多層含水層海潮效率推估之研究

黃賢統[1]　　**黃成良**[2]　　**徐輝明**[3]

[1]國立宜蘭技術學院土木工程系教授

[2]國立宜蘭技術學院土木工程系講師

[3]國立宜蘭技術學院土木工程系副教授

摘　　要

本計劃一面利用既有自動水位監測系統繼續觀測地下水位，同時就其所提供之長期地下水位記錄對照有完整記錄梗枋潮位站之潮汐資料，分析研究沿海地區地下水之海潮效率及稽延時間。計劃中為探討地層參數作抽水試驗，參照前期土壤粒徑分析所得之滲透係數，研判結果一號井及二號井之貯水係數依序為 0.0346 及 0.0345，導水係數則依序為 14.84 m^2/hr 及 17.1 m^2/hr。過程中先就本地區代表性之潮汐資料及未受人為影響之地下水位歷線，求得潮汐與地下水感潮曲線方程式，分別掌握其振幅與周期，其次將潮汐方程式、抽水試驗水文地質參數及感潮地下水位方程式之相關資料整合，就二者之波動做相關係數分析，得知大潮稽延時間於二號井約為 20 小時，與理論值相當接近，但流壓面之感潮振幅則與理論值差異甚大，假設將所有影響因子集中為振幅 h_x 指數項內之一參數，經就理論值及觀測值推估適合本地區之校正參數為 0.406，介入此一地區性之校正因子於指數中，可得較為滿意之結果。

A Study on Tidal Efficiency in the Multiple Aquifer

S.T. HWANG [1]   C.L. HWANG [2]   H.M.Hsu [3]

[1] Professor, [2] Instructor and [3] Associate professor of
Department of Civil Engineering, National ILan
Institute of Technology, I-Lan, Taiwan, R.O.C.

ABSTRACT

The project is an extension of the previous project [A Study of Tidal Efficiency in the Multiple Aquifers (I)]. The recorded data at those locations compare with the nearby tide information which has been thoroughly recorded through years at Gen-Font Tide Station to analyze the tidal efficiency and the time lag at the seashore area. To determine the theoretical values of the tidal efficiency and the time lag; both soil grain-size analyses and pumping tests are performed to find out the characteristic of aquifer including storage coefficient and transmissivity. The determined values of storage coefficient at the locations denoted as #1 and #2 are 0.0346 and 0.0345 respectively, while 14.84 m^2/hr and 17.1 m^2/hr for the values of transmissibility. The conclusions are twofold as follows. (I) First of all, the equations of tide- and groundwater-fluctuation curves resulting from the representative tide information and groundwater level hydrograph respectively, are used to know the amplitude and period of the fitted curve, then to calculate the corresponding value of time lag through the analysis of correlation coefficient, for example about 20 hours for the location #2. On the other hand, the theoretical value of time lag as mentioned above are compared to know the accuracy of process. Taking the location #2 as an example, the theoretical value of time lag is very close to the one determined from the above-mentioned process (20 hours). (II) Secondly, the similar process as using in the analysis of time lag is applied for the tide-induced groundwater amplitude in the analysis of the tidal efficiency. It is found that the determined values of the induced amplitude of piezometric surface are not close to the theoretical ones. However, the difference can be reduced by introducing a modification factor into the calculation. For the area under investigation in this project, the satisfactory result may be shown if the value of factor is equal to 0.406.

KEYWORDS: Tidal Efficiency, Time Lag, Storage Coefficient, Transmissivity

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摘 要

本計劃一面利用既有自動水位監測系統繼續觀測地下水位，同時就其所提供之長期地下水位記錄對照有完整記錄梗枋潮位站之潮汐資料，分析研究沿海地區地下水之海潮效率及稽延時間。計劃中為探討地層參數作抽水試驗，參照前期土壤粒徑

分析所得之滲透係數，研判結果一號井及二號井之貯水係數依序為 0.0346 及 0.0345，導水係數則依序為 14.84 m^2/hr 及 17.1 m^2/hr。過程中先就本地區代表性之潮汐資料及未受人為影響之地下水位歷線，求得潮汐與地下水感潮曲線方程式，分別掌握其振幅與周期，其次將潮汐方程式、抽水試驗水文地質參數及感潮地下水位方程式之相關資料整合，就二者之波動做相關係數分析，得知大潮稽延時間於二號井約為 20 小時，與理論值相當接近，但流壓面之感潮振幅則與理論值差異甚大，假設將所有影響因子集中為振幅 h_x 指數項內之一參數，經就理論值及觀測值推估適合本地區之校正參數為 0.406，介入此一地區性之校正因子於指數中，可得較為滿意之結果。

I. INTRODUCTION

The eastern coast of I-Lan area locates the study site where three groups of wells are drilled 300m, 450m, and 1300m away from the coast, respectively (Fig. 1). At the locations of these three groups of wells, long-term auto-recorded monitors are set to read groundwater level. On the other hand, the monthly recorded tide data at the Gen-Font Tide Station where is about 25km north toward the study site are taken into considerations. These tide records and their corresponding groundwater levels reading from wells at the period of Dec., 1995 to Mar., 1996 are used to analyze tidal effects at the same period of time.

The aquifer is composed of alluvial sediments and it is classified as the free aquifer for shallow layers. To present the free aquifer, there are two important factors, transmissivity (T) and storage coefficient (S). These two factors are determined by a pumping test which is carried out at wells #1 and #2 respectively. Furthermore, to verify the accuracy of the two factors, the grain-size analyses in laboratory held in the previous study (Hwang, 1995) for all boring cores are used to estimate hydraulic conductivity (K).

The whole process may be detailed as follows: (1) plotting tide-induced groundwater hydrographs, (2) performing pumping tests, (3) determing both tide- and its induced groundwater- curve fitting equations, (4) incorporating a modification factor in the theoretical tide-induced groundwater equation within the study area for the purpose of calibration.

II. MATERIALS and METHODS

Materials

Two instruments, groundwater level monitors and a set of pumping test equipments, are used. The former consists of a data logger and a pressure transducer and the later contains a speed-adjustable deep-well pump and a groundwater-level sensor.

Tidal Effect

The governing equation of one-dimensional flow in a free aquifer (Todd, 1980) is

$$\frac{\partial^2 h}{\partial x^2} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (1)$$

where

h = the net rise or fall of the piezometric surface,

x = the distance inland from the outcrop,

S = the storage coefficient,

T = the transmissivity,

t = time.

By imposing two boundary conditions,

$h = h_0 \sin \omega t$, at $x = 0$

$h = 0$, at $x = \infty$

where

h_0 = the amplitude of tide,

ω = the angular velocity for the tidal period t_0, $\omega = \frac{2\pi}{t_0}$,

the solution is

$$h = h_x \sin(\frac{2\pi}{t_0}(t - x\sqrt{\frac{t_0 S}{4\pi T}})) \qquad (2)$$

where $h_x = h_0 e^{-x\sqrt{\pi S / t_0 T}}$ is the amplitude of groundwater fluctuation at distance x, and then by introducing a parameter time lag,

$$t_L = x\sqrt{\frac{t_0 S}{4\pi T}} \qquad (3)$$

where t_0, S, and T are defined same as above. The equation (2) becomes,

$$h = h_x \sin(\frac{2\pi}{t_0}(t - t_L)) \qquad (4)$$

Correlation Coefficient

$$\gamma = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \qquad (5)$$

where

x_i = i-th tidal height,

$\overline{x}$ = the average value of x,

y_i = i-th fluctuation of groundwater,

$\overline{y}$ = the average value of y.

Grain-Size Analysis

In order to perform grain-size analyses in laboratory, nine cores provide samples on the basis of one sample out of every 5-m core`s depth from which a few specimens are then taken. In this way, thirty specimens are taken for the nine cores. By means of grain-size analyses from those specimens for each core, thirty grain-size distribution curves are plotted to determine the hydraulic conductivity K (Hazen ,1893) which is then utilized to verify the transmissivity T in the next step.

$$K = 100 D_{10}^2 \qquad (6)$$

$C_u = D_{60} / D_{10}$

$C_d = (D_{30})^2 / (D_{10} \times D_{60})$

where

K = hydraulic conductivity (cm/sec) ,

D_m = m-th percentile of grain size,

C_u = coefficient of uniformity ,

C_d = coefficient of curvature.

Pumping Test

A pumping test is conducted at wells #1 and #2, respectively. According to Boulton (1954), the governing equation for a pumping test in a free aquifer is

$$T\left(\frac{\partial^2 d}{\partial r^2}+\frac{1}{r}\frac{\partial d}{\partial r}\right)=S\frac{\partial d}{\partial t}+D_i S_y\int_0^t \frac{\partial d}{\partial t}e^{-D_i(t-\tau)}d\tau \qquad (7)$$

By corporating an initial condition: $d \to 0, when\ t<0$ and

boundary conditions: $d \to 0, when\ r \to \infty\ and\ t \geq 0$,

the solution is solved as

$$d=\frac{Q}{4\pi T}W\left(u_{AY},\frac{r}{D_t}\right) \qquad (8)$$

where

d = drawdown(m),

$W\left(u_{AY},\frac{r}{D_t}\right)$ = well function,

$$u_{AY}=\begin{cases} u_A=\dfrac{r^2 S}{4tT} & (applicable\ for\ small\ value\ of\ t) \\ u_Y=\dfrac{r^2 S_y}{4tT} & (applicable\ for\ large\ value\ of\ t) \end{cases},$$

r = distance from pumped well to observation well(m),

Q = pumping rate(m^3/hr),

t = time after pumping start(hr),

T = trnasmissivity(m^2/hr),

S = storage coefficient.

S_y= specific yield

Using Type Curve Matching method (Prickett, 1965), the values of T and S are then determined. The T values are compared with the one resulting from the above- mentioned grain-size analyses to see whether these T values are reasonable or not. If not, further adjustifications may be required.

$$T = \frac{Q}{4\pi d} W\left(u_{AY}, \frac{r}{D_t}\right) \qquad (9)$$

$$S = \frac{4Tt}{r^2/U} \qquad (10)$$

where Q, d, W, t, r, U, S, T= defined same as before.

III. PROCEDURE

The procedures using within the scope of this study are steplized as follows:

(1) record groundwater levels through three monitors set at well sites consistantly.

(2) conduct two pumping tests to estimate T and S values; meanwhile, the T values

are verified in comparison with the K values obtained from grain-size analysis.

(3) select two tides with the largest amplitudes for every months in a period of Nov. 1995 to March 1996, and each tide(denoted as tide A) together with next two following tides(denoted as tides B and C) is studied to confirm a tidal effect induced on groundwater level. The study may become tedious for picking up two more tides in the study; however, it is worthwhile of increasing the accuracy of analysis for the tidal effect induced on groundwater level.

(4) use tide A to make correlation coefficient analysis with four days` groundwater levels, then to select highly correlated data initially. By checking those data with the groundwater hydrograph as well as correlation-analysis results of tides B and C, the most proper tide-influenced groundwater duration is decided and so as amplitude and time lag.

(5) plot the fitting curves for tides and their corresponding groundwater fluctuation, respectively. From those curves, the empirical fitting curve equations are obtained by means of regression analysis.

(6) determine the tide-induced groundwater equation from the tide-induced fluctuation amplitude h_x and time lag t_L by considering storage coefficient S and transmissivity T from pumping tests and also amplitude h_0 and period t_0 from tide-curve equations.

(7) compare the theoretical tide-induced groundwater equation with the groundwater fluctuation curves, which are plotted from the observed data as mentioned in step (5).

(8) compare both h_x and t_L from step(6) with the observed values from step (4) to decide the application of the theoretical equation with the recommened values of parameters.

(9) Finally, a modification factor may or may not be incorporated depended on whether the theoretical and observed data match to each other or not.

IV. RESULTS

To present the results with a manner of clearness, a series of figures and tables are organized as follows.

(1) The raw data and time-drawdown curve of two pumping tests (Fig.2).

(2) The correlation coefficients for tide and groundwater level (Table 2).

(3) Tide-influenced groundwater hydrographs (Fig. 3).

(4) Tide- and groundwater-fluctuation curves (Fig. 4).

(5) Analyses table of tide-induced amplitude and time lag (Table 3).

(6) Tide-induced amplitude modification factor (Table 4).

V. CONCLUSIONS

This project is a second-year project, within these two years, a lot of field and lab jobs are done; therefore, the resulting data are shown in this paper. Using the methodology introduced in this project to study those data for the tidal efficiency in a free aquifer, the following conclusions are made.

(1) The results of pumping tests as shown in Fig. 2, S = 0.0346 & T = 14.84m^2/hr at well #1 and S = 0.0345 & T = 23.21m^2/hr at well #2, show that the values of storage coefficient S are quite acceptable in a free aquifer for S in a range of 0.02 ~ 0.3.

(2) The K values from grain-size analysis in laboratory are 9.03×10^{-3} cm/sec (K_1) and 2.89×10^{-2} cm/sec (K_2) (Table 1). To verify the accuracy of T values, these K values multiplying an aquifer depth with a base of the bottom of well determing the T values to chcek another set of T values from pumping tests as listed in Fig.2. The comparisons show that the two sets of the T values are in the same order, and hence the results of pumping test are acceptable.

(3) There are two observations as indicated in Table 2.

A. By observing the relationship between tides(A, B and C) and groundwater level fluctuation, the earliest fluctuation duration is indeed induced by tide A. In other words, the most suitable tide-influenced groundwater duration need not have the highest correlation coefficient to the largest-amplitude tide (i.e, tide A in this study).

B. The tide-influenced fluctuation durations with high correlation cofficients can also reflect on the groundwater hydrographs.

(4) As explaining in procedure (8), both h_x and t_L are compared to their observed values to decide the application of the theoretical equation with recommened values of parameters.The values of observed t_L are around 20 hours and those values are very close to the theoretical t_L (Table 3). Therefore, the theoretical equation for the prediction of t_L is quite practical. However, taking the comparisons for the fluctuation amplitude, the prediction seems to not work at all due to the large difference between the theoretical and observed values (Table 4).

(5) The inconsistency exists for fluctuation amplitudes between the theoretical and observed values. It is believed that this inconsistency may be caused by a number of effects, such as human factors, unenough data, simplified hydrogeological assumptions

and idealized boundary conditions for deriving a theoretical equation. To consider field applications for the theoretical equation, it is practical for combining all these effects into a modification factor. For this purpose, a modification factor or so-called local factor C is introduced into fluctuation amplitude equation, $h_x = h_0 e^{-CX\sqrt{\pi S / t_0 T}}$, to represent these effects more or less depending on the local area of its application. Nevertheless, this factor may be varied for different areas and be modified more accurately if more observed data are available. This study concludes that the C value should take as 0.406 for the study area.

(6) Because geological layers of shallow coast aquifer within the study area are not distinguished well, and human factors are not easily quantilize as well, it is lack of accuracy for building up a longitudinal groundwater profile which may help us understand the direction of groundwater flow.

VI. ACKNOWLEDGEMENTS

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Fig. 1. Study area location and well site

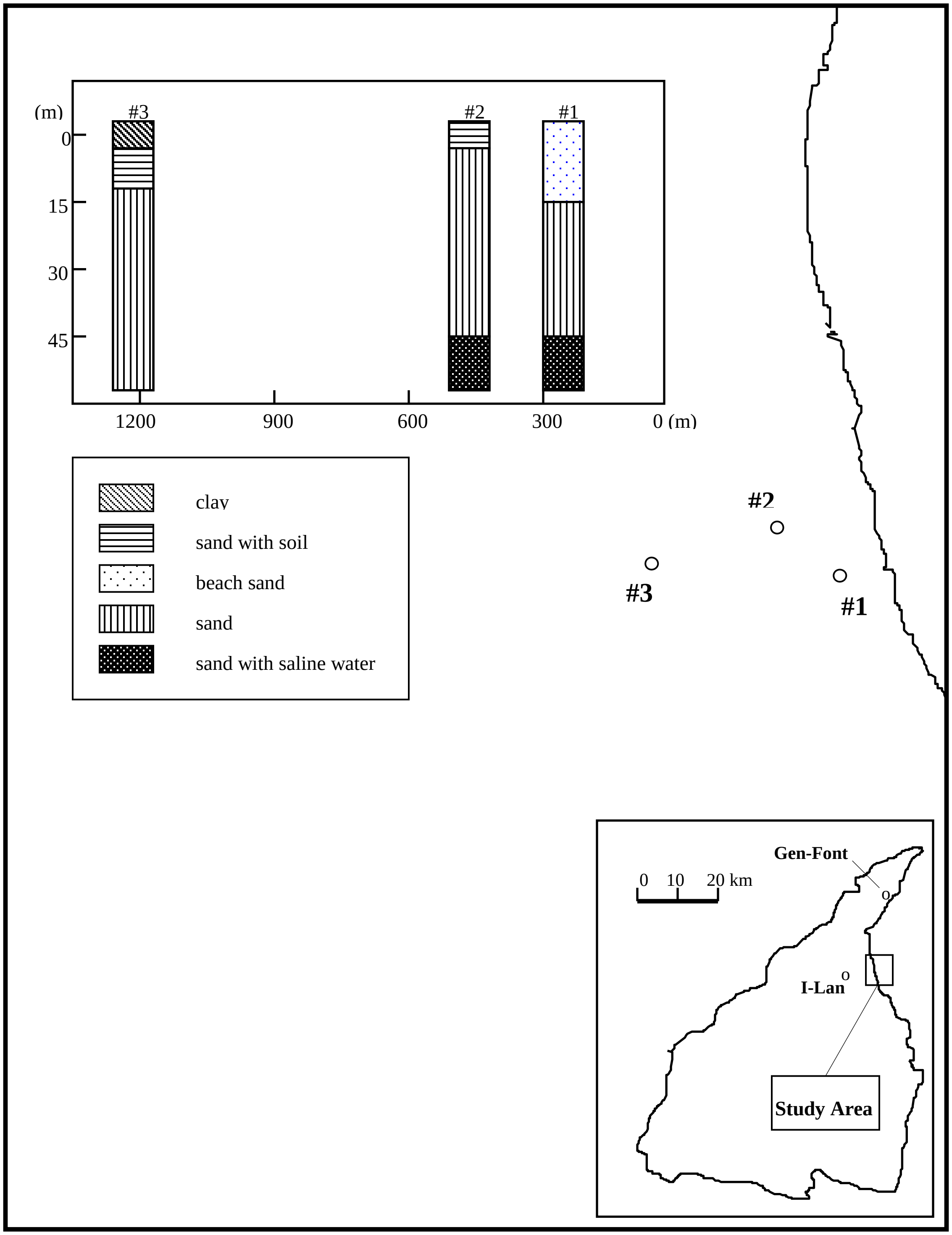


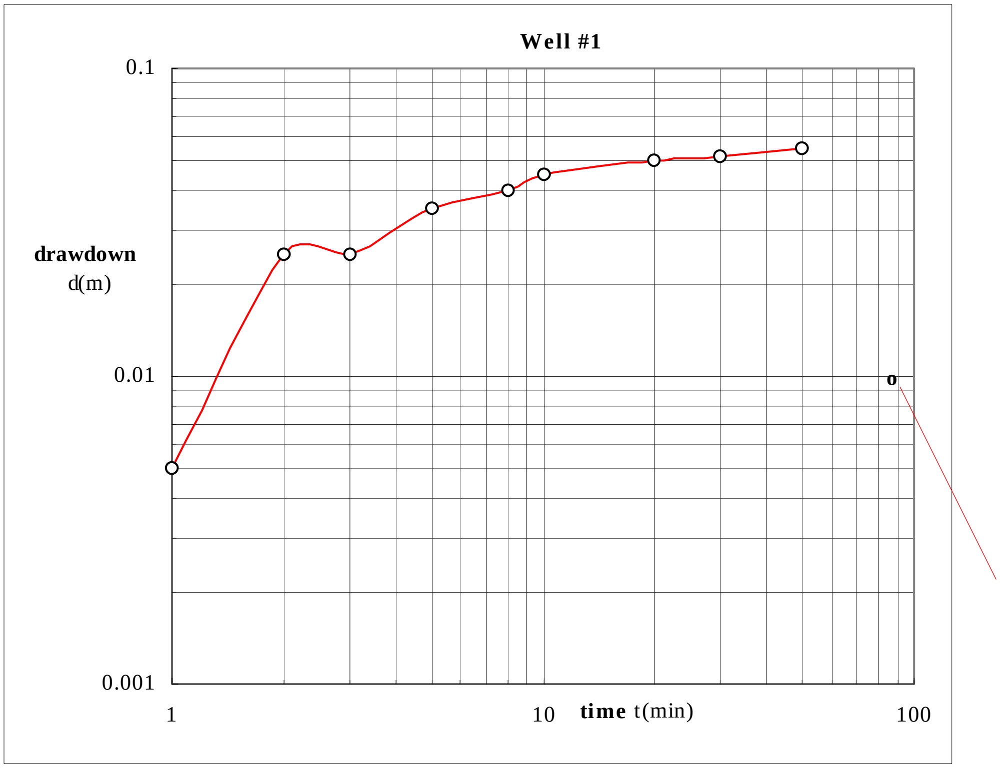
Fig. 2. The raw data and time-drawdown curve of two pumping test

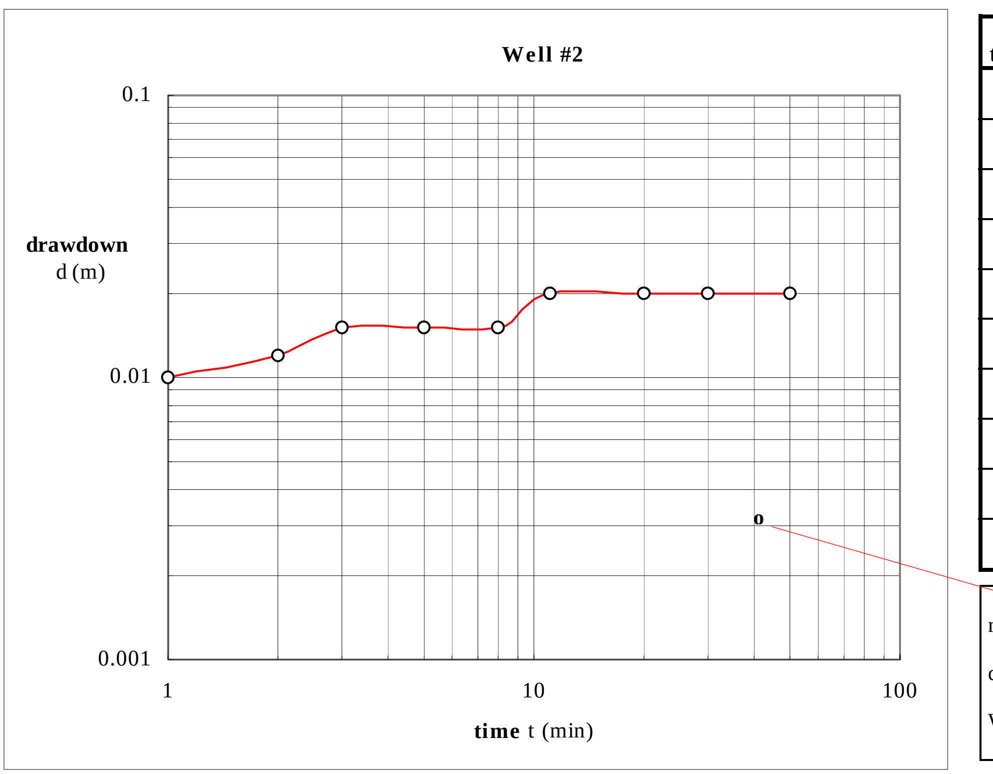
t (min)	d (m)
0	0
1	0.005
2	0.025
3	0.025
5	0.035
8	0.040
10	0.045
20	0.050
30	0.052
50	0.055

match point:

d=0.01m t=85min

W=1.0 1/u=1000





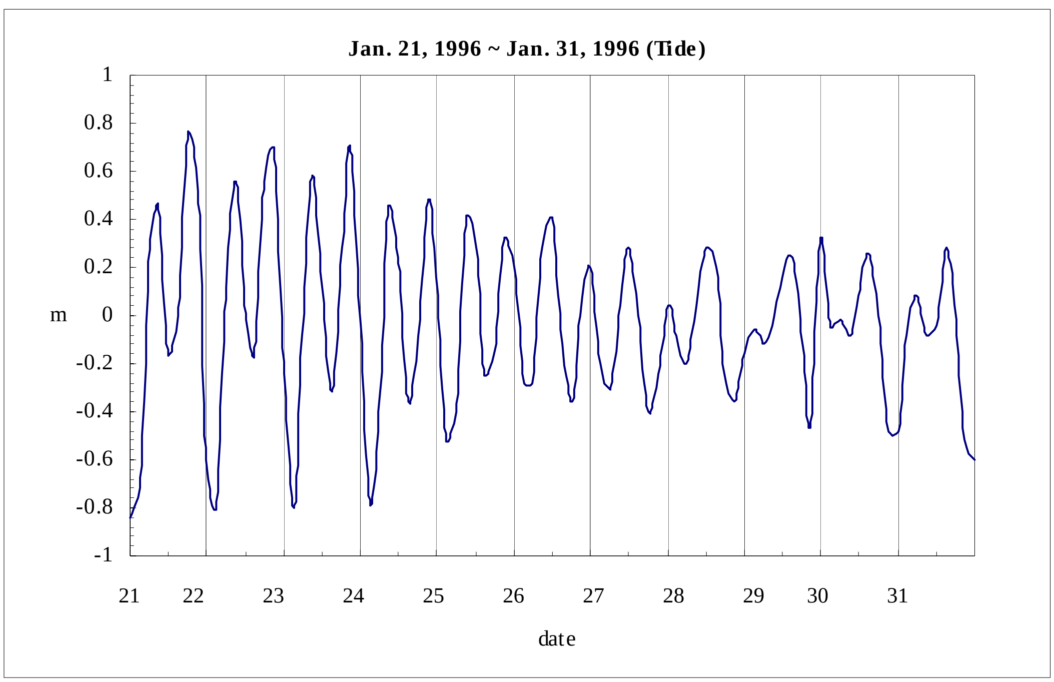
t (min)	d (m)
0	0
1	0.010
2	0.012
3	0.015
5	0.015
8	0.015
10	0.020
20	0.020
30	0.020
50	0.020

match point :

d=0.0038m t=40min

W=1.0 1/u=1000

Fig. 3. Tide and groundwater hydrograph from Jan. 21, 1996 to Jan. 31, 1996



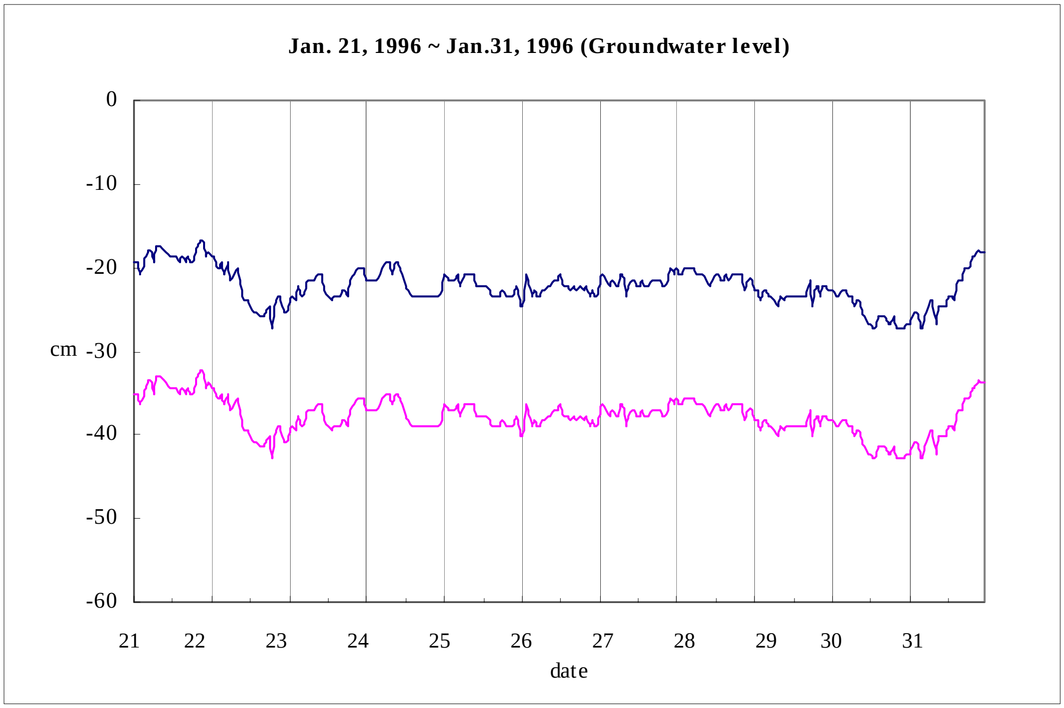
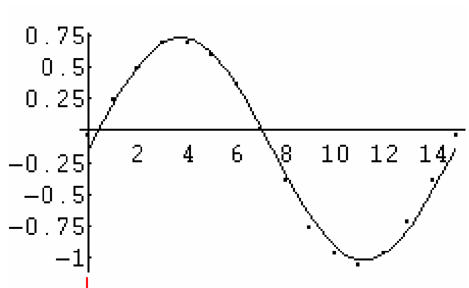
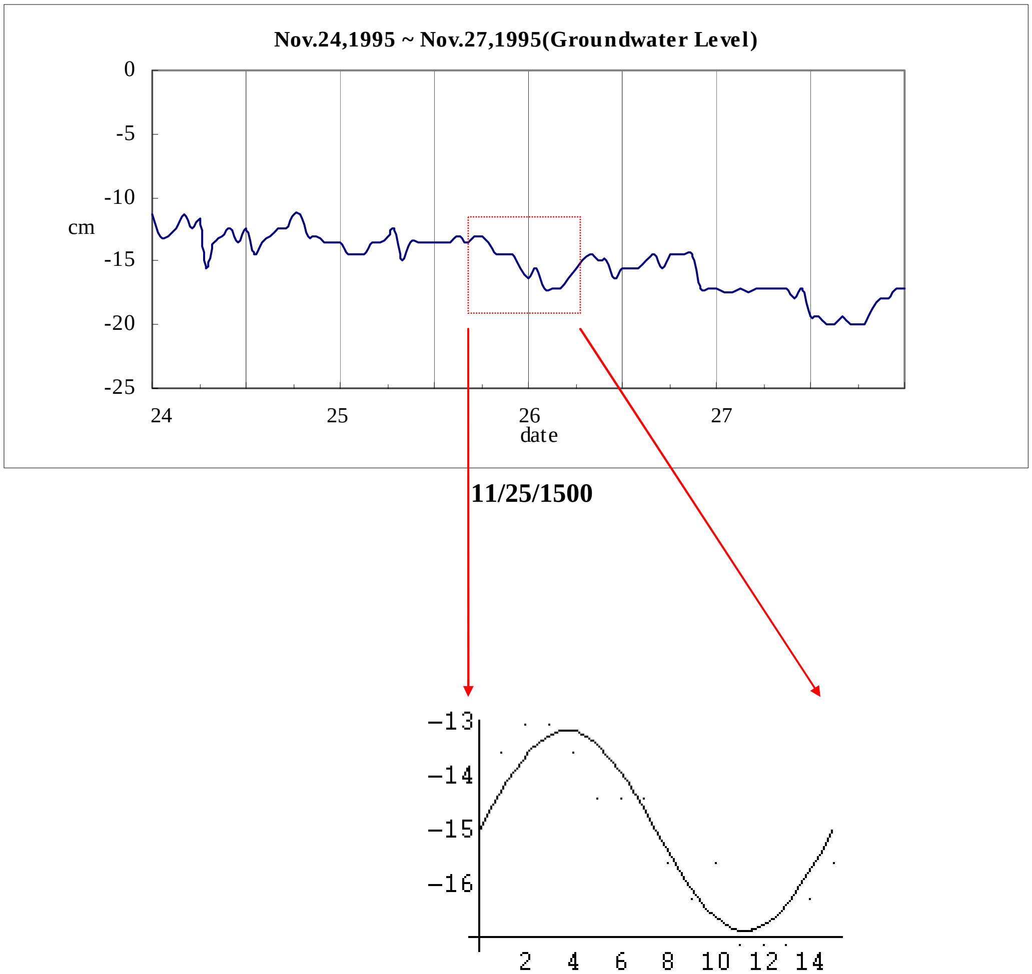


Fig. 3. Tide- and groundwater-fluctuation curve



Tide 84-11-24A

11/24/1600



Groundwater

Table 1. Hydraulic conductivity for grain-size analysis

	HYDRAULIC CONDUCTIVITY (cm/sec)	
DEPTH(M)	**WELL #1**	**WELL #2**
5	0.0324	-
10	0.0324	0.0324
15	0.0324	0.0289
20	0.0256	0.0361
25	0.0324	0.0324

30	0.0324	0.0110
35	0.0225	0.0828
40	0.0256	0.0096
45	0.0110	0.0085
50	0.0090	0.0144
55	-	0.0079
60	-	0.0110

Table 2. The correlation coefficients for tide and groundwater level

		Correlation Coefficient		
Date	Time	Tide A	Tide B	Tide C
"01/08/96"	"16:00:00"	0.4090		
	"17:00:00"	0.2723		
	"18:00:00"	0.0655		
	"19:00:00"	-0.0957		
	"20:00:00"	-0.1862		
	"21:00:00"	-0.1881		
	"22:00:00"	-0.1781		
	"23:00:00"	-0.2733		
"01/09/96"	"00:00:00"	-0.3963		
	"01:00:00"	-0.5194		
	"02:00:00"	-0.5508		
	"03:00:00"	-0.6078		
	"04:00:00"	-0.6929		
	"05:00:00"	-0.7250		
	"06:00:00"	-0.7589		
	"07:00:00"	-0.6548	-0.7405	
	"08:00:00"	-0.4632	-0.6690	
	"09:00:00"	-0.3144	-0.6657	
	"10:00:00"	-0.0726	-0.4812	
	"11:00:00"	0.1579	-0.2936	
	"12:00:00"	0.3876	-0.1114	
	"13:00:00"	0.5547	0.0858	
	"14:00:00"	0.6620	0.3906	
	"15:00:00"	0.5898	0.5876	
	"16:00:00"	0.3757	0.6199	
	"17:00:00"	0.0578	0.5978	0.2030
	"18:00:00"	-0.2704	0.5422	-0.0743
	"19:00:00"	-0.5561	0.2477	-0.3253
	"20:00:00"	-0.7207	-0.0704	-0.5572
	"21:00:00"	-0.8579	-0.4393	-0.6970
	"22:00:00"	-0.8666	-0.7131	-0.7537
	"23:00:00"	-0.8494	-0.8882	-0.8509
"01/10/96"	"00:00:00"	-0.7878	-0.8528	-0.7872

		Correlation Coefficient		
Date	Time	Tide A	Tide B	Tide C
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	"19:00:00"	-0.0957		
	"20:00:00"	-0.1862		
	"21:00:00"	-0.1881		
	"22:00:00"	-0.1781		
	"23:00:00"	-0.2733		
"01/09/96"	"00:00:00"	-0.3963		
	"01:00:00"	-0.5194		
	"02:00:00"	-0.5508		
	"03:00:00"	-0.6078		
	"04:00:00"	-0.6929		
	"05:00:00"	-0.7250		
	"06:00:00"	-0.7589		
	"07:00:00"	-0.6548	-0.7405	
	"08:00:00"	-0.4632	-0.6690	
	"09:00:00"	-0.3144	-0.6657	
	"10:00:00"	-0.0726	-0.4812	
	"11:00:00"	0.1579	-0.2936	
	"12:00:00"	0.3876	-0.1114	
	"13:00:00"	0.5547	0.0858	
	"14:00:00"	0.6620	0.3906	
	"15:00:00"	0.5898	0.5876	
	"16:00:00"	0.3757	0.6199	
	"17:00:00"	0.0578	0.5978	0.2030
	"18:00:00"	-0.2704	0.5422	-0.0743
	"19:00:00"	-0.5561	0.2477	-0.3253
	"20:00:00"	-0.7207	-0.0704	-0.5572
	"21:00:00"	-0.8579	-0.4393	-0.6970
	"22:00:00"	-0.8666	-0.7131	-0.7537
	"23:00:00"	-0.8494	-0.8882	-0.8509
"01/10/96"	"00:00:00"	-0.7878	-0.8528	-0.7872
	"01:00:00"	-0.6529	-0.8388	-0.7346
	"02:00:00"	-0.4748	-0.7413	-0.5982
	"03:00:00"	-0.2279	-0.6480	-0.3642
	"04:00:00"	0.0696	-0.6272	-0.0885
	"05:00:00"	0.3814	-0.3624	0.2329
	"06:00:00"	0.6630	-0.0587	0.4309
	"07:00:00"	0.6525	0.3526	0.5036
	"08:00:00"	0.6337	0.6973	0.4722

	"01:00:00"	-0.6529	-0.8388	-0.7346
	"02:00:00"	-0.4748	-0.7413	-0.5982
	"03:00:00"	-0.2279	-0.6480	-0.3642
	"04:00:00"	0.0696	-0.6272	-0.0885
	"05:00:00"	0.3814	-0.3624	0.2329
	"06:00:00"	0.6630	-0.0587	0.4309
	"07:00:00"	0.6525	0.3526	0.5036
	"08:00:00"	0.6337	0.6973	0.4722
	"09:00:00"	0.5926	0.8235	0.4798
	"10:00:00"	0.5839	0.7159	0.4882
	"11:00:00"	0.6169	0.5094	0.5386
	"12:00:00"	0.6373	0.3967	0.5866
	"13:00:00"	0.6939	0.4396	0.6798
	"14:00:00"	0.7962	0.6279	0.8329
	"15:00:00"	0.7255	0.7114	0.7668

10	lapse	0.002	factor C	0.41		0.408		0.406		0.4
Tide				地下水位振幅 (cm)			Δ^2		Δ^2	
Amplitude (m)	ω	period	observed	theoretical	Δ^2	theoretical		theoretical		theor
0.8745	0.42	14.9600	1.8497	1.9609	0.0124	1.9975	0.0219	2.0349	0.0343	2.0
0.70998	0.42	14.9600	1.6444	1.5920	0.0027	1.6217	0.0005	1.6521	0.0001	1.6
0.6584	0.42	14.9600	0.9527	1.4763	0.2742	1.5039	0.3038	1.5320	0.3356	1.5
0.60878	0.42	14.9600	0.4673	1.3651	0.8059	1.3906	0.8524	1.4166	0.9011	1.4
0.8811	0.42	14.9600	1.1778	1.9757	0.6366	2.0126	0.6969	2.0503	0.7612	2.0
0.34	0.628	10.0051	2.7274	0.3271	5.7613	0.3346	5.7254	0.3423	5.6888	0.3
0.6338	0.45	13.9626	1.1911	1.2438	0.0028	1.2679	0.0059	1.2924	0.0103	1.3
0.3565	0.628	10.0051	1.2647	0.3430	0.8495	0.3509	0.8351	0.3589	0.8205	0.3
0.5783	0.42	14.9600	1.6001	1.2967	0.0920	1.3210	0.0779	1.3457	0.0647	1.3
0.8071	0.45	13.9626	2.0692	1.5839	0.2355	1.6146	0.2067	1.6458	0.1792	1.6
0.735	0.45	13.9626	1.1975	1.4424	0.0600	1.4703	0.0744	1.4988	0.0908	1.5
0.6599	0.45	13.9626	0.5628	1.2950	0.5362	1.3201	0.5735	1.3457	0.6129	1.3
0.4041	0.571	11.0038	1.0229	0.4824	0.2921	0.4929	0.2809	0.5037	0.2696	0.5
0.6376	0.45	13.9626	1.8823	1.2513	0.3982	1.2755	0.3682	1.3002	0.3388	1.3

0.7854	0.45	13.9626	3.3402	1.5413	3.2359	1.5712	3.1295	1.6016	3.0228	1.6
0.5027	0.628	10.0051	1.6631	0.4837	1.3911	0.4947	1.3651	0.5061	1.3387	0.5
0.8747	0.45	13.9626	0.8075	1.7166	0.8264	1.7498	0.8879	1.7837	0.9529	1.8
0.5203	0.483	13.0087	0.4461	0.8863	0.1938	0.9041	0.2097	0.9222	0.2267	0.9
0.517	0.571	11.0038	0.9788	0.6172	0.1308	0.6307	0.1212	0.6444	0.1118	0.6
0.7191	0.483	13.0087	1.6496	1.2249	0.1804	1.2495	0.1601	1.2746	0.1407	1.3
0.5534	0.571	11.0038	1.5429	0.6606	0.7784	0.6751	0.7531	0.6898	0.7278	0.7
0.6318	0.524	11.9908	1.5768	0.9086	0.4465	0.9276	0.4215	0.9469	0.3967	0.9
0.8026	0.393	15.9877	8.0645	5.7692	5.2684	5.8438	4.9316	5.9193	4.6018	5.9
0.2879	0.628	10.0051	0.5578	1.0325	0.2253	1.0494	0.2417	1.0666	0.2588	1.0
0.6394	0.393	15.9877	1.9171	4.5961	7.1770	4.6555	7.4989	4.7157	7.8321	4.7
0.2706	0.628	10.0051	0.7671	0.9704	0.0413	0.9863	0.0481	1.0025	0.0554	1.0
0.5374	0.393	15.9877	4.0376	3.8629	0.0305	3.9128	0.0156	3.9634	0.0055	4.0
					######		######		######	