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# Simulation for the effect of vertical groundwater flux on the subsurface temperature distribution

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## Abstract

Subsurface temperature is affected by heat advection due to groundwater advection. Temperature-depth profile can be perturbed especially when there are significant vertical groundwater flux caused by external force such as injection or extraction. This research is to clarify the change of subsurface temperature distribution when the 40m×10m sandy aquifer is stimulated by two different vertical flux(case1: $\pm 10^{-5} m^3/s$, case2: $\pm 4\times 10^{-5} m^3/s$) using a program called HydroGeoSphere. The resulting temperature distribution contour map shows pumping causes vertical attraction of water from deeper and warmer place which result in rising up isotherm. Additionally more injection/extraction rate, more vertical groundwater flux leads to faster increase in temperature near the pumping well.

**key word**: groundwater temperature, groundwater flux, modeling, HydroGeoSphere.

## 1. Introduction

Subsurface temperature distribution includes valuable but secret key to understand the history and the dynamic variation of the given system. It is represented generally by the geothermal gradient of the subsurface, however, it can be disturbed easily by groundwater flow. When there is significant amount of vertical groundwater flux, temperature distribution is affected a lot by colder recharging and warmer discharging.

Previous works have shown the measured temperature-depth profile(Taniguchi, 2004; Miyakoshi, 2005) and calculated the recharging and discharging rate from the profile using this equation(Bredehoeft and Papadopulos, 1965) which explains the steady state heat conduction and advection on vertical direction.

$$\frac{\partial^2 T}{\partial z^2} + \frac{c_W \rho_W V_z}{K}\frac{\partial T}{\partial z} = 0$$

Type curve approach gives a kind of Peclet number which represent the ratio of the vertical flow velocity to the thermal conductivity($V_z/K$) and we can finally obtain the vertical flux from the value.

This research takes the reverse process, that is, the recharging and discharging rate is given at first throughout the 40m×10m xz-domain and then HydroGeoSphere simulate and predict the subsurface temperature distribution until 20 days have passed. The input parameters for the simulation are shown in the Table 1.1.

| parameter | value |
|---|---|
| hydraulic conductivity | $10^{-5}$ ms$^{-1}$ |
| porosity | 0.1 |
| thermal conductivity of bulk | 1.644 kgms$^{-3}$℃$^{-1}$ |
| specific heat capacity of solid | 947.17 m$^2$s$^{-2}$℃$^{-1}$ |
| solid density | 2650 kgm$^{-3}$ |
| thermal conductivity of water | 0.5 kgms$^{-3}$℃$^{-1}$ |
| specific heat capacity of water | 4185 m$^2$s$^{-2}$℃$^{-1}$ |
| fluid density | 1000 kgm$^{-3}$ |
| injection rate | (case1) $10^{-5}$ m$^3$s$^{-1}$ |
|  | (case2) $4\times10^{-5}$ m$^3$s$^{-1}$ |
| extraction rate | (case1) $10^{-5}$ m$^3$s$^{-1}$ |
|  | (case2) $4\times10^{-5}$ m$^3$s$^{-1}$ |

Table 1.1. Model parameters used in the simulation.

## 2. Numerical Simulation

The model is constructed as a 40m×10m homogeneous sandy aquifer and initial head is 8m. Left($x=0$) and right($x=40$) boundary is given as constant head 8.1m, 7.9m respectively and bottom($z=0$) is totally no flow boundary. Therefore, the groundwater flow is from left to right at the beginning. Also, Temperature of the whole domain is 15℃ but the bottom is set to 17℃ as it describes the exaggerated geothermal heating condition.

Then, two wells for injection and extraction are installed at $x=10$ and $x=30$ respectively. They are screened from $z=3$ to $z=6$ since drawdown cannot affect the pumping at the range of depth. Two different injection/extraction rate are given through these wells(case1: $\pm10^{-5}\text{m}^3/\text{s}$, case2: $\pm4\times10^{-5}\text{m}^3/\text{s}$). In this situation, head distribution in steady state is as like following Figure 2.1.

Temperature of injected water plays an important role as a thermal boundary condition. It is given as constant 14℃ which is lower than initial temperature of the domain and the resulting temperature profile right below the injection well will be the coldest. As the time goes, temperature distribution becomes to be more and more perturbed by vertical flux around the extraction well. The temperature contour is rising with time below the extraction well and the rising speed is faster when the system is stimulated by the larger vertical flux(Figure 2.2).

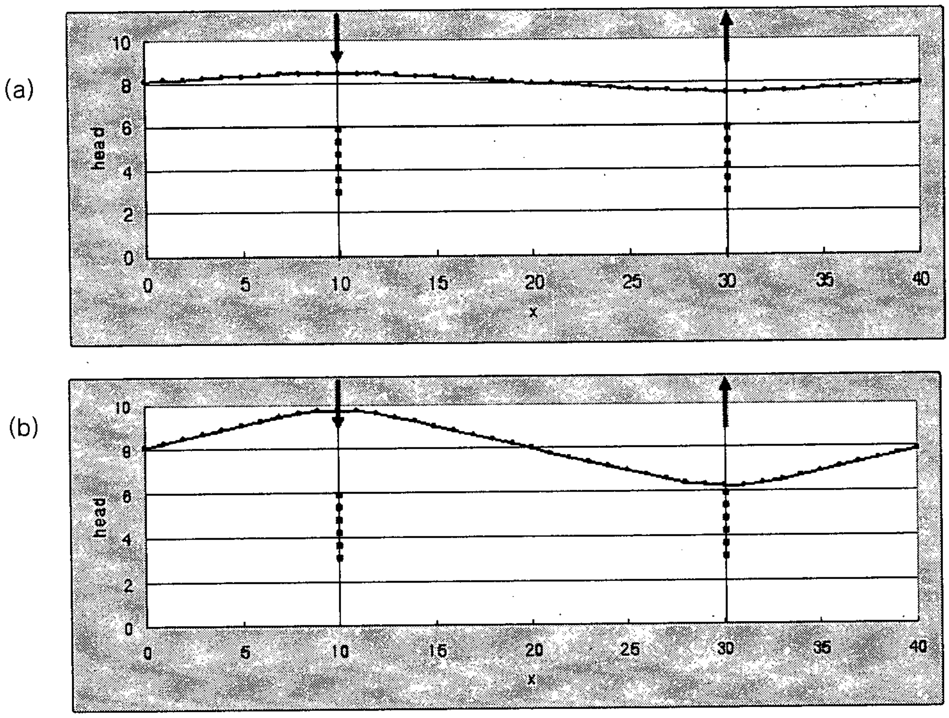
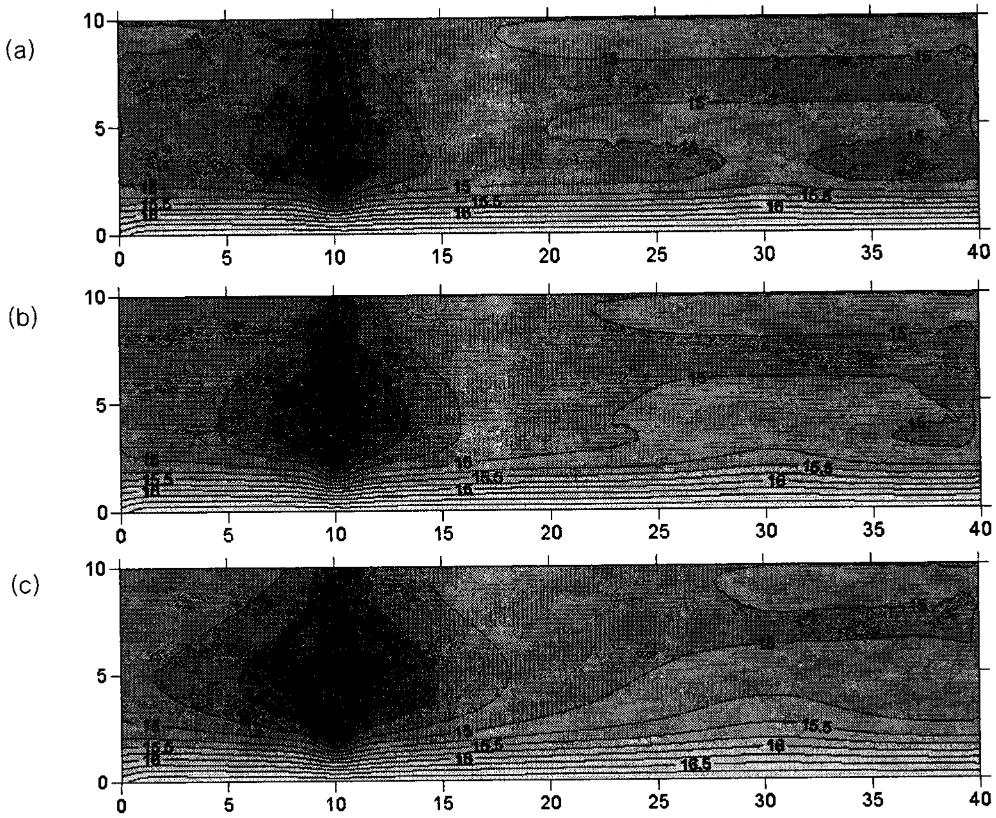


Figure 2.1. Steady state head distribution (a)in case1, (b)in case2 due to injection/extraction This graph is exaggerated in head direction.



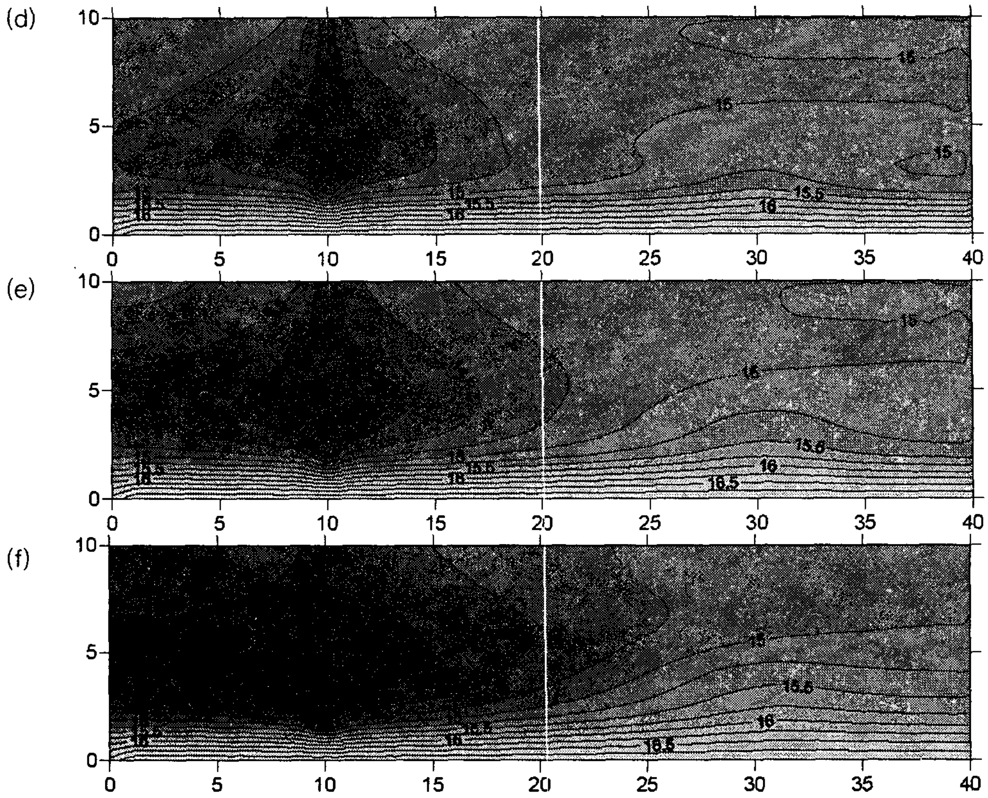


Figure 2.2. Temperature distribution in case1 after (a)5 days, (b)10 days, (c)20 days and in case2 after (d)5 days, (e)10 days, (f)20 days.

## 3. Conclusion

Warmer water once located in the deeper place is rising with time by the upward flux due to pumping and the larger vertical flux causes the faster increasing in temperature below the extraction well. This result coincides in Taniguchi's observation(1999) which concludes that subsurface temperature is higher in the discharge area than in the recharge area of groundwater flow system.

## 4. References

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