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Determination of recharge fraction of injection water in combined abstraction-injection wells using continuous radon monitoring

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ABSTRACT

The recharge fractions of injection water in combined abstraction-injection wells (AIW) were determined using continuous radon monitoring and radon mass balance model. The recharge system consists of three combined abstraction-injection wells, an observation well, a collection tank, an injection tank, and tubing for heating and transferring used groundwater. Groundwater was abstracted from an AIW and sprayed on the water-curtain heating facility and then the used groundwater was injected into the same AIW well by the recharge system. Radon concentrations of fresh groundwater in the AIWs and of used groundwater in the injection tank were measured continuously using a continuous radon monitoring system. Radon concentrations of fresh groundwater in the AIWs and used groundwater in the injection tank were in the ranges of 10,830–13,530 Bq/m^3 and 1500–5600 Bq/m^3, respectively. A simple radon mass balance model was developed to estimate the recharge fraction of used groundwater in the AIWs. The recharge fraction in the 3 AIWs was in the range of 0.595–0.798. The time series recharge fraction could be obtained using the continuous radon monitoring system with a simple radon mass balance model. The results revealed that the radon mass balance model using continuous radon monitoring was effective for determining the time series recharge fractions in AIWs as well as for characterizing the recharge system.

1. Introduction

Water scarcity has become a critical concern worldwide due to climate change, population growth and increasing water use. Water levels in many aquifers have declined significantly as a result of excessive withdrawals to meet the needs of increasing urban, industrial and agricultural development (Doll et al., 2012). Groundwater has been widely used as a thermal source in water-curtain heating facilities at green-house cultivation complexes during the winter season (November–March) in Korea. Groundwater levels have declined significantly as a result of over abstractions during winter at most green-house complexes in Korea. One approach to overcome the water shortages is to recharge groundwater by surface spreading or by direct aquifer injection methods. In surface spreading, recharge waters percolate from spreading basins through the unsaturated soil and ground zone. Although the surface spreading method for artificial recharge is cost effective, it has many disadvantages compared to direct aquifer injection methods such as greater land area requirement, evaporative losses, and vulnerability to contamination (Bouwer, 2002; Minsley et al., 2011). Artificial recharge wells can generally be classified into shallow and deep wells that are screened into the target aquifer. Over the last several decades, recharge via high capacity, large-diameter deep wells has become the most common approach in artificial recharge system. However, these wells are expensive, as they require a great amount of logistical and infrastructure support for operation and maintenance (Handel et al., 2014). Groundwater recharge has been estimated by employing water table fluctuation and chloride mass balance methods (Sharada et al., 2006).

In this work, we installed and investigated combined abstraction-injection wells (AIW) as a recharge system. Three AIWs were installed near the water-curtain heating facilities in a green-house cultivation complex. A pumping pipe (10 m length) and an injection pipe (40 m length) were installed inside the AIW. Groundwater was abstracted through the pumping pipe from the AIW for heating the green-house. The used groundwater was then

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collected in a storage tank after filtration by sand filter units. The used groundwater was then recharged into AIW through the injection pipe in the AIW. The most outstanding feature of the combined abstraction-injection well is that it can inject recharge water through an injection pipe into the AIW as well as pumping groundwater or mixed water through the pumping pipe from the same AIW. It is very important to determine the recharge fraction of the used groundwater for characterization of the recharge system when using combined AIWs. A simple radon mass balance model for evaluating the recharge fraction of used groundwater in AIWs was applied. An observation well (OW) was also installed near the AIW to find the water level variation with operating conditions of the recharge system. However, the issue of water level variation is beyond the scope of this article, a long-term monitoring must be required in a future study.

2. Materials and methods

2.1. Recharge system

The study site is a small green-house complex, where nine green-houses coupled with water-curtain heating facilities were operated to cultivate strawberries during the winter season (November to March). Water-curtain heating facilities operated at night time (generally from 5 p.m. to 9 a.m.). The recharge system at the site has one observation well (OW) and three combined abstraction-injection wells (AIW). The buried depth of the OW (diameter: 50 mm) was 50 m below the land surface and was located in front of the green-house complex. The buried depths of three AIWs were 50 m and they were constructed in the furrow between the green-houses. The distance of AIW-1, AIW-2 and AIW-3 from the OW were 80 m, 60 m and 20 m, respectively (Fig. 1). Each AIW has an injection pipe (diameter: 50 mm) and an abstraction pipe (diameter: 50 mm) inside a large diameter external pipe (diameter: 250 mm, depth: 50 m) (Fig. 2). For the colder injection water could be well mixed with warmer fresh groundwater before the mixed water was abstracted through the abstraction pipe, and injection and abstraction pipes were constructed at 40 m and 10 m depth in AIW, respectively. The groundwater cycle in the recharge system was as follows; 1) abstracted from AIWs through an abstraction pipe → 2) sprayed on the roofs of green-houses by the water-curtain facility → 3) collected in a collection tank → 4) transferred into an injection tank through heating pipe buried underground beneath the green-houses → 5) injected into AIWs through an injection pipe → 6) mixed with fresh groundwater in AIWs → 1).

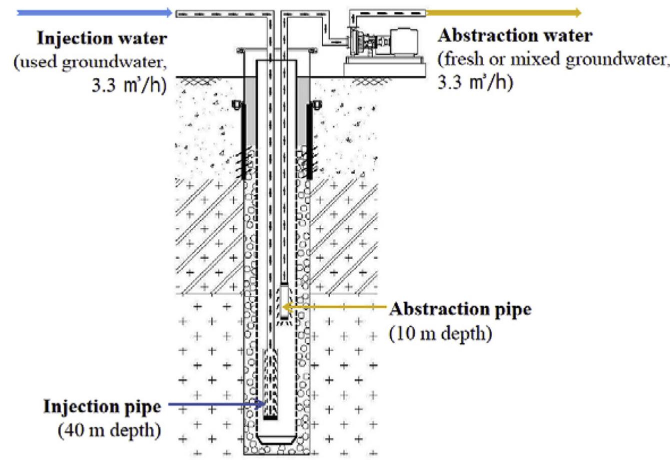

Fig. 2. Structure of the combined abstraction-injection wells constructed at the study site.

2.2. Continuous radon monitoring

A continuous radon monitoring system (CMS) was used for the measurement of ^{222}Rn in fresh and mixed groundwater abstracted from each AIW. Radon concentration in injection water in the injection tank was also measured continuously using the CMS. The CMS, which was developed in previous work, is based on stripping radon from water and measuring its radon-in-air activity concentration. Typical differences between the CMS and the commercial AQUA system (Durrage Co., US) are the stripping methods and air

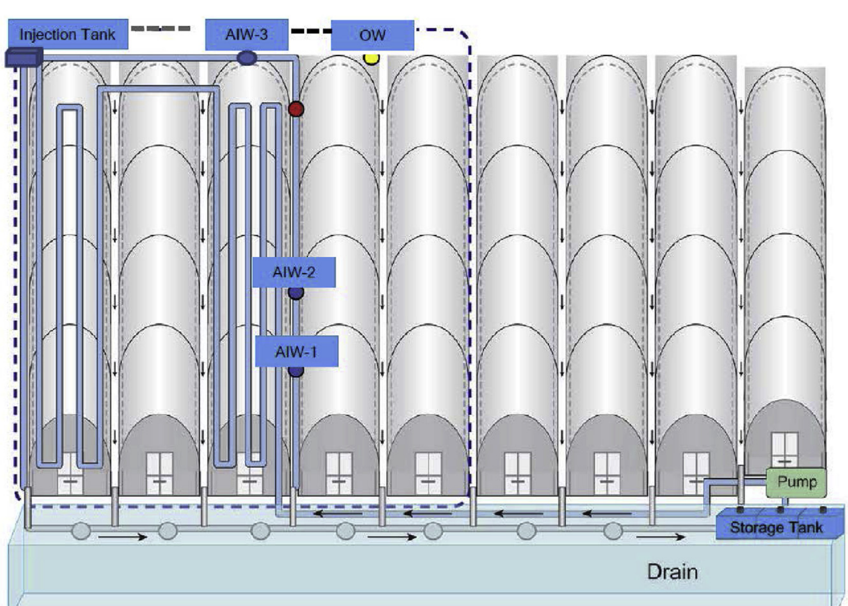

Fig. 1. Schematic diagram and positions of the three abstraction-injection wells (AIW) and one observation well (OW).*. Sand filtration units were placed in front of the storage tank.