Pumping simulations using 3D analysis on multi-pumping wells

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ABSTRACT: 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 this that the fluctuation of water level group wells cause accuracy by using our model made in the present study.

SUBJECT: Modelling and numerical methods

KEYWORDS: field measurements, fluid flow, numerical modelling

1 GENERAL INSTRUCTIONS

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. 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.

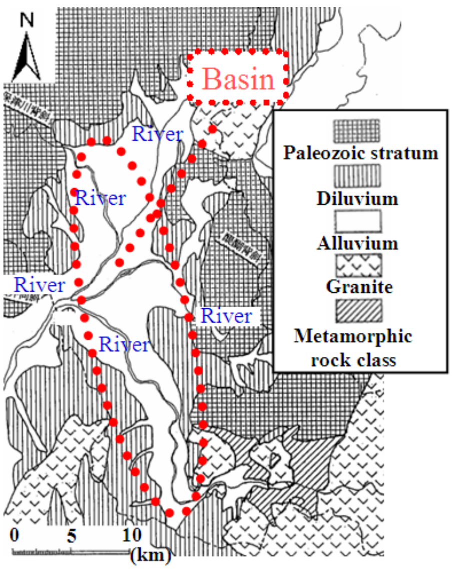

Figure 1. Geologic map.

3 GROUNDWATER USE STATE

3.1 *Groundwater use state of private well*

100 private wells were confirmed as a result of arranging the past material concerning the use of the wells. Fig. 2 shows the ratio of the pumping discharge and the ratio categorized according to the depth. Most wells are 1,000m^3 or less, considering the results of arranging the data of these 595 wells. And the well of about 90 percent is shallower than 150m. On the other hand, as the pumping well for waterworks are installed with the strainer in the point of about 150m-300m, we think that private wells have little influence on the result.

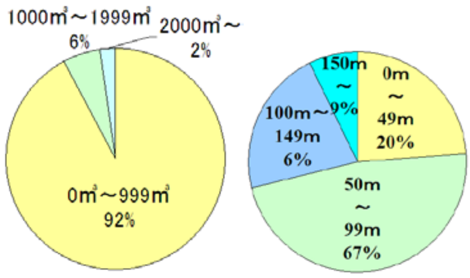

Figure 2. The ratio of the pumping discharge and the depth

3.2 *Groundwater use state of waterworks*

Fig. 3 shows the position of the pumping wells and the monitoring wells at the waterworks in the examined region. There are 27 pumping wells at the waterworks and 6 monitoring wells.

3.2.1 *Water level under pumping for waterworks*

In each pumping well, the water level is regularly measured, and we have understood a long-term fluctuation of the water levels. Moreover, we practiced pumping examinations in the digging of the pumping well in each waterworks to calculate the ground physical properties value, coefficient of permeability, specific storage, sustained yield. These data can also be useful for the analysis. The fluctuation of water level of the pumping well in the foothill and that of the pumping well in the plain land are different.

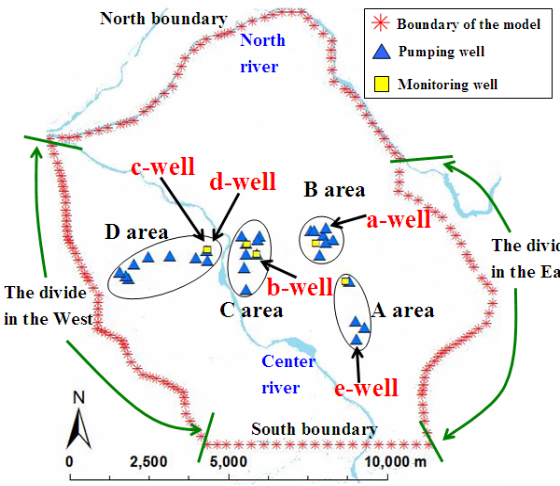

Figure 3. The location of pumping wells and monitoring wells in the examined region

The two characteristic of fluctuations of water levels are shown. Fig. 4, Fig. 5 shows the relationship between the changes in the groundwater level and the amount of pumped groundwater (A+B+C area). In a-well, the blank of the pumping discharge from September 1987 to March 1988 shows the period of no pumping measurement. After the beginning of the observation, the groundwater level decreased about 10m for 16 years until 1995, though the pumping discharge decreased. And, as a result of the washing construction this year, the water level recovered by about 11.5m. After that, though there are a few increases and decrease, the water level has been almost steady as a result of constant pumping of about 900m^3/day. In b-well, the groundwater level has been steady, even when 3,000m^3 of water a day is pumped or there are large increases and decreases of the pumping discharge. The water level recovered by about 5m in the month when there is no pumping. The groundwater level is steady in the vicinity of T.P.0m, though the water level somewhat falls by pumping. Overall, the water level changes with the pumping discharges. The pumping discharge is decreased and is fixed in the area B now so that the water level is steady. However, in B region, it is necessary to consider the well interference in the pumping because the wells are set up in the most crowded region. On the other hand, the groundwater level is overall steady in C region though pumping is most active. It is thought that this originates in the fact that 4 out of 8 pumping wells are set up with 300m in depth unlike other waterworks.

3.2.2 *Water level of monitoring well*

3.2.2.1 *Consideration of fluctuation of water level that total pump discharge of D area causes*

Fig. 6 shows the relation of a total pumping discharge of the waterworks in D region and the fluctuation of water level in the deep monitoring c-well.

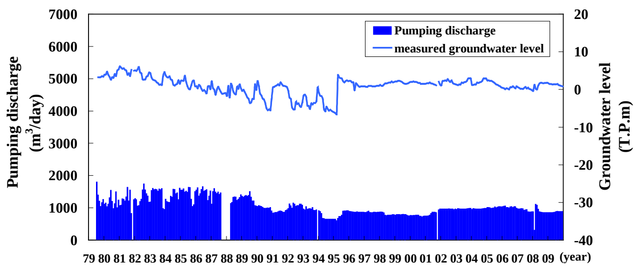

Figure 4. The amount of pumping (A+B+C area) and the groundwater level of a-well (foothill)

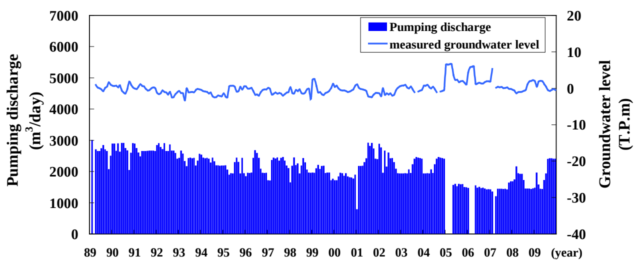

Figure 5. The amount of pumping (A+B+C area) and the groundwater level of b-well (smooth ground)

The groundwater level tends to decrease in summer when there is more pumping charge, and it recovers in winter when a pump discharge is little. Moreover, considering a long-term observational result, the groundwater level has decreased by about 3m by having gradually increased the pumping discharge from 1987 to 1998. Afterwards, the water level has been steady because of the constant pumping discharge from 1998 to 2003. After 2003 the groundwater level is in a sudden recovery although the reduction of the pumping discharges in all filtration plants in D region are just a little. As a reason, the pumping discharge of the d-well which is the nearest the monitoring wells decreases greatly, compared with the change of a total pumping discharge of the waterworks in D region.

3.2.2.2 *Consideration of fluctuation of water level that amount of rainfall causes*

Fig. 7 shows the relation of the fluctuation of water level in the shallow monitoring c-well and the amount of the rainfall. The amount of the rainfall greatly influences the fluctuation of water level in the shallow monitoring wells, 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. From the observation, we understand the causes that affect each layer, which the fluctuation of water level of shallow wells is greatly influenced by the amount of rainfall and that of deep wells in this region is greatly influenced by the pumping discharge. Moreover, it is recognized that the influence that pumping exerts on the groundwater level is very large compared with the influence that the rainfall exerts on groundwater. Therefore, it is important to accurately understand the influence of pumping on the groundwater level.

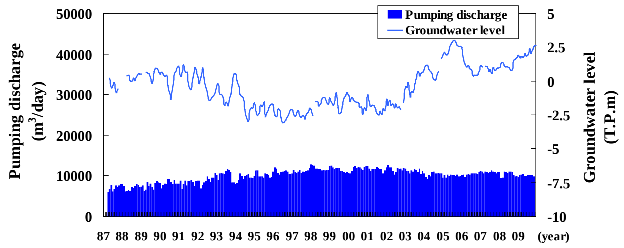

Figure 6. Total pump discharge of D area and groundwater level of deep monitoring c-well

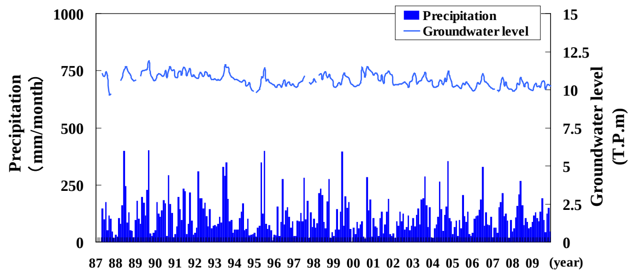

Figure 7. The amount of the rainfall and groundwater level of shallow monitoring c-well

4 PUMPING SIMULATION

4.1 *Outline*

Here, we describe the method of making a groundwater pumping simulation model to examine the influences on the groundwater level that wells for waterworks. The input data are the amount of the rainfall, the ground level, the coefficient of permeability and boundary conditions, etc. In this study, we make the stratum model by considering geological features of this region for the start, and perform the seepage flow analysis using the finite element method. We construct the pumping simulation model, matching the water level obtained by the node of the pumping well for waterworks to an actual water level while changing the ground physical value.

4.2 *Modelling*

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 8 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.

4.3 *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 mesh model. A perpendicular direction is displayed at 8 times magnification.

4.4 *Input condition*

4.4.1 *Boundary conditions*

We set a prescribed 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.

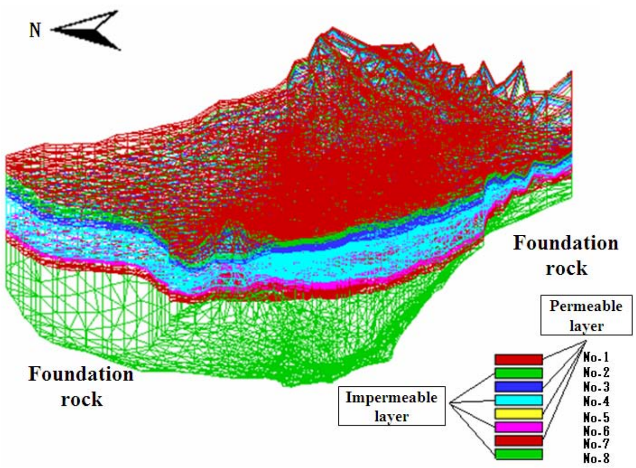

Figure 8. The 3D mesh model

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. In the case of private wells we decide to set the node of which layer of the stratum model, considering the pumping discharge from the depth data of the well and the positional data of strainer described in the past material. 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. In the steady analysis, the pump discharge from the private well by is set. Based on the initial conditions obtained from the results, we set the pumping discharge of the waterworks to perform a non steady analysis.

4.4.2 *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.

Setting	Coefficient of Permeability X Y (cm/s)	Coefficient of Permeability Z (cm/s)	Specific storage (1/m)	Effective porocity (%)
No.1	5.0×10^{-1}	5.0×10^{-2}	1.20×10^{-4}	20
No.2	7.5×10^{-4}	7.5×10^{-5}	1.95×10^{-3}	10
No.3	5.0×10^{-2}	5.0×10^{-3}	2.00×10^{-4}	20
No.4	7.5×10^{-5}	7.5×10^{-6}	1.95×10^{-3}	10
No.5	5.5×10^{-3}	5.5×10^{-4}	2.00×10^{-4}	20
No.6	7.5×10^{-5}	7.5×10^{-6}	1.95×10^{-3}	10
No.7	8.5×10^{-3}	8.5×10^{-4}	2.00×10^{-4}	20
No.8	7.5×10^{-5}	7.5×10^{-6}	1.95×10^{-3}	10

4.5 *Result*

One example from each waterworks of a result of the identification calculation is shown. Fig. 9, Fig. 10 shows the result of e-well and b-well. In e-well, the trend is taken from 2005 to June 2009. However, after the pumping discharge is increased by about 200m^3/day, actual groundwater falls by about 5m, while the analytical groundwater level falls only by about 1m. On the other hand, an analytical result of b-well is highly accurate. The water level recovers by about 5m while there is no pumping. Thus, the fluctuation of water level can be reproduced accurately. The analytical result of other pumping wells in each waterwork shows about the same tendency.

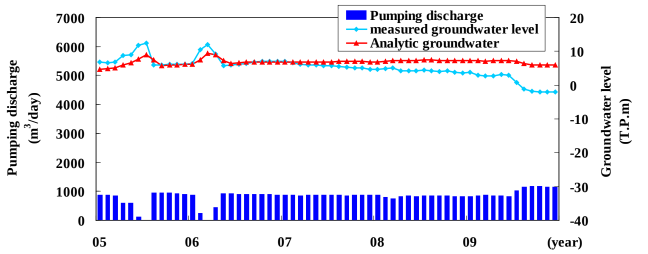

Figure 9. Comparison between values measured and the predictions of analysis at e-well

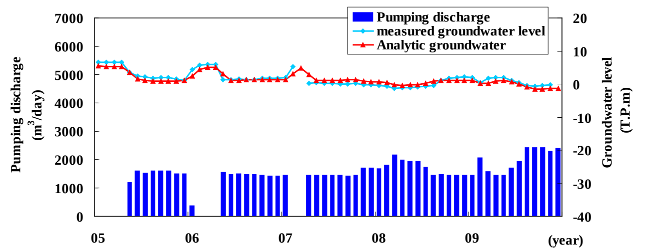

Figure 10. Comparison between values measured and the predictions of analysis at b-well

5 CONCLUSIONS

In this research, we analyzed to examine how the pumping wells influence groundwater properties. In the examination, we construct the stratum model in detail, analyze the seepage flow by the finite element method, and compare the change of the groundwater level that the group of pumping wells caused with the actual measurement values. As a result, it can be seen from this that the fluctuation of water level group wells cause accuracy by using our model made in the present study. 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 ground water in this region, and for the prevention of troubles concerning the wells, subsidence, and uplifts.

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