Letter to the Editor

Reply to Zekâi Şen's Comments

I appreciate Zekâi Şen’s concerns and comments about “Monitoring Well Placement [MWP] Using Conditional Simulation of Hydraulic Head.” His concern about our disregard for hydraulic conductivity data was addressed by us in a paper also published in Mathematical Geology a couple of issues before MWP (Weber et al., 1991). In the first paper, we utilized inverse modeling (Cooley, 1977, 1979, 1982, 1985) which allowed us to incorporate available aquifer data, including anisotropic hydraulic conductivity data, into our estimation process for monitoring well placement.

However, during the inverse-modeling study we realized that hydraulic conductivity data is not as common as one would wish. The Pittman study site used in MWP had no available hydraulic conductivity data. Since that time, I have encountered several other sites where, at best, specific capacity data were available (Johanson, 1992). Specific capacity and the more-common slug-test estimates yield no information on anisotropy. Given this common situation, MWP was aimed at improving monitoring well placement using available hydraulic-head data. If more data are available, we certainly encourage using more intensive approaches, such as inverse modeling, preferably as we described it.

In the remainder of this reply, I'd like to clarify some points from the original paper:

Anisotropy: Two types of anisotropy are mentioned in MWP, anisotropy in hydraulic conductivity, and anisotropy in variogram range of hydraulic head. These are two distinctly different aquifer properties and have different effects on the flow field. Anisotropy in hydraulic conductivity indicates that at a point, flow in one direction is easier than in another. Often this results from fractures in the aquifer or consistent depositional fabric—vertical anisotropy is common in layered sedimentary rocks. Anisotropy in hydraulic conductivity may be determined over a large aquifer volume by pump tests or at a small scale from core analysis. Anisotropy is not necessarily consistent from scale to scale, nor are estimates of hydraulic conductivity. At the scale that dominates contaminant migration, pump tests give average values which are often insufficiently detailed.
Small-scale heterogeneities dominate the migration of contaminants, and these are seldom detected by pump tests. Identifying the patterns in heterogeneity, if present, is one use of the variogram. Anisotropy in variogram range indicates the greater persistence of values in a direction. A classic example of this is the geological map of the Valley and Ridge Province, where outcrops persist long distances along the axes of folds but only short distances perpendicular to the folds. Thus, anisotropy in variogram is a measure of patterns in heterogeneity. We assumed heterogeneity in hydraulic head was a result of heterogeneity in transmissivity (hydraulic conductivity multiplied by aquifer thickness). Heterogeneity certainly affects ground-water flow direction, but head contours and flow lines are still perpendicular, unlike the case for anisotropic hydraulic conductivity. The preferred direction of heterogeneity found at the Pittman site, which resulted in our anisotropic variogram, we believe is a result of the geological process that deposited the alluvium. Buried channels ran generally in a downhill direction, as expected.

Hydraulic Head: Negative hydraulic heads are certainly plausible physically. Hydraulic head is dimensionally a length, measured above an arbitrary datum, usually sea level. Here in New Orleans, we seldom encounter a positive hydraulic head value. The mean surface we chose to fit to the hydraulic head was based on our understanding of the regional geohydrology. The flow is from the mountains northward to the Las Vegas wash. This was the trend we chose to remove. We saw no physical justification for considering another variable. Hydraulic head does vary temporally. We had the advantage of working in a climate with virtually no vegetation and no surface water. Recharge is from the mountains to the south. Therefore, though the regional trend in hydraulic head may rise and fall, locally we expect the residuals to remain relatively consistent. Certainly, we would like to check this assumption.

Variogram: Choosing a model variogram should include a consideration of the physical system being modeled. We chose a Gaussian model because hydraulic head varies very little on a short scale—we seldom encounter underground waterfalls—and it fit the data best at short lags. The longer lags used data outside but surrounding our study grid. At those lags the number of pairs used to compute the variogram becomes much smaller, by necessity. The model we chose was a compromise, of course, but was our best choice for representing the physical nature of hydraulic head.

Flow Lines: Contrary to Sen's comments, our flow lines showed considerable variation. The histogram in Fig. 11 in MWP is based on a single starting point for flow lines on the southern border, 4000 feet from the northern border. Yet the flow lines cross the northern border as much as 4000 feet apart.

In conclusion, assumptions about geohydrologic systems are often hard to justify. Most slug-test and pump-test analysis methods assume isotropy and homogeneity, seldom ever met completely. However, the estimates from these