# Report for 2005AR79B: The Ground Water Flow System in the Alluvial Aquifer of the Arkansas River at Dardanelle, Arkansas

Publications

- Conference Proceedings:
  - Kline, Stephen W., Timothy M. Kresse, John A. Fazio, William L. Prior, William D. Hanson, Rober A. Miller, Tyler M. Treece, Jody B. Adams, and David W. Hebard, 2005, Groundwater Flow and Chemistry in Alluvium of the Arkansas River in Central Arkansas: A Progress Report: Abstracts with Programs--Geological Society of America, v. 37, no. 7, p 214.
- Other Publications:
  - Kline, Stephen W., Timothy M. Kresse, John A. Fazio, William L. Prior, William D. Hanson, Roger A. Miller, Tyler M. Treece, Jody B. Adams, and David W. Hebard, 2005, Groundwater Flow and Chemistry in Alluvium of the Arkansas River in Central Arkansas: A Progress Report: Abstracts with Programs--Geological Society of America, v. 37, no. 7, p. 214.

Report Follows

## Problem and Research Objectives

The alluvial aquifer of the Arkansas River in central Arkansas is the richest supply of groundwater in the entire Arkansas River Valley area, supplying municipalities such as Dardanelle, agriculture, industry, and individual households. There are also many areas of wetlands on the flood plain that caps the alluvium with possible hydraulic connection to the aquifer. The present research has the goal of fully characterizing the hydrologic properties of the aquifer in the vicinity of Dardanelle and to produce a calibrated and verified numerical flow model with a view to expanding the characterization and modeling to the rest of the same segment of the aquifer system in the future. A calibrated and verified flow model can be used to predict potential impacts from further development of various supply systems from the aquifer.

## Methodology

We have approached this problem by installing a series of monitoring wells that are being used for a number of purposes related to the goal of the project. By careful sampling and analysis of sediment penetrated during drilling of the wells we are deriving a clearer understanding of the distribution of sediment of the aquifer. Above the water table a continuous sampler in the hollow-stem auger drilling rig was used to obtain *in situ* sediment samples that were examined in the field. Below the water table the continuous sampler could not hold the saturated sediment, so samples were obtained by taking what was "spun up" and/or sampling what was retained on auger flights. Samples obtained by either method have been taken to the lab for grain size analysis.

At ten sites, pairs of monitoring wells were installed, one to intersect the lower part of the aquifer and the other to intersect the water table. There are also five "test wells" that the City of Dardanelle has drilled for determining new locations for expansion of their municipal well field, and they have given us access to these wells. Two drive-point piezometers have also been installed. These wells are being used to monitor water level changes in the aquifer over time, both short term variations related to the pumping schedule of the municipal well field, and longer term variations related to seasonal weather patterns and to variation in stage of the Arkansas River. The wells are also being used to conduct aquifer tests to determine the distribution of properties such as hydraulic conductivity and storativity in the aquifer. The aquifer tests include both pumping aquifer tests and slug tests. Pneumatic slug tests have been particularly useful in these highly conductive sediments. Finally, the wells are being used for taking water samples for chemical analysis. A suite of inorganic parameters are being measured to evaluate chemical evolution of the aquifer water and to determine the degree of infiltration of Arkansas River water into the aquifer. Also the water is being analyzed for a host of potential organic contaminants.

All the information that is being gathered will be used to construct a numerical flow model using Visual MODFLOW (software by Waterloo Hydrogeologic, Inc.). At the time of this writing, construction of the flow model has only barely begun and some of the parameters mentioned above are still being obtained. The water levels and the mixing

characteristics of aquifer and river sources expressed in the geochemistry will be used in model calibration and verification.

**Principal Findings and Significance**

Although the flow model has not yet been completed, a number of important components have been determined in regard to the physical hydrology of the aquifer and its geochemistry. For example, there is a much better understanding of the sediment distribution in the aquifer with implications regarding its hydrology. The alluvial sediment varies from about 16 to 22 m thick above Atoka shale and sandstone, thinning away from the river. The upper 8 to12 m consists of very fine silty sands with numerous, discontinuous clay-rich layers, which appear to be more continuous in farther reaches from the river. These sediments represent natural levee and crevasse splay deposits near the river, and flood basin deposits toward the outer margin of the alluvium. The lower section contains medium to very coarse sands and gravelly sand formed from channel bars, point bars, and channel lag deposits. The saturated zone is in the lower section in most of the area but extends up a short distance into the upper, fine-grained section in the area farther from the river; although in every location we sampled, saturation was below the lowest clay-rich layer, indicating unconfined hydraulic conditions. The heterogeneity of the sediment in the saturated zone means that permeability will be very heterogeneous producing complex flow patterns in the aquifer. The apparently more continuous clays in upper section of the alluvium in the outer reaches of the flood plain and the more discontinuous clays nearer the river indicate that an uneven recharge value from infiltration of meteoric water will need to be assigned in the flow model, with more aerial recharge in the portion of the aquifer nearer to the river.

Ground-water level measurements show that outside the immediate area of Dardanelle's municipal well field, the natural hydraulic gradient is towards the Arkansas River, with the aquifer discharging into the river. This pattern is interrupted by composite cones of depression in the municipal well field. However, a small groundwater ridge remains between the well field and the river most of the year. Nevertheless, during periods of sustained high river stage the gradient is reversed in the area bordering the river, and the river infiltrates the aquifer and feeds into the well field. One high-river-stage event of three weeks duration induced a reversal of gradient 600 m wide in the area outside the city's well system, and the gradient reversal penetrated even farther where the effect of the river stage was complimented by drawdown of the water table within the well field. Seasonal water level fluctuations observed thus far in the aquifer appear to corroborate the implications of aerial recharge distribution indicated by the distribution of clay layers in the upper section of the alluvium discussed above. After periods of substantial rainfall began in mid to late winter, water levels in monitoring wells began to rise in areas nearer to the river, but continued to fall farther out from the river. One other observation with regard to water level measurements implies reduced aerial recharge in the outer portion of the flood plain. An earlier ground water flow model of the area (Kline and others, 2003), based on published regional information, applied a homogeneous value for aerial recharge, except that it was reduced a little in the area of the city to account for paved areas there. That model predicted that the water level in the aquifer would extend up to

near the land surface in areas farthest from the Arkansas River, but the water level in a drive-point piezometer installed in that area consistently rests nearly 6 m below the surface. The fact that water levels in the aquifer throughout the area are consistently 6 to 15 m below the land surface suggests that at least many of the wetlands in other portions of the Arkansas River flood plain may not have hydraulic connection with the groundwater system. Of course, that will have to be determined on a case by case basis in the future.

The variation in aquifer permeability suggested by the variation in sediment encountered in drilling is borne out by slug tests conducted thus far. Problems with pumping aquifer tests and with slug tests carried out by conventional methods raised concerns whether hydraulic conductivity in the aquifer could be determined with any degree of accuracy. However, we obtained a "pneumatic slug", which when combined with a relatively new slug test analysis model (Butler and Garnett, 2000) obtains excellent results in these highly conductive sediments. The range of hydraulic conductivity values that we have obtained thus far, with a few more wells to be tested, is from 18 to 96 m/d. These values represent the average hydraulic conductivity over the 10 ft screens in the monitoring wells. It is very likely that thin channel lag gravels that have been encountered in drilling would have much higher hydraulic conductivity, but without being able to isolate them we cannot say just how high.

There are a number of definite matters with regard to issues of water chemistry of the aquifer that are of significance. These have to do with oxidation/reduction processes, chemical evolution of water in the aquifer, mixing of water from the Arkansas River, and flow paths of water in the aquifer.

The sampling of water from both shallow and deep portions of the aquifer reveal redox processes at work in the aquifer. Water from near the water table, where relatively oxygen-rich meteoric recharge water first arrives and where water is in contact with gaseous phases in the vadose zone, shows higher Eh (oxidation potential) than water deeper in the aquifer. The mean nitrate-N concentration for samples from the shallow wells was 3.5 mg/L, as compared to the mean concentration of 1.8 mg/L for deep well samples. In four samples from deep wells with iron concentrations >10 mg/L, nitrate-N concentrations were non-detect, revealing nitrate reduction at depth with complete reduction of nitrate where iron exceeds 10 mg/L. The highest concentration of nitrate (17.9 mg/L) was in a shallow well in an area outside of town where corn fields surround the well site, the elevated nitrate coming from over-fertilization.

Iron, manganese, and arsenic all show definite trends of increasing concentration with decreasing Eh, especially Fe and As. All the samples with Eh greater than 200 mV have low (<1 mg/L) to non-detect Fe concentrations and low (<5 μg/L) As concentrations. At Eh values <200 mV, Fe concentrations exceed 10 mg/L and As concentrations generally are above 5 μg/L. The Fe and the As appear to be from reductive dissolution of Fe-oxides and oxyhydroxides in the alluvial sediment. There are detrital grains of magnetite, ilmenite, and hematite in the sediment and also there is reddish staining on grains of sands above the water table. Likely this staining is from Fe-oxyhydroxides that were

precipitated onto the grains while they were in an oxidizing condition during the transportation or deposition phase. Arsenic would have been co-precipitated with the Fe. Then in the reducing conditions in the lower part of the aquifer Fe and the co-precipitated As are dissolved together. One sample had an As concentration of 19 µg/L, exceeding the EPA MCL of 10 µg/L. Causes of the reducing chemistry in the lower part of the aquifer are likely the oxidation of *in situ* detrital grains of organic matter and/or interaction with organic-rich shales of the underlying Atoka Formation. The interface between shale bedrock and the alluvial sediments is a zone of gummy black clay, the upper weathered surface of the bedrock. The highest Fe and As concentrations are from wells outside the area of the municipal well field. Samples taken from within the well field have lower values probably because of infiltration and mixing of oxygen-rich river water, and also perhaps from the vertical component to flow in the aquifer induced by the pumping wells pulling oxygenated water downward in the vicinity of the wells.

Besides the redox processes, one of the best indicators of chemical evolution of waters in the aquifer is seen with comparing Na/Cl molar ratios to molar ratios of $(Ca+Mg)/HCO_3$ and the involvement of sulfate. If Ca is progressively exchanging for Na on exchangeable cation sites on minerals of the aquifer (primarily clays) a trend of increasing Na/Cl ratios of equivalent concentrations should be seen along with a decreasing $(Ca+Mg)/HCO_3$ trend. If the original water of the aquifer derived its Na, Cl, Ca, Mg, and $HCO_3$ from dissolution of halite and carbonate minerals, then the "origin" of that trend would intersect at x and y values of 1.0 on a graph of these ratios. Such a trend is evident in the molar ratio plot for the Dardanelle samples, but the "origin" of the trend starts at a much higher $(Ca+Mg)/HCO_3$ ratio, that is, close to 1.6 instead of 1.0. The high $(Ca+Mg)/HCO_3$ ratio for this "origin" is explained by an excess amount of Ca in the water being contributed by dissolution of gypsum. If Na/Ca is plotted against $(Ca+Mg)/(HCO_3 + SO_4)$, the same trend is seen, but the origin is now at approximate x and y values of 1.0, where it would be expected to be if the Ca in the water was from both carbonates and from gypsumm.

A number of chemical parameters indicate the infiltration of Arkansas River water into the aquifer in the area of the city well field. The best indicator is that of chloride in the deep wells (including the city pumping wells which are screened in the lower 10 ft of the aquifer). Analysis of water samples taken in both August 2005 and in February 2006 show the highest chloride values to be in the Arkansas River with progressively lower values in wells progressively farther from the river and farther into the city well field. A good example is an inspection a transect of wells from the river to the southernmost municipal well field. From a concentration of 9 mg/L in the farthest inland city pumping well, chloride concentrations increase to 24, 31, 42, 62, and 71 mg/L in five approximately equal-spaced wells moving eastward toward the river, which has a concentration of 185 mg/L; clearly reflecting the strong influence of river water infiltration in the aquifer.

A matter that complicates the interpretation that elevated chloride concentrations are the result of river water infiltration is that wells located farthest up-gradient from the city well field also have elevated chloride values (>40 mg/L), though not as elevated as

chloride in the river water. The complication is resolved by examining a plot of Br vs Cl in the samples. This plot has two definite trends, and the same trends are seen in the two sets of samples taken 6 months apart. One trend starts from a cluster of points with low values of both Br and Cl and trends towards progressively higher values of Cl with very little Br enrichment; the Arkansas River sample is the maximum-Cl end of this trend. All the points along this trend are from samples taken from wells along the river-to-well-field transect. The second trend starts at the same cluster of points with low Cl and Br values and has increasing values of Br along with Cl-enrichment. All the points along this trend are from samples taken from the up-gradient wells. So the Br-enrichment trend along with Cl-enrichment indicates water derived from within the aquifer without mixing in of river water.

Mean and median chloride concentrations were significantly lower in shallow well samples (12 and 11 mg/L, respectively) than in deep well samples (45 and 35 mg/L, respectively), even in wells closest to the river, suggesting that infiltration of river water is dominantly through the coarser-grained sediment at the base of the aquifer.

It is striking to note that, with regard to the analyses from the two sampling dates, the results are very consistent for each sampling site. The Cl decrease from the river into the well field, the trends in Br vs Cl plots, and Piper diagram plots of the major cations and anions are very similar for each shallow and each deep well sample and for the city pumping wells and the city test wells and the river. Evidently the water moving past the monitoring wells and the water moving into the city supply wells maintains a very constant flow path and chemical evolution. It may be significant that there were no major sustained Arkansas River high stage events between the two sampling dates, for such events may disrupt the normal flow pattern.

A particularly striking example of consistency of chemical analyses is with a pair of shallow/deep wells placed only about 2 meters apart at an up-gradient site designated well D-5S and D-5D. Due to the unexpected shallowness of the base of the aquifer at that point and problems encountered during drilling, the “shallow” well has the bottom and top of its screened interval only 0.84 m (2.76 ft) higher than the bottom and top of the “deep” well. In spite of such a small difference, during both sampling times the D-5S (shallow) well’s screen straddled the water table and the D-5D’s screen was completely below the water table. In spite of the nearness horizontally and the only slight depth difference, there is a great difference in the Piper diagram plot of the major ion concentrations between the two wells, yet the February sample for the shallow well plots very close to the August sample for the shallow well, and the same goes for the deep well. The two wells are consistently drawing water along significantly different flow paths. This indicates that water flow in the aquifer is greatly influenced by preferential flow paths. It is likely that the deeper of the two wells has hydraulic connectivity more directly with a highly permeable gravel layer than the upper well, and that the gravel zone brings in some significantly different water, chemically speaking, than what is encountered in the shallower zone.

Another implication has to do with infiltration from the Arkansas River. As discussed above, there were a couple of times since our water-level monitoring began when the Arkansas River held a high stage for a significant time period such that the gradient reversed and clearly there was infiltration from the river into the well field. The second event was the smaller of the two, sustaining a reversed gradient for about one week. It began only a few days after the water samples were taken in the August sampling time. It is possible that these two events are responsible for the apparent mixing of infiltrated river water with aquifer water seen in the chemical analyses discussed above. However, the remarkable similarity of analyses for each well at the second sampling time in February, so long after the August sampling time, leads us to think that there may be a more constant infiltration of Arkansas River water into the supply-well field than what is produced by relatively short-lived gradient reversals during exceptionally high river stage events.

Contrary to this thought, though, are the observations with regard to water-level distribution discussed above. There are monitoring wells between the river and the well field in which the measured water level stands consistently slightly higher than the daily average water level in the Arkansas River (which fluctuates daily due to power generation needs at the hydroelectric dam just upstream from Dardanelle). The solution to the discrepancy may be in the fact that the head in the deeper part of the aquifer that is indicated by the water level in the deep monitoring wells is the <u>average</u> head over the 10-foot interval of the well screen. It is likely that gravel layers within the lower part of the stratigraphy, although probably fairly thin, are significantly more conductive than the average hydraulic conductivity of the 10-foot interval. Water drawing to the pumping wells in the cone of depression will transmit easier through the gravel layers. The result would be that reduction in hydraulic head induced by the pumping wells would propagate farther within the conductive gravel layers than in the rest of the sediment. In other words, the cone of head depression from the pumping wells would extend out farther within the gravel layers than within the rest of the sediment, perhaps even reaching the Arkansas River. The result would be that head distribution through much of the thickness of the aquifer would register a ground water ridge between the well field and the river, and water in that part would be transmitting down the head gradient from the ridge to the river and from the ridge to the well field. At the same time, water within highly conductive intervals would register a downward head gradient all the way from the river into the well field with flow from the river to the well field causing a degree of river infiltration to show up in the monitoring wells and city supply wells. More work is needed to determine just what is happening. Perhaps some nested piezometers tapping small elevation intervals through the saturated zone and/or numerical modeling could resolve the issue.