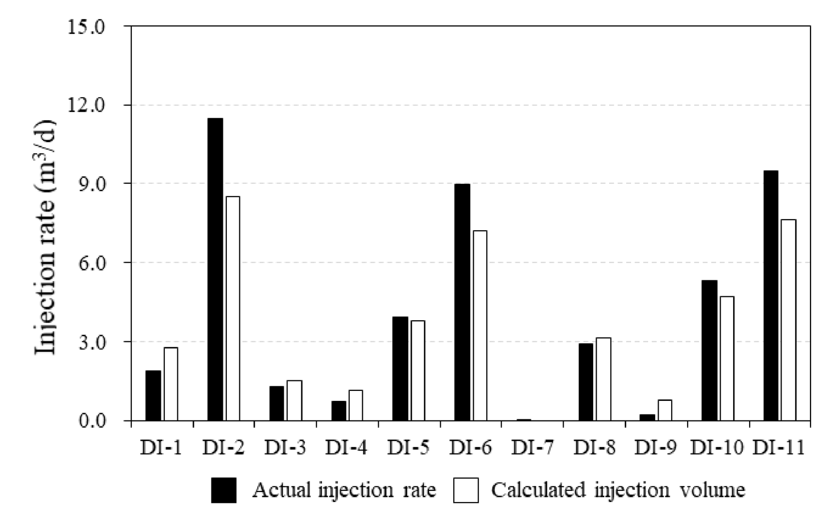

Fig. 5. Comparison of the actual and calculated injection rate considering the interference effect.

- At this time, the amount of rise in the groundwater level due to interference during injection can be calculated using Equation (1), and it can be expressed as the sum of the amount of rise at the distance (D) from the injection well (Fig. 4).
- As a result of calculating the average water level rise due to interference during simultaneous injection of injection wells at 3 m intervals under the same conditions as in the field experiment, the average was about 0.598 m.
- During simultaneous injection of injection wells, the actual injection rate is 0.04 to 11.48 m^3/d, and the calculated injection rate considering the interference effect is similar to –0.28 to 8.53 m^3/d (Fig. 5).

3. Deriving an appropriate design plan for the artificial recharge facilities

- In order to derive an appropriate design plan, the total injectable rate was calculated for when the same number of injection wells are installed, and when the maximum number of injection wells is installed according to the injection interval.
- When the injection wells are maximally installed at intervals of 3 to 20 m for each injection line, 10.1 to 96.9 m^3/d for each injection interval is shown. When the injection interval is about 8 to 10 m, the total injection rate is proportional. It was found that the number of injection wells decreased and the injection rate decreased when the injection was over 11 m. Therefore, the arrangement of injection wells in artificial enrichment facilities in this study area showed the highest efficiency when injecting at intervals of about 8 to 10 m for each injection line considering the uncertainty of hydraulic conductivity, and the total injection wells in 4 lines The number was 34 ~ 42, and the total injection amount was 94.5 ~ 96.9 m^3/d. At this time, the difference in the total injection amount in the four lines is as low as about 2.4 m^3/d. Considering the construction cost and maintenance of the artificial enrichment facility, it seems to be the optimal arrangement method when the number of injection wells is arranged at 10 m intervals (Table 2).

Table 2. Total number and rate of injection wells for each injection interval.

10 injection wells installed per injection interval																		
Interval (m)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number of injection wells	34	34	34	34	34	34	34	34	-	-	-	-	-	-	-	-	-	-
Rate (m3/d)	5.5	26.8	43.3	56.7	68.1	78.0	86.7	94.5	-	-	-	-	-	-	-	-	-	-
Maximum injection well installation per injection line																		
Interval (m)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number of injection wells	62	58	54	50	46	42	38	34	30	26	24	24	20	20	18	16	16	16
Rate (m3/d)	10.1	45.7	68.7	83.4	92.2	96.4	96.9	94.5	89.6	82.6	80.4	84.3	73.3	76.1	70.9	65.0	66.9	68.7

Conclusion

- In this study, the appropriate injection amount and injection interval of the artificial groundwater cultivation facility in the upstream small basin area were evaluated.
- As a result of comparing the single well injection test and the multi-well injection test, the injection efficiency was about 4.4 to 95.4% compared to that of the single well injection during multi-well injection due to the interference effect of the injection well. When placed in consideration of the interference effect of nearby implantation definitions, the appropriate implantation interval was found to be 8 to 10m. Considering the construction cost and maintenance of the artificial recharge facility, the proper number of injection wells is 34, and if the injection wells are installed at intervals of 10m, the total injection rate is 94.5m^3/d.
- In the future, it is expected that a more accurate injection amount can be derived if the injection rate is evaluated by examining the hydraulic characteristics of the actual injection point.

Acknowledgement

- This work was supported by the Korea Ministry of the Environment (MOE) and the Korea Environmental Industry & Technology Institute (KEITI) through the “Demand Responsive Water Supply Service Program (#146523).”