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EVALUATION OF GROUNDWATER-STREAM INTERACTION IN AN URBAN STREAM, CHEONGGYECHEON, KOREA

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Abstract

Cheonggyecheon, covered and paved with concretes for about more than 50 years, is a losing stream crossing over the downtown of Seoul, Korea. Due to several environmental and economic problems about the Cheonggyecheon area, the Cheonggyecheon restoration construction has started in 2003. In restoration of Cheonggyecheon, hydraulic barriers are to be installed so as to reduce stream depletion rates for maintaining the stream flow with supplying a certain amount of water. This study evaluates the groundwater-stream interaction by analyzing stream depletion rates of Cheonggyecheon. Results show that significant stream depletion occurs at the up-midstream where the Seoul subway lines are concentrated. Simulation results demonstrate that both horizontal and vertical hydraulic barriers impeding groundwater flow into subway lines are more efficient than a horizontal barrier only for stream depletion rate reduction.

key words: groundwater-stream interaction, stream depletion rate, numerical modeling, Cheonggyecheon

1. Introduction

Cheonggyecheon, located in Seoul, Korea, is a stream crossing over the downtown of Seoul from east to west (Figure 1). It is approximately 5.8km long and 20-30m wide. Cheonggyecheon has been covered for about more than 50 years, and the covered area has served as a road. Due to several environmental and economic problems in this area, the 'Cheonggyecheon restoration project' was developed and the restoration construction started in 2003. For restoration of Cheonggyecheon, the stream depletion rate must be evaluated for maintaining stream flow. The objective of this paper is to evaluate the stream depletion rates of Cheonggyecheon by numerical modeling.

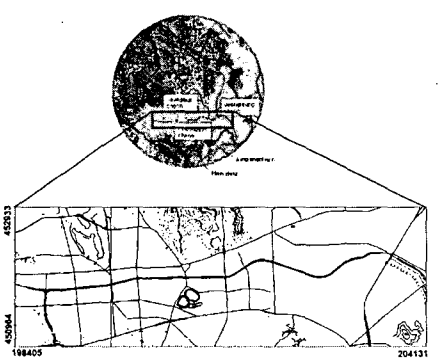

Figure 1. Map of the study area, Cheonggyecheon, Korea

2. Hydrological Characteristic of the Cheonggyecheon area

The hydrogeological characteristic of the Cheonggyecheon varies with the portion of the stream segment. Cheonggyecheon is narrow at the upstream (~10m) and it becomes wide as it reaches the downstream (30~40m). At the upstream, Cheonggyecheon is usually observed as either a dry or disconnected losing stream where the measured groundwater table is lower than the bottom of the stream. In contrast, Cheonggyecheon is often found to be connected to the groundwater table at its downstream as the Jungreung-cheon and Sungbook-cheon confluence at the downstream. The aquifer mainly consists of 4 geologic layers: medium to coarse alluvial sands (2-5m), weathered soil (1-2m), weathered granite (at least 10m), and a fractured granitic base rock. The hydraulic conductivity values of each layer and streambed are listed in Table 1. The vertical heterogeneity of aquifer material can attribute to the perched groundwater table, which is sometimes found in the mid-upper portion of the stream. The annual precipitation rate is approximately 1200mm/year. Note that the development of subway stations nearby makes a significant influence on the groundwater system in the Cheonggyecheon area. The Seoul subway stations are developed along the northern and southern boundaries of the Cheonggyecheon area, inducing groundwater discharge of 29,000m^3/day into subway tunnels in 2003 (Seoul Metropolitan Rapid Transit Corporation, 2003).

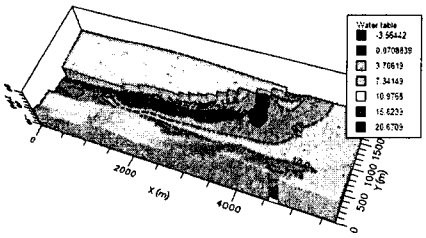

Figure 2. The simulated hydraulic head distribution at steady state.

3. Results and Discussion

3.1. Groundwater flow modeling

A three-dimensional finite difference grid was constructed for modeling groundwater flow in the Cheonggyecheon area (Figure 2). The recharge rate is assumed to be 10 % of annual precipitation and a potential evapotranspiration rate is assumed to be 1000mm/year with the effective depth of 0.3m. Figure 3 illustrates the simulated hydraulic head distribution at steady state. It shows that groundwater flow occur from west to east and from the center of the Cheonggyecheon to the northern and southern boundaries. In the longitudinal cross section of the Cheonggyecheon, the simulated groundwater table is mostly below the ground surface at upstream and midstream (disconnected stream) while it is above the ground surface at some portions of up-midstream and downstream (Figure 3). This can be attributed to the clay patches observed in the aquifer of up-midstream and increase of stream inflow caused by confluence with Sungbook cheon and Jungreung cheon. In the transverse cross section, the distributions of groundwater table are distinct for different portions of the stream (Figure 4). At upstream and midstream, the hydraulic gradient is steep in the north-south direction while it is gentle at downstream. This can be explained

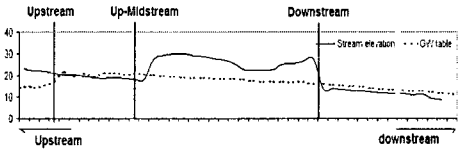

Figure 3. Groundwater table distribution in the longitudinal section of the Cheonggyecheon.

by the fact that Seoul subway lines are more focused at up and midstreams than downstream. Figure 4(b) shows the perched groundwater table, which is sometimes found in up-midstream.

3.2. Analysis of stream depletion rates

The stream depletion rates were calculated by using simulation results. The calculated stream depletion rates are plotted along the longitudinal section of Cheonggyecheon in Figure 5. The x axis presents the distance from west to east. Figure 5 (left) shows that calculated stream depletration rates are significant at up-midstream for steady state.

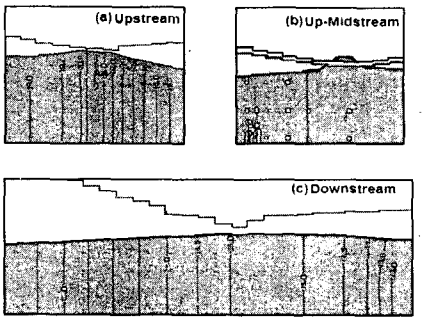

Figure 4. Groundwater table distribution in the transverse section of the Cheonggyecheon: (a)upstream; (b) up-midstream; (c) downstream.

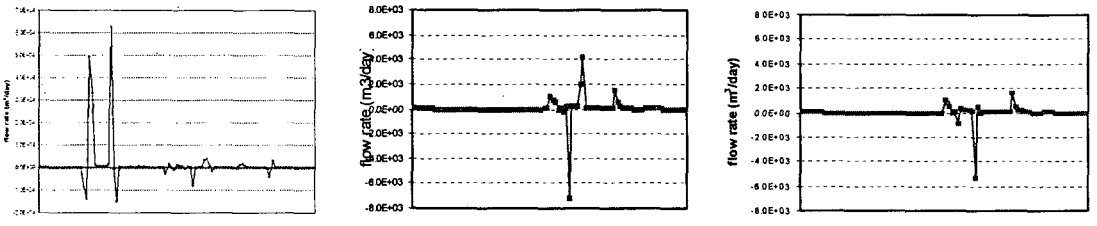

Figure 5. Calculated stream depletion rates: steady state (left); with a horizontal barrier (middle); with horizontal and vertical barriers (right).

Results show that stream depletion rates into adjacent aquifers (~ 6000m³/day) is significantly higher than groundwater outflow to the stream (~ about 2000m³/day). It is noted that calculated stream depletion rates are very larger than values commonly reported in natural streams. This can be explained by that the Cheonggyecheon is an urban stream, which is affected by artificial factors such as excessive pumping nearby and groundwater discharges into underground tunnels of the Seoul subway system. This suggests that hydraulic barriers should be installed for maintaining stream flow in the Cheonggyecheon so as to avoid groundwater outflow to the north-south boundaries where subway stations are located and extra pumping occurs. Figure 5 shows the estimated stream depletion rates with simulation results when only horizontal semi-pervious layer is installed and both horizontal and vertical hydraulic barriers are installed, respectively. Results demonstrate that hydraulic barriers can significantly reduce the stream depletion at the area where the subway lines are concentrated. It is also shown that both horizontal and vertical barriers are needed for efficient depletion reduction.

4. Summary & Conclusion

The groundwater-stream interaction in an urban stream, Cheonggyecheon, is numerically evaluated by analyzing stream depletion rates in this study. Results show that

the stream depletion rates are significant at the portions where Seoul subway stations are concentrated. Simulation results also demonstrate that stream depletion can be reduced with help of horizontal and/or vertical hydraulic barriers. It is concluded that hydraulic barriers can effectively reduce the stream depletion rates so as to maintain stream flow in Cheonggyecheon.

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