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AQUIFER DIFFUSIVITY DETERMINATION FROM AQUIFER RESPONSES TO THE RIVER STAGE FLUCTUATIONS IN A MANGYEONG-RIVER FLOODPLAIN

A convolution equation for the flood wave response model was used to estimate aquifer diffusivities using the ground water levels of the selected well in a Mangyeong-river floodplain. Ground water levels of no rainfall periods showing high correlations with the river stages near the river were used as inputs of the flood wave, in which uncertain riverbed leakance and possible rainfall recharge can be neglected. Pumping test can provide a local property of the aquifer, but flood wave response technique become a good tool in a sense that the overall aquifer diffusivity related with hydraulic interaction of a river-aquifer system can be estimated. The flood wave response technique proposed in this study can be effective when the response peaks by flood waves are clearly defined, and the observed ground water heads are highly correlated with the river stage fluctuations.

Сверточное уравнение для модели уровня паводковой воды было использовано для оценки коэффициента диффузии водоносного горизонта с привязкой к уровням грунтовой воды в пойме р.Мангйонг. Уровни грунтовой воды в периоды отсутствия атмосферных осадков, демонстрирующие высокие данные корреляции с уровнем водотока, были использованы в качестве вводных данных по уровню паводковой воды, при которых можно пренебречь неподдающимися определению уровнями утечки через русло реки и уровнями пополнения подземных вод за счет атмосферных осадков. Пробное откачивание может дать данные по локальным свойствам водоносного слоя, в то время как методика измерения уровня паводковой воды является отличным средством с точки зрения оценки общего коэффициента диффузии водоносного горизонта, связанного с гидравлическим взаимодействием системы река – водоносный слой. Методика измерения уровня паводковой воды, предлагаемая в настоящей статье, может быть эффективно использована в тех случаях, когда есть возможность четко определить пиковые уровни паводковой воды, а наблюдаемое гидростатическое давление подземных вод имеет четкую корреляцию с колебаниями уровня воды в реке.

INTRODUCTION

Under suitable field conditions, it is possible to calculate the aquifer diffusivity, i.e. the ratio of transmissivity to storage coefficient, of alluvial aquifers by analyzing their response to river stage fluctuations, which is known as the flood wave response technique (Pinder et al., 1969; Hall and Moench, 1972; Jha et al., 2004). In this approach, an analytical model relating the river stage to groundwater level is used. The advantages of this approach are that by using simple equations, reasonably accurate estimates of parameter values could be made, which are cost effective and less time-consuming compared with other methods.

STUDY SITE

The site for this study is a floodplain of the Mangyeong River located in the western part of the Korean Peninsula. Various agricultural activities related with rice farming and greenhouse cultivation are being practiced as the fertility of the soil has been maintained thanks to the frequent floods (Fig.1). Figure 2 shows the locations of the developed wells. Most of the developed wells yielded ground water in gravel and sand (GS) layer that can be

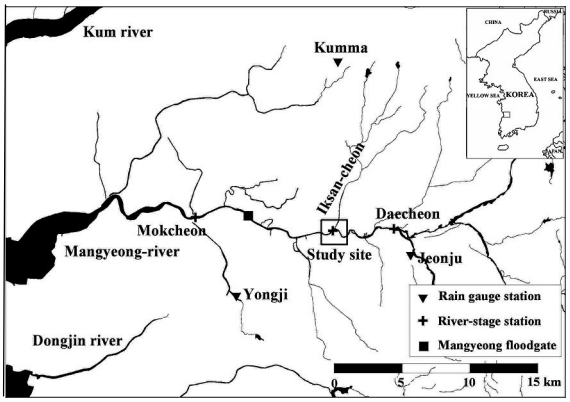


Fig.1. Site location

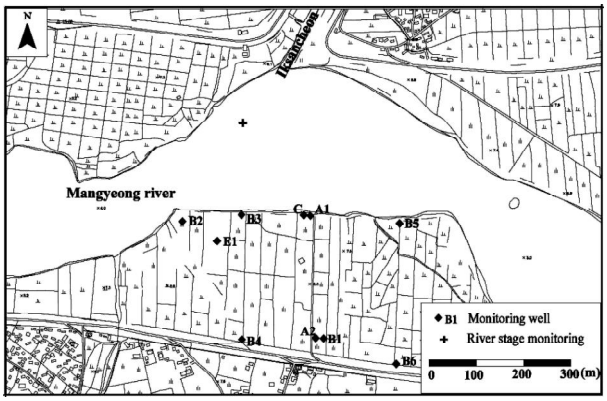


Fig.2. Location of the monitoring wells

thought to be the main aquifer in the site. The thickness of the GS layer ranges from 4,0 to 6,7 m, and the average thickness of the layer is 5,7 m. Completely weathered zone (WZ) layer which comes from granite bedrock is distributed under the GS layer. The thickness of WZ layer ranges from 6,2 to 16,0 m, and the average thickness of the layer is 11,3 m. The average thickness of alluvium on study site is 23,8 m.

Ground water levels and stream stages are monitored using an automatic water level device from 14 July, 2004 to 29 December, 2005. A gate 7,1 km downstream from the study site opens and shuts for flood controls and sustainable supply of irrigation water by preventing salt water upcoming. Since the periodic components by the gate operations and tidal effects are dominant on the study site, periodic components are shown in the river stage records, and the river stages have just weak correlation with rainfall.

The ground water levels of the wells distant from the river are higher than those of the wells adjacent to the river in low river stage periods. On the contrary, the situations are frequently reversed in high river stage periods. The ground water level fluctuations show little correlation with rainfall, but good correlation with river stages. The correlation coefficients of the ground water levels of the wells (B2, B3, B5, A1, and C wells) adjacent to the river are higher than those (B1, B4, B6, A2 and E1 wells) distant from the river. The ground water level fluctuations near the river indicate high correlation coefficient to one another, as these are directly influenced by the river stage fluctuations together.

METHOD

The analytical solution used in this study is based on convolution theorem and impulse response functions(Pinder et al, 1969). The stage hydrograph is approximated by a series of discrete steps. In a semi-infinite homogeneous isotropic confined aquifer, the influence of each increment in river stage on the head may be found by solving the following set of equations:

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

$$h(0,t) = \begin{cases} 0 & \text{when} \quad t \le 0 \\ \Delta H_m & \text{when} \quad t > 0; \end{cases} \qquad (1a)$$

$$\frac{\partial h(\infty,t)}{\partial x} = 0; \qquad (1b)$$

$$h(x,0) = 0, \qquad 0 \le x < \infty, \qquad (1c)$$

where h is the change in hydraulic head [L], α is the diffusivity, ratio of transmissivity to coefficient of storage, $[L^2/T]$, and ΔH_m is the instantaneous rise of stage at time $t = m\Delta t$ where m is an integer. The solution to this problem is available from the analogous problem in heat flow (Carslaw and Jaeger, 1959, p.305). This solution may be written with some changes in notation as

$$\Delta h_m = \Delta H_m erfc \frac{x}{2\sqrt{\alpha t}}. \qquad (2)$$

Since Eq.1 is linear, the change in ground water head is given by summing the values of

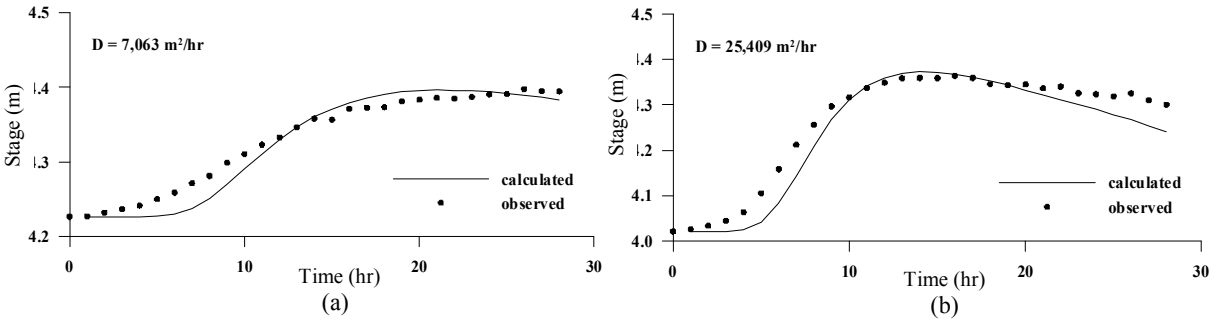


Fig.3. Hydrograph matching, (a) B3-B4(GS), (b) B5-B6(WZ)

Δh_m computed for each ΔH_m over the period $(p-m)\Delta t$, and we can write

$$h_p = \sum_{m=1}^{p} \Delta h_m = \sum_{m=1}^{p} \Delta H_m \{erfc \frac{u}{2\sqrt{p-m}}\};$$

$$u = \frac{x}{\sqrt{\alpha \Delta t}}, \qquad (3)$$

where h_p is the head at a distance x from the river at time $p\Delta t$, $p\Delta t$ is the total time since the beginning period of analysis, where p is the number of time intervals.

The substitution of groundwater level for river stage is required so that the relationship between a observation well near the river and a distant well more closely approximates the theoretical conditions of the Eq.3. The substitution of the groundwater levels of a monitoring well near the river also eliminates the effects of possibly lower hydraulic conductivity of the riverbed.

RESULTS AND DISCUSSION

A lot of flood waves are identified during the observation periods, and ground water levels of the well adjacent to the river (B2, B3 and B5 wells) show a strong correlation with the river stage fluctuations. Eq.3 basically is one dimensional, and the flood wave of the river stage propagates perpendicularly from the river. Then, two pairs of the analyzed ground water levels are those in GS and WZ layers of the B3 and B4 wells, B5 and B6 wells. When the ground water levels of B4 is the target of calibration, B3 ground water level is used to be a substitute of the river stage. In case of B6, the ground water level of B5 will be a substitute of the river stage. The distance between B3 and B4 is 282 m, and the distance between B5 and B6 is 320 m.

Hydrograph was matched on the rising limb and peak arrival time, and the root mean square errors between calculated and observed ground water levels were minimized. Table 1 shows the results of application of flood wave response technique using Eq.3.

Table 1. Aquifer diffusivities estimated by the flood wave response model

Input	Output	Analysis period	Aquifer diffusivity (m^2/hr)
B5(10)	B6(11)	9 Dec. – 10 Dec. 2004	36,559
		10 Dec. – 11 Dec. 2004	38,194
		13 Dec. – 14 Dec. 2004	39,627
		6 Dec. – 21 Dec. 2004	37,584
B5(30)	B6(27)	27 Aug. – 28 Aug. 2004	25,409
		30 Aug. – 3 Sep. 2004	33,573
		13 Sep. – 21 Sep. 2004	39,902
B3(11)	B4(14)	27 Aug. – 28 Aug. 2004	7,063

Figure 3 shows the hydrograph matching the calculated ground water level response to the observed ground water level for each well. As shown in figure 3, the matching of the two successive flood waves or long term ground water levels was poor. This may be because irrigation and local pumping for the agricultural activity of greenhouse, or rice farming can influence the ground water level changes. Other factors that the matching of the calculated and observed ground water levels come from the inherent assumptions of Eq.3. The best hydrograph matches can be produced when the assumption of constant transmissivity for the aquifer was satisfied.

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