Groundwater flow and subsurface thermal regime

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Declines in hydraulic head and accompanying land subsidence in the Nobi Plain have been sever due to pumping of groundwater for industrial and agricultural uses during last 35 years. Moreover, annual mean air temperature increased about 2 degree during the last 100 years in the Nobi Plain. The purpose of this study is to understand the effect of regional groundwater flow system, pumping and surface warming on the subsurface thermal regime.

Numerical simulations show that the main factor to form subsurface thermal regime in the Nobi Plain is regional groundwater flow but effect of pumping is little. Surface temperature warming causes subsurface temperature inversions in the recharge area, which is manifested as a low or inverse temperature gradient in the subsurface shallow layer.

Generally, subsurface thermal regime is formed by not only thermal conduction but also advection owing to groundwater flow. Moreover, subsurface thermal regime is affected by changes in surface temperature, too. The most recent major climatic change, the rapid warming has caused a temperature inversion that is manifested as a low or inverse temperature gradient in the subsurface shallow layer in many parts of North America, Europe and Australia, at a depth of 50 to 100 m. In the Nobi Plain, decrease of hydraulic head accompanied by subsidence has been severe during the last 35 years owing to pumping of groundwater. More than 50 observation sites with one to three nested wells ranging from 50 to 400m below the land surface were installed to monitor groundwater levels and land subsidence. The purpose of this study is to understand the subsurface thermal regime in quantitatively. In this study, regional groundwater flow, local groundwater flow much affected by pumping due to human activities, and surface temperature warming owing to urbanization are treated as three effects on subsurface thermal regime, and estimate these effects on subsurface thermal regime by means of observation in the field and a three-dimensional numerical model of groundwater flow and heat transfer.

The distribution of hydraulic head indicates that groundwater recharge occurs at the northern and eastern parts of the plain. Groundwater flows to the central part of the plain and discharges to Ise Bay. The observed pattern of hydraulic heads is more complicated than the simulated one in the case of no pumping. The regional flow pattern, however, is similar, that is, the regional groundwater flow system is dominated by the effects of topography and geology. Field observations show that subsurface temperatures and gradients in the recharge area are lower than in the discharge area. Furthermore, there is a zone of high temperature in the central portion of the plain where there is heavy pumping. Results from numerical modeling show that the observed distribution of hydraulic head is influenced by pumping much more than the observed distribution of subsurface temperature. The observed high temperature zone in the central portion of the plain could be simulated by the steady-state calculation of heat transfer in the case of no pumping. This fact shows that the subsurface thermal regime is hardly influenced by pumping. Transient modeling of heat transfer including the effects of pumping shows that the distribution of subsurface temperature has not been significantly affected by pumping within the last 35 years. Taking into account pumping effects in detail, surface heat is transported downward owing to the induced recharge in heavy pumping area around the center of the plain and subsurface temperature decreases slightly at the depths shallower than 100m below the land surface in this area. As a result of simulation which include the effect of surface temperature warming, subsurface temperatures in shallow layer are affected by changes of surface temperature and pumping. In the recharge area, we can simulate temperature inversions anywhere at the depth between 50m and 200m below the sea level, because subsurface temperature has been cooled with the advective heat transfer by the downward groundwater flow from the surface. While in the discharge area, temperature inversions are hardly simulated because subsurface temperature has been heated by regional groundwater flow more than by the effect of surface warming.