3D seepage flow simulation of groundwater by many pumping wells in Kyoto Basin

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3D seepage flow simulation of groundwater by many pumping wells in Kyoto Basin

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In this research, we chiefly proceed on-site measurement and analysis to examine how the pumping wells influence groundwater properties. The examined region is surrounded by mountains formed by a bowl shaped depression in the Paleozoic strata and granite. The paleozoic strata basin rock is an impermeable bed upon which there is a permeable diluvium and then alluvium. It is estimated a lot of groundwater is saved. However, if an excessive pumping is continued, it can cause the exhaustions of the groundwater and the subsidence, and especially multiple wells which take a large amount of water in a small area are considered to have a great impact. We established a 3D model for groundwater and make suggestions for the adequate management of the groundwater by a pumping simulation analysis. This simulation was the subject of which was a pumping well for water service - water levels for one pump were large. As a result, it can be seen from our research that the fluctuation of water level caused by group wells has been reproduced accurately by using our model.

1. INTRODUCTION

In the management and a usage of a groundwater resource, we need to work on an accurate grasp of the current situation and to make a future vision in the region where the groundwater exploitation is active. If an excessive pumping is continued, it can cause the exhaustions of the groundwater and the subsidence. It takes 1400 years for groundwater to recover the original resources, and 16 days for rivers. There is a character that the groundwater level drawn up in a short term is not recovered easily because the restoration period of it is extremely long compared with rivers, lakes and marshes water, etc. Therefore, it is required to make a sustainable method for the usage of the groundwater that takes surrounding environment into consideration. In the past research, a common aquifer was examined in one municipality. This simulation was undertaken where the scope was expanded, the subject of which was a pumping well for water service - water levels for one pump were large. To use the groundwater resource in this region effectively, we examine the influence on peripheral groundwater properties especially where a large amount of pumping from the wells for waterworks is being practiced. We use it as a technique to maintain a surrounding groundwater environment.

2. GEOLOGICAL CONDITIONS

The examined region is elongated basin from the south to the north with 3.5-10km in width and 36km in length. Fig. 1 shows the geologic map of the surrounding examined region.

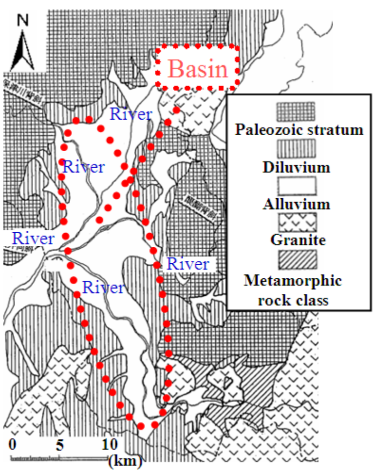

Figure 1 Geologic map

As is clearly shown in the figure, the Paleozoic stratum is distributed in the northern and the eastern parts of the basin, and the granites in the southern part, and both of them form the bedrocks. These bedrocks are thought impermeable layers and Osaka layer built up in the diluvium epoch is distributed in the concave portion enclosed by these bedrocks. The deepest point of the bedrock in the whole area of the basin is about 800m. It is thought that a large amount of groundwater exists in the basin that has the above-mentioned and the geological structures.

3. GROUNDWATER USE STATE

Fig.2 shows the positions of the pumping wells at the waterworks in the examined region. There are 4 pumping wells in A area, 7 in B area, 8 in C area, 8 in D area, and 6 observation wells. That is to say 27 pumping wells in total are set up at the waterworks. In each well, the water level is regularly measured, and there is data concerning a long-term fluctuation of water level. Based on them, we considered the fluctuation of water level by pumping from a peripheral wells and recovery of well ability after washing construction. Fig.3, Fig.4 show the water level measurement results in a-point and b-point.

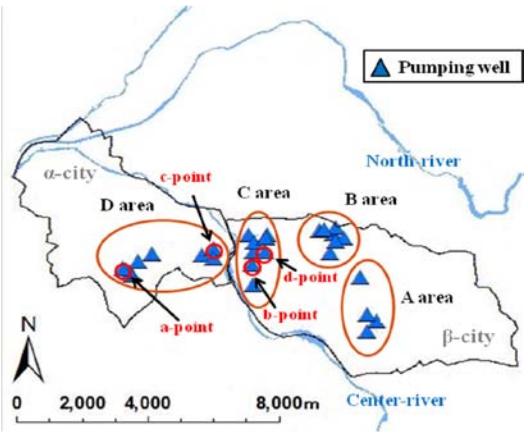

Figure 2 The positions of the pumping wells

(1) a-point
The well in this point is set up in the foothill where the altitude is high compared with other wells. In such a foothill and the periphery of mountain, the alternation of strata with sand and marine clay that is called Osaka layer exists. The layer is different from the stratum on smooth ground that consists of the sandy layer. Therefore, it is a region where the fluctuation of water level by pumping appears greatly. Since the water level has decreased although the pumping discharge was gradually decreased after the beginning of the observation, the washing construction was done in 1992. However, the water level decreased by about 10m in 10 years after construction. Then, the washing construction that used medicine in 2001 was done, and the water level has recovered. However, after that, the fluctuation of water level by the increase and decrease of the pumping discharge has been large, and the water level has not been steady.

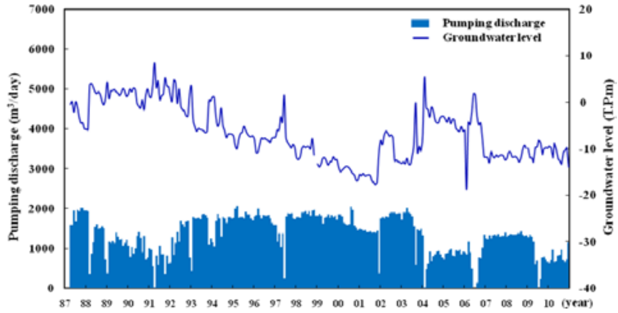

Figure 3 The water level and the pumping discharge in a-point

(2) b-point
The water level of this well in this point is the steadiest in the observed region. Because, the well is set up in the near of center-river, in addition, the depth is deep, and the coefficient of permeability of the aquifer is high. A big change of the water level is not seen though the pumping discharge is gradually decreased to about half the amount from 2005 to 2006. Therefore, it is thought that a steady pumping can be done in this point from now on.

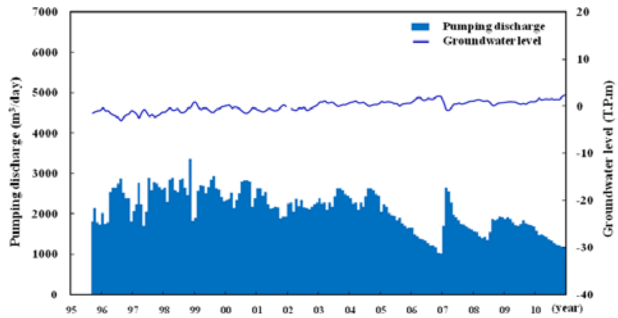

Figure 4 The water level and the pumping discharge in b-point

4. WATER LEVEL OF OBSERVATION

The influence that the amount of the rainfall and the pumping discharge gave the groundwater level was examined by considering the tendency of the fluctuation of water level in shallow and deep observation wells. The fluctuation of water level in this region is thought to be influenced by the amount of the rainfall in a shallow layer, and by the pumping discharge in a deep layer. Especially, it is important to accurately understand the influence on the groundwater level by pumping.

(1) Consideration of fluctuation of water level that pumping discharge of waterworks causes

Fig.5 shows the relation between the fluctuation of water level and the total pumping discharge of D area in c-point which is the deep observation well. From a long-term observational result, it is admitted that the total pumping discharge and the groundwater level of deep well are related. The groundwater level has decreased by about 3m when the pumping discharge is gradually increased from 1987 to 1998. Thereafter, when the pumping discharge was made constant from 1998 to 2003, the water level was steady. After 2003, the groundwater level has recovered rapidly only by slightly decreasing total pumping discharges of D area. The reason is that the pumping discharge in the pumping well which is the nearest the observation well decreased from 2003.

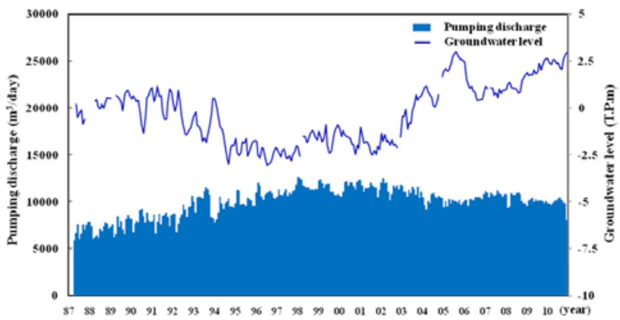

Figure 5　The water level and the total pumping discharge of D area in c-point

(2) Consideration of fluctuation of water level that amount of rainfall causes

Fig.6 shows the relation between the fluctuation of water level and the amount of the rainfall in d-point which is the shallow observation well. The amount of the rainfall greatly influences the fluctuation of water level in the shallow observation well, and the water level tends to rise in summer when the amount of the rainfall is large, and to decrease in winter when the amount of the rainfall is a little.

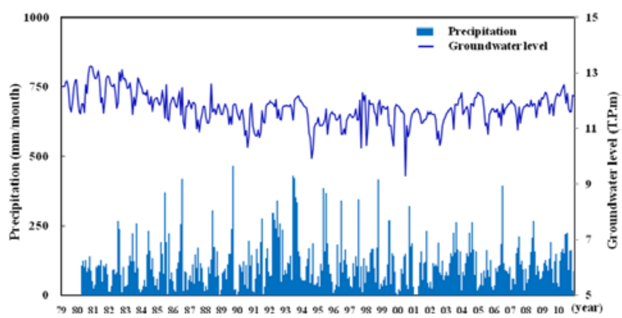

Figure 6　The water level and the amount of the rainfall in d-point

5. ANALYTICAL MODEL'S MAKING

(1) Modeling

Fig.7 shows the position of the boundary. The boundary of the east and the west side is set based on the divide. By using a simple model, the south side is outside of the influence radius obtained from the water level descent by pumping. Accumulative layer on the bedrock is to be modeled in the perpendicular direction, and we divide it into 9 layers based on the positions of strainers of the wells and the geological features, using the past data of the modeled region. The bedrock shape was made based on the data of the seismic reflection method and the gravity survey.

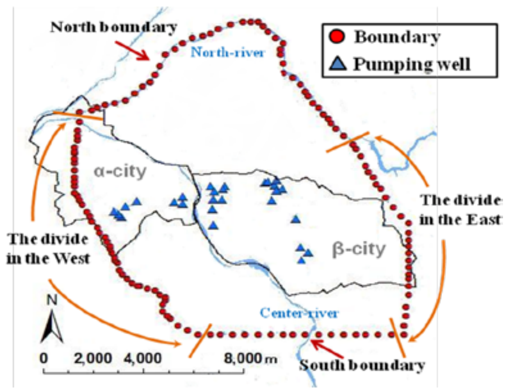

Figure 7　Position of the boundary

(2) Mesh partition

The number of nodes of analytical meshes is 77,176, and the number of elements is 144,543. Fig.8 shows the 3D model. A perpendicular direction is displayed at 6 times magnification.

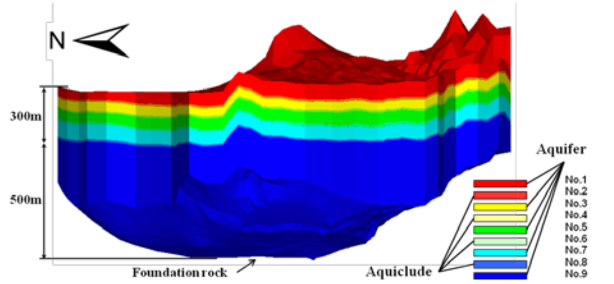

Figure 8　The 3D model

6. PUMPING SIMULATION ANALYSIS

In the analysis, we assume that the groundwater flow is in the steady state, and conduct a steady state analysis under an appropriate boundary condition once, and the result is set as the initial state on a broader basis. In addition, we set the pumping discharge for waterworks, when doing non steady analysis. And, the influence on the water level by pumping from many wells was examined.

(1) Input condition

- **Boundary condition**

We set a prescribed head boundary at the ground level nodes of both north river and center river, and set all nodes of the divide in the east and the west as an impermeable boundary, and set all other nodes that compose the bedrocks at the bottom part as an impermeable boundary and the nodes that form the ground level as the rainfall infiltration boundary.In general, it is said that the amount of recharge of groundwater was about 29-33% of the rainfall. From this reason, the amount of recharge of groundwater is set at 30%. We set all nodes at the south side as a free boundary. The pumping discharge of a private well is set at the pumping amount described in the past material as a prescribed flux boundary, and, similarly, the average value of monthly pumping for waterworks is a prescribed flux boundary. The pumping discharge for waterworks is set from the positions of strainers as a prescribed flux boundary by the node in No.3, No.5, and No.7 layer.

- **Ground physicality parameter**

Table 1 shows the ground physicality parameter. We perform the identification calculation using the physical properties value from the result of the pumping test in the case of pumped layer, and referring to the document in the case of other layers. We decide final ground physical properties value by matching the groundwater level obtained at the node of the pumping well for waterworks to an actual groundwater level these 5 years.

Table 1 The ground physicality parameter

Layer	Coefficient of permeability (cm/s)		Specific storage (l/m)	Effective porosity (%)
	X・Y	Z		
No.1	5.0×10^{-1}	5.0×10^{-2}	1.2×10^{-4}	20
No.2	9.0×10^{-4}	9.0×10^{-5}	2.0×10^{-3}	10
No.3	7.0×10^{-2}	7.0×10^{-3}	1.2×10^{-4}	20
No.4	4.0×10^{-5}	4.0×10^{-6}	2.0×10^{-3}	10
No.5	5.0×10^{-2}	5.0×10^{-3}	1.2×10^{-4}	20
No.6	4.0×10^{-5}	4.0×10^{-6}	2.0×10^{-3}	10
No.7	7.0×10^{-3}	7.0×10^{-4}	1.2×10^{-4}	20
No.8	4.0×10^{-5}	4.0×10^{-6}	2.0×10^{-3}	10
No.9	5.0×10^{-3}	5.0×10^{-4}	1.2×10^{-4}	20

(2) Result

Fig.9 and Fig.10 show the comparison of the analytical result and the measured water level in c-point and d-point. The well in c-point was set up in the near of center-river, and the fluctuation of water level was comparatively steady. The water level recovered by about 2m in the actual measurement when the pumping discharge was decreased in March 2007. However, the analytic water level has only recovered by about 0.6m. The analytical result of d-point was able to reproduce the tendency of the fluctuation of water level, such a decrease in water level when pumping discharge was increased and a recovery of water level when pumping was stopped. The analytical result of other pumping wells in each waterworks shows about the same tendency. Thus, the fluctuation of water level is thought to have been able to reproduce accurately.

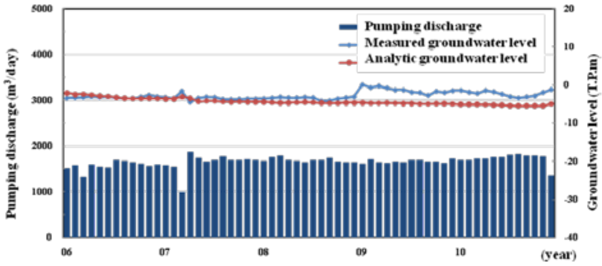

Figure 9 The analytical result in c-point

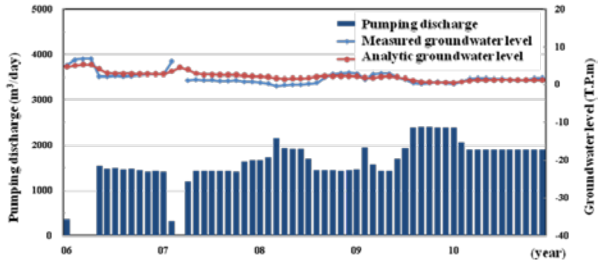

Figure 10 The analytical result in d-point

7. CONCLUSIONS

In this research, we analyzed to examine how the pumping wells influence groundwater behavior. We construct the stratum model in detail, analyze the seepage flow and compare the change of the groundwater level that the group of pumping wells caused with the actual measurement values. As a result, the fluctuation of groundwater level was able to be reproduced in high accuracy in the constructed model. If the pumping well is newly established, using this model based on the result of measurement of the water level for 20 years or more, we want to forecast its future influence on the water level. We also want to use it as a model that can propose an appropriate groundwater control for the long-lasting use of groundwater in this region.

REFERENCES

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