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Reply

J. J. Jiao

Department of Earth Sciences, University of Hong Kong, Hong Kong, China

Z. Tang

Institute of Environmental Geology, China University of Geosciences, Wuhan, China

We appreciate the interest of *Volker and Zhang* [this issue] in our paper [*Jiao and Tang*, 1999] in which an analytical solution has been derived to study the influence of leakage on tidal response in a coastal leaky confined aquifer system. Like any other analytical solutions, our analytical solutions have assumptions. Our assumptions are essentially based on the three assumptions introduced by *Hantush and Jacob* [1955] in developing an analytical solution for radial groundwater flow in a multilayer aquifer system caused by pumping: (1) The head in the layer supplying the leakage is constant; (2) the permeability contrast in the semipervious layer and in the aquifers is very great, so that the flow is vertical in the semiconfining bed and horizontal in the aquifers; and (3) the storage in the semipervious layers is neglected. These assumptions are apparently valid for some leaky aquifer systems since their analytical solution has become classic and has been widely used in analyzing pumping test data.

In addition to the above assumptions, we assumed that the shallow unconfined aquifer has a large specific yield which can damp effectively the tidal effect so that the tidal fluctuation in the unconfined aquifer is negligible compared to that in the confined aquifer. This assumption is largely based on the theoretical and field studies carried out by *White and Roberts* [1994, pp. 39–40]. They concluded, "the attenuation of the tidal response with distance varies markedly for confined and unconfined aquifers. Confined aquifers even of medium to low permeability have a stiff response and exhibit low attenuation with fluctuations potentially extending to a hundred metres or more from open water. Unconfined aquifers are heavily damped and unless the permeability is above about 10^{-4} m/s (8.64 m/d) significant fluctuations are unlikely to extend to more than about 20 or 30 m from open water."

While we believe that our assumptions are reasonable and the analytical solution is applicable to some coastal leaky confined aquifer systems, the accuracy of our solution depends on how close the aquifer condition is to the above assumptions. In our paper, we discussed how the groundwater level fluctuation would change with leakance L, which is the ratio of the hydraulic conductivity (k') of the semiconfining unit over the thickness (b') of the semiconfining unit. We gave different values of L: 0, 0.01, 0.05, and 1/day. *Volker and Zhang* [this issue] investigated the accuracy of our solution for different leakance L of the leaky layer using a numerical model. They concluded that for a leakance of 1/day, the error is significant.

We thank them for their comments which provoke us to think carefully about the physical implication of leakance and the realistic range of it for real leaky aquifer systems. We now feel that it is unrealistic to give L a value of 1/day. This value means that the hydraulic conductivity of the semipervious layer equals numerically the thickness of the semipervious layer. That is, if the thickness equals 10 m, the hydraulic conductivity equals 10 m/d. In this case this layer is obviously too permeable to be called a semipervious layer. This probably violates the second assumption of *Hantush and Jacob* [1955], which is valid

Table 1. Leakance Calculated From Some Well-Documented Pumping Test Data of Leaky Confined Aquifer Systems in Literature[a]

Case Studies	Confined Aquifer Parameters: T, m²/d	S	b, m	Semipervious Layer Parameters: K', m/d	S'	b', m	L, per day	Reference
1	108	0.000036	13.7	0.013	0.001	4	0.00325	*Sheahan* [1977]
	158	0.000045	13.7	0.013	NA	4	0.00325	*Batu* [1998]
	114	0.00003	13.7	0.013	0.0035	4	0.00325	*Batu* [1998]
2	1624	0.000112	28.3	0.0016	0.003	9.1	0.000176	*Neuman and Witherspoon* [1972]
	1624	0.000112	28.3	0.0016	0.012	15.2	0.000105	*Neuman and Witherspoon* [1972]
3	7.31	0.000098	6.1	0.00816	0.004	3	0.00272	*Dawson and Istok* [1991]
4	733	0.00009	15.6	0.0021	0.00047	13.1	0.000160	*Chen and Jiao* [1999]
5	753	0.00004	NA	NA	NA	NA	0.000012	*Batu* [1998], *Hantush* [1956]
6	1097	0.000092	NA	NA	NA	NA	0.000004	*Batu* [1998], *Hantush* [1956]

[a]NA means data are not available. The three sets of data in case 1 were obtained using different parameter estimation methods based on the same set of field pumping test data. The units in cases 2 and 3 were English system in the original paper and are converted into metric system. The data of case 4 are arithmetic average values of four different zones in the original paper; Li Hailong compiled the data and is acknowledged.

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only if the hydraulic conductivity of the main aquifers is 2 orders greater than that of the semipervious aquifer [*Javandel and Witherspoon*, 1968]. When L is as great as 1, most probably the unconfined and the confined aquifers cannot be regarded as two aquifers separated by a semipervious layer at all.

It is of interest to see what is the range of the leakance in real leaky aquifer systems. We have compiled values of L from various pumping test data available in literature on leaky confined aquifer systems. The results are listed in Table 1. As can be seen, L is much smaller than 1. It seems that a value of $L = 1$ is very unrealistic.

To conclude, it is inappropriate to use the solution for an aquifer system with L being as great as 1. When $L = 1$, the hydraulic conductivity of the middle layer is probably far too large for a semipervious layer. For most leaky confined aquifer systems the leakance is much smaller than 1, and there will be no problem at all using our analytical solution.

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J. J. Jiao, Department of Earth Sciences, University of Hong Kong, James Lee Building, Pokfulam Road, Hong Kong, People's Republic of China. (jjiao@hku.hk)

Z. Tang, Institute of Environmental Geology, China University of Geosciences, Wuhan 430074, People's Republic of China.

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