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## High-resolution Characterization of Chemical Heterogeneity in an Alluvial Aquifer

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**Abstract** The high-resolution capabilities of direct-push technology were exploited to develop new insights into the hydrochemistry at the margin of an alluvial aquifer. Hydrostratigraphic controls on groundwater flow and contaminant loading were revealed through the combined use of direct-push electrical conductivity (EC) logging and geochemical profiling. Vertical and lateral variations in groundwater chemistry were consistent with sedimentary features indicated by EC logs, and supported a conceptual model of recharge along the floodplain margin.

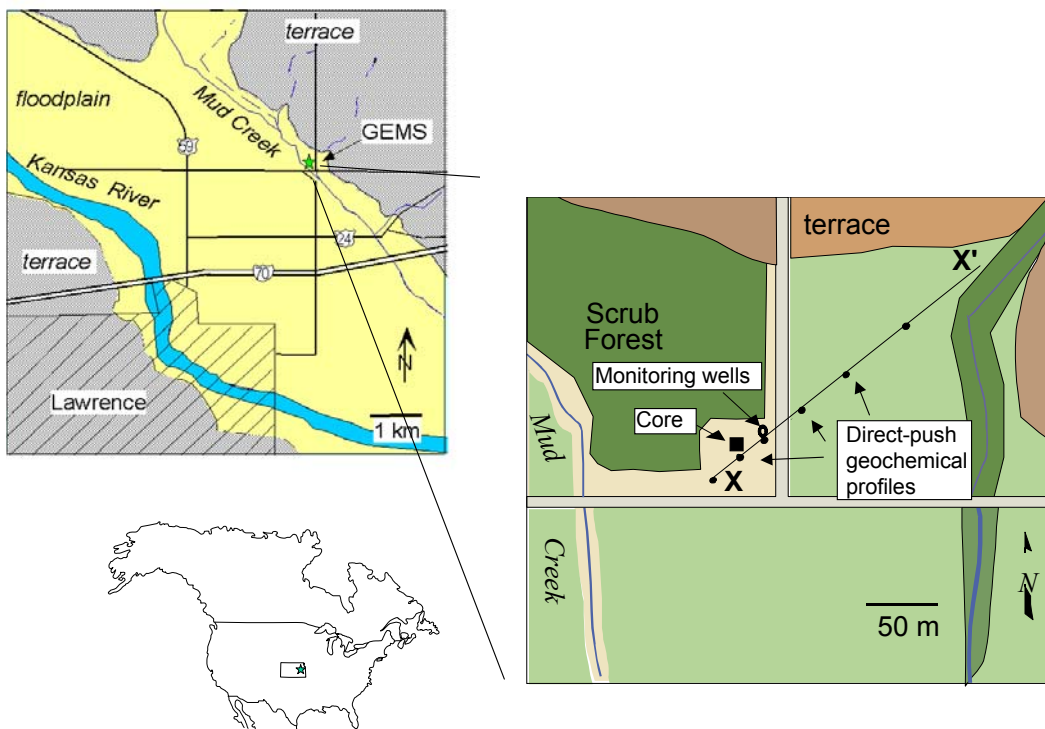
**Key words** direct-push, alluvial aquifer, heterogeneity, floodplain margin, geochemical profiling, electrical conductivity

### INTRODUCTION AND BACKGROUND INFORMATION

Prediction of the fate of reactive constituents in groundwater requires accurate assessment of hydrochemical conditions in the subsurface. In alluvial aquifers, the presence of complex hydrostratigraphic features can lead to chemical zonation over short distances. Conventional drilling-based approaches typically result in data points (wells) that are too far apart to allow for the identification of such variations. In the last decade, direct-push technology has become a widely used alternative to drilling-based methods for investigations of organic contaminants in groundwater. We recently developed a direct-push geochemical profiling approach that allows detailed characterization of inorganic chemical parameters (Schulmeister et al., 2001). When used in combination with direct-push electrical conductivity (EC) logging, hydrostratigraphic controls on the inorganic hydrochemistry of an aquifer can be identified. An example application of this new high-resolution approach for the geochemical characterization of an aquifer is presented here.

The investigation took place at the Geohydrologic Experimental and Monitoring Site (GEMS), a research site of the Kansas Geological Survey at which a great deal of

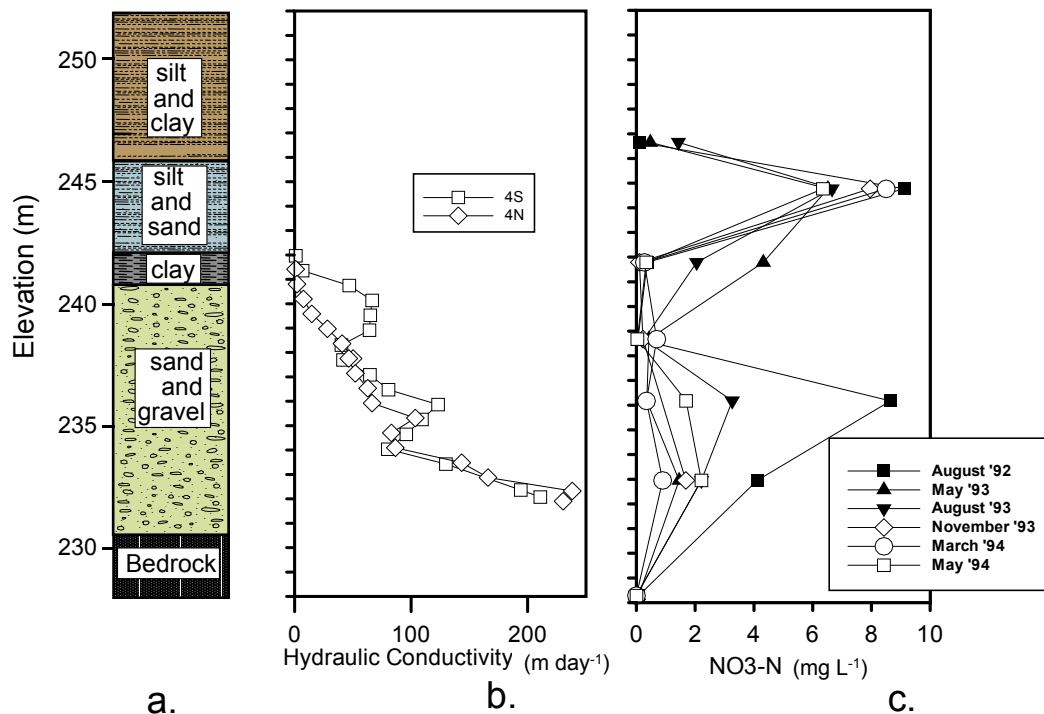
previous work has been done (e.g., Butler et al., 1999, 2002; Schulmeister, 2000). GEMS is located near the margin of the floodplain of the Kansas River, a tributary to one of the major river systems in the United States (Figure 1). The site is underlain by 22 m of alluvial sediments above a silty sandstone bedrock. The alluvium is composed of 11 m of sand and gravel that is overlain by 11 m of clay, silt, and sand (Figure 2a). The sand and gravel interval, which acts as a semiconfined aquifer and is the primary focus of this study, consists of a fining-upward sequence with interbedded clay lenses (Figure 2b). Data collected previously from monitoring wells at the site demonstrated vertical variations in  $\text{NO}_3$  concentrations that were difficult to interpret based on assumptions of regional nonpoint-source loading (Figure 2c).  $\text{NO}_3$  was present in both the silt-and-sand interval and the lower portion of the aquifer, but not in the upper portion of the aquifer. The stratified nature of the alluvium and the site's proximity to the edge of the floodplain led to an investigation of the potential importance of the floodplain margin in controlling the  $\text{NO}_3$  distribution and other aspects of the hydrochemistry of the site.



**Figure 1** Location of the study site (GEMS)

Direct-push geochemical profiling and EC logging were conducted using a track-mounted rig with a hydraulic slide and a high-frequency percussion hammer. The geochemical profiling tool consisted of a short (10 cm) screened section that was attached to a string of steel drive rods. Samples were obtained in a single probehole as the tool was progressively advanced to depths of interest. Field measurement of specific conductance and dissolved oxygen (DO) was performed with a flow-through cell and multiparameter sonde, and samples were collected for laboratory analysis of  $\text{NO}_3$ , Fe, and Mn (Schulmeister et al., 2001). EC logging was conducted using a Wenner-array probe (Christy et al., 1994). Previous work at this site has shown that it is possible to use electrical conductivity measurements to represent the distribution of clay materials in the alluvium (Butler et al., 1999; Schulmeister et al., 2003). A series

of EC logs were therefore used to construct a conceptual hydrostratigraphic model of the floodplain margin. This model guided subsequent geochemical profiling activities.



**Figure 2** Geology, hydraulic conductivity, and NO<sub>3</sub> at GEMS. **a.** Geologic description of core materials. **b.** Hydraulic conductivity profiles in the lower 11 m of alluvium from multilevel slug tests at two wells (Butler et al., 2002). **c.** NO<sub>3</sub> profiles from conventional monitoring wells with screened intervals of 0.7 m (Schulmeister, 2000).

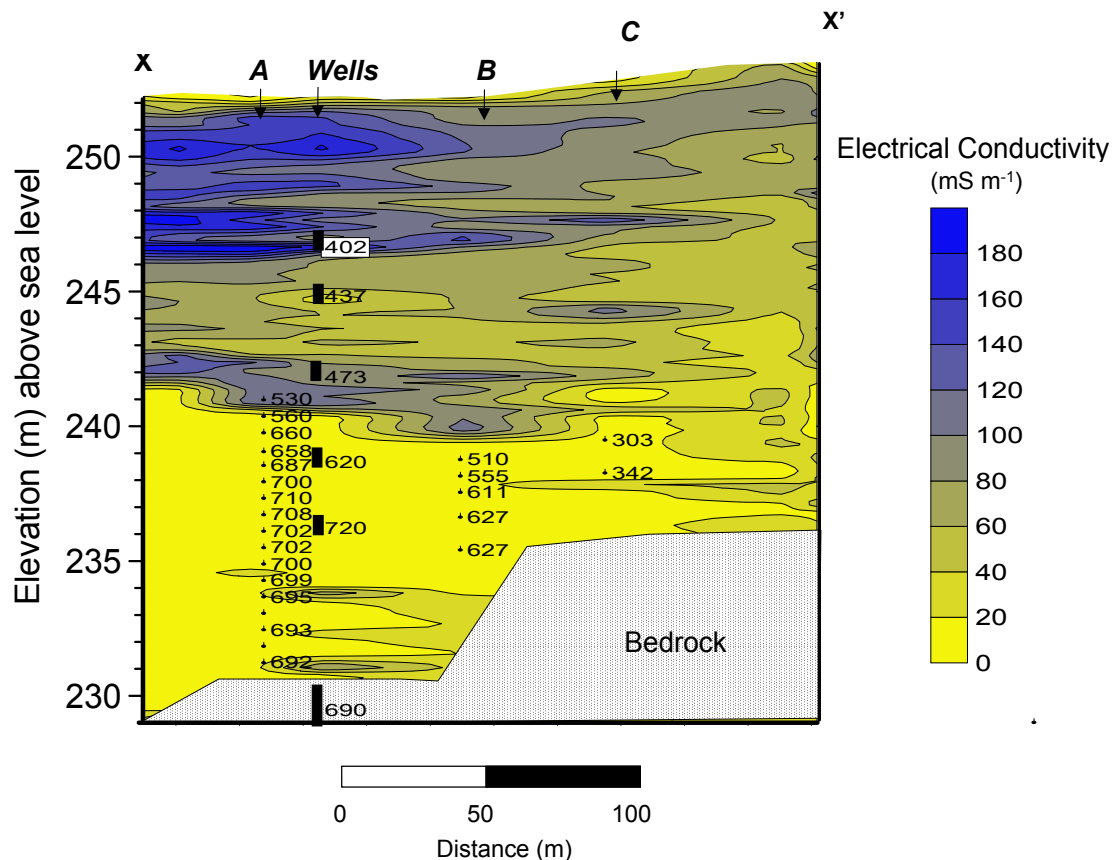
## ELECTRICAL CONDUCTIVITY MODEL OF HYDROSTRATIGRAPHY

Direct-push electrical conductivity logs were obtained along a transect oriented perpendicular to the bedrock valley wall (Figure 3). This transect was believed to be roughly aligned along the direction of flow in the upper alluvium. The EC cross-section revealed the coarsening of sediments in the upper part of the alluvium in the direction of the floodplain margin and the disappearance of the fine-grained silt and clay layers that extend laterally across a large portion of the floodplain. As described below, the horizontal continuity of interbedded fine and coarse sediments provides a possible explanation for the chemical stratification observed at the site (e.g., Figure 2c).

## HYDROCHEMICAL FACIES AT THE FLOODPLAIN MARGIN

Geochemical profiling was conducted at three locations in clay-free zones indicated by the EC logs (Figure 3). The data from the direct-push profiles were combined with those from the monitoring wells to delineate lateral and vertical variations in

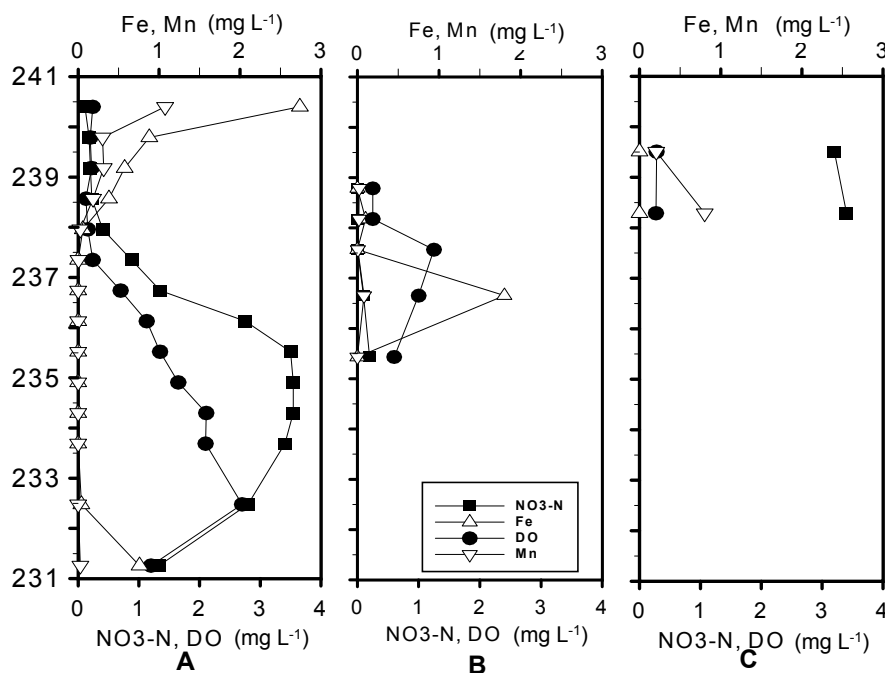
groundwater specific conductance. Relatively low specific-conductance values were observed in the overlying less-permeable material, in the upper part of the aquifer, and near the floodplain margin. The deep portion of the aquifer generally contained groundwater with relatively high specific conductance. This contrast in fluid chemistry suggests different sources for the groundwater. Groundwater in the upper alluvium and near the edge of the floodplain appears to have originated as recharge along the more-permeable floodplain margin. In contrast, groundwater in the deeper portions of the alluvium appears to have originated as lateral inflow from the more central parts of the floodplain. The intermediate specific conductance values in the middle profile (profile B) appear to indicate a region in which these waters are mixed.



**Figure 3** Electrical conductivity cross-section X-X' (see Figure 1). Intervals sampled by monitoring wells are indicated by black bars. A, B, and C indicate direct-push geochemical profile locations. Groundwater specific conductance measurements ( $\mu\text{S}/\text{cm}$ ) are listed next to each sampling point. Direct-push samples were taken approximately every 0.61 m when clays did not block the screen of the sampler.

Variations in concentrations of additional constituents were consistent with those observed for specific conductance (Figure 4). In direct-push profile A, a steep chemical gradient occurred at an elevation of 238 m with an increase in DO and  $\text{NO}_3$ , and the disappearance of Fe and Mn. The  $\text{NO}_3$  profile was in agreement with the monitoring-well data (Figure 2c). Higher  $\text{NO}_3$ , specific conductance, and hydraulic conductivity in the deeper portion of the aquifer suggest that the  $\text{NO}_3$  in that interval may have entered the site through deep lateral flow from the central reaches of the floodplain. Groundwater chemistry in this portion of the aquifer was similar to that

observed in wells located in the aquifer at greater distances from the floodplain margin.



**Figure 4** Direct-push chemical profiles from three locations along the EC traverse.

Consistent with the specific conductance data, a different groundwater chemistry was observed at profile C than elsewhere at the site. The low levels of DO and Fe were similar to those observed in the upper part of the aquifer in the other profiles. However, the higher levels of  $\text{NO}_3$  and Mn indicate a different groundwater source and possible contamination from agricultural activities in the overlying soils. The vertical movement of  $\text{NO}_3$  through the coarse sediments that occur near the floodplain margin, coupled with transport of this contamination along the sandier strata indicated on the EC cross-section, provides a possible explanation for the presence of  $\text{NO}_3$  in shallow wells elsewhere at the site (Figure 2c).

In profile B, the increase in DO and absence of Fe and Mn near the top of the aquifer indicates that the redox conditions observed in the first profile may extend laterally across the site. Very low levels of  $\text{NO}_3$  in the high-DO zone, however, suggest that  $\text{NO}_3$  either did not reach this part of the aquifer or was diluted by another source. The presence of Fe in the high-DO zone supports the hypothesis of mixing of groundwater from different sources within the vicinity of profile B. The absence of  $\text{NO}_3$  in the upper portion of the aquifer in profiles A and B may also be explained by  $\text{NO}_3$  reduction. This is consistent with nitrogen-isotope data collected in previous work (Schulmeister, 2000).

## CONCLUSIONS

The unprecedented level of detail afforded by direct-push technology allowed important information to be obtained regarding site-specific controls on groundwater

flow and solute transport. The conceptual model generated as a result of the direct-push investigation provided insights that would have been difficult to recognize using conventional methods. The direct-push profiling identified recharge at the floodplain margin as a possible contributor to the stratified groundwater chemistry and the nitrate contamination observed in the upper portion of the alluvium. These insights should prove to be extremely valuable for directing and constraining future modeling efforts.

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