A Statistical Study on the Groundwater Fluctuation at Konan Aquifer

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Abstract : Groundwater table of eight wells in Konan aquifer substantially moves up and down in a year. Employing multiple regression analysis, seasonal movement of groundwater table is well formulated, using daily rainfall, near by Monobe River stage, daily mean atmospheric pressure, daily mean air temperature, daily mean relative humidity, daily mean wind speed, daily amount of global solar radiation, Seasonal Factor (SF, a dummy variable, and equals to unity during winter, i.e., from 1st of January to 22nd of March, and equals to zero from 1st of April to 1st of November), Weir Factor (WF, a dummy variable specifically for two wells, namely well No.3 and No.4, if the rubber dam on the Koso River near two wells is up, WF = 1, and if down, WF = 0). Data from November, 2001 to October, 2002 is used for parameter identification (the period is hereafter called "period of identification"), and accuracy of the model is verified using the data from November, 2000 to October, 2001 (the period is hereafter called "period of verification"). The latter data was observed once a week as a rule, and the former was observed almost every other day. To transform the data into daily ones, Spline interpolation (Sakurai.A.,1981)[1)] is utilized, and Spline interpolated data analyses and non-interpolated data analyses were compared. The best formulae developed here are Case No.4 (non-interpolation) for well No. 1, 2, 3, 5, 6 and 7, and Case 7 (Spline interpolation) for no.4 and 8 in **Table 5** respectively.

Keyword : Groundwater, Konan Aquifer, Seasonal Fluctuation of Groundwater

1. Introduction

The Earth is called "a water planet", and has 14 billion km^3 of water on it. But usable fresh water is only 0.01% of it. According to the report of World Meteorological Organization, 95% is seawater, 1% is salty water in lakes and swamps, and 2.5% is fresh water. 70% of fresh water forms ice at the poles, and the rest 30%, i.e. 0.01% of total water, 105,000 km^3 is fresh water at rivers, lakes, swamps and underground. 21st century is forecasted to be "Century of water resources". Water resources including groundwater are getting more and more precious.

At Konan Plain, the east of Kochi Plain, groundwater is used for greenhouses, fish cultures, domestic use and factories and getting more and more precious year by year. Future groundwater use is prospected to increase in both agricultural and industrial sectors. Groundwater along the coast is threatened by seawater intrusion. Groundwater is a limited and precious water resources and therefore, research work is necessary to sustain and promote groundwater use in this area. The purpose of this study is to develop a promising formula to forecast daily fluctuation of groundwater at eight wells by using multiple regression analysis approach as well as to make the mechanism of groundwater fluctuation clearer.

2. Study area

Study area, as is shown in **Fig. 1**, bounded by the Monobe River to the west, by the Koso River to the east, by mountains to the north, and by the Pacific Ocean to the south. The Karasu River flows in the center of Konan area from north to south. Eight observed wells are located all in Noichi Town and are numbered from No.1 to No.8. Out of total area of more than 2,200ha, approximately 1,502.5 ha is paddy fields, 488 ha is upland, and 186.5 ha is under greenhouse cultivation. Groundwater flows from north to south, and it is believed that a lot of groundwater is recharged by the Monobe River and paddy field. At the coastal area, groundwater is intruded by seawater, but observed eight wells locate relatively inland area, and none of them have been intruded by seawater so far.

There exist three dams on the upper and middle Monobe, and two weirs on the lower Monobe. Godo weir is located at Igenoki, Tosayamada Town (see **Fig.1**) and water diverged mainly to Tosayamada town, Nankoku City and Kochi City, but small portion of it is diverted to Noich Town and the small canal is called “Buyoji yu” (“yu” means channel in Japanese). Togo weir locates at Machida, lower than Godo weir, diverts water mainly for Noichi Town and Yoshikawa Village. The channel is called “Uwa yu”. There are irrigation canal networks for rice paddy fields in Konan area, and as well as the rivers and paddy fields, these canals are considered to be a recharge source of Konan aquifer.

Geology is consisted of alluvial and diluvial sand originated from ancient Monobe, and volcanic origin permeable roam, but here and there exists relatively impermeable soils in the center and southern Konan Basin. The hydraulic conductivity of the basin is high, and ranges from 65 to 804m/day (by Jha, M.K. et. al., 2002)[2].

3. Methodology

By use of multiple regression analysis, groundwater surface fluctuation model is expressed by such meteorological data as daily rainfall, daily mean stage of adjacent Monobe River stage, atmospheric pressure, daily mean air temperature, daily mean relative humidity, daily mean wind speed, daily global solar radiation, Penman's daily potential evapotranspiration, and dummy variables which represent irrigation or season and up and down of a rubber dam on the Koso River. Groundwater data from 1st of November, 2001 to 31st of October, 2002, which amounts to 198, is used for parameter identification. Best model is selected as the one which has the maximum coefficient of multiple determination. Data from 1st of November, 2000 to 31st of October, 2001 (data number amounts to 54) is used for verification of the accuracy of the model. The accuracy is evaluated by relative error R.E.

$$\text{R.E.} = \sqrt{(\sum (Y_O - Y_{cal})^2/n)}/(\sum Y_O/n) \qquad (1)$$

where, Y_O : Observed groundwater table elevation, Y_{cal} : Calculated groundwater elevation by

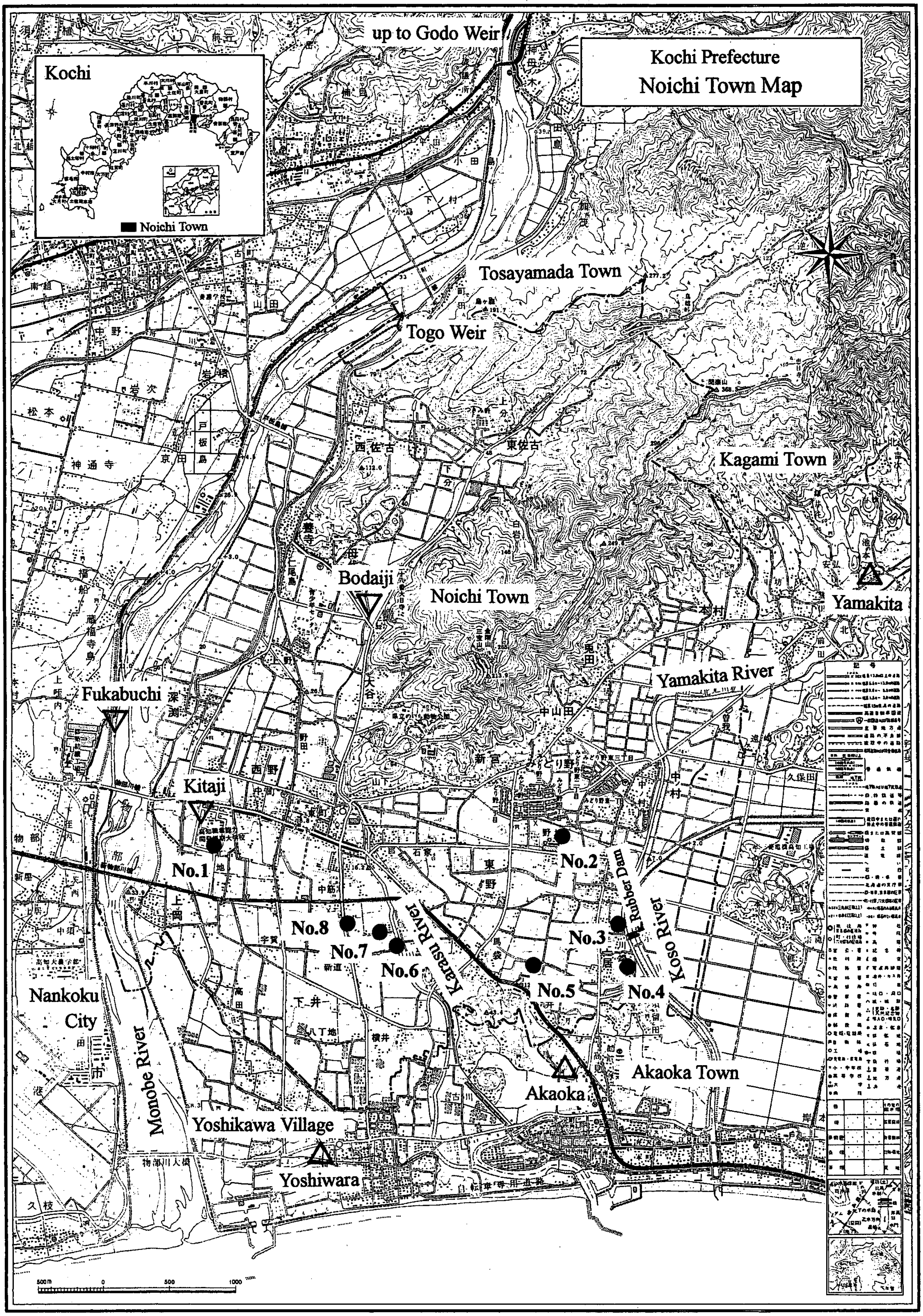

Fig. 1. Observing stations and wells

multiple regression model, n : data number, for period of parameter identification, n = 198, for period of verification, n = 54. Smaller the R.E., better performances the model has.

Groundwater depths from the well tops had been researched by using WL-30 rope water surface detector by Alfa Kogaku Co., Ltd. From November, 2000 to October, 2002. The data was observed at different time intervals. Most of the data in 2001 and 2002 was observed by once a week base, while some of them in 2002 were observed by every-other-days base, and few of them was by everyday base. This different interval is not necessarily fatal weak point in developing the regression models, but there would be some benefit to get better model if we can use daily base data from the viewpoint of constant interval and hence consistency of data.

Spline interpolation is the method to interpolate between the sample points by high order polynomial function. Whole sample data are not necessarily expressed by a function, and usually several functions are utilized to cover the whole data. At that time, not only the sample points values, but also first, second, third, or higher order differential coefficients at the points are to be equated. In this paper, third order function was employed. The concept is simple, but this method can produce a simple but well fitted functions. Because the differential coefficients are continuous at the connected points (nodes), the developed Spline function is quite smooth and looks natural. Spline interpolation method is used at wide engineering field now. Here, in this groundwater study, once a week groundwater surface elevation was observed between 1st of November, 2000 to 7th of February, 2002 and every-other-day data were collected from 8th of February, 2002 to 27th of November, 2002, though some duration such as from 20th of March, 2002 to 28th of May, 2002, and from 11th of July to 8th of August, 2002, elevations were observed everyday. Therefore, there are a lot of missing data for daily bases and interpolation is necessary to express continuous change of groundwater surface elevation. However, interpolated values are not real observed values. So, sometimes the result can be misleading.

In regression analyses, daily groundwater elevation is taken as dependent variable (y), and daily rainfall (R), daily mean stage of the Monobe River at Fukabuchi gauging station (FS), daily mean atmospheric pressure (P), air temperature(T), relative humidity (RH), wind speed(W), global solar radiation (Q), Penman's potential evapotranspiration (E_p), paddy field irrigation factor (IF), and winter season factor (SF) are taken as independent variables (x_i). Irrigation factor IF is equals to unity if irrigated, and equals to 0 if not. The detail will be given in the next chapter. Season factor SF is unity if season is winter (from 1st of January to 22nd of March) and is 0 if not (from 1st of April to 31st of October). Weir Factor (WF) is also considered for well No.3 and No.4, where, if the rubber dam (weir) on the Koso River near No.3 and No.4 wells is raised up, WF = 1, and if flattened down, WF = 0. As for these dummy variables, see **Table 6** in detail.

Precipitation data was observed at Bodaiji, Kitaji, Yoshiwara, Akaoka, Yamakita by Noichi Municipal Office and Konan Cable Television. But because of out of order of Konan TV system during March and April, 2002, precipitation, temperature and relative humidity data in March and April, 2002 were made up for by the data of Kochi Airport Branch of Kochi Meteorological Observatory, and data of wind speed and daily sunshine hours for the same duration are filled up by data observed by Gomen AMeDAS (Automated Meteorological Data Acquisition System, founded by Japan Meteorological Agency) station, and Atmospheric pressure data for the period is covered by Kochi Station, Kochi Local Meteorological Observatory, Japan Meteorological Agency. For each well, the nearest rainfall station data among the above five rainfall stations is applied. At that time, Thiessen Method is applied to decide which station data should be applied for each well. As a consequence, Kitaji data is applied to No.1 and 8, Akaoka to No.2, 3, 4 and 5, Yoshiwara to No.6, 7 and 8. For No.8, Kitaji and Yoshiwara data are applied because it is almost the border of both stations. Fukabuchi river stage data was observed by Kochi Construction Office, Ministry of Land, Infrastructure and Transport.

Characteristics of each well are as follows.

No.1: Located in the southern edge of athletic ground of Poli-Tech College Kochi. Groundwater is pumped up for one hour on the fourth Monday or Tuesday every month by Kochi Prefectural Government. In the south of the well, green houses and paddy fields spread out. Well diameter is about 10cm. Elevation of the pipe top of the well is 18.510m.

No.2: Located in the small park in front of Noichi Chuo Hospital. There are residences and paddy field in surroundings. Well diameter is about 35cm. The pipe top elevation of the well is 10.290m.

No.3: Located about 100m upstream of Kawakita bridge, 60m upstream of rubber dam, 35m west of the Koso River. A paddy lot is adjacent to the well. Shirokaki, or paddling in the rice paddy, started on 17th of July, 2002. Usually, paddling is done in March or April in Kochi Plain, but in the area near well No.3, 4 and 5, not a few paddy fields are paddled in July, too. This is because rice is grown after sweet potatoes. Water surface is greatly affected by nearby rubber dam. Usually the dam is upstanding and groundwater table is balanced with this raised dam water surface. But when the discharge increases, and the pressure by the overflow water upon the dam increases, the dam is automatically flattened down. While the dam is down, groundwater table at well No.3 also depletes down. A few days after, when the discharge decreased, a dam operator comes to raise the dam. Then the groundwater table recovers rapidly. An inhabitant said there used be springs before rubber dam was constructed. According to him, the groundwater comes from the Monobe River, and after the Koso River was amended, the groundwater table was depleted and springs had disappeared. Well diameter is about 35cm. Elevation of the pipe top of the well is 5.990m.

No.4: Located at 185m downstream of the rubber dam on the Koso River, across a road (bank) and paddy field, 60m far from the river. The well is east edge of a paddy field, and a concrete irrigation canal is adjacent (about 4m from the well). The rice paddy paddling started on 25th of March and rice was harvested on 4th of August, 2002. The groundwater of this well is also affected by up and down of the rubber dam, but the influence is the opposite of that of well No.3. Just after the dam is flattened down, the groundwater table rises. This is probably because well No.3 is located dowmstream of the rubber dam, and groundwater flow increases after flattened down of the rubber dam. Well diameter is about 35cm. Elevation of the top of the well is 5.000m.

No.5: located along a asphalt concrete road, and two paddy field lots are adjacent. The lot in the south was used for greenhouse sweet potato cultivation till the last third of April. Houses were removed at the last third of May, and rice paddy paddling started on 10th of July. The harvesting was on the 4th of November. The other adjacent paddy in the west of the well was paddled on 30th of May, and harvesting was 1st of August, 2002. Across the road to the north, there is a concrete irrigation canal and paddy field and green houses. Well diameter is about 35cm. Elevation of the pipe top of the well is 8.930m.

No.6: Located in the west of Karasugawa bridge on the Karasu River. The adjacent paddy field in the west was paddled in the last third of March, and rice was harvested in mid-August. There is a canal with a weir of 4 m wide in the south. Well diameter is about 35cm. Elevation of the pipe top of the well is 12.820m.

No.7: Located at the southern edge of a asphalt concrete road. There is an adjacent leek upland field and beyond it, there are rice paddy fields in the south. There are green houses in the north beyond the road. Leek was harvested on 8th of September and leek was planted again on 11th of the same month. Groundwater was pumped up for irrigation once or twice a week irregularly. Well diameter is about 35cm. Elevation of the top of the well is 13.548m.

No.8: Located inside of a greenhouse, in which flowers were cultivated. Harvesting of the flower was 28th of June, 2002. There is a small irrigation canal adjacent in the west. Well diameter is about 35cm. Elevation of the top of the well is 13.760m.

So-called Penman's potential evapotranspiration is not real evapotranspiration from the ground at all. But it is considered as evapotranspiration from the grassland per unit area (mm) under full water-supply condition, and is often considered as an index of real evapotranspiration, especially in humid area like Japan. The equation of Penman's potential evapotranspiration ET_{Pen} (mm H_2O) is as follows (J.S.I.D.R.E.,1999)[3].

$$ET_{Pen} = \frac{\Delta}{\Delta + \gamma} \frac{S}{l} + \frac{\gamma}{\Delta + \gamma} f(u_2)(e_{sa} - e_a) \qquad (2)$$

where, S : net radiation ($MJ \cdot m^{-2}$)

$$S = (1 - \alpha) Q_T - \sigma (t + 273.2)^4 \cdot (0.56 - 0.092 \cdot 0.866\sqrt{e_a}) \cdot (0.1 + 0.9 \cdot n / N)$$

α : Albedo

Q_T : global solar radiation($MJ \cdot m^{-2}$)

d, $\underline{d}$: distance between the Sun and Earth, and that of yearly mean

$d/\underline{d}$: $1.0000 + 0.01676 \cdot \cos\{0.977 (J - 186)\}$

J : number of days from 1st of January

ω_0 : time angle at sunset (rad)

$$\omega_0 = \cos^{-1}(-\tan\phi \tan\delta)$$

ϕ : latitude of the spot

δ : declination of the day

$$\delta = 23.45 \cos(0.966 \cdot (J - 173))$$

n : sunshine hours (hr)

N : possible hours of sunshine (hr)

t : air temperature (℃)

e_a : atmospheric vapor pressure (hPa)

σ : Stefan-Boltzmann constant

$$(\sigma = 5.671 \cdot 10^{-11} \cdot kW \cdot m^{-2} \cdot K^{-4} = 4.900 \cdot 10^{-9} \cdot MJ \cdot m^{-2} \cdot K^{-4} \cdot d^{-1})$$

Δ : gradient of saturated vapor pessure against air temperature at the specified air temperature. ($hPa \cdot ℃^{-1}$)

$$\Delta = 0.4495 + 0.2721 \cdot 10^{-1} \cdot t + 0.9873 \cdot 10^{-3} \cdot t^2 + 0.2907 \cdot 10^{-5} \cdot t^3 + 0.2538 \cdot 10^{-6} \cdot t^4$$

γ : wet and dry bulb constant (= 0.66 $hPa \cdot ℃^{-1}$)

l : latent heat (MJ /kg)

$$l = 2.5 - 0.0024 \cdot t$$

$f(u_2)(e_{sa} - e_a)$: evaporation estimating scheme by Dalton (mm/d)

$$f(u_2) = 0.26\ (1 + 0.54u_2)$$

u_2 : daily mean wind speed at 2 m above the ground (m/s)

$$u_2 = u_H \cdot \log 200 / \log (100 \cdot H)$$

u_H : wind speed at H m above the ground (m/s)

H : height of the wind speed meter above the ground (m)

e_{sa} : saturated vapor pressure at the air temperature (hPa)

e_a : atmospheric vapor pressure (hPa)

$$e_a = e_{sa} \cdot RH/100$$

RH : relatrive humidity (%)

In this study, albedo = 0.22 is adopted to the calculation considering the fact that there are not only paddy fields, whose albedo is supposed to be less than 0.2, in this area, but also greenhouses, upland fields, residential area and roads whose albedo is supposed to be more than 0.2 (J.S.I.D.R.E., 1989)[4].

Latitude is taken as $\phi = 33°\ 33'$ (Noichi Town municipal office).

The installed height of wind speed meter of Bodaiji, Kitaji, Yoshiwara, Akaoka, Yamakita is H = 10m from the ground, while that of Gomen station, Kochi Local Observatory is H = 6.5m.

These different heights from 2 m were adjusted to 2 m by 1/7 power rule. Moreover, relationship between Q_T/Q_a and n/N at Kitaji, Yoshiwara and Akaoka are studied (Fig.2). where, Extraterrestrial horizontal solar radiation Q_a (MJ $\cdot$ m^{-2}) is given as follows.

$$Q_a = 1.37 \cdot 10^{-3} \cdot (d/\underline{d})^2 \cdot 86400/\pi \cdot (\omega_0 \sin\phi \sin\delta + \sin\omega_0 \cos\phi \cos\delta) \qquad (3)$$

4. Result and discussion

(1) Relationship between global solar radiation and sunshine hours

This topic is not the one of groundwater in reality. But one of the author has been studied this theme for long time, and have a keen interest in the regional difference of the relationship between standardized global solar radiation (Q_T/Q_a) and ratio of sunshine hours aginst possible hours of sunshine (n/N). **Fig.2** shows relationship between daily Q_T/Q_a and n/N of three stations (Kitaji, Yoshiwara and Akaoka) from 1st of September, 2000 to 31th of October, 2002. Three stations' solar characteristics do not show much difference each other and here shown as one relationshoip. The relationship is expressed as follows.

$$Q_T/Q_a = 0.177 + 0.599 \cdot (n/N) \qquad (r^2 = 0.933,\ s = 0.0534,\ n = 2373) \qquad (4)$$

$$Q_T/Q_a = 0.113 + 0.613 \cdot (n/N)^{0.6} \qquad (r^2 = 0.959,\ s = 0.0415,\ n = 2373) \qquad (5)$$

$$Q_r/Q_a = 0.143 + 0.935\,(n/N) - 0.369(n/N)^2 \qquad (r^2 = 0.953,\ s = 0.0448,\ n = 2373) \qquad (6)$$

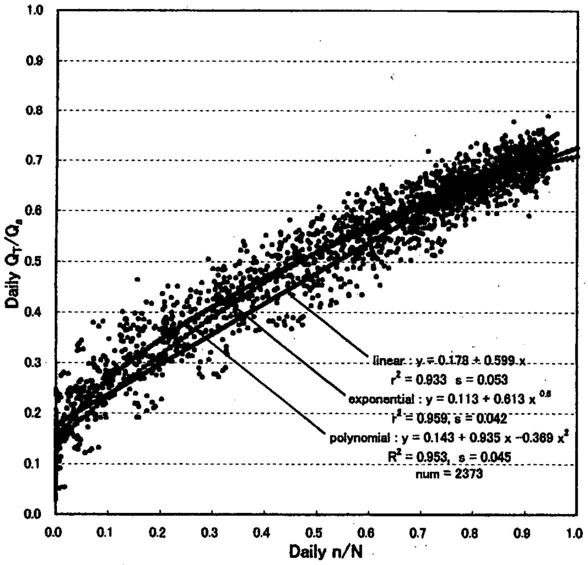

Fig. 2. Relationship between daily Q_T/Q_a vs. n/N at Kitaji, Yoshiwara and Akaoka

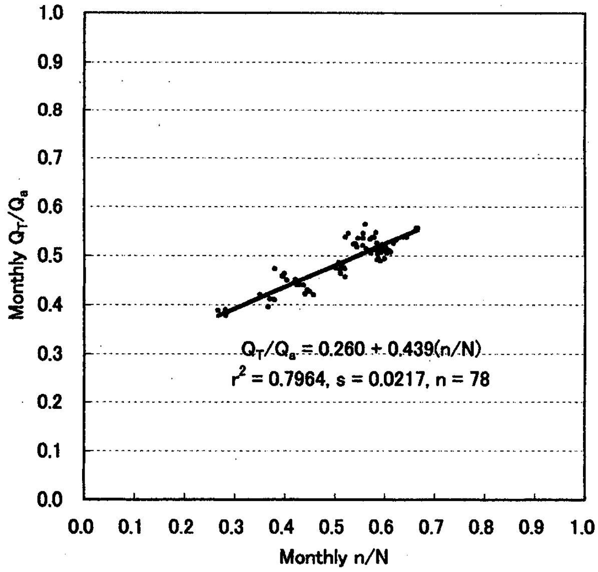

Fig. 3. Relationship between monthly Q_T/Q_a vs. n/N at Kitaji, Yoshiwara and Akaoka

where, Q_T is daily global solar radiation (MJ · m^{-2} · day^{-1}) measured by electric pyrheliometer, and, Q_a is extraterrestrial horizontal solar radiation (MJ · m^{-2} · day^{-1}), n is daily hours of sunshine, measured by solar cell sunshine recorder, N is daily possible hours of sunshine. r^2 is coefficient of simple determination (square of regression coefficient r), s is standard error, and n is data number. Among eqs. (3), (4), (5), eq. (4) is the best judging from r^2 and s.

As for monthly Q_T/Q_a and n/N, the result is as follows (see **Fig.3**).

$$Q_T/Q_a = 0.26 + 0.439 \cdot (n/N) \qquad (r^2 = 0.796,\ s = 0.0217,\ n = 78) \qquad (6)$$

(2) Correlation between groundwater table elevations of eight observed wells

Table 1 shows coefficients of simple determination r^2 between groundwater table elevations of eight observed wells from 1st of November, 2001 to 31st of October, 2002. The table shows that correlations between groundwater table elevations of wells No.1, 2, 5, 6, 7 and 8 are strong, but those of

Table 1. Simple regression relationship between well stages (r^2)
(without considering ups and downs of rubber dam on the Koso River, data number = 198)

	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
No.1		0.9362	0.6633	0.7027	0.8710	0.9685	0.9739	0.9721
No.2	0.9362		0.6721	0.7345	0.9044	0.9635	0.9604	0.9497
No.3	0.6633	0.6721		0.6094	0.7611	0.7182	0.7059	0.6955
No.4	0.7027	0.7345	0.6094		0.8178	0.7479	0.7397	0.7184
No.5	0.8710	0.9044	0.7611	0.8178		0.9340	0.9180	0.8956
No.6	0.9685	0.9635	0.7182	0.7479	0.9340		0.9984	0.9932
No.7	0.9739	0.9604	0.7059	0.7397	0.9180	0.9984		0.9974
No.8	0.9721	0.9497	0.6955	0.7184	0.8956	0.9932	0.9974	

No. 3 and 4 are rather weak. Well No.3 and 4 are adjacent to the Koso River, and there exist a rubber dam. It is considered that ups and downs of the rubber dam affect elevations of the groundwater tables of these wells. According to the eye observation and inspection of No.3 and No.4 groundwater stages, ups (well No.4) and downs (well No.3) of the groundwater table caused by downs of the rubber dam were 13 times in this duration, and data of these days are deleted and the correlations were recalculated. The resulted r^2 values are shown in **Table 2.** This table shows that groundwater table fluctuations of well No.3 and 4 are highly correlated. Groundwater table fluctuation of well No.5 is also correlated with those of No.3, but not so much with No.4. Those of No.5 are correlated with those of No.2, 3, 6, 7 and 8, and especially with those of No.3 and 6.

(3) Correlations between groundwater table fluctuations and meteorological data

Fig.4 shows change in groundwater surface of eight wells as well as rainfall, daily mean temperature and daily mean relative humidity at Bodaiji and changes in the Monobe River stage at Fukabuchi

Table 2. Simple regression relationship between well stages (r^2)

(13 down data of rubber dam on the Koso River are deleted from above-mentioned 198 data,i.e., data number = 185)

	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
No.1		0.9377	0.8222	0.7630	0.8730	0.9686	0.9740	0.9724
No.2	0.9377		0.8284	0.7838	0.9045	0.9648	0.9616	0.9516
No.3	0.8222	0.8284		0.9245	0.9464	0.8799	0.8669	0.8516
No.4	0.7630	0.7838	0.9245		0.8706	0.8123	0.8025	0.7851
No.5	0.8730	0.9045	0.9464	0.8706		0.9359	0.9199	0.8987
No.6	0.9686	0.9648	0.8799	0.8123	0.9359		0.9984	0.9934
No.7	0.9740	0.9616	0.8669	0.8025	0.9199	0.9984		0.9976
No.8	0.9724	0.9516	0.8516	0.7851	0.8987	0.9934	0.9976	

*The deleted data (when rubber dam is down) are that of 11/5, 2001 and 5/4, 5/5, 5/16, 5/17, 6/30, 7/1, 7/10, 8/9, 8/10, 8/11, 10/7, 10/8, 2002.

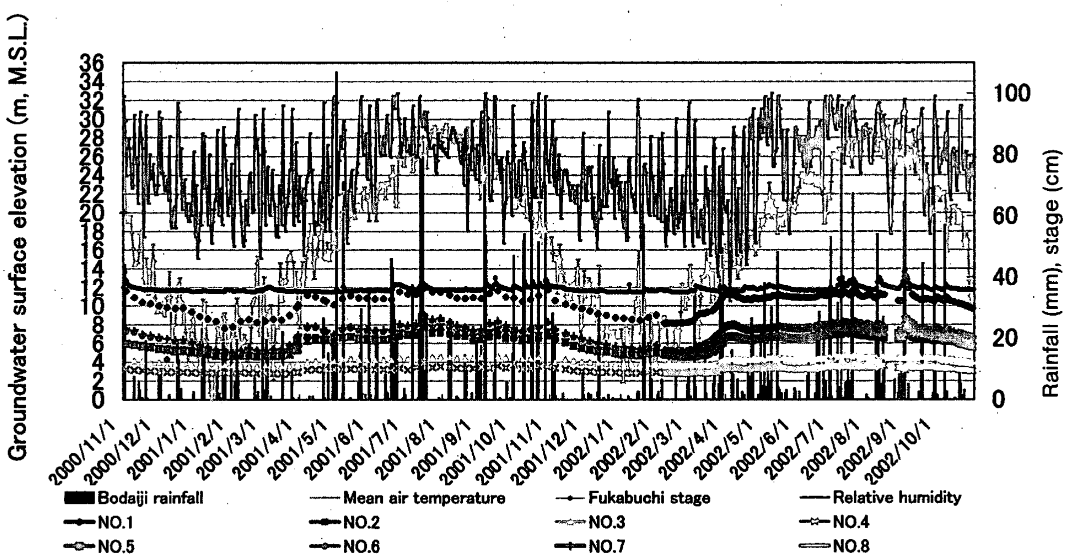

Fig. 4. Observed groundwater variation, Bodaiji rainfall, mean air temperature and Fukabuchi stage of the Monobe River

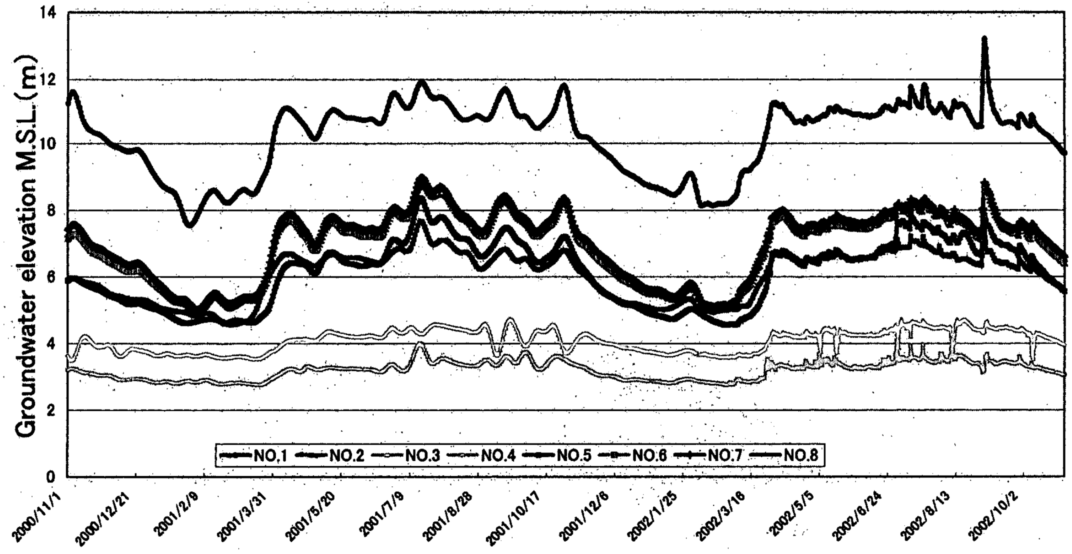

Fig. 5. Spline interpolated groundwater variation of eight wells

from 1st of November, 2000 to 31st of October, 2002. It looks as if groundwater variation is somehow related to rainfall, air temperature, and humidity. This is why the relationship between groundwater and meteorological data has been investigated by multiple regression analysis.

Fig.5 shows Spline interpolated fluctuation of groundwater surfaces of eight wells. From the figure, groundwater table falls down gradually from November to February, and rise up rapidly at the midst of March. This rising up phenomena seasonally coincides with that of paddling of rice paddy field. That is why dummy Irrigation Factor (IF) and Season Factor (SF) are introduced in this analysis. Looking at the fluctuation of No.3 and No.4 well in **Fig.5**, sudden rise up and fall down are observed. This is considered to be the effect of ups and downs of the rubber dam on the Koso River. By this reason, Weir Factor (WF) is introduced. Judging from elevations of the groundwater tables, groundwater flows from well No.1 to other wells, and noting that elevation of No.6, 7 and 8 are higher than No.2 and No.5, groundwater flows from well No.6, 7, and 8 to well No. 2 and 5. In the same way, groundwater flows from well No.2 and 5 to well No.3 and 4. In short, groundwater flows from west to east.

First of all, simple regression analysis was employed, where, dependent variable y = groundwater surface elevation, and independent variables x = rainfall, Fukabuchi River stage of the Monobe River, daily mean atmospheric pressure, daily mean air temperature, daily mean relative humidity, daily mean wind speed, daily global solar radiation, and Penman's potential evapotranspiration of the same day, of the one day ago, of the two days ago, and so on. The resulted r^2 (coefficient of simple determination, square of coefficient of correlation) are shown in **Fig.6(a) -(h)**.

Fig.6(a) shows that the highest r^2 is gotten mostly with previous day's rainfall, but there is an exception. No.3 well shows rainfall of five days ago is the highest r^2, which implies the possibility of belonging a different aquifer from others. According to **Fig.6(b)**, most wells show the highest correlation with Fukabuchi stage just on the day. But, again, No.3 well shows different tendency; four-day-ago stage has the strongest correlation. **Fig.6(c)** shows No.1, 2, 6, 7, 8 are the almost same tendency, but No.3, 4, 5 are different. **Fig.6(d)** shows daily mean temperature is highly related with groundwater surface, and on-the-day air temperature is the highest correlation, and correlation decreases as antecedent days increases, which may mean that seasonal movements of groundwater stage and air

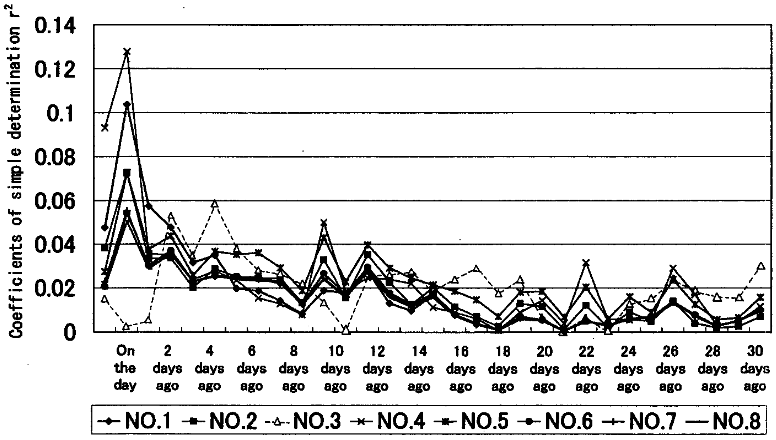

Fig. 6(a). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent rainfall (x)

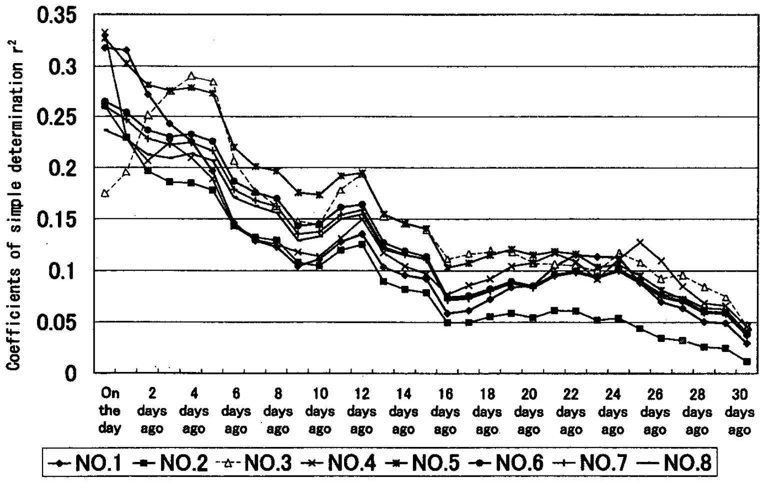

Fig. 6(b). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent Fukabuchi stage (x)

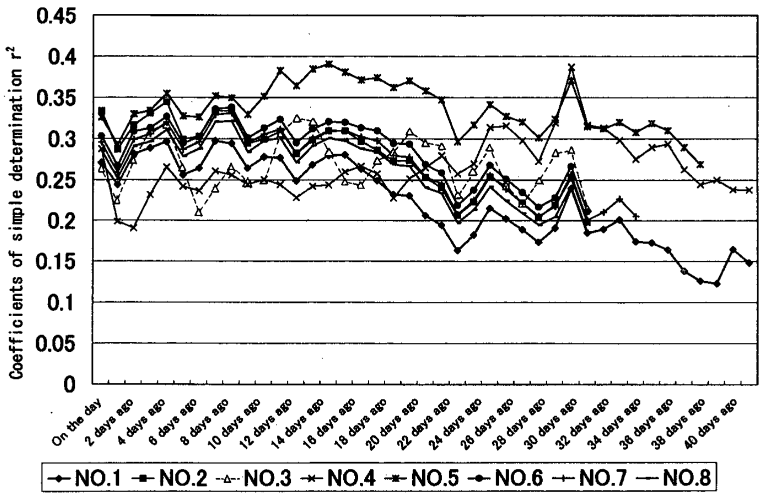

Fig. 6(c). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent atmospheric pressure (x)

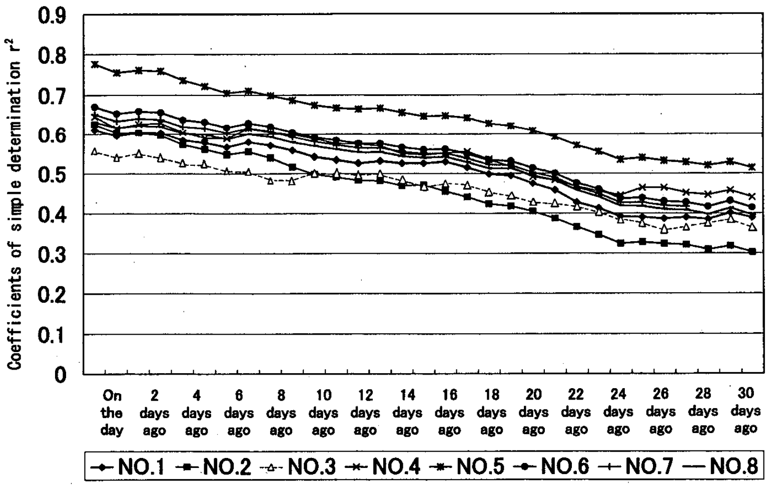

Fig. 6(d). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent daily mean air temperature (x)

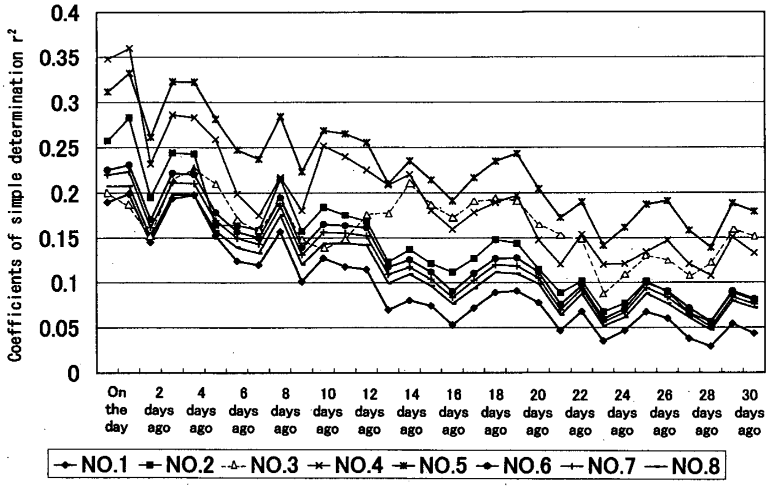

Fig. 6(e). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent relative humidity (x)

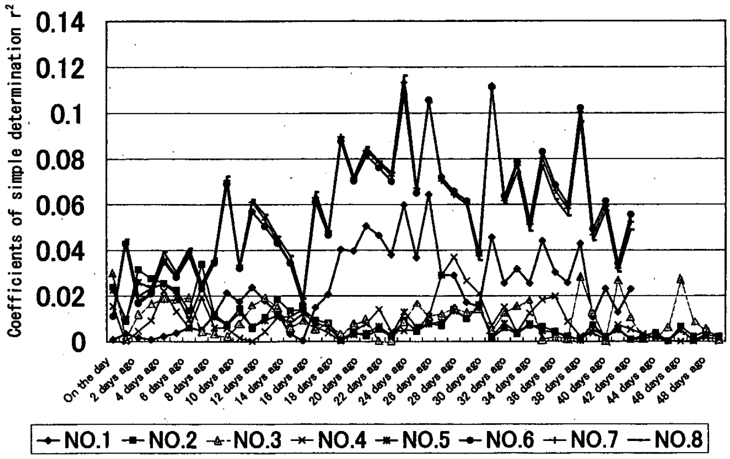

Fig. 6(f). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent daily mean wind speed (x)

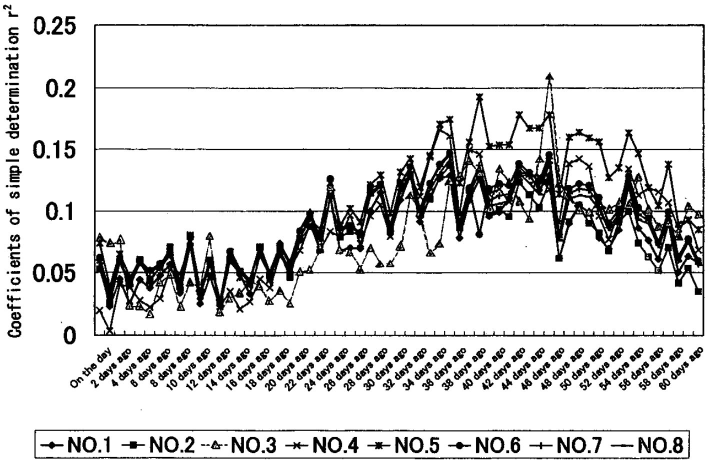

Fig. 6(g). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent daily global solar radiation (x)

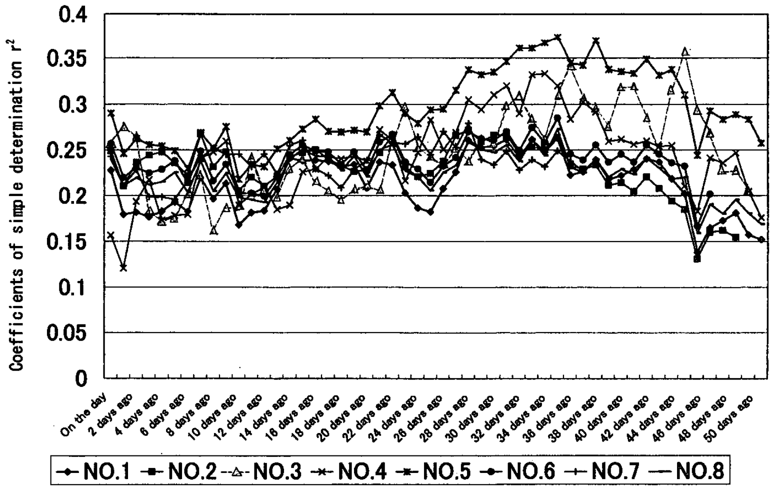

Fig. 6(h). r^2 of simple regression analyses between groundwater surface stage (y) and antecedent Penman's potential evapotranspiration (x)

temperature are quite similar. **Fig.6(e)** shows that No.3 well has similar tendency with no.1, 2, 6, 7 and 8 within initial eight days ago, but more than nine days ago, well No.3 approaches to No.4 and 5. **Fig.6(f)** shows that wind speed has lower correlation with groundwater movement, and No.6, 7, and 8 wells show quite similar movements. Well No.1 looks somehow similar to them. Actually, these four wells look having correlation with wind speed, but No.2, 3 and 4 do not look so. **Fig.6(g)** shows that global solar radiation has relatively high correlation with groundwater surface movement in cases more than thirty days ago. The reason is probably, groundwater table movement is highly seasonal, and global solar radiation goes ahead of air temperature by almost one or two months. **Fig.6(h)** shows that Penman's potential evapotranspiration goes 20 to 40 days ahead of groundwater stage movement.

Fig7(a)-(h) show r^2 between Spline interpolated groundwater table movement of eight wells and meteorological elements. **Fig.7(a)** shows that Spline interpolation decreases the maximum r^2 value because it interpolate without considering rainfall effect. The figure also shows the r^2 curves against antecedent days are more smooth than none-interpolation (**Fig.6(a)**). The fact that groundwater stage

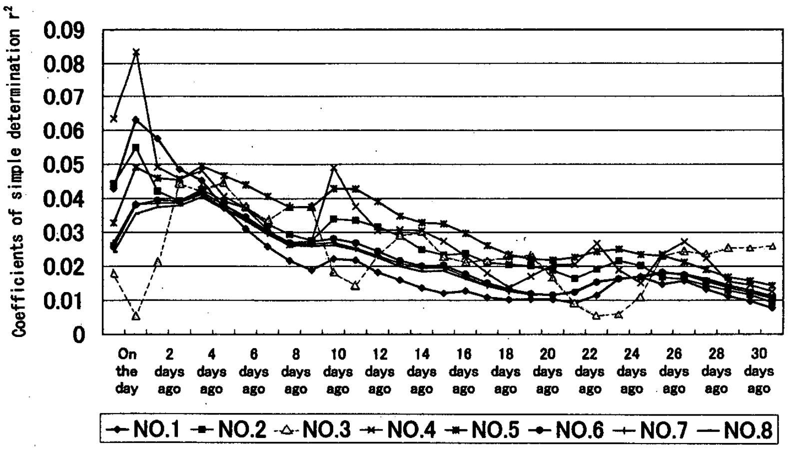

Fig. 7(a). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent rainfall (x)

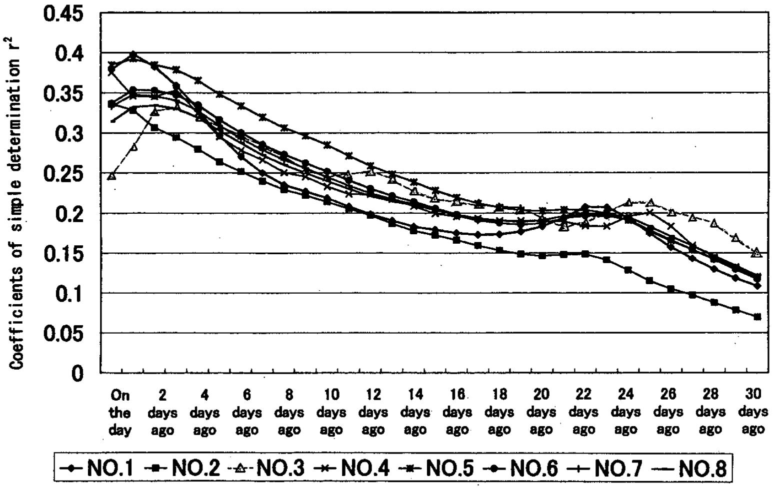

Fig. 7(b). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent Fukabuchi stage (x)

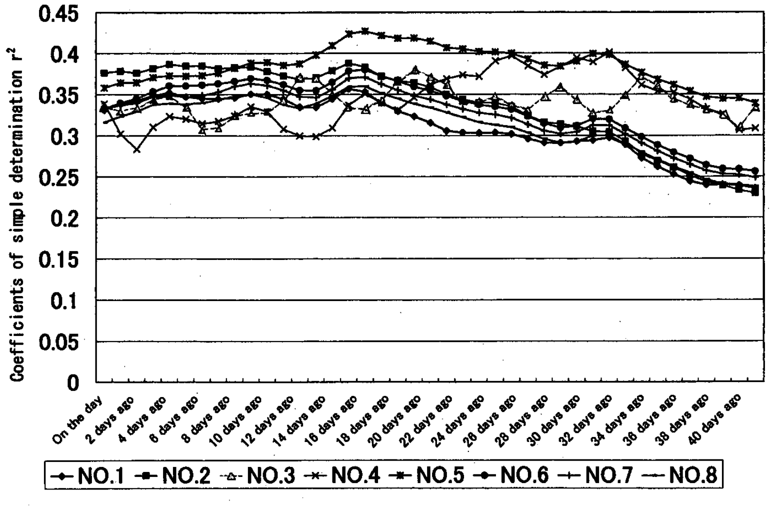

Fig.7 (c). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent atmospheric pressure (x)

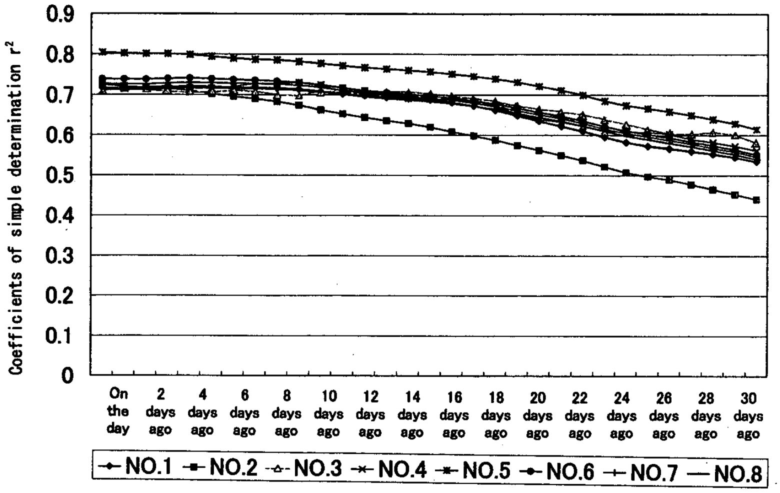

Fig. 7(d). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent daily mean air temperature (x)

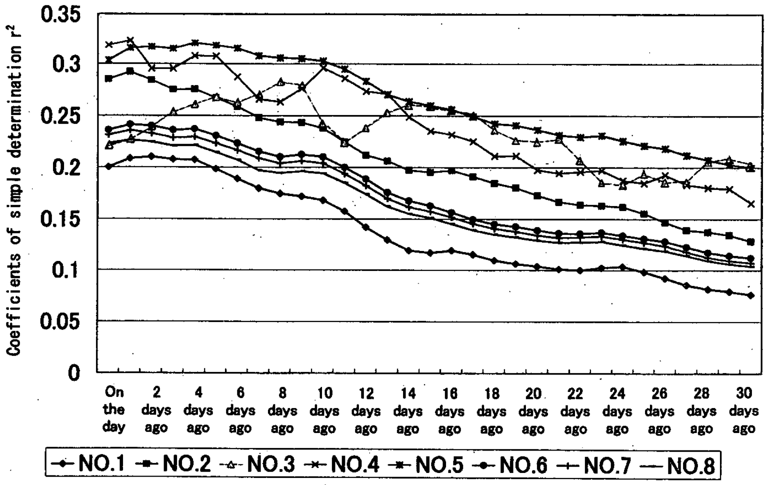

Fig. 7(e). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent relative humidity (x)

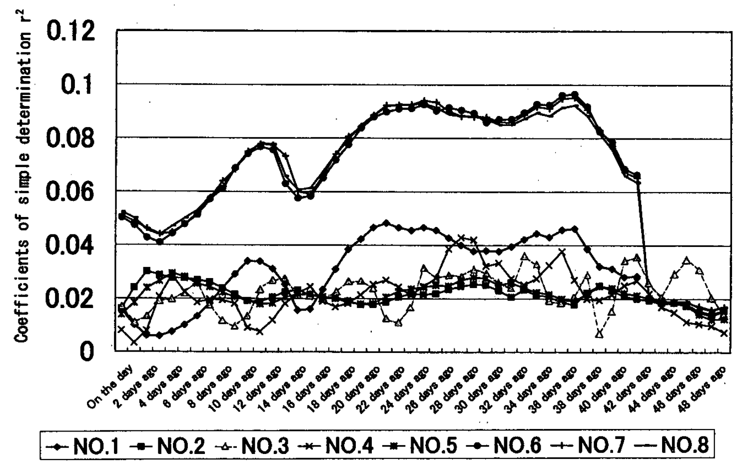

Fig. 7(f). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent daily mean wind speed (x)

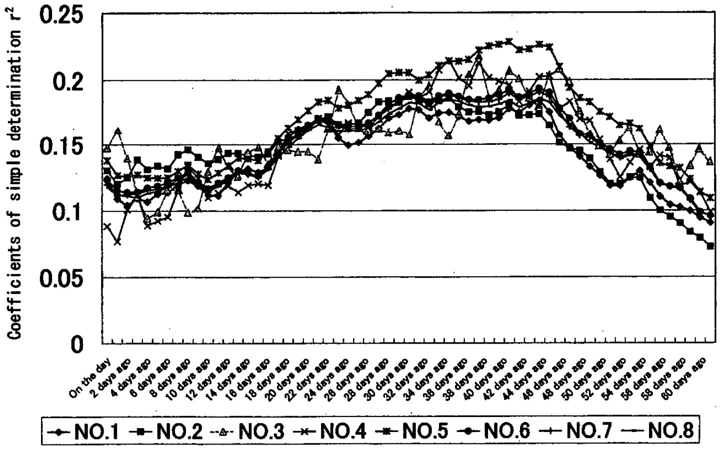

Fig. 7(g). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent daily global solar radiation (x)

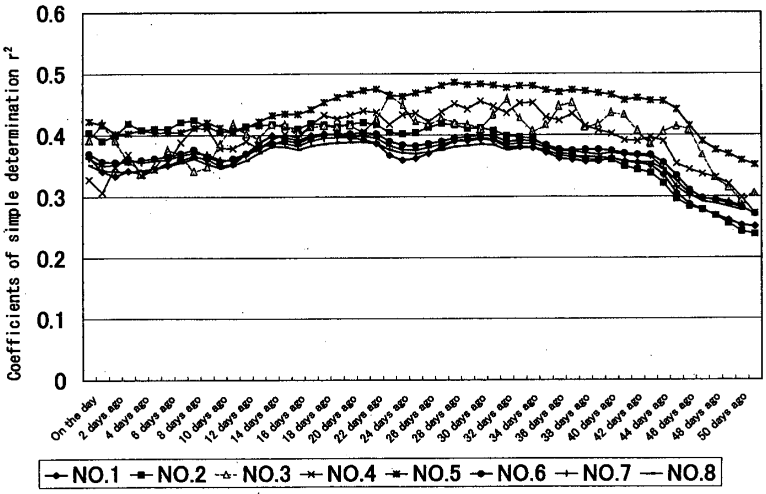

Fig. 7(h). r^2 of simple regression analyses between Spline interpolated groundwater surface stage (y) and antecedent Penman's potential evapotranspiration (x)

of well No.3 falls down on the first day after rainfall may look curious, but actually, if it rains hard, flow of the Koso River increases, and the rubber dam would be flattened down by increased overflowing water pressure, accordingly groundwater near the river also falls down. The reason that groundwater rising of No.4 well at the first day after rainfall is the highest is because No.4 well locates just under the rubber dam and if rubber dam is flattened down after big rain and increase of flow and water pressure, groundwater below the dam rise up rapidly because of increased groundwater flow. This phenomena implies that groundwater flow from the west to well No.4 prevails that from upstream well No.3. Otherwise, groundwater table of well No.4 should fall down as that of No.3 falls down. **Fig7(b)** shows that comparing with **Fig6(b)**, mostly the effect of the Monobe River takes one more day to attain the wells. The reason is because Spline interpolation does not involve the effect of rainfall except that only well No.2 shows on-the day response. This is probably because this well responds more quickly to the Monobe River stage than any other well (see **Fig.6(b)**). **Fig7(c)** shows that No.3 well and No.4 well occasionally respond the opposite up and down directions, but No.4 and No.5 moves mostly the same directions, which again implies that groundwater of No.4 well is charged from the direction of well No.5 (i.e., from the west). The graph shows that well No.1, 2, 6, 7, 8 moves in the same direction considering the effect of antecedent atmospheric pressure. **Fig.7(d)** shows stage of well No.3 and No.4 move almost in the same manner as No.1, 6, 7 and 8 considering the effect of daily mean air temperature, but r^2 of No.2 decreases faster than other wells which implies that groundwater table movement of No.2 well is more strongly influenced by recent air temperature compared with other wells. And No.5 well show higher r^2 value, which implies the susceptiveness of air temperature, which in turn symbolizes the effect of the season. **Fig.7(e)** shows that groundwater table movement of well No.3 has maximum r^2 corresponding to RH of eight antecedent day, though other wells have maximum r^2 corresponding to that of one antecedent day. If we can consider RH involves the effect of evaporation, then it might be said that well No.3 is less susceptible to evaporation than other wells. **Fig.7(f)** shows that well No.7 and 8 is one group, and other wells are the other group. The effect of wind speed on the former group of wells decreases rapidly corresponding to more than 42 days ago. Anyway, r^2 values of wind speed correlation are not so high and the effect of wind speed is limited. **Fig.7(g)** shows that the effect of daily global solar radiation is rather seasonal, because r^2 value shows maximum at around forty antecedent days. Wells No.3, 4 and 5 show slightly different responses to the solar radiation, but it should not be overemphasized. **Fig.7(h)** shows Penman's potential evapotranspiration does have some seasonal effect on groundwater movement, and wells No.3, 4 and 5 have slightly different response from other wells, but again, the fact should not be overemphasized.

Table 3 and **Table 4** show the maximum r^2 of the relationship between groundwater table elevation and various independent variables by simple regression analyses. In these tables, A (Akaoka), B (Bodaiji), K (Kitaji), and Y (Yoshiwara) are the location of the meteorological stations of Noichi Cable TV. Based upon these data, eight multiple regression models are developed (see **Table 5**).

Table 3. Antecedent days which has the largest coefficient of simple determination with groundwater surface fluctuation

No.	Rainfall	Fukabuchi river-stage	Atmospheric pressure	Air temperature	Relative humidity	Wind speed	Global solar radiation	Penman's Potential ET
1	1d(0.104 B)	0d(0.318)	7d(0.298)	0d(0.611 K)	1d(0.199 K)	25d(0.064 K)	42d(0.132 K)	35d(0.263 K)
2	1d(0.073 A)	0d(0.260)	4d(0.345)	0d(0.626 A)	1d(0.283 A)	7d(0.034 A)	35d(0.137 A)	35d(0.263 A)
3	5d(0.059 A)	4d(0.290)	12d(0.325)	0d(0.555 A)	4d(0.228 A)	0d(0.030 A)	45d(0.209 A)	45d(0.357 A)
4	1d(0.128 A)	0d(0.333)	29d(0.387)	0d(0.646 A)	Id(0.360 A)	27d(0.037 A)	34d(0.166 A)	34d(0.334 A)
5	1d(0.073 A)	0d(0.327)	14d(0.391)	0d(0.777 A)	1d(0.332 A)	4d(0.025 A)	38d(0.193 A)	35d(0.374 A)
6	1d(0.054 Y)	0d(0.264)	8d(0.338)	0d(0.670 Y)	1d(0.231 Y)	30d(0.112 Y)	35d(0.147 Y)	35d(0.285 Y)
7	1d(0.055 Y)	0d(0.259)	8d(0.332)	0d(0.651 Y)	1d(0.224 Y)	30d(0.112 Y)	35d(0.146 Y)	35d(0.249 Y)
8	1d(0.051 Y)	0d(0.236)	8d(0.322)	0d(0.632 Y)	1d(0.208 Y)	23d(0.116 Y)	35d(0.142 Y)	35d(0.272 Y)

* xxd stands for xx days antecedent meteorological component (rainfall, stage, air pressure,etc.) which has the biggest r^2.

** Number in the parenthesis is the biggest coefficient of simple determination.

*** K stands for Kitaji, A for Akaoka, B for Bodaiji and Y for Yoshimura.

(4) Result of multiple regression analyses

In **Table 5**, suffixes of the variables denote antecedent days. For example, $x_1 = R_1$ denotes an independent variable x_1 is daily rainfall on one day before the water table measurement, $x_6 = W_{25}$ denotes another independent variable x_6 is daily mean wind speed of 25 days ahead of the day that groundwater table is measured, and $x_4 = T_0$ denotes an independent variable x_4 is daily mean air temperature on the same day as groundwater table is measured.

This table shows that for the period of parameter identification, Case 3, Case 2, Case 4, Case 7, Case 7, Case 3, Case 3, Case3 have the minimum relative error1 for well No.1, 2, 3, 4, 5, 6, 7 and 8 respectively. But, for the period of verification, using the same parameter as the ones determined from the period of parameter identification, Case 4, Case 4, Case 4, Case 7, Case 4, Case 4, Case 4, Case 7 have the minimum relative error2 for well No.1, 2, 3, 4, 5, 6, 7 and 8 respectively. The independent variables in Table 5 are determined by employing Variable Increasing Scheme of multiple regression analysis. As a result, the effectiveness of dummy variables such as SF and WF are verified to be useful, i.e., groundwater table is affected by seasonal factor and up and down of the rubber dam on the Koso River. Moreover, for some particular wells, Spline interpolation could give the better result.

Fig.8(a) to **Fig8(h)** show the observed and calculated groundwater stage fluctuations. **Fig.8(a)** shows that even the period of parameter identification, the lowest part and the rising phase of the water table in February and March, and the recession phase in October do not match very well. **Fig.8(b)** and **Fig.8(c)** show that there are some incomprehensible miss-fitting in July of the period of verification. And the inadequacy of depleting phase of October, 2000 is exaggerated. **Fig.8(d)** is fairly good shape, but **Fig.8(e)** is not. **Fig.8(f)** is the worst one from the relative error's viewpoint, but an unusually departing point is seen in December, 2000, and except this point, it is admissible. **Fig.8(g)** and **Fig.8(h)** show medium class errors and unfitness. Sudden rise up of groundwater table in July cannot be expressed by these formulae.

Table 4. Antecededent days which has the largest coefficient of simple determination with interpolated groundwater surface fluctuation by Spline function

Well No.	Rainfall	Fukabuchi river stage	Atmospheric pressure	Air temperature	Relative humidity	Wind speed	Global solar radiation	Penman's Potentioal ET
1	1d(0.063 B)	1d(0.398)	15d(0.357)	4d(0.722 K)	2d(0.201 K)	21d(0.048 K)	43d(0.184 K)	18d(0.402 K)
2	1d(0.055 A)	0d(0.336)	15d(0.388)	0d(0.725 A)	1d(0.293 A)	2d(0.030 A)	30d(0.187 A)	8d(0.424 A)
3	5d(0.044 A)	3d(0.332)	19d(0.381)	1d(0.716 A)	8d(0.282 A)	32d(0.036 A)	45d(0.208 A)	23d(0.464 A)
4	1d(0.084 A)	0d(0.375)	31d(0.401)	7d(0.729 A)	1d(0.323 A)	27d(0.043 A)	34d(0.214 A)	30d(0.455 A)
5	4d(0.050 A)	1d(0.392)	16d(0.427)	0d(0.804 A)	4d(0.321 A)	4d(0.030 A)	40d(0.228 A)	28d(0.486 A)
6	4d(0.042 Y)	1d(0.354)	16d(0.380)	4d(0.742 Y)	1d(0.241 Y)	36d(0.097 Y)	43d(0.193 Y)	21d(0.404 Y)
7	4d(0.041 Y)	1d(0.348)	16d(0.371)	4d(0.731 Y)	1d(0.236 Y)	36d(0.095 Y)	43d(0.191 Y)	21d(0.400 Y)
8	4d(0.041 Y)	2d(0.334)	16d(0.360)	4d(0.717 Y)	1d(0.226 Y)	24d(0.093 Y)	43d(0.186 Y)	21d(0.389 Y)

* xxd stands for xx days antecedent meteorological component (rainfall, stage, air pressure,etc.) which has the biggest r^2.

** Number in the parenthesis is the biggest coefficient of simple determination r^2.

*** Alphabets in the perenthesis, K stands for Kitaji, A for Akaoka, B for Bodaiji and Y for Yoshimura.

Table 5. Result of multiple regression analyses for eight cases

Case 1	Well No.	Independent variables	R^2	s	n	R. Error 1	R. Error 2
Case 1	Well 1	$x_1=R_1, x_2=FS_0, x_3=P_7, x_4=T_0, x_5=RH_1, x_6=W_{25}, x_7=Q_{42}$	0.703	0.514	198	0.0474	0.0602
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_4, x_4=T_0, x_5=W_7, x_6=Q_{35}$	0.682	0.341	198	0.0527	0.0688
	Well 3	$x_1=R_5, x_2=FS_4, x_3=P_{12}, x_4=T_0, x_5=W_0, x_6=Q_{45}, x_7=D$	0.781	0.141	198	0.0326	0.0439
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{29}, x_4=T_0, x_5=W_{27}, x_6=Q_{34}, x_7=D$	0.759	0.129	198	0.0378	0.0467
	Well 5	$x_1=R_1, x_2=FS_0, x_3=P_{14}, x_4=T_0, x_5=RH_1, x_6=W_4, x_7=Q_{38}$	0.810	0.380	198	0.0573	0.0682
	Well 6	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}$	0.728	0.450	198	0.0610	0.0817
	Well 7	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}$	0.712	0.471	198	0.0624	0.0767
	Well 8	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{23}, x_7=Q_{35}$	0.706	0.480	198	0.0645	0.0836
	mean		0.735	0.363	198	0.0520	0.0662
Case 2	Well 1	$x_1=R_1, x_2=FS_0, x_3=P_7, x_4=T_0, x_5=RH_1, x_6=W_{25}, x_7=Q_{42}, x_8=IF1$	0.845	0.373	198	0.0343	0.0674
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_4, x_4=T_0, x_5=W_7, x_6=Q_{35}, x_7=IF1$	0.858	0.228	198	0.0351	0.0621
	Well 3	$x_1=R_5, x_2=FS_4, x_3=P_{12}, x_4=T_0, x_5=W_0, x_6=Q_{45}, x_7=WF, x_8=IF1$	0.859	0.113	198	0.0262	0.0431
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{29}, x_4=T_0, x_5=W_{27}, x_6=Q_{34}, x_7=WF, x_8=IF1$	0.834	0.107	198	0.0317	0.0463
	Well 5	$x_1=R_1, x_2=FS_0, x_3=P_{14}, x_4=T_0, x_5=RH_1, x_6=W_4, x_7=Q_{38}, x_8=IF1$	0.887	0.293	198	0.0441	0.0704
	Well 6	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=IF1$	0.858	0.326	198	0.0441	0.0852
	Well 7	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=IF1$	0.854	0.337	198	0.0445	0.0845
	Well 8	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{23}, x_7=Q_{35}, x_8=IF1$	0.843	0.352	198	0.0467	0.0846
	mean		0.855	0.266	198	0.0383	0.0680
Case 3	Well 1	$x_1=R_1, x_2=FS_0, x_3=P_7, x_4=T_0, x_5=RH_1, x_6=W_{25}, x_7=Q_{42}, x_8=IF2$	0.881	0.326	198	0.0300	0.0641
	Well 6	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=IF2$	0.892	0.285	198	0.0385	0.0833
	Well 7	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=IF2$	0.893	0.288	198	0.0381	0.0837
	Well 8	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{23}, x_7=Q_{35}, x_8=IF2$	0.892	0.291	198	0.0390	0.0880
	mean		0.890	0.298	198	0.0364	0.0798
Case 4	Well 1	$x_1=R_1, x_2=FS_0, x_3=P_7, x_4=T_0, x_5=RH_1, x_6=W_{25}, x_7=Q_{42}, x_8=SF$	0.867	0.345	198	0.0317	0.0354
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_4, x_4=T_0, x_5=W_7, x_6=Q_{35}, x_7=D$	0.837	0.245	198	0.0377	0.0493
	Well 3	$x_1=R_5, x_2=FS_4, x_3=P_{12}, x_4=T_0, x_5=W_0, x_6=Q_{45}, x_7=WF, x_8=SF$	0.891	0.100	198	0.0230	0.0366
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{29}, x_4=T_0, x_5=W_{27}, x_6=Q_{34}, x_7=WF, x_8=SF$	0.822	0.111	198	0.0327	0.0410
	Well 5	$x_1=R_1, x_2=FS_0, x_3=P_{14}, x_4=T_0, x_5=RH_1, x_6=W_4, x_7=Q_{38}, x_8=SF$	0.898	0.279	198	0.0418	0.0582
	Well 6	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=SF$	0.882	0.298	198	0.0402	0.0624
	Well 7	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{30}, x_7=Q_{35}, x_8=SF$	0.877	0.308	198	0.0408	0.0489
	Well 8	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=T_0, x_5=RH_1, x_6=W_{23}, x_7=Q_{35}, x_8=SF$	0.877	0.311	198	0.0417	0.0469
	mean		0.869	0.250	198	0.0362	0.0473
Case 5	Well 1	$x_1=R_1, x_2=FS_0, x_3=P_7, x_4=E_{P35}, x_5=SF$	0.852	0.361	198	0.0335	0.0389
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_4, x_4=E_{P35}, x_5=SF$	0.822	0.255	198	0.0394	0.0544
	Well 3	$x_1=R_5, x_2=FS_4, x_3=P_{12}, x_4=E_{P45}, x_5=WF, x_6=SF$	0.855	0.114	198	0.0266	0.0423
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{29}, x_4=E_{P34}, x_5=WF, x_6=SF$	0.777	0.123	198	0.0365	0.0454
	Well 5	$x_1=R_1, x_2=FS_0, x_3=P_{14}, x_4=E_{P35}, x_5=SF$	0.865	0.318	198	0.0482	0.0728
	Well 6	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=E_{P35}, x_5=SF$	0.862	0.320	198	0.0435	0.0721
	Well 7	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=E_{P35}, x_5=SF$	0.861	0.326	198	0.0434	0.0576
	Well 8	$x_1=R_1, x_2=FS_0, x_3=P_8, x_4=E_{P35}, x_5=SF$	0.855	0.335	198	0.0452	0.0550
	mean		0.844	0.269	198	0.0395	0.0548
Case 6 (Spline)	Well 1	$x_1=R_1, x_2=FS_1, x_3=P_{15}, x_4=T_4, x_5=W_{21}, x_6=Q_{43}$	0.766	0.525	365	0.0522	0.0518
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_{15}, x_4=T_0, x_5=RH_1, x_6=Q_{30}$	0.747	0.350	365	0.0575	0.0687
	Well 3	$x_1=R_5, x_2=FS_3, x_3=P_{19}, x_4=T_1, x_5=RH_8, x_6=W_{32}, x_7=Q_{45}, x_8=WF$	0.789	0.150	365	0.0336	0.0469
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{31}, x_4=T_7, x_5=RH_1, x_6=W_{27}, x_7=Q_{34}, x_8=WF$	0.790	0.128	365	0.0410	0.0412
	Well 5	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_0, x_5=RH_4, x_6=Q_{40}$	0.843	0.384	365	0.0580	0.0785
	Well 6	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_4, x_5=W_{36}, x_6=Q_{43}$	0.773	0.473	365	0.0686	0.0726
	Well 7	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_4, x_5=W_{36}, x_6=Q_{43}$	0.761	0.494	365	0.0703	0.0666
	Well 8	$x_1=R_4, x_2=FS_2, x_3=P_{16}, x_4=T_4, x_5=W_{24}, x_6=Q_{43}$	0.747	0.515	365	0.0733	0.0688
	mean		0.777	0.377	365	0.0568	0.0619
Case 7 (Spline)	Well 1	$x_1=R_1, x_2=FS_1, x_3=P_{15}, x_4=T_4, x_5=W_{21}, x_6=Q_{43}, x_7=SF$	0.900	0.344	365	0.0332	0.0367
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_{15}, x_4=T_0, x_5=RH_1, x_6=Q_{30}, x_7=SF$	0.868	0.253	365	0.0416	0.0500
	Well 3	$x_1=R_5, x_2=FS_3, x_3=P_{19}, x_4=T_1, x_5=RH_8, x_6=W_{32}, x_7=Q_{45}, x_8=WF, x_9=SF$	0.880	0.114	365	0.0236	0.0392
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{31}, x_4=T_7, x_5=RH_1, x_6=W_{27}, x_7=Q_{34}, x_8=WF, x_9=SF$	0.861	0.105	365	0.0338	0.0381
	Well 5	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_0, x_5=RH_4, x_6=Q_{40}, x_7=SF$	0.925	0.265	365	0.0412	0.0681
	Well 6	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_4, x_5=W_{36}, x_6=Q_{43}, x_7=SF$	0.911	0.297	365	0.0429	0.0627
	Well 7	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=T_4, x_5=W_{36}, x_6=Q_{43}, x_7=SF$	0.909	0.305	365	0.0436	0.0496
	Well 8	$x_1=R_4, x_2=FS_2, x_3=P_{16}, x_4=T_4, x_5=W_{24}, x_6=Q_{43}, x_7=SF$	0.905	0.316	365	0.0458	0.0457
	mean		0.895	0.250	365	0.0382	0.0488
Case 8 (Spline)	Well 1	$x_1=R_1, x_2=FS_1, x_3=P_{15}, x_4=E_{P18}, x_5=SF$	0.895	0.352	365	0.0339	0.0403
	Well 2	$x_1=R_1, x_2=FS_0, x_3=P_{15}, x_4=E_{P8}, x_5=SF$	0.866	0.254	365	0.0426	0.0521
	Well 3	$x_1=R_5, x_2=FS_3, x_3=P_{19}, x_4=E_{P23}, x_5=WF, x_6=SF$	0.857	0.124	365	0.0269	0.0417
	Well 4	$x_1=R_1, x_2=FS_0, x_3=P_{31}, x_4=E_{P30}, x_5=WF, x_6=SF$	0.831	0.115	365	0.0375	0.0412
	Well 5	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=E_{P28}, x_5=SF$	0.901	0.304	365	0.0489	0.0760
	Well 6	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=E_{P21}, x_5=SF$	0.905	0.306	365	0.0444	0.0688
	Well 7	$x_1=R_4, x_2=FS_1, x_3=P_{16}, x_4=E_{P21}, x_5=SF$	0.904	0.312	365	0.0447	0.0550
	Well 8	$x_1=R_4, x_2=FS_2, x_3=P_{16}, x_4=E_{P21}, x_5=SF$	0.901	0.323	365	0.0469	0.0492
	mean		0.883	0.261	365	0.0407	0.0530

*R. Error 1 (Relative Error 1) stands for the relative error for period of parameter determination (Nov. 2001-Oct. 2002)

**R. Error 2 (Relative Error 2) stands for the relative error for period of inspection (Nov.2000-Oct. 2001)

***IF1, IF2, SF and WF are dummy variables and given in Table 6.

Table 6. Defintion of IF1, IF2, SF and WF

Dummy variable	Well No.	Duration and value of dummy variable
IF1	No.1	2002/3/23-2002/10/24 : dummy variable = 1, otherwise dummy variable = 0
	2	2002/3/23-2002/10/14 : dummy variable = 1, otherwise dummy variable = 0
	3	2002/3/28-2002/10/07 : dummy variable = 1, otherwise dummy variable = 0
	4	2002/3/27-2002/10/06 : dummy variable = 1, otherwise dummy variable = 0
	5	2002/3/28-2002/10/11 : dummy variable = 1, otherwise dummy variable = 0
	6	2002/3/22-2002/10/22 : dummy variable = 1, otherwise dummy variable = 0
	7	2002/3/22-2002/10/24 : dummy variable = 1, otherwise dummy variable = 0
	8	2002/3/24-2002/10/24 : dummy variable = 1, otherwise dummy variable = 0
IF2	No.1, 6, 7, 8	2001/11/1 (dummy variable = 0.34) -2001/12/3 (dummy variable = − 0.3) : dummy variable linearly changes by -0.02/day.
		2001/12/4- 2002/3/10 : dummy variable = − 0.3
		2002/3/11 (dummy variable = − 0.29) -2002/3/23 (dummy variable = 1) : dummy variable linearly changes by + 0.1/day.
		2002/3/23- 2002/9/27 : dummy variable = 1
		2002/9/28 (dummy variable = 0.98) -2002/10/31 (dummy variable = 0.36) : dummy variable changes linearly by −0.02/day.
SF	All wells	2001/11/1- 2001/12/12 : dummy variable = 0
		2001/12/13 (dummy variable = 0.02) -2002/1/1 (dummy variable = 1) : dummy variable linearly changes by + 0.02/day.
		2002/1/1- 2002/3/22 : dummy variable = 1
		2002/3/23 (dummy variable = 0.9) -2002/4/1 (dummy variable = 0) : dummy variable linearly changes by −0.1/day.
WF	No.2, 4, 5, 6, 7, 8	If rubber dam on the Koso River is up, then WF = 1, and if not, WF = 0 for well No.3 and 4.

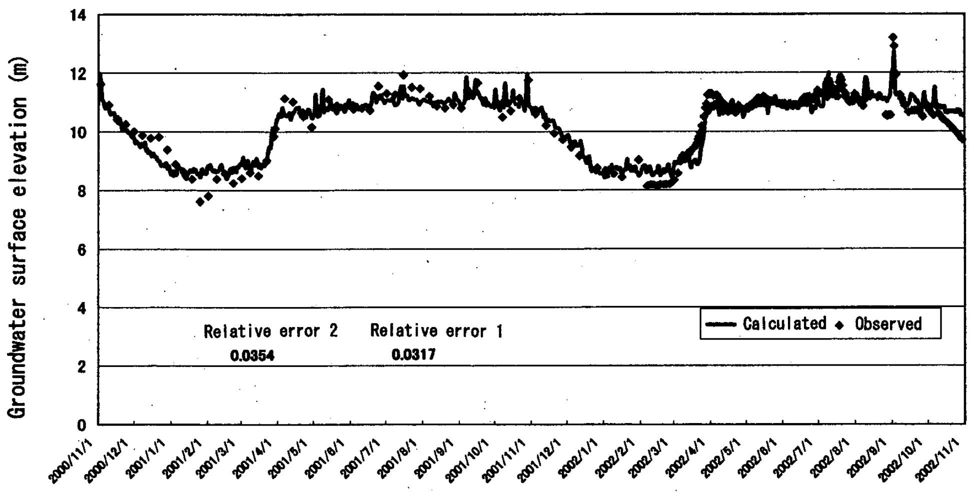

Fig. 8(a). Observed and calculated groundwater fluctuation of well No.1 by Case 4

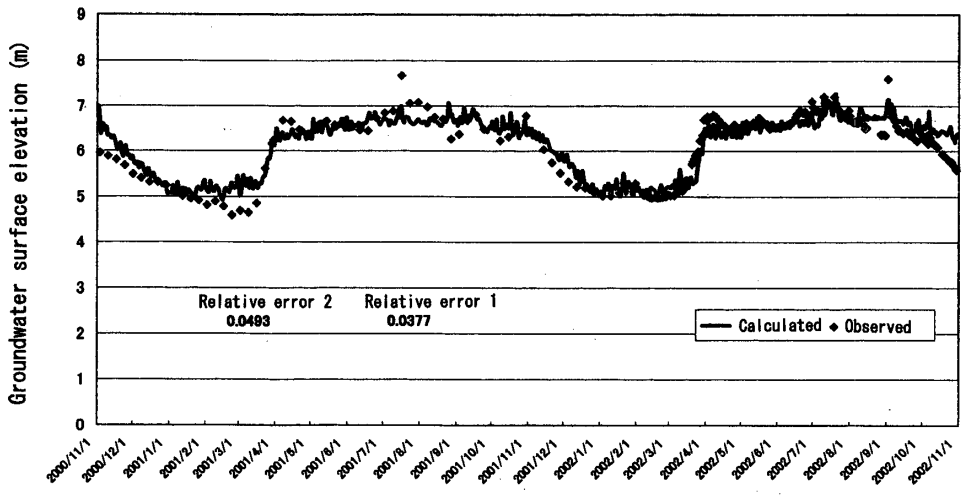

Fig. 8(b). Observed and calculated groundwater fluctuation of well No.2 by Case 4

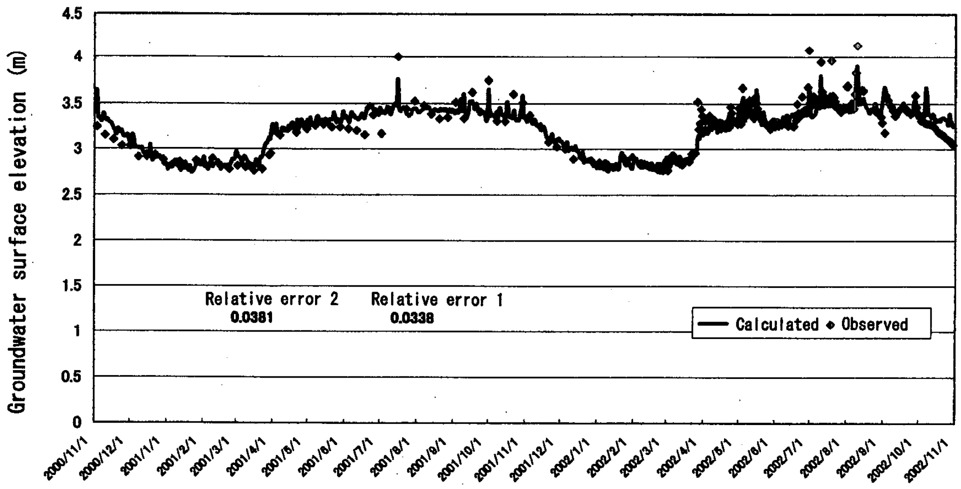

Fig. 8(c). Observed and calculated groundwater fluctuation of well No.3 by Case 4

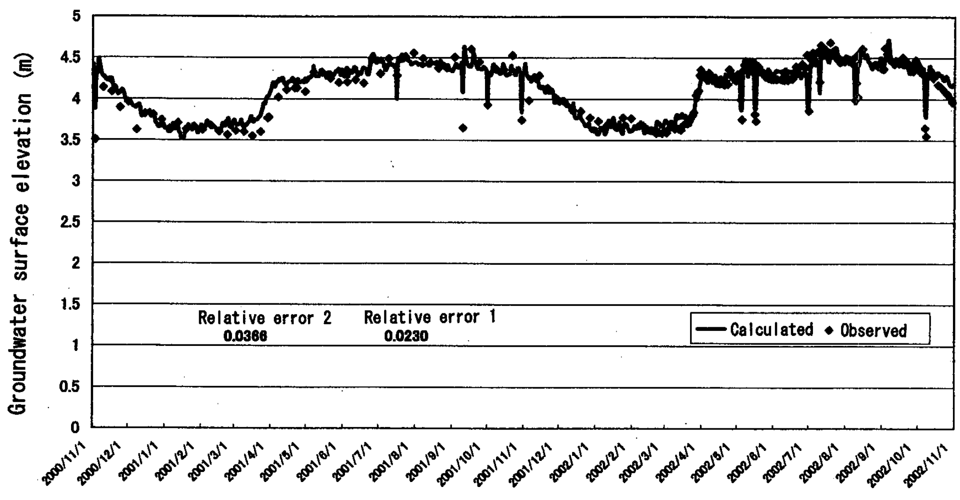

Fig. 8(d). Observed and calculated groundwater fluctuation of well No.4 by Case 7

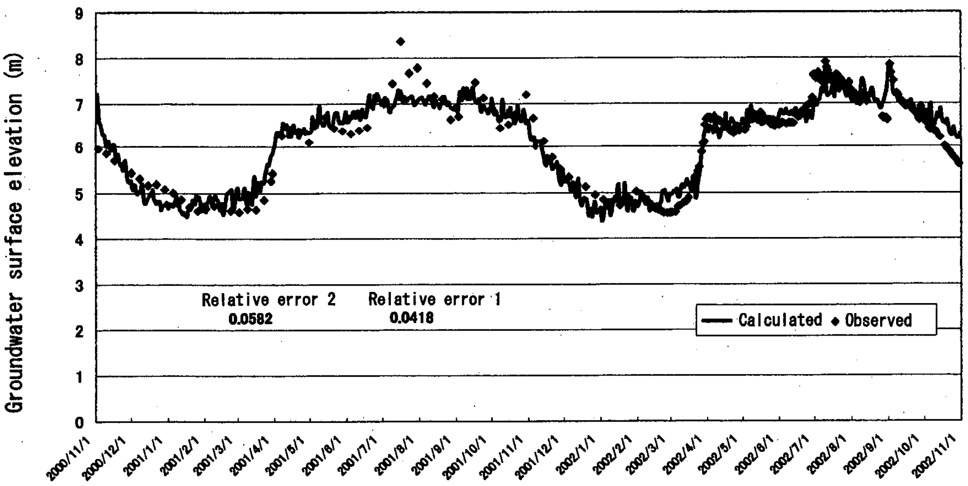

Fig. 8(e). Observed and calculated groundwater fluctuation of well No.5 by Case 4

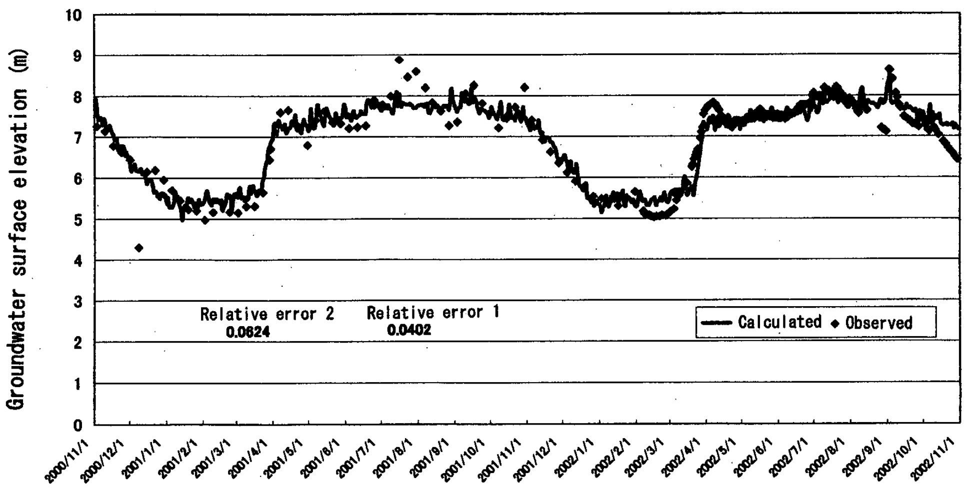

Fig. 8(f). Observed and calculated groundwater fluctuation of well No.6 by Case 4

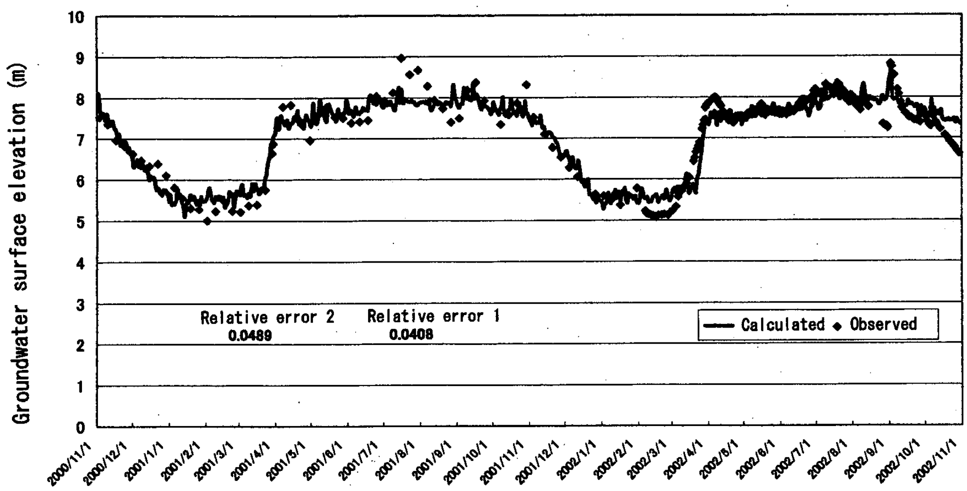

Fig. 8(g). Observed and calculated groundwater fluctuation of well No.7 by Case 4

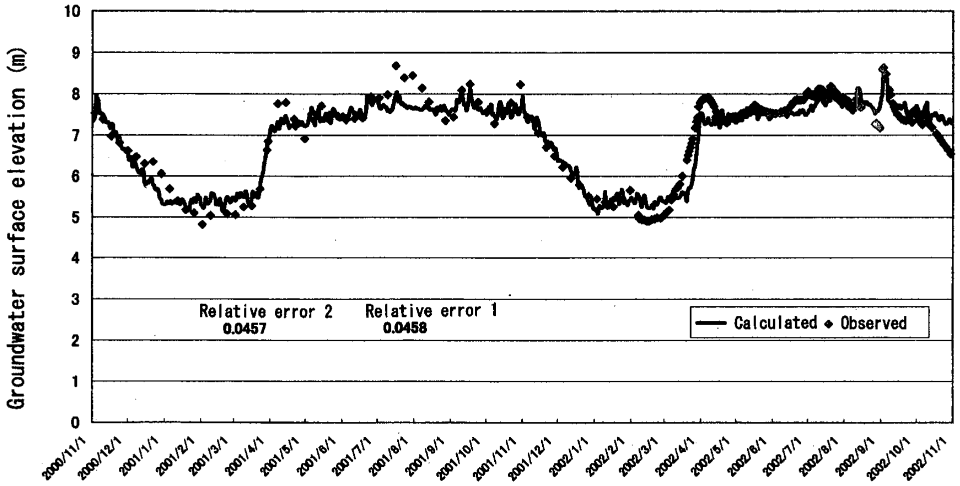

Fig. 8(h). Observed and calculated groundwater fluctuation of well No.8 by Case 7

5. Conclusion

The following statement would be appropriate for the conclusion.

1) Ups and downs of groundwater table in Konan area are fairly well expressed by such daily meteorological data as rainfall, river stage, atmospheric pressure, mean air temperature, relative humidity, wind speed, and global solar radiation.
2) The effect of rainfall, river stage and relative humidity appears to influence rather rapidly, but other factors act very slowly, which implies factors except rainfall, river stage and relative humidity are significant only to express seasonal movements, i.e., groundwater table fluctuation is highly seasonal and it coincide with seasonal change of irrigation period, hot summer temperature, rainfalls in this district, atmospheric pressure, etc.
3) To get better estimates, some dummy variables such as Seasonal Factor (expresses winter), Weir Factor which expresses up and down of the rubber dam on the Koso River, are necessary. The former is necessary because groundwater table greatly influenced by paddy field irrigation and seepage from irrigation canals.
4) The direction of groundwater flow in Konan aquifer is from north to south and from west to east.
5) Wells No.3 and No.4 show different characteristics from others. To understand this, the effect of rubber dam is considered as Weir Factor WF, and introducing it, R.E. is improved. To get better performance, probably the Koso River stage should be added, and observations should be done by daily bases.

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