Pumping Simulation using 3D Ground Water Flow Model in Kyoto

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The area of the analytical model is located in the southern part of Kyoto prefecture, it has a typical ground water basin shape and three rivers flow through it. The rivers flow into the area between two mountains, then flow out to Osaka. Due to the fact that the underground water in the basin flows out from this point only, it is estimated that abundant underground water is saved in the Kyoto basin. This research is focused on Joyo city which has long used plenty of underground water for the public, agricultural and industrial water supplies. In recent years, excessive pumping has caused subsidence and the depletion of water resources. This research purposes to establish a three dimensional groundwater flow model and make suggestions for the adequate management of the underground water by a pumping simulation analysis.

1. INTRODUCTION

In Kyoto, underground water has been used for a long time, for instance in cultural use, like making tofu and dyeing kimono and for daily life.

Kyoto has a typical groundwater basin shape and there are three main rivers in the area; the Uji River, Kizu River and Katsura River. These rivers flow into the area between the Tennou-zan and Otoko-yama mountains, then flow out to Osaka. Due to the fact that the underground water in Kyoto basin flows out from this point only, it is estimated that abundant underground water is saved.

The quantity of underground water is calculated to be 21.1 billion tons and is comparable to the volume of water in Lake Biwa (25 billion tons).

This research is focused on Joyo city which is located in the southern part of Kyoto prefecture. In Joyo city 80 percent of its water for daily life comes from underground water. In recent years, excessive pumping has caused subsidence and the depletion of water resources in the area. This research paper purposes to establish a three dimensional groundwater flow model and make suggestions for the adequate management of groundwater by a pumping simulation analysis.

2. GEOLOGICAL CONDITIONS IN KYOTO

Kyoto basin is surrounded by mountains made of the basement rock - Paleozoic strata and granite, Fig.1. These mountains flow underground with a gentle gradient towards the centre of the basin.

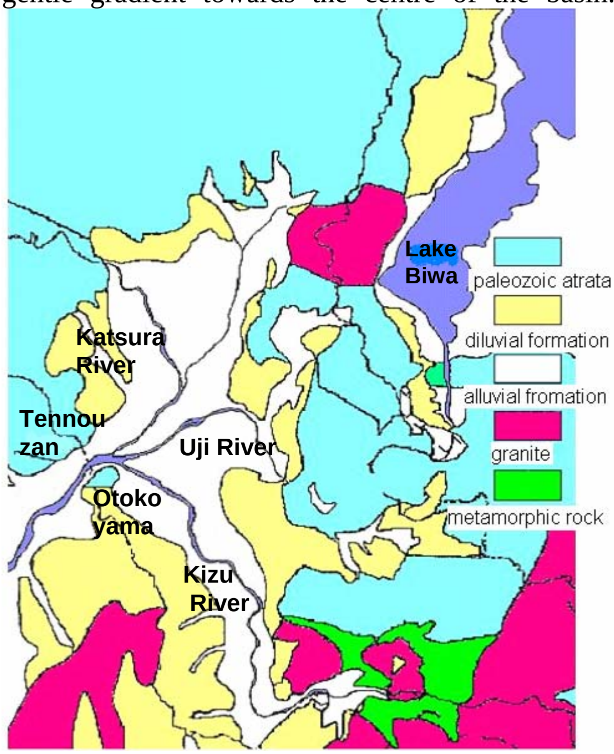

Fig.1 Geological map on the Kyoto basin

The basement rock has a bowl shape and sedimentary layers after the tertiary era accumulated on it. It is an impermeable bed; diluvial formations and alluvial formations consist of unconsolidated sediment which has a permeable and an impermeable layer. This means that the sediment can save a lot of underground water. The area of the analytical model has sand gravel in shallow layers, and the deeper layers consist of clay and sand gravel.

3. GROUNDWATER RESOURCES IN JOYO CITY

(1)Water supply project in Joyo city

The water supply project in Joyo city was authorized in 1962. After that, many water supply projects were established. In recent years underground water has been allocated for the public water supply as the population has grown. Since the area has abundant underground water, the first water treatment plant was established in 1971, the second in 1973, and the third in 1978.

Fig.2 shows the amount of pumped water and the public water from Kyoto prefecture. In 2006, the volume of the public water supply was 9,500,000m^3/year in Joyo city. Of this, 80 percent (7,500,000m^3/year) come from underground water. As the diagram below shows, currently 60 percent of pumped water is recorded as coming from the third water treatment plant. It is the area's major plant.

(2)Private Wells

There are 505 wells known in Joyo city. Fig.3 shows the location of these wells. Fig.4 shows the total amount of wells using underground water. The wells are used for agricultural and industrial purposes and for life's daily needs. There are many shallow wells, less than 100 meters in depth and there some industrial wells, some of which are very deep (more than 100 meters). Most wells are used for agriculture, and used in the farming seasons (spring, summer and autumn). The wells are second most used for industry, and are used all year round for this purpose. The remaining wells are for commercial and domestic use. It is also thought that there are other wells that exist but, these wells are not recorded or analyzed this paper. The quantity of total pumped underground water is calculated to be approximately 25,000,000m^3. This amount of water is equal to over 2.5 times the public water supply in Joyo city.

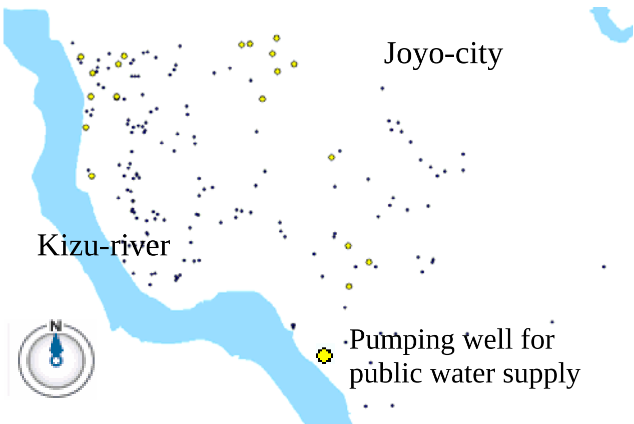

Fig.3 The position of wells in Joyo city

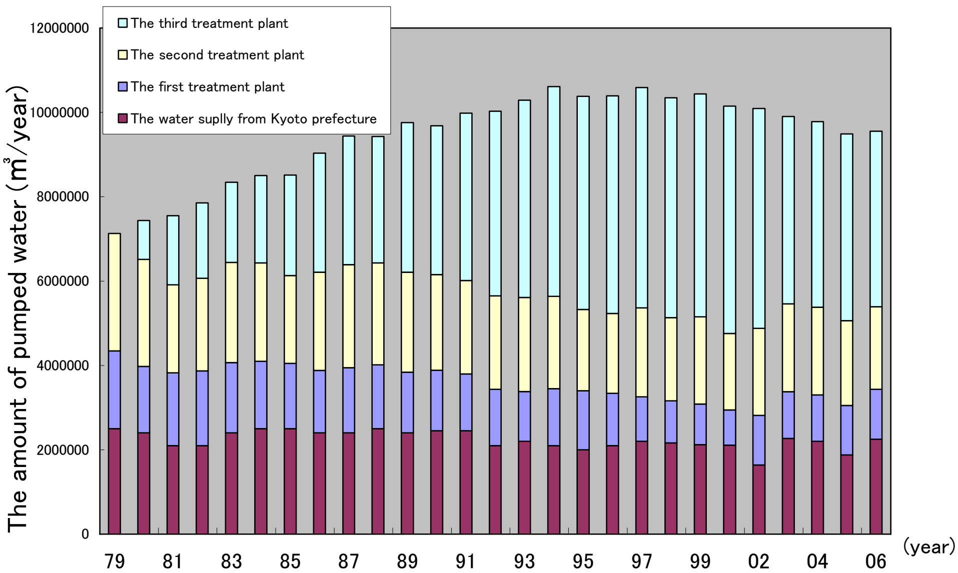

Fig.2 Some public water supply

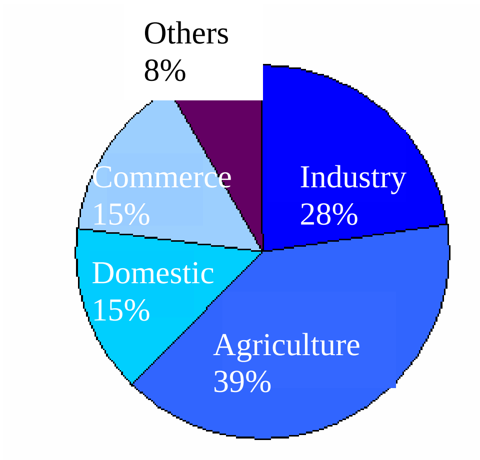

Fig.4 Total amount using underground water

(3) Changes to the underground water level of observation wells

Observation wells are used for the measurement of the water level, and not for the pumping of underground water. Surrounding wells and climate conditions influence changes in the underground water level, and the underground water level in an aquifer can be exactly calculated. There are two kinds of observation wells, shallower observation wells for unconfined underground water and deeper observation wells for confined underground water. The relationship between the changes of water level in shallow wells with precipitation, and the relationship between changes of water level in deep wells with the amount of pumped underground water for public water supply will be analyzed.

1) Changes of underground water in shallow wells

Shallow wells are generally intended for unconfined aquifer, near the ground. The underground water level of the aquifer is influenced by precipitation. In Joyo city, there are two shallow observation wells; Yamazaki Well and Tsuji Well. Fig.5 shows the relationship between the underground water level in the Yamazaki Well and precipitation. As Fig.5 shows, a large drawdown was caused when there were bad draughts in 1994 and 2000. However since then, the underground water level has been generally stable. It is evident; therefore, evident that the underground water level has been influenced by precipitation.

2) Changes to underground water in deep wells

In deep wells, underground water is pumped up from a confined aquifer, which is below the clay impermeable layer. In Joyo city, there are three observation wells, Nishida Well and Tsuji Well and the second water treatment plant's observation well. Fig.6 shows the relationship between the changes in water level and the amount of pumped underground water in the second water treatment plant observation well. In this well, the underground water level tended to decrease until the late nineties, however in 2000, the water level seemed to stabilize, with fluctuations in the short term.

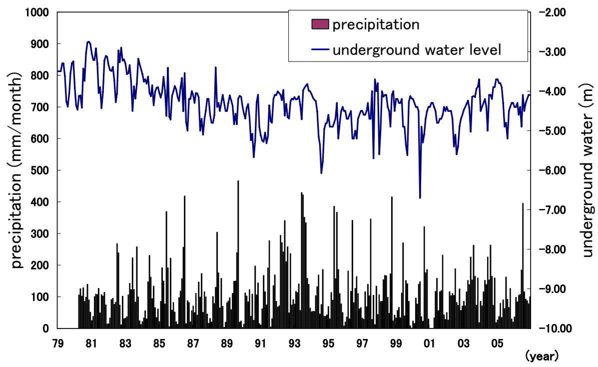

Fig.5 Yamazaki observation well and precipitation

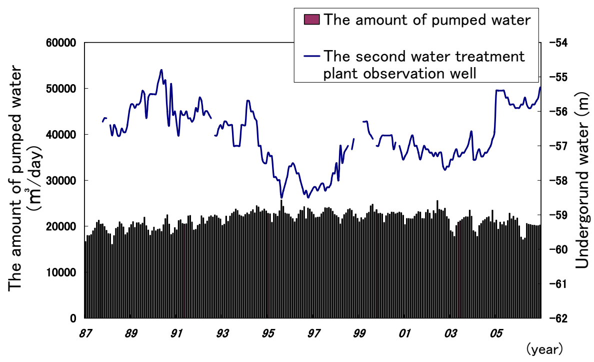

Fig.6 The second water treatment plant observation well and the amount of pumped water

4. ANALYSIS MODEL

This analysis model has been established by making the underground water level at the point of pumping match the real underground water level while changing the parameters.

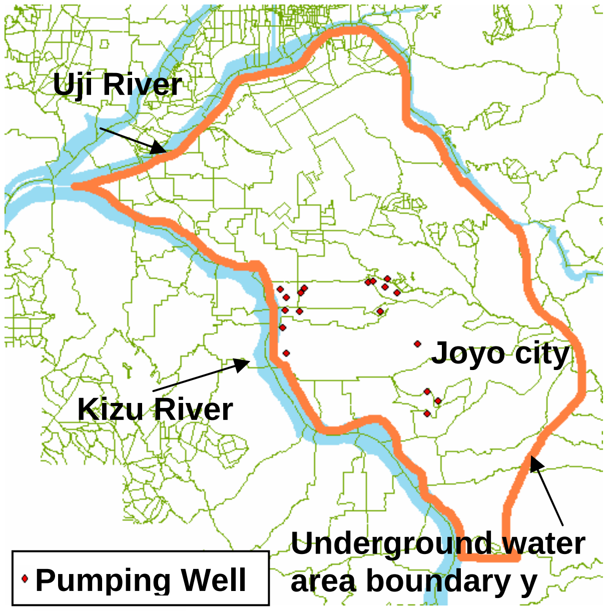

Fig.7 The area of analysis model

(2) Mesh division

The planar mesh divisions, fundamental density radii are 370m. Private wells are 70m. And wells for public water supply are 0.7m. In vertical, the layers boundaries conform to the element boundaries. The model below is divided into 51255 node points and 93648 elements. The model is shown in Fig.9.

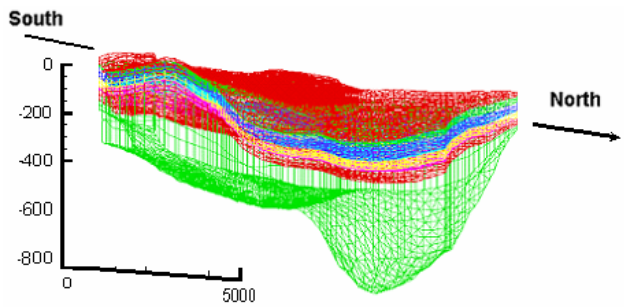

Fig.9 The mesh analysis model

(1) Area of analysis

The analysis range is the inside of the heavy line in Fig.7. The boundary is Kizu-river on the west side, Uji-river on the north side, and the east boundary is set by the guidelines from The National Underground Water Handbook. The south boundary has been set at a distance from the area influenced by underground water level changes. This boundary is three kilometers from the southernmost well. In vertical, the boundary is set to include sedimentary layers on the basement rock. The sedimentary layers have been simplified into eight layers from boring data, and the position of the screens in the wells and geological features in the area influence the shape of the layers. Fig.8 shows the model classified by color and seven times in vertical. The layers are labeled as No.1, No.2, and so on from the upper layers.

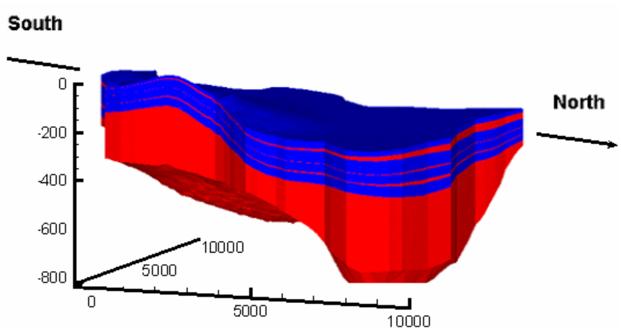

Fig.8 The analysis model

(3) Input condition parameters

The boundary conditions are set as follows. Kizu-river and Uji-river are treated as a water level fixed boundaries on the ground and impermeable boundaries at the side. The underground water area boundary is impermeable as well, and south boundary is a fixed water level boundary. The nodes on the basement rock are all impermeable boundary. On the ground, the nodes are a rain boundary.

Private wells are given a set given discharge boundary condition. The condition is set by reference to a well register book; the depth of the well and a position of the screens. Pumping wells for public water are given a set discharge boundary condition as well.

There has been difficulty in determining an initial condition because of lack of hydrogeological data. Therefore, it is set by result of a steady analysis with the boundary condition of the rivers, wells and side and underground boundaries mentioned above.

5. RESULT OF ANALYSIS

(1) Hydrological parameter

The hydrological parameters are determined so that the underground water level at the nodes of the pumping wells match the real water level. The various geological features of the layers are not considered or shown in this analysis. Hydrological parameters are shown in Table.1 on following page.

Table.1 Hydrological parameter

	K_{xy} (cm/s)	K_z (cm/s)	S_s (1/m)	e (%)
No.1	1.0×10^{-1}	1.0×10^{-2}	6.0×10^{-3}	0.40
No.2	5.0×10^{-4}	5.0×10^{-5}	1.0×10^{-3}	0.60
No.3	3.0×10^{-2}	3.0×10^{-3}	5.0×10^{-3}	0.38
No.4	5.0×10^{-5}	5.0×10^{-6}	8.0×10^{-3}	0.58
No.5	2.0×10^{-3}	2.0×10^{-4}	4.0×10^{-3}	0.36
No.6	5.0×10^{-4}	5.0×10^{-5}	6.0×10^{-3}	0.56
No.7	8.0×10^{-2}	8.0×10^{-3}	4.0×10^{-3}	0.34
No.8	2.0×10^{-4}	2.0×10^{-5}	4.0×10^{-3}	0.54

(2) Pumping wells for the public water supply

There are nineteen wells in the first, second and third water treatment plants and they are shown in Fig.3. This research analyses the ten years from 1997 to 2006, and considers the effectiveness of this model, by comparing changes in underground water levels in pumping simulation to real water level changes. The results are shown in Fig.10 to Fig.15. The six graphs show data from two pumping wells at each treatment plant.

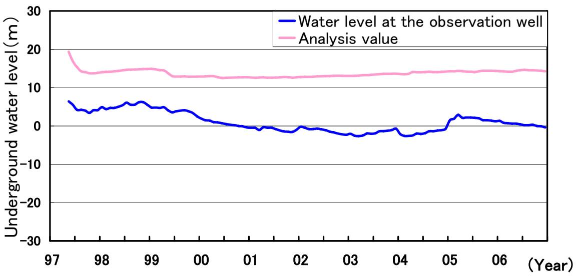

Fig.10 Well No.1 at the first water treatment plant

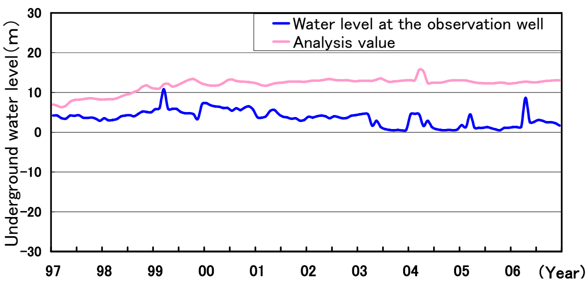

Fig.11 Well No.4 at the first water treatment plant

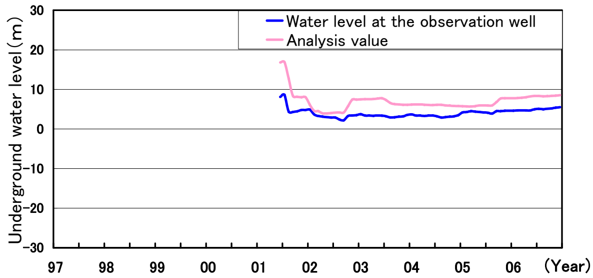

Fig.12 Well No.5 at the second water treatment plant

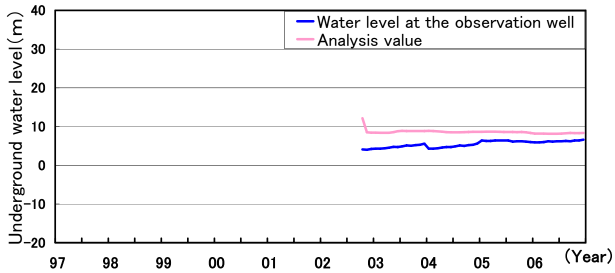

Fig.13 Well No.8 at the second water treatment plant

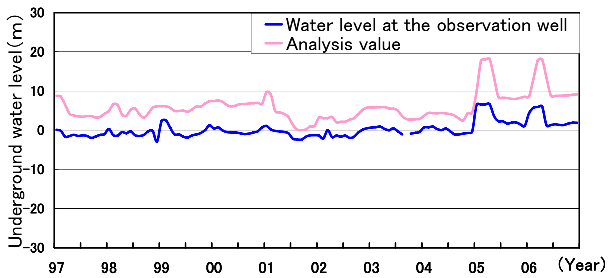

Fig.14 Well No.4 at the third water treatment plant

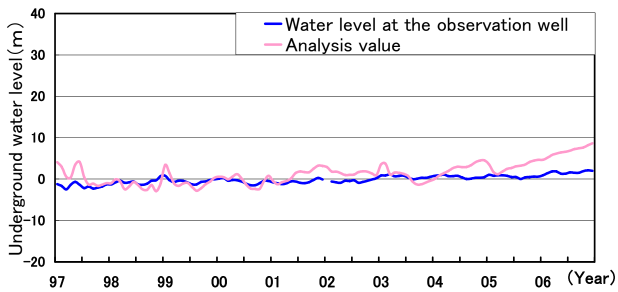

Fig.15 Well No.6 at the third water treatment plant

6. CONCLUSION

The first water treatment plant is located on a forest slope. From the analysis it is evident that there is a difference between the analysis model and the real underground situation. This is due to the fact that, there is about ten meters difference between the analysis value and the real underground water level at the pumping well.

The second water treatment plant is also on a high elevation. The layers are very complicated so it has been difficult to identify both the analysis value and underground water level.

The third water treatment plants results are good. The underground water level behavior in the short term is shown approximately.

The analysis model was made more accurate by altering the parameters. Challenges for the future will be the improvement of the model and reviewing the hydrological parameters.

REFFERNECE

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