

Overview of Research at the Geohydrologic Experimental and Monitoring Site

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Prepared for presentation at field trip of
The 43rd Annual Midwest Ground Water Conference
Lawrence, Kansas
October 12, 1998

KGS Open File Report #98-45

Site Characterization Research at the Geohydrologic Experimental and Monitoring Site

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The Geohydrologic Experimental and Monitoring Site (GEMS) is a research area that was established in 1988 by the Kansas Geological Survey on land owned by the University of Kansas Endowment Association. This site is part of the Robinson Tract of the Kansas Ecological Reserves, which is managed for the University of Kansas Endowment Association by the Experimental and Applied Ecology Program of the University of Kansas. Since its inception, GEMS has been the site of an extensive program of research directed at the development and refinement of field methodology for the characterization of the hydraulic properties of saturated flow systems. This research has been funded by a variety of sources, which have included internal funding from the Kansas Geological Survey, and external funding from the National Science Foundation, the Department of Defense, and various competitive grant programs administered by the United States Geological Survey. Jim Butler and Carl McElwee have co-led this research effort, while Geoff Bohling and John Healey have made significant contributions. Students from the Departments of Geology and Civil Engineering at the University of Kansas have contributed to this work, and have used portions of it for theses and reports.

The philosophical basis of the site characterization work at GEMS can be summed up in the following three statements: 1) a considerable body of research has identified the spatial distribution of hydraulic conductivity as a significant control on the movement of contaminants in the subsurface; 2) our capabilities for modeling the effects of spatial variations in hydraulic conductivity on contaminant transport have far outstripped our ability to characterize these variations in the field; and 3) significant improvements in our capability to assess the risk posed by a site of groundwater contamination or to design effective remediation schemes are likely to occur as a result of significant improvements in the field methodology used in site characterization activities. In this presentation, aspects of three research projects currently underway at GEMS will be discussed.

1) Use of Slug Tests in Site Characterization - The slug test is a widely used field method for the estimation of hydraulic conductivity at sites of suspected groundwater contamination. This technique essentially involves changing the head in a well from static conditions in as near an instantaneous manner as possible, and then measuring the subsequent recovery of head in that well back to static conditions. The head measurements can be used to estimate the hydraulic conductivity of the material adjacent to the screened or open interval through comparisons with theoretical models of test responses. The slug test has become such a commonly used field method as a result of its logistical and economic advantages over alternative approaches. These advantages include low cost, simplicity, relatively short duration, utility in low-permeability units, perceived straightforward analysis, and the fact that a test can be configured so that no water is added to or removed from a well during test initiation. A particular advantage for investigations

in heterogeneous sequences is the technique's ready adaptability to units of greatly differing permeability. Despite its many advantages, much of the data currently obtained from slug tests are, and often rightfully so, viewed with considerable skepticism. For the last eight years, personnel at the Kansas Geological Survey have pursued theoretical and field research directed at improving the quality of information that can be obtained from a program of slug tests. The theoretical components of this effort have led to the development of new models for slug tests in partially penetrating wells in confined and unconfined formations (Hyder et al., 1994; Chapters 5-6 of Butler (1997)), and for slug tests in formations of very high permeability (McElwee and Zenner, 1998; Chapter 8 of Butler (1997)). The field components of this research have led to the definition of a series of practical guidelines for the design, performance, and analysis of slug tests (Butler et al., 1996; Butler, 1997). In this presentation, several methods for initiation of slug tests will be discussed, and the pneumatic initiation method will be demonstrated;

2) Field Verification of the Dipole Flow Test - The dipole flow test (DFT) is a promising new approach for the estimation of vertical variations in hydraulic conductivity (Zlotnik and Zurbuchen, 1998). This technique is a single borehole test in which a three-packer tool is placed in the screened (open) interval of a well. A small downhole pump moves water from one chamber of the tool to the other through the center of the middle packer, thereby setting up a circulation pattern in the adjacent formation (see Figure 1). The head difference between the two chambers at steady state is used to estimate the hydraulic conductivity of near-well portions of the formation. The DFT research at GEMS has been directed at examining several issues of relevance for practical field applications. These include the time required to obtain steady state and its dependence on the characteristics of the formation and test equipment, the impact of well installation and development procedures, the dependence of parameter estimates on pumping rate, and the applicability of the method to heterogeneous systems (Butler et al., 1998). Results show that the DFT is particularly useful in high-K media because the time to steady state is short (a matter of seconds) and non-Darcian head losses are negligible. Although the approach is based on the assumption of a locally homogeneous formation, comparisons of DFT results with geophysical logs indicate that the DFT can provide useful information in highly heterogeneous systems as well. The DFT research at GEMS is part of a joint research project on the DFT carried out by researchers at the Kansas Geological Survey and the University of Nebraska at Lincoln. In this presentation, a DFT tool designed by Vitaly Zlotnik and colleagues at the University of Nebraska at Lincoln will be discussed;

3) Hydraulic Tomography for Estimation of Interwell Variations in Hydraulic Conductivity - A major problem with most single-well hydraulic tests (including the slug test and the dipole flow test) is that the resulting parameter estimates represent conditions in the immediate vicinity of the test well, and thus may provide relatively little insight into conditions outside the near-well region. Hydraulic tomography is the name given to a recently proposed field approach designed to obtain information about spatial variations in hydraulic conductivity outside of the near-well region. This method essentially consists of the performance of a series of short-term pumping tests in which the position of the stressed interval in the pumping well, isolated with packers, is varied between tests to produce a 'crossed' streamline pattern similar to the crossed raypaths of a typical

crosshole seismic tomography experiment (see Figure 2). The viability of hydraulic tomography hinges on the availability of detailed information about vertical and lateral variations in pumping-induced head changes (drawdown). Nests of piezometers placed in a series of relatively closely spaced boreholes could provide the needed data density if the piezometers were small enough that a large number could be placed together. The logical extension of such an approach would be the utilization of the multilevel sampling wells commonly employed in large-scale tracer tests. These wells (henceforth designated MLSs) consist of bundles of small diameter (often < 5 mm ID) tubing. Although the large number of tubes (often 15-17) in a MLS could result in descriptions of vertical variations in drawdown at a scale that has previously been unobtainable, the small tubing diameter has made the measurement of drawdown a significant challenge. Recently, work at the Kansas Geological Survey has demonstrated that drawdown can be measured in the small-diameter tubing of an MLS using miniature fiber-optic pressure sensors or air-pressure transducers (Butler et al., 1997a). Ongoing field and theoretical work is directed at assessing the potential of this promising new field approach (Butler et al., 1997b). In this presentation, methods for measuring drawdown in the small-diameter tubing of an MLS will be discussed.

REFERENCES - additional information about the topics discussed in this presentation can be found in the following publications:

- Butler, J.J., Jr., *The Design, Performance, and Analysis of Slug Tests*, Lewis Publishers, Boca Raton, 252 pp., 1997.
- Butler, J.J., Jr., Healey, J.M., Zlotnik, V.A., and B.R. Zurbuchen, *The dipole flow test for site characterization: Some practical considerations*, Kansas Geological Survey Open-File Report 98-20, 23 pp., 1998 (also poster presentation at Spring 1998 Conf. of the American Geophysical Union).
- Butler, J.J., Jr., McElwee, C.D. and G.C. Bohling, *Transient head data from multilevel samplers: A promising new approach for subsurface characterization*, Kansas Geological Survey Open-File Report 97-36, 27 pp., 1997a (also poster presentation at Spring 1997 Conf. of the American Geophysical Union).
- Butler, J.J., Jr., McElwee, C.D., and D.D. Davies, *Hydraulic tracers: A new tool for characterizing subsurface variations in hydraulic conductivity*, Kansas Geological Survey Open-File Report 97-70, 18 pp. 1997b (also poster presentation at Fall 1997 Conf. of the American Geophysical Union).
- Butler, J.J., Jr., McElwee, C.D., and W.Z. Liu, *Improving the reliability of parameter estimates obtained from slug tests*, *Ground Water*, v. 34, no. 3, pp. 480-490, 1996.
- Hyder, Z., Butler, J.J., Jr., McElwee, C.D., and W.Z. Liu, *Slug tests in partially penetrating wells*, *Water Resour. Res.*, v. 30, no. 11, pp. 2945-2957, 1994.
- McElwee, C.D., and M.A. Zenner, *A nonlinear model for analysis of slug-test data*, *Water Resour. Res.*, v. 34, no. 1, pp. 55-66, 1998.
- Zlotnik, V.A., and B.R. Zurbuchen, *Dipole probe: Design and field applications of a single-borehole device for measurements of small-scale variations of hydraulic conductivity*, *Ground Water*, v. 36, no. 6, in press, 1998.

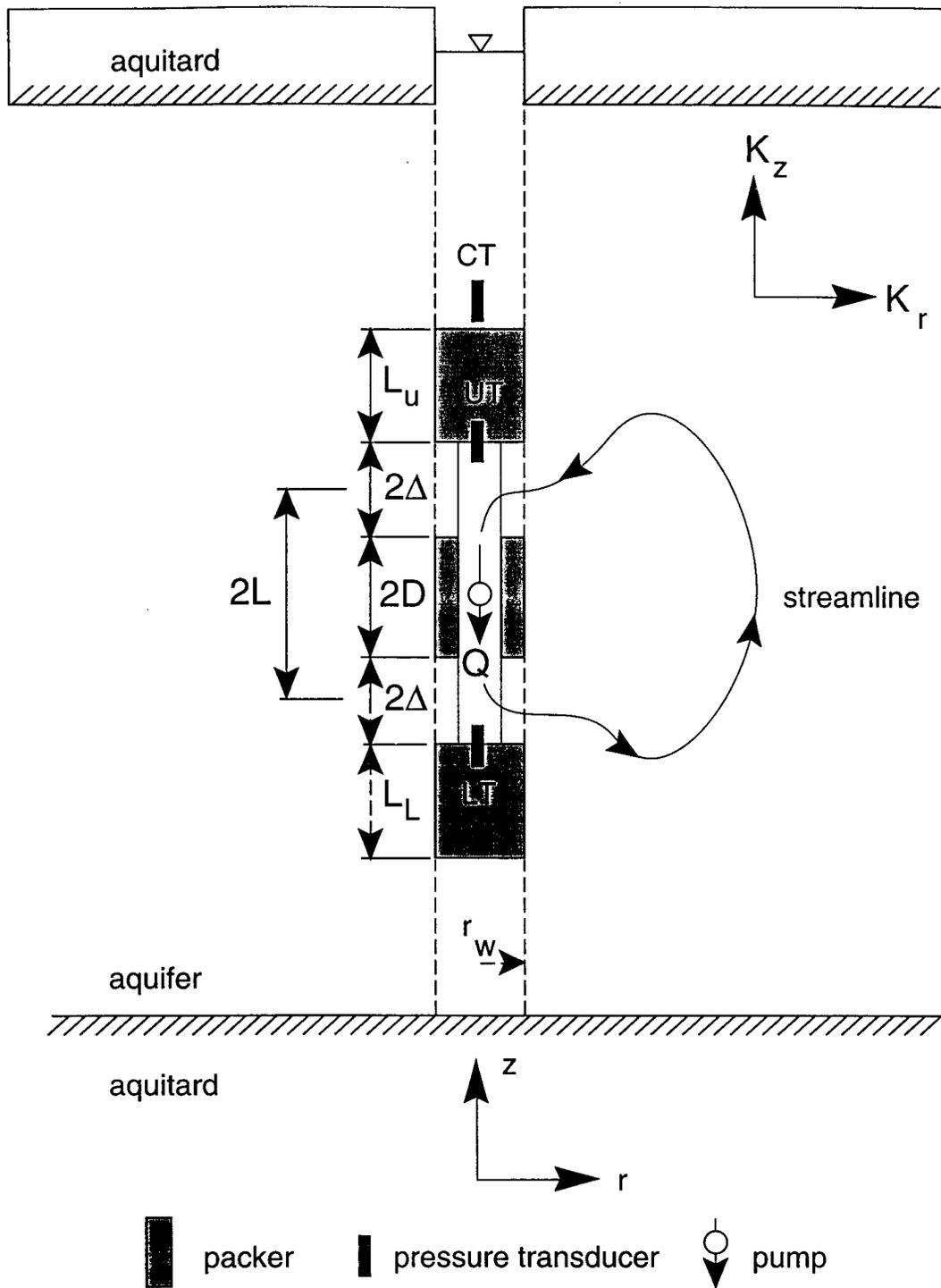


Figure 1 - Schematic of the dipole flow test

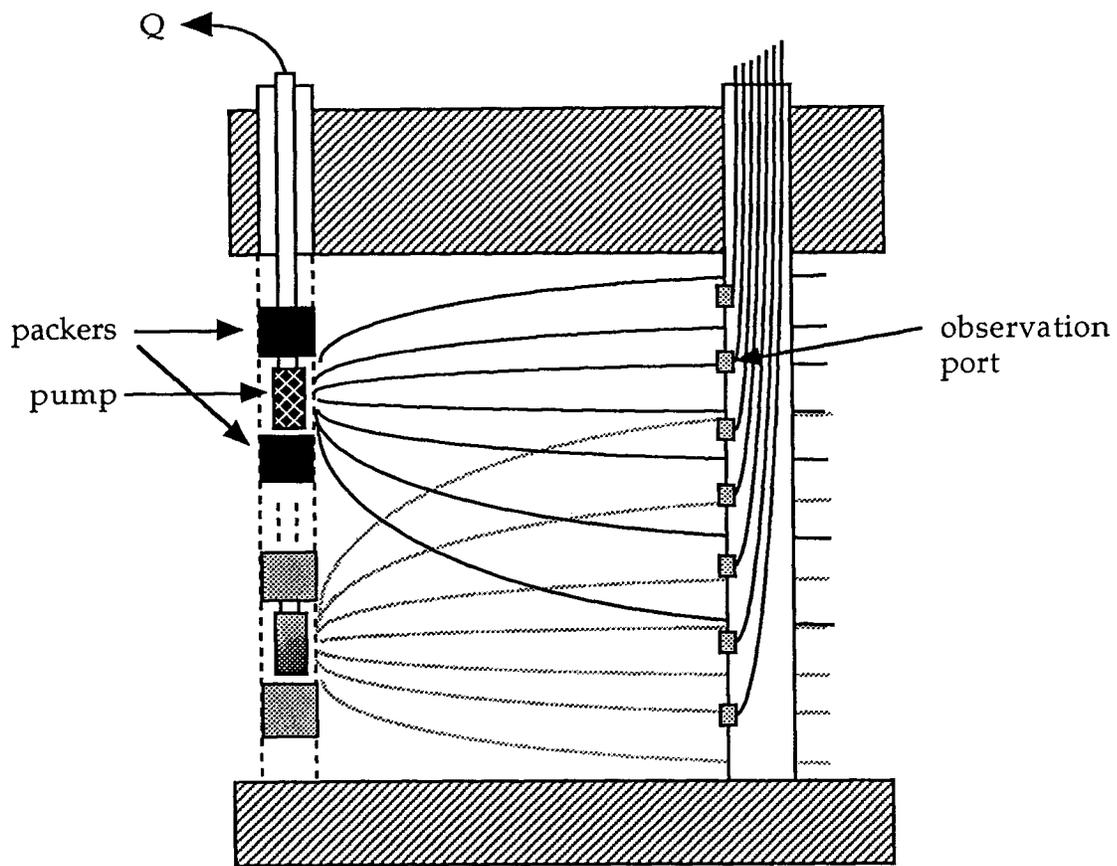


Figure 2 - Schematic cross-sectional view of hydraulic tomography arrangement

Hydrology and Groundwater Chemistry at the Geohydrologic Experimental Monitoring Station (GEMS)

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The Geohydrologic Experimental and Monitoring Site (GEMS) is located near the margin of the Kansas River floodplain, 3.4 km. north of the Kansas River in Douglas County, Kansas. The Kansas River alluvial aquifer system is an important source of drinking water for northeast Kansas, and is similar to other large floodplain alluvial aquifers along tributaries to the Mississippi River system. Subsurface and upland sediments at GEMS are composed of glaciofluvial terrace deposits associated with Pleistocene episodes of downcutting and alluviation. The northern boundary of the modern floodplain, approximately 120 meters from GEMS, marks the position of an ancestral bedrock valley wall in the subsurface. GEMS' location with respect to the edge of the floodplain affords an opportunity to examine the fate and transport of agrichemicals or other contaminants that may enter the groundwater as the result of increased hydraulic loading near the margins of large alluvial aquifer systems.

The hydrogeochemistry at GEMS site was evaluated through the seasonal sampling of four well clusters. The monitoring wells are constructed of two-inch diameter PVC tubing with screen lengths of 0.5 to 0.75 meters. Wells in each cluster are finished at 6, 8, 11, 14, 17, and 20 meters below ground surface, with an additional well in each well group is screened over the lower 9 meters of the aquifer. Suction and pressure-vacuum lysimeters sample the unsaturated zone at two of the well clusters.

The alluvium beneath GEMS is approximately 21 meters thick and is composed of interlayered, stream-channel sand and overbank deposits. The upper 11 meters of sediment is primarily silt and clay, and contains several fine to medium-grained sand layers. The lower 10 meters of alluvium consists of a fining-upward sequence of pebble to fine sand-sized particles, with interbedded material of differing permeability present both site-wide and as discontinuous lenses. The stratified nature of the sediments is reflected in hydraulic conductivity variations observed with depth. Permeameter tests conducted on undisturbed sediment cores from the lower 10 m of alluvium range in hydraulic conductivity from 10^{-1} to 10^{-4} m/s in vertical profile. The layered sediments appear to constrain the groundwater chemistry at the site, as vertical stratification is also observed in chemical profiles at GEMS. Variations in major ion concentrations, dissolved oxygen, and temperature appear coincident with permeability variation and indicate a vertical redox zonation in the aquifer.

The aquifer at GEMS is significantly influenced by vertical recharge near the floodplain margin and fluctuations in the water level of the Kansas River. Horizontal hydraulic gradients in the fine-grained sediments at GEMS are observed to fluctuate over an order of magnitude, and over an 80 degree range in flow direction. Although nitrogen-based fertilizers have never been used at GEMS, urea and $(\text{NH}_4)_2\text{PO}_4$ are routinely applied to crops bordering the eastern, upgradient side of the site. Analysis of groundwater chemistry in monitoring wells separated by a

distance of 40 meters demonstrates that horizontal hydrochemical gradients exist at GEMS with a concomitant reduction of the agriculturally derived nitrate. A decrease in dissolved oxygen and an increase in calcium, sodium, magnesium, and sulfate concentrations are observed in the direction of groundwater flow. Nitrate reduction along the flow path is indicated by a decrease in nitrate concentrations and a corresponding increase in $\delta^{15}\text{N}$. Horizontal redox gradients are stable at some, but not all monitoring depths.

Chemical stratification observed in profile at GEMS supports the findings of other authors who recommend closely-spaced, vertical monitoring for accurate assessment of hydrochemical conditions in alluvium. The steep, lateral, chemical gradients observed at GEMS may be a product of the site's proximity to the edge of the floodplain. The spatial variation in groundwater chemistry, coupled with significant temporal variations in the hydraulic gradient are most likely a reflection of dynamic hydrochemical conditions that may exist near floodplain margins. Such conditions should be considered in the design of hydrogeology investigations conducted on the margins of floodplains.

