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# Feasibility of Using Groundwater Thermal Energy from a Limestone Aquifer for Medical Center Heating and Cooling

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## INTRODUCTION

The growing demand for low-carbon energy in the building sector has accelerated the adoption of groundwater heat pump (GWHP) systems, which utilize aquifers as renewable heat sources and sinks for space conditioning. Open-loop systems, in particular, provide high thermal efficiency and stable performance when favorable hydrogeological conditions—such as high transmissivity and consistent groundwater quality—are present. However, the long-term sustainability of such systems requires a clear understanding of heat transport processes and potential thermal interference between injection and extraction wells.

This work builds upon international studies that highlight the influence of advective–dispersive heat transport and aquifer heterogeneity on thermal plume evolution (Pophillat et al., 2020; Capozza et al., 2013; Herbert et al., 2013). Previous research on GWHP systems has shown that adequate well spacing and balanced heating–cooling loads help minimize thermal short-circuiting and maintain system efficiency over long operational periods. By integrating these concepts with site-specific field data from a GWHP project in Samcheok City, Gangwon Province, South Korea, this study provides a reference for sustainable GWHP design in carbonate aquifers. Results indicate that even under intensive seasonal operation, groundwater-level changes remain localized (<0.5 m) and thermal disturbances remain confined near the wells, supporting the feasibility of long-term geothermal utilization for institutional facilities.

This study presents a numerical analysis of a GWHP system designed for the Samcheok Medical Center, which is underlain by a permeable limestone aquifer. Using a three-dimensional finite-element model (FEFLOW; Diersch, 2014), hydraulic and thermal responses were simulated for both heating and cooling operations. The model was calibrated using field pumping-test results to estimate hydraulic conductivities. Two operational scenarios—one with separated wells and one with alternating well configurations—were evaluated to assess drawdown, reinjection temperature, and long-term thermal transport.

## 1 STUDY SITE

The Samcheok Medical Center is situated in a geologic setting primarily composed of Paleozoic carbonate rocks, dominated by the Pungchon Limestone Formation of the Chosun Supergroup, underlain by shale and quartzite units of the Myobong and Jangsan formations. Overlying these bedrock units is an alluvial and weathered layer approximately 58 m thick, consisting of unconsolidated sand and gravel. Beneath this zone, the main aquifer develops within fractured and karstified limestone exhibiting high secondary permeability (Figure 1).




**Figure 1. Conceptual building layout of Samcheok Medical Center (left) and geologic map of the site (right).**

### 1.1 Hydrogeology

Two test wells (W-1: 63.3 m; W-2: 132.7 m) were drilled for hydrogeological and geothermal assessment. Transmissivity values ranged between 560 and 850 $m^2$/day, and hydraulic conductivities ranged between 7–12 × $10^{-4}$ m/s, indicating a productive aquifer. The storage coefficient was estimated between 0.005 and 0.007. During pumping tests, stable groundwater levels were measured at approximately 5 m below ground surface, with water-level changes limited to about 0.5 m due to the high permeability of the limestone aquifer.

As shown in Figure 2, temperature logging revealed groundwater temperatures between 14.2°C and 15.1°C, suitable for air-conditioning operations in local climatic conditions. Water-quality analyses indicated slightly elevated chloride concentrations in W-1, suggesting minor influence from local anthropogenic sources, while W-2 met domestic water standards. Both wells were classified as suitable for internal-circulation open-loop geothermal use, with W-1 proposed as an injection well and W-2 as a production well.

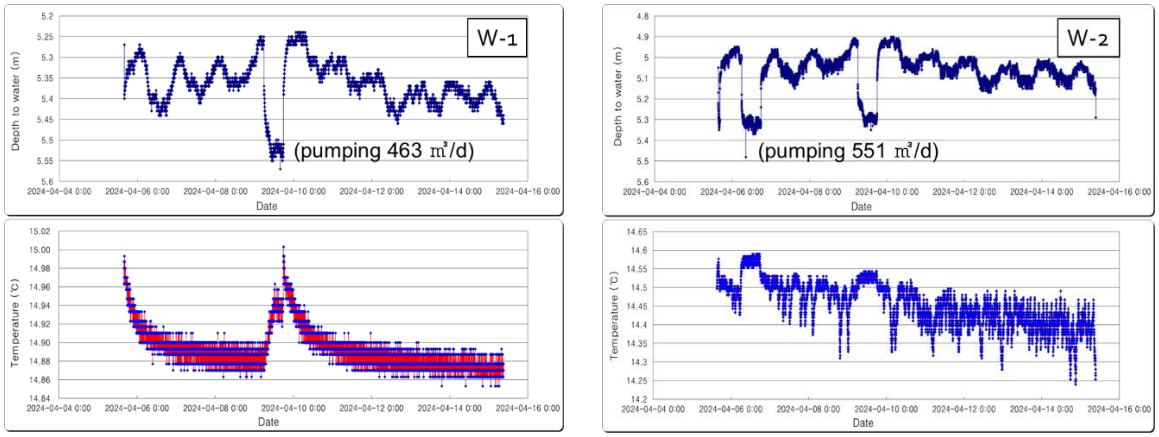



**Figure 2. Groundwater-level and temperature variations during pumping tests for W-1 (left) and W-2 (right).**

### 1.2 Numerical simulation

Numerical modeling was conducted using FEFLOW to evaluate the feasibility of the geothermal system. The model domain encompassed the project area laterally and extended to a depth of 130 m. The target aquifer, located between 60 and 130 m depth, was represented as a high-conductivity limestone layer. Two operational scenarios were simulated:

1. **Separated configuration** with 12 injection wells in the upper zone and 16 extraction wells in the lower zone.
2. **Alternating configuration** where injection and pumping operations rotate among adjacent wells.

During the heating period, the reinjection temperature was assumed to be 4°C lower than the extracted groundwater temperature, whereas during cooling the reinjection temperature was 5°C higher. Hydraulic conductivity was calibrated using a 12-hour pumping test at Well W-2 (550 $m^3$/d), resulting in $K_{x,y}$ = 5 × $10^{-4}$ m/s and $K_z$ = 1 × $10^{-4}$ m/s.

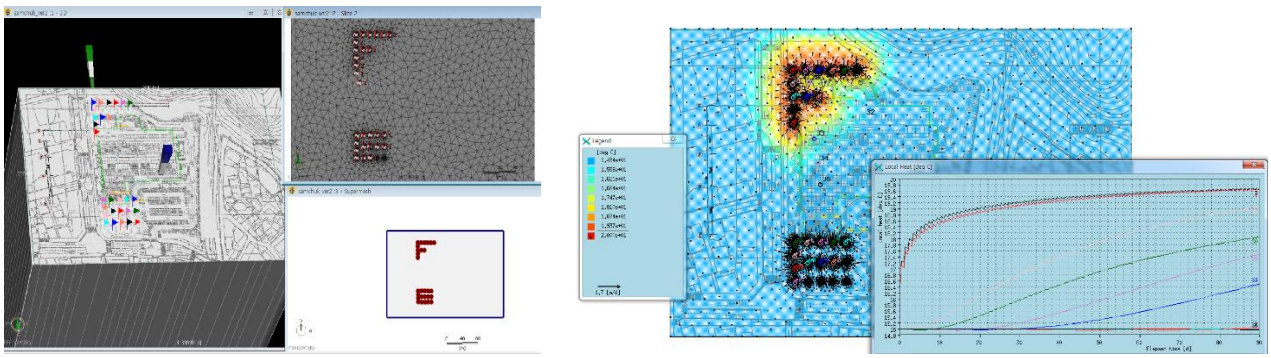


**Figure 3. The groundwater level and temperature changes during pumping test period in the two wells of W1 (left) and W2 (right).**

### 1.3 Results

The simulation results indicate that groundwater-level variations caused by pumping and injection were less than 0.5 m and remained localized near the geothermal wells. For 14 injection wells, the maximum rise was approximately 0.45 m, while pumping wells showed a maximum drawdown of approximately 0.50 m.
During cooling operation (90 days, 8 hours/day, reinjection at 20°C), groundwater temperatures near injection wells increased from an initial 15°C to approximately 19.7°C, with negligible thermal interference between upper and lower well groups. During heating operation (reinjection at 11°C), temperatures near injection wells decreased to about 11.2°C, while extraction-well temperatures remained close to initial conditions. These results indicate that both heating and cooling operations are sustainable, with limited long-term thermal degradation.

## 2. CONCLUSION

The feasibility of an open-loop groundwater heat pump system was evaluated using simplified operational scenarios for heating and cooling. Hydrogeological investigations confirmed that the underlying limestone aquifer provides a highly productive and thermally stable groundwater source suitable for sustainable geothermal utilization. Field tests and numerical modeling indicate that the proposed system can operate effectively under practical conditions.
Simulation results show that groundwater-level and temperature changes remain localized near the wells, and long-term impacts on the aquifer are minimal. The modeled scenarios demonstrated stable hydraulic behavior, limited thermal interference, and effective heat-exchange performance throughout seasonal operations. The integrated approach combining hydrogeological assessment and numerical modeling offers a robust framework for designing efficient open-loop geothermal systems in carbonate aquifers. These findings confirm that the Samcheok Medical Center project can contribute meaningfully to low-carbon energy supply and serve as a reference for future applications of sustainable GWHP technology.

**Acknowledgements**

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