Models for Predicting Ground Water Level

Modèles de Prédiction des Niveaux d'Eau Sous-Sol

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SYNOPSIS Both simulation model and statistical model are constructed for predicting the variation in groundwater level at Gifu locality in Japan. Computed variations from two models are compared with observed data from 1974 to 1976. Observed variation accords well with the computed one from the statistical model rather than from the simulation. The paper aims to describe the characteristics of each model and limitations to use.

INTRODUCTION

In Gifu-Ogaki district, it has been expected to make clear how much pumpage can be utilized without changing the quantity of groundwater in future. The geological and hydrologic conditions have not been inquired in detail, but 36 wells have been set to supervise the groundwater level. Under these circumstances we have tried to investigate the predicting model, first requesting for simulation model(SM) and second for statistical model(STM). As a result, it is clear that two models have very different characteristics respectively. Observation wells whose data are used for STM are located as is shown in Fig.1(b), and the area analyzed by SM is shown in a finite grid scheme in Fig.1(c).

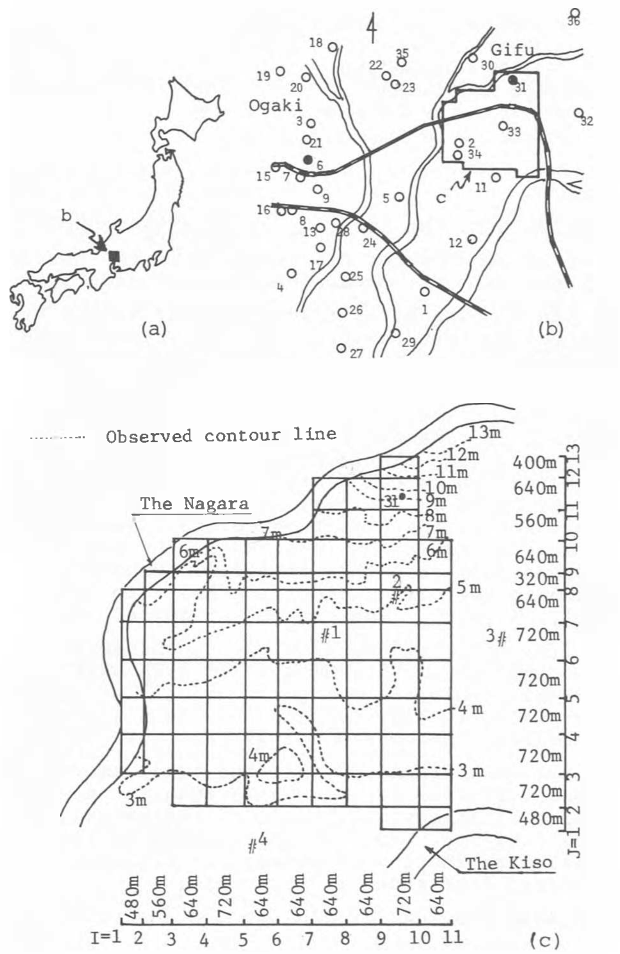

Fig.1 Analyzed Regions. (a)Japan. (b)Gifu-Ogaki District. (c)Finite Grid Scheme for the Simulation Model.

SIMULATION MODEL(SM)

The south area of Gifu analyzed by SM as quasi-three-dimensional is bounded by two rivers, the Nagara and the Kiso in Fig.1(c). Sands and gravels are mainly accumulated except the surface layer and of high permeability shown in Table.I. From these data and geological observations, transmissivity and storage coefficients are estimated according to the general relatons among specific yield, gradation and porosity of soils and the results are obtained in Fig.2(a) in which estimated parameters are modified a little by the identification process stated later. The fundamental equation of groundwater flow at the steady state is given by

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = W(x,y,t) \qquad (1)$$

$$q_x = -T_x \cdot \frac{\partial h}{\partial x}\ , \quad q_y = -T_y \cdot \frac{\partial h}{\partial y} \qquad (2)$$

Table.I Transmissivities from Pumping Tests

No.	Place	Transmissivity(cm^2/s)	Well Depth(m)
#1	Rokujo	1.48×10^3	23.5
#2	Tenman koen	$2.08 \sim 2.98 \times 10^3$	20.0
#3	Minamimachi	1.36×10^3	36.0
#4	Yanaizu	4.64×10^3	24.0

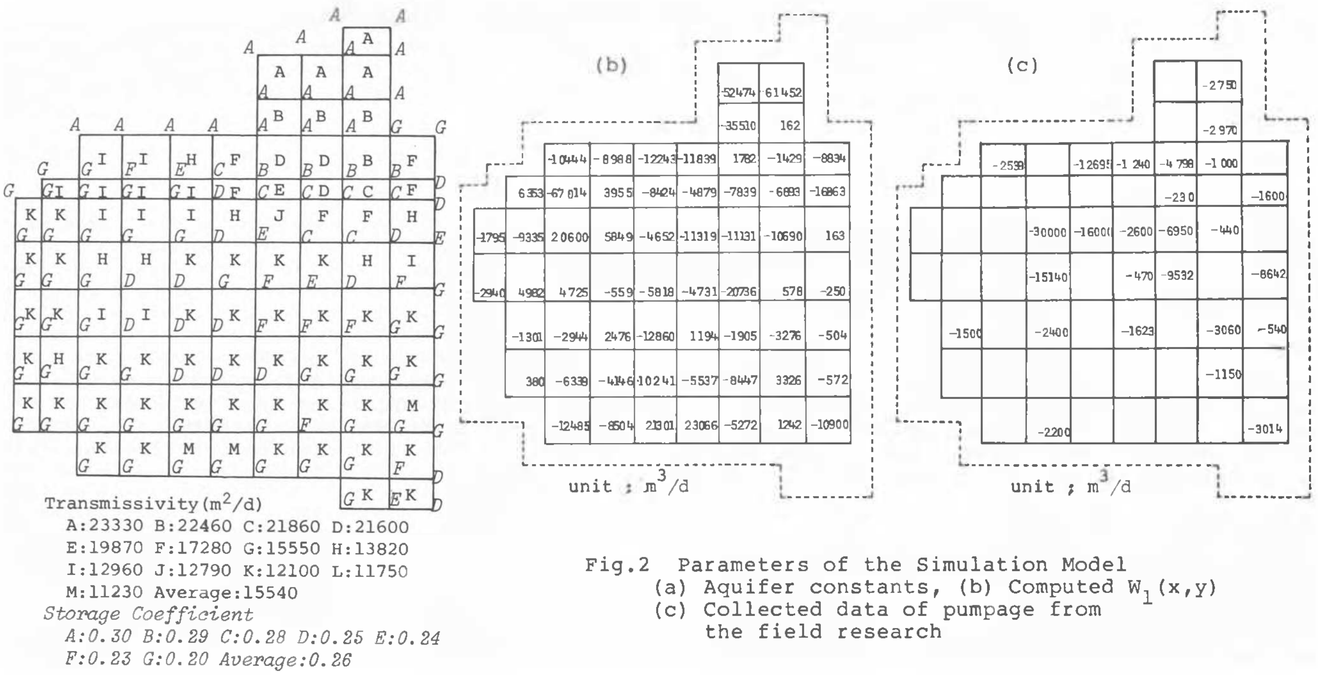

Fig.2 Parameters of the Simulation Model
(a) Aquifer constants, (b) Computed $W_1(x,y)$
(c) Collected data of pumpage from the field research

in which h is the head, q_x, q_y are the components of groundwater discharge, W is the source of recharge(plus) or drainage(minus) and T_x, T_y are the components of transmissivity in the x, y-direction respectively. In the present case, the thickness of aquifer is included in transmissivity because the thickness is not known.

Among the parameters in Eqs.(1) and (2), the source W is regarded as the most uncertain quantity and , like the identification model, this is devised to be calculated in the constructing process of SM as follows. If we choose the stable and little amount of rainfall season, the source W in Eq.(1) is regarded as the one produced only from the artificial pumpage including the circulation from layer to layer, namely, $W_1(x,y)$. The contour of dotted lines in Fig.1(c) was obtained from the synchronous investigation on Feb.2nd and 3rd 1973 when the flow was stable. From Eqs.(1) and (2) using the water level in Fig.1(c) and the transmissivity in Fig.2(a), we obtain $W_1(x,y)$ as shown in Fig.2 (b). It is computed so that the total amount of computed sources can be nearly equal to that of pumpage after several trials of rearranging the transmissivity. Fig.2(b) corresponds to the actual distribution of pumpage in Fig.2(c) collected from about fourty users.

Nonsteady groundwater flow can be analyzed by

$$S \cdot \frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = W(x,y,t) \qquad (3)$$

and Eq.(2), where S is the storage coefficient and the source W is now reconsidered by

$$W(x,y,t) = W_1(x,y) + W_2(x,y,t) \cdot \alpha \qquad (4)$$

where W_2 is the precipitation and α is the rate of seepage to aquifer, $0 \leq \alpha \leq 1$, for Gifu α is assumed to be 1.

Computed variations by SM and observed ones are compared with each other as shown in Fig.3 at Kyomachi observation well. They agree as a whole. There are many unavoidable uncertainty in parameters of SM such as boundary conditions, quantities of pumpage and influence of rainfall,etc. We could modify some combinations of parameters to adjust themselves so that computed variations may fit the actual behavior of groundwater. If so, however, we have to pay more attention to the site investigation, by which we can make clear the true site conditions. It would take a vast amount of labours and costs. On the contrary, the data of groundwater level as well as hydrologic characteristics have bee put in order so far.

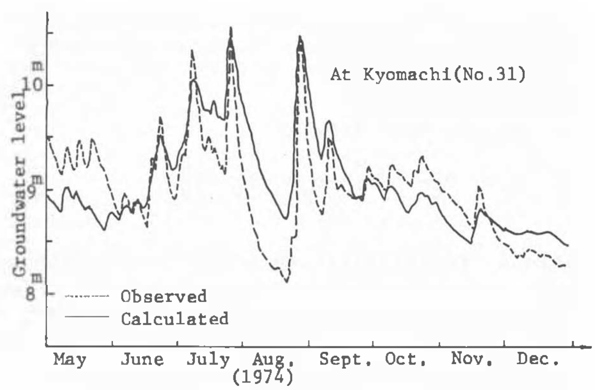

Fig.3 Comparison of the Observed Groundwater Level with the Computed one by SM

STATISTICAL MODEL(STM)

In order to formulate the STM, we should select and collect parameters making an influence on the groundwater flow. According to the previous study, six factors are adopted together with the groundwater level(h) ; namely, the rainfall(W) including snowfall, the river water level(H) at the nearest point around the region under consideration, the pumping rate of discharge(Y), the humidity(m), the temperature(T) and the atmospheric pressure(P).

In the data analysis concerning groundwater, any kind of factor should be represented by a value at a finite time interval, for example, a mean value per an hour, a day or a month etc. The groundwater level, of course, changes hourly, and yet, the variation in level during a day is not so great under usual circumstances. From this point of view, the data are rearranged in a daily unit in the following, although the analysis based on the monthly data are examined but unsuccessful.

There are number of obsevation points for any factor like rainfall and river water level, and the correlation between some factors at different two points are calculated at every combination. In the result, rainfall factors are correlated with greater coefficient than 0.960 and river water level are correlated more than 0.923 in Gifu-Ogaki area. Then, the data of rainfall at Gifu Meteorological Observatory and river level at Nagara are representative.

As the first step, a correlation between each factor and groundwater level are calculated, and time lag is regarded as the delayed time interval at the maximum coefficient of correlation between a time series data of each factor and groundwater level. Time lag is 2 ~ 3 days for rainfall in most cases and 0 ~ 1 days for river water level.

Most probably fitting time series data of each factor are used for the principal component analysis, exclusive of the data of pumpage due to the lack of daily data. For each factor,

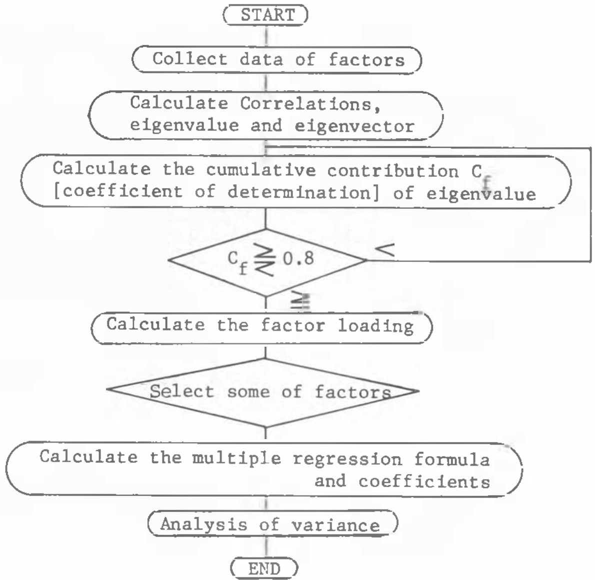

Fig.4 Flow Chart for the Statistical Model

factor loading, eigenvector, eigenvalue and cumulative contribution to the first principal component, the second ····· are calculated until the percentage of cumulative contribution of n-th principal component exceeds 80 %. Two examples calculated at Kyomachi well and Ogaki well from Dec.1974 to Nov.1975 are shown in Table.II. At Kyomachi where unconfined flow occurs, a factor loading of river water level is greater, but at Ogaki where confined flow occurs, that of atmospheric pressure is greater than expected.

Multiple regression analysis(MRA) plays a role on estimating b_i in the linear type of equation given by

Table.II Examples of Results from the Principal Component Analysis

Observation point	Season	Principal component	Cumulative contribution	Factor loading						Eigenvalue
				X_1[h]	X_2[W]	X_3[H]	X_4[P]	X_5[T]	X_6[m]	
Kyomachi (No.31)	[1[	Z_1	33.7 %	0.891	0.458	0.894	-0.363	-0.289	0.018	2.019
	[2]	Z_1	39.2 %	0.923	0.451	0.696	-0.332	0.721	0.427	2.352
	[3]	Z_1	38.8 %	0.835	0.538	0.841	-0.441	-0.396	0.532	2.329
	[4]	Z_1	39.6 %	0.904	0.611	0.789	0.426	-0.544	-0.287	2.374
Ogaki (No.6)	[1]	Z_1	25.8 %	0.408	-0.447	-0.429	0.764	0.296	-0.570	1.547
	[2]	Z_1	42.0 %	0.897	0.409	0.598	-0.541	0.723	0.615	2.523
	[3]	Z_1	39.1 %	0.720	0.554	0.589	-0.694	-0.589	0.590	2.348
	[4]	Z_1	37.9 %	0.870	0.018	0.513	0.593	-0.886	-0.337	2.272

[1] Dec.1974 ~ Feb.1975 [3] June.1975 ~ Aug.1975
[2] Mar.1975 ~ May.1975 [4] Sept.1975 ~ Nov.1975

Table.III Examples of Results from the Multiple Regression Analysis

Observation point	Season	Partial regression coefficient						Multiple correlation coefficient R	F value
		b_1 [W]	b_2 [H]	b_3 [P]	b_4 [T]	b_5 [m]	b_0		
Kyomachi [No.31]	[1]	-0.0005	0.6659		0.0012	-0.0002	1.7666	80.0	37.3
	[2]	-0.0013	1.0318		0.0382	0.0043	-7.7231	87.9	74.2
	[3]	-0.0015	0.9245		-0.0182	-0.0009	-4.9589	89.6	88.7
	[4]	-0.0023	0.9954		-0.0308	0.0016	-5.8796	89.0	81.7
Ogaki [No. 6]	[1]		-0.1076	-0.0007	0.0039	-0.0011	10.3740	27.4	1.7
	[2]		0.1668	-0.0065	0.0190	0.0004	13.4183	85.2	57.7
	[3]		0.2242	-0.0074	-0.0257	-0.0041	14.9139	70.3	18.9
	[4]		0.2579	-0.0009	-0.0177	-0.0003	7.6044	80.7	40.1

[1] Dec.1974 - Feb.1975 [3] June.1975 - Aug.1975
[2] Mar.1975 - May.1975 [4] Sept.1975 - Nov.1975

$$h = b_0 + b_1W + b_2H + b_3P + b_4T + b_5m \qquad (5)$$

where h is designated by [m], W [mm/d], H [m], P [mb], T [°C] and m [%].
First step of MRA is to select the factor whose absolute magnitude of factor loading is greater than about 0.4. Then, using the data of selected facters and groundwater level, MRA is carried out. Two cases of results are shown in Table.III corresponding to Table.II, where blank spaces mean that its factor is omitted. Thus the coefficients of linear Eq.(5) are estimated using the data from Dec.1974 to Nov.1975 for every four season. Using the coefficients and observed data of other hydrologic factors in 1975, the groundwater levels are computed and compared with the observed ones as shown in Fig.5. Sufficient results are obtained.

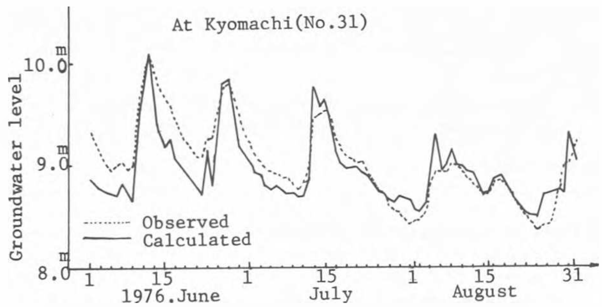

Fig.5(a) Comparison of the Observed Groundwater Level with the Computed One by STM

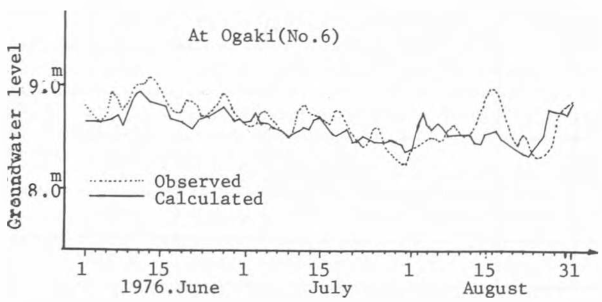

Fig.5(b) Comparison of the Observed Groundwater Level with the Computed One by STM

CONCLUSIONS

The authors can not simply compare SM with STM but are surprised at the sufficiently good results obtained from STM, although it may be justly deserved because STM is formulated statistically so as to fit and express all the data as much as possible. Comparing the results of SM with STM, the authors recognize some characteristics of each model as follows.

(1) The geological and hydrologic properties of aquifer are not necessary for STM but for SM, whereas the groundwater flow mechanism cannot be made clear by STM but SM at present, although STM can be interpreted as containing the influence of geological and boundary condition if measured data of factors are collected enough to analysis.

(2) Difficulty in selecting the necessary factors for STM resembles the difficult problem of identification process in SM. The new factor whose influence on groundwater flow is found out can be introduced to SM.

(3) Analyzing accuracy of STM is not quite so good for the unusual phenomena which have factors that vary more than the data used in analysis. The influence of each factor depends on the magnitude of the partial regression coefficient.

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