

Field observation and simulation of groundwater level changes due to urbanization in the Yata River basin, Japan

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Abstract Groundwater level changes in the Yata River basin (Japan) were investigated first by comparing the results of simultaneous field observations in 1999 and 2000, with those of the 1970s. It was found that the water levels of the shallow aquifer had fallen by a few metres; urbanization is considered to be the main reason. To predict groundwater level changes due to the further urban development in combination with construction of a new railway, a grid-based hydrological model was then applied to the basin. The calculated groundwater levels show a reasonable agreement with the observed ones. It is concluded that the groundwater level would decrease by at most 2.5 m soon after the further urban development if no mitigation alternatives are taken.

Key words aquifer; groundwater level; hydrological model; urbanization; Yata River, Japan

INTRODUCTION

Urban development, with other human activity and land-use changes has significant effects upon the hydrological cycle in terms of both water quantity and quality. For the purpose of mitigating undesirable effects, it is necessary to study and predict these kinds of effects quantitatively.

The study area, the Yata River basin, is located in the Ibaraki prefecture, Japan, and has an area of 167 km². Urbanization started in the basin in the 1970s, and in combination with construction of a new railway, the land use of five districts with a total area of 13 km² is scheduled to turn from fields or forest to business or residential. As part of the development planning, a research project was commenced to estimate the impact of the further urbanization on the hydrological cycle and propose effective alternatives. The project includes both long-term monitoring and assessment of change in the hydrological cycle due to this planned development.

In the first part of this paper, the results of simultaneous field observations from October 1999 to July 2000 are shown and compared with those of the 1970s. In the second part, a grid-based hydrological model, which considers the surface and subsurface flow as an integrated system, is proposed and applied to the basin. The simulations are carried out for two cases, i.e. the pre-development condition and the post-development condition.

FIELD OBSERVATION RESULTS

The Yata River basin

The Yata River basin has a topography that gently slopes from the northwest down to the southeast. Three main rivers flow in the basin and empty into the Ushiku Lake. Land-use data for 1994 shows that 14% of the basin is paddy field, other farmland and forest occupy about 50%, and the rest is covered by urban related area. The topsoil is mainly Kanto loam, except for alluvial silt or sand in riparian zones, with a non-continuous thin clay soil layer below the topsoil. Beneath the clay soil layer are two main aquifers separated by one aquitard; the upper one is a shallow unconfined aquifer and the lower is a confined aquifer. The average thickness of the loam layer, the unconfined aquifer and the confined aquifer are roughly 2 m, 10 m and more than 50 m, respectively.

Sixty-three draw wells were selected for groundwater investigation: four of them are situated in the confined aquifer and the rest in the shallow aquifer. Simultaneous groundwater level observation was carried out in four periods: 6–8 October and 9–11 December 1999, and 26–27 May and 28–29 July 2000.

Observation results

The observations show that the water levels of the shallow aquifer reach their peaks in August, and they are lowest in March. On the contrary, the water level of the confined aquifer starts to decrease rapidly in May and recovers to its original level at the end of September. This is mainly because the confined groundwater is pumped for paddy irrigation. During the irrigation period, which is usually from April to August, the shallow aquifer is recharged from the irrigated paddy area, causing the groundwater level to rise. An average increase of 1 m can be estimated from the observed results.

Differences in measured water level between the present and the 1970s were calculated for the same wells and same seasons. The water levels of the unconfined aquifer were found to now be 1 m to 5 m lower, except for only a few wells. Besides the difference in meteorological conditions, the decrease in the natural land area and the increase in impervious area due to urbanization, are considered to be the main reasons.

MODEL DESCRIPTION AND SIMULATION RESULTS

Model description

For simulation, a distributed hydrological model developed for water and energy transfers, was employed (Jia *et al.*, 1998). The model is grid-based and the state variables include depression storage on land surfaces and canopies, soil moisture content, land surface temperature, groundwater level, water stage in rivers, etc. The groundwater flow component of the model can describe two-dimensional interacting flows of multi-layered aquifers. The water exchange between aquifer and river is calculated according to the hydraulic conductivity of riverbed material and the difference between river water stage and groundwater level. In this study, the computational time step and grid size were set to be 1 h and 100 m respectively.

Data and parameters

For model simulation, many kinds of data and parameters are necessary. Among them for the present (pre-development) condition, ground elevation, land use, population and meteorological data were obtained from available databases; data on water supply, agricultural and industrial water use had to be aggregated from unprocessed data sources. Data on inter-basin water transfers were also collected. For the future (post-development) condition, land use and population planning data were used, whereas the other data were based on the present condition. The hydraulic parameters of topsoils and aquifers were setup by referring to the results of related investigations (Geological Survey of Japan, 1988). The initial and boundary conditions were determined according to the field observations mentioned above.

Simulation results

Groundwater level variations in the shallow aquifer have been continuously recorded at two observation wells since August 1999 (Fig. 1). Seasonal variations of groundwater level can be clearly seen. Figure 2 shows the comparison of calculated and observed groundwater levels for all the simultaneous observation wells within the water-

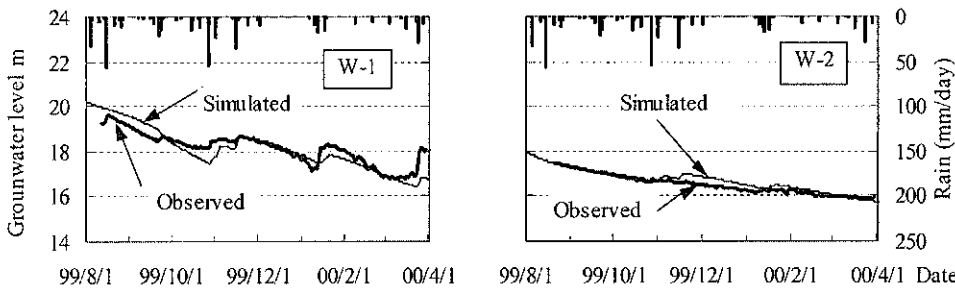


Fig. 1 Comparison of observed and simulated groundwater level (observation wells W-1 and W-2 are located in the middle of the basin).

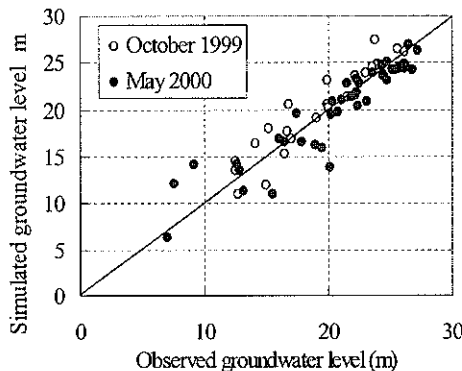


Fig. 2 Comparison of observed and simulated groundwater level for all the simultaneous observation wells within the basin, in October 1999 and May 2000.

shed. Although there are some obvious differences between the calculated and the observed results, both figures show that the model gives satisfactory results. This model was then applied to the basin to estimate the hydrological change after the further development, under the same meteorological conditions of the period January 1998 to May 2000. The simulation results show that recharge to the shallow aquifer would reduce by an average of 300 mm year^{-1} in the area of planned urban development. Figure 3 shows the difference in the shallow groundwater levels at the end of May 2000, between the pre- and post-development condition, and that groundwater level decreases mainly within the development areas. Further study will be carried out to assess the impacts of such hydrological changes and mitigation alternatives, and support decisions on balancing various needs.

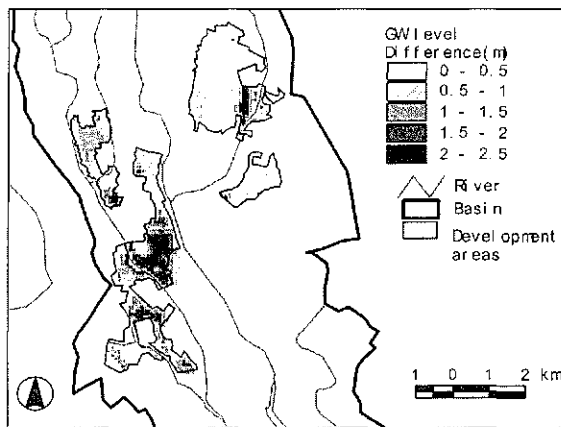


Fig. 3 Difference in the shallow groundwater levels at the end of May 2000, between the pre- and post-development condition.

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