The Impact of Stream-Aquifer Interactions on Ground-Water Quality in the Alluvial Aquifer of the Middle Arkansas River

D.O. Whittemore, J.J. Butler, Jr., J.M. Healey, S.E. McKay, M.S. Aufman, and R. Brauchler
Kansas Geological Survey , University of Kansas, Lawrence, KS 66047

ABSTRACT

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Recent studies at a research site in the middle Arkansas River valley downstream of Larned demonstrate the impact of stream-aquifer interactions on ground-water quality. High flows in the Arkansas River infiltrate rapidly into the shallow alluvial aquifer, especially when ground-water levels are low. Thus, changes in the river water quality have a large influence on the quality of the shallow ground water. The salinity of high flows in the Arkansas River downstream of Larned varies appreciably. River flow derived from Colorado is saline, whereas high flows from the Pawnee River are fresh. There has been no significant upstream source of saline water reaching the study site near Larned since late summer 2001, but there have been four short periods during this time (up through fall 2004) when Arkansas River flow at the site has exceeded 100 ft^3/sec as a result of high flows from the Pawnee River. Conductance measurements in observation wells in the alluvial aquifer reflect the spatial and temporal freshwater influx from these high flows. The freshwater migrates through the upper part of the alluvial aquifer but does not reach the deeper aquifer, as a result of the short-term nature of the high flow and the retardation of downward ground-water flow by clay-rich layers within the aquifer. Heterogeneities within the alluvial aquifer also cause the freshwater influx to move in an uneven spatial pattern.

The dissolved solids concentration in the alluvial ground water before the high-flow events or at a distance from the river channel is substantially greater than in the recent high river flows. The source of the dissolved solids is a mixture of past high flows from Colorado that entered the shallow alluvium, and local ground waters in which the dissolved solids content has increased from evapotranspiration. Ground-water consumption by phreatophytes and irrigation return flow through soils are the major mechanisms responsible for evapotranspiration concentration.

High flows in the Arkansas River (>100 ft^3/sec) near Larned that are derived from Colorado generally last for longer periods than those caused by Pawnee River storm flow. The longer duration should allow the saline river water to penetrate farther from the river into the shallow alluvial aquifer, as well as deeper into the aquifer. During the last few decades, decreases in Arkansas River flow from Colorado and infiltration of the river water into the alluvial and High Plains aquifers in southwest Kansas have decreased the amplitude and duration of saline high flows reaching Larned. Dry climatic conditions and local and regional irrigation pumping have also contributed to low or no flow conditions in the Arkansas River near Larned. The resulting lower water levels in the alluvial aquifer allow a greater amount of recharge during recent high-flow events, thereby more substantially affecting the alluvial ground-water quality. The substantial spatial and temporal variations in ground-water quality based on observations and inferred from past river-water quality have an important bearing on approaches to ground-water sampling for examination of contaminant transport caused by stream-aquifer interactions.

Figure 1. The Kansas Geological Survey is studying stream-aquifer interactions and methods for determining phreatophyte consumption of ground water in the riparian corridor of the middle Arkansas River in south-central Kansas (Figure 1). The main study area is the Larned Research Site located in the Arkansas River valley several miles downstream of the confluence with the Pawnee River in Larned (Figure 2). As a part of this research, we have examined changes in the water quality of the alluvial aquifer and river. We have found that there are substantial variations in the dissolved solids content of the alluvial ground water on scales ranging from decades to hours.

Ground water in the river valley is influenced by interaction with river water. There are mainly three sources of river water: 1) periods of high flow from Colorado, 2) intense local rainfall, especially from the Pawnee River basin, and 3) ground-water discharge. The relative amounts of these components has changed over the last half century due to water consumption within and upstream of the subbasin.

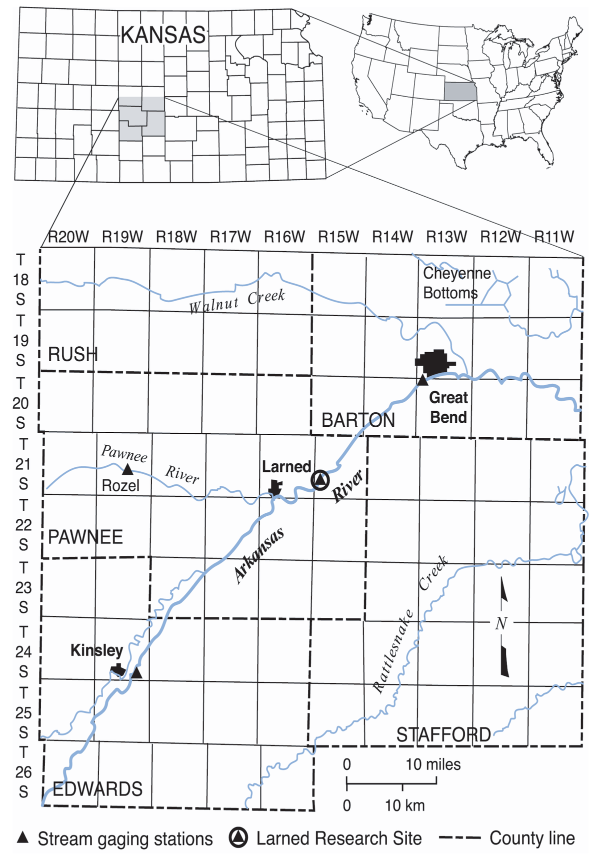


Figure 2. Arkansas River valley at the Larned Research Site. The trees are dominated by cottonwood with smaller percentages of willow and mulberry. Although the photograph shows flow in the river, the usual condition during the last few years (and at present) has been a dry river bed.

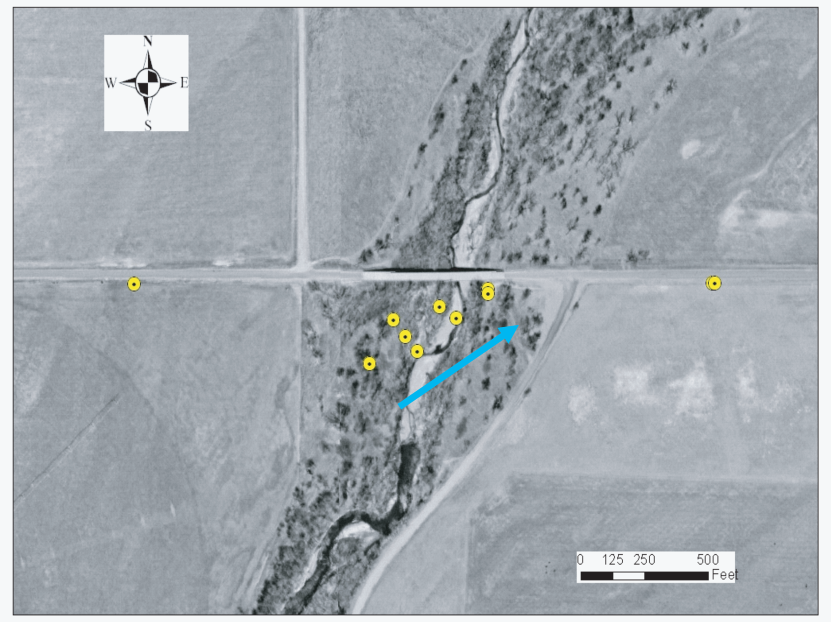
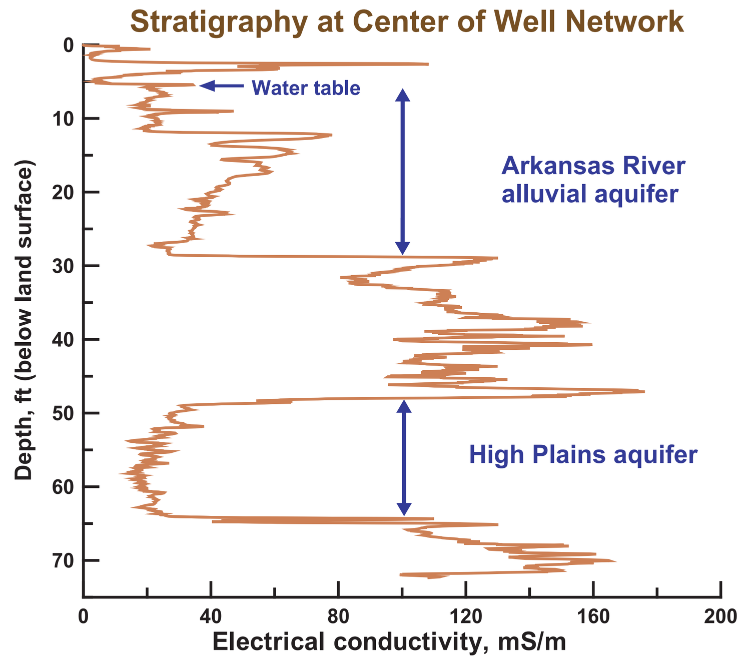


Figure 3. Winter 2000 aerial photo of the area of the Larned Research Site. There was low flow in the river channel at the time of the photo as indicated by the dark sinuous line. The yellow dots indicate the locations of observation wells in the research area. There are wells at multiple depths at a few of the yellow dot locations. The general direction of ground-water flow during very low or no flow conditions is shown by the blue arrow. This flow direction is influenced by regional water-level declines caused by irrigation pumping. A USGS gaging station is located at the bridge crossing the river.

Figure 4. Electrical conductivity of the sediments underlying a location near the Arkansas River at the Larned Research Site based on a Geoprobe profile. The low conductivity sediments are sands and gravels that comprise the alluvial aquifer and the underlying High Plains aquifer. The two aquifer systems are separated by a clay-rich zone. The focus of this poster is on the dissolved solids in the ground water in the alluvial aquifer. Clay layers in the middle part of the alluvial aquifer substantially restrict the depth of influence of ground-water recharge during high river flows.



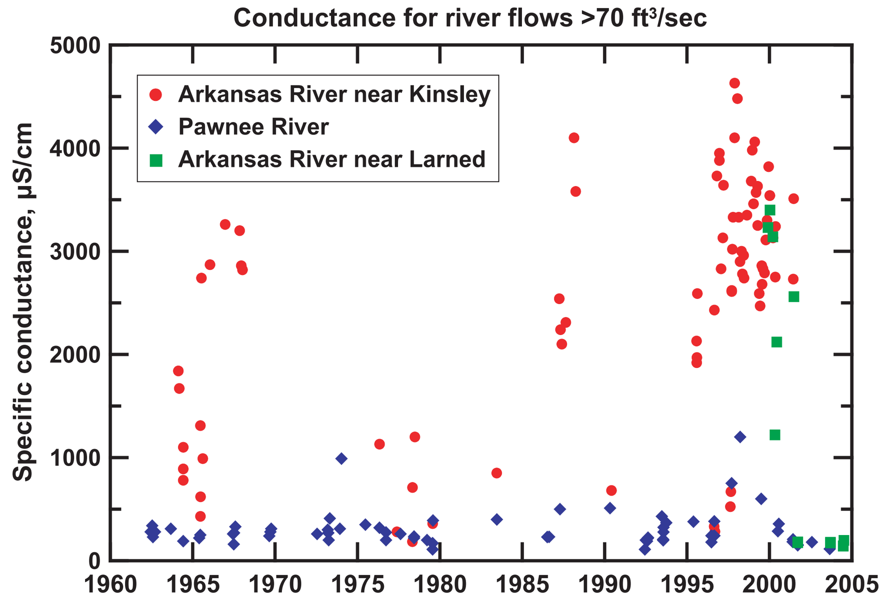


Figure 5. Specific conductance of flows >70 ft^3/sec in the Arkansas River near Kinsley and Larned and in the Pawnee River since 1963. The conductance of flows >70 cfs in the Arkansas River near Kinsley has often been high, reflecting saline waters from the upper Arkansas River derived from Colorado. In contrast, the conductance of Pawnee River water has nearly always been below 1,000 µS/cm, indicating freshwater runoff. The variation in the high-flow water quality is an important factor governing the dissolved solids content of ground water in the alluvial aquifer of the study area. The gaging station near Larned started in the fall 1998. The high conductance of the Arkansas River water near Larned around 2000 and the low conductance in recent years for flows >70 ft^3/sec are related to the high flow sources.

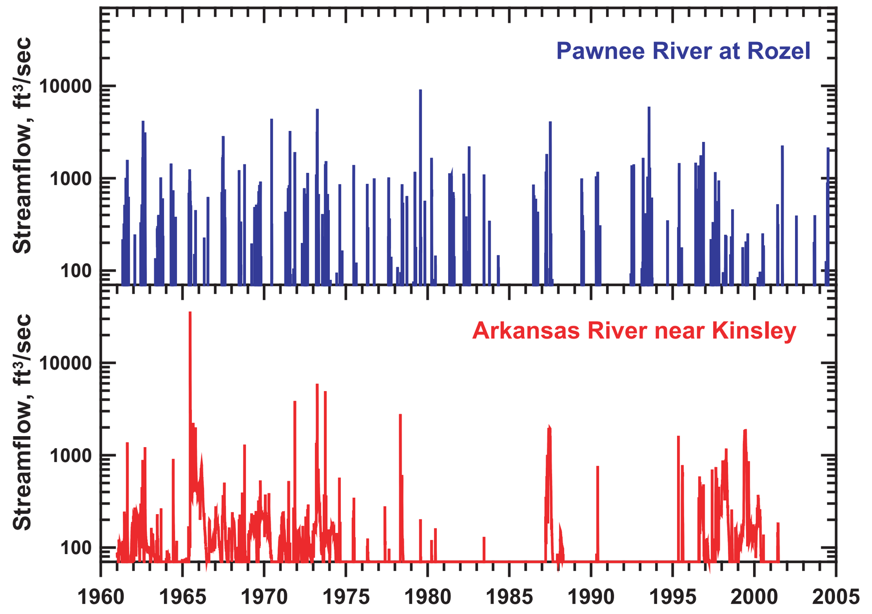


Figure 6. Distribution of flows >70 ft^3/sec in the Pawnee River at Rozel and Arkansas River near Kinsley. The Pawnee River has high flows in nearly all years. The Arkansas River near Kinsley has had a periodic pattern of a year to a few years of high flows during the last 3 decades. Flows from the upper Arkansas River to the station near Kinsley have generally decreased due to increased water use in Colorado and increased infiltration to the High Plains aquifer in southwest Kansas related to ground-water level declines in the aquifer. Flows near Kinsley have also decreased as a result of smaller ground-water discharge in the middle Arkansas River subbasin related to water consumption.

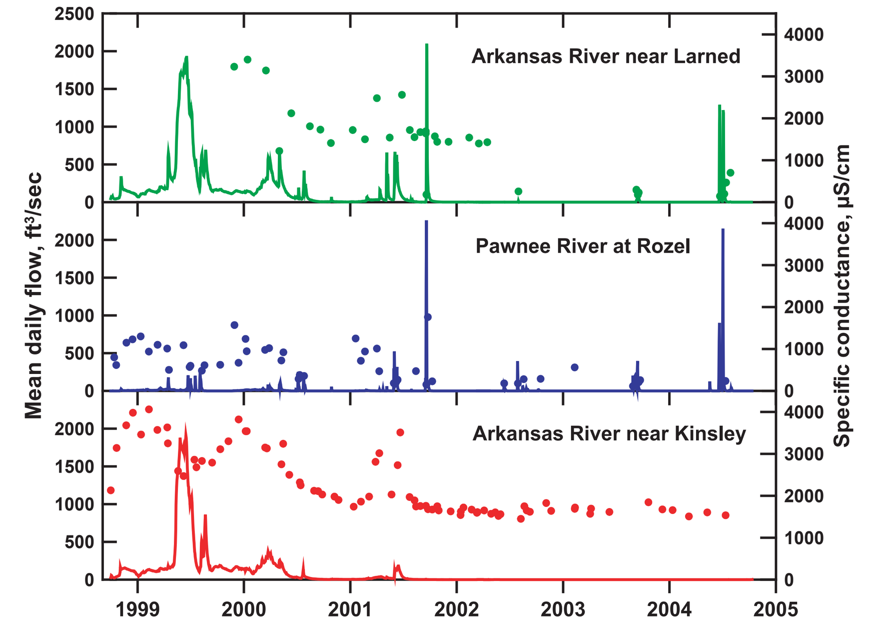


Figure 7. Specific conductance of periodic flows in the Arkansas and Pawnee rivers during the last several years. Substantial flows, shown by the solid line, occurred in the Arkansas River at the Larned site from the fall of 1998 through mid 2000. These flows were primarily saline as indicated by the dots that represent specific conductance of the river water. The main source of the water was the upper Arkansas River as represented by the pattern in the flow and conductance for the river at the upstream gaging station near Kinsley. During this time the flow in the Pawnee River was low to moderate. During the last couple years, the flows in the Arkansas River near Larned have been low in conductance. The main source of the flow for this period has been low conductance water from the Pawnee River, as indicated by the flow and conductance pattern similar to that for the Arkansas River near Larned.

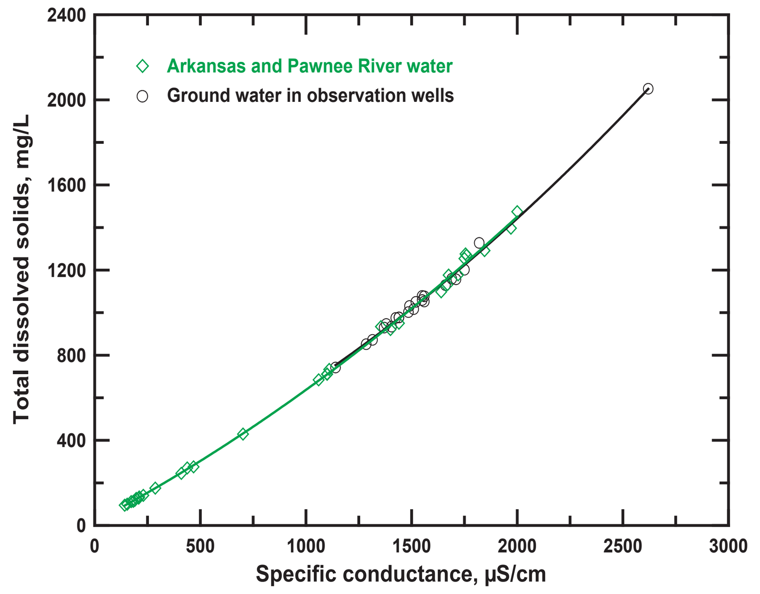


Figure 8. Relationship between total dissolved solids (TDS) and specific conductance in surface and ground water in the middle Arkansas River subbasin based on KGS water analyses. The ground water samples were collected from observation wells in the alluvial and High Plains aquifers at the Larned Research Site. The data show that the TDS-conductance relationship is consistent for both the surface and ground waters. Thus, specific conductance is a good measure of the water salinity.

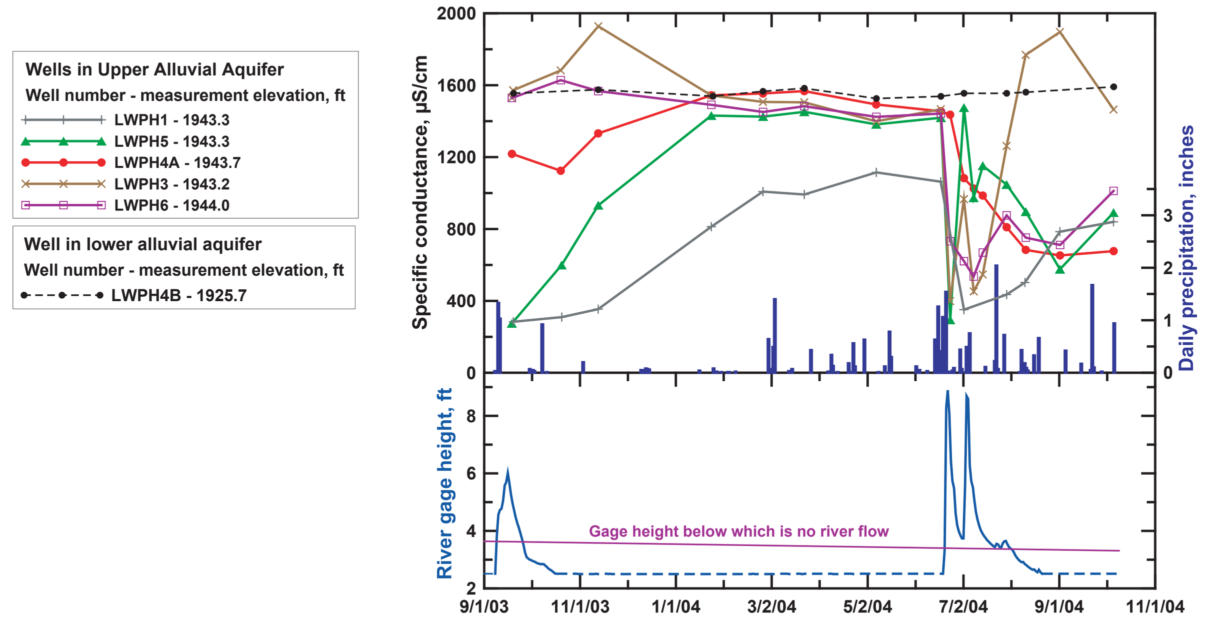


Figure 9. Periodic measurements of specific conductance of ground water at similar elevations in five observation wells in the upper alluvial aquifer and a well in the lower alluvial aquifer at the Larned Research Site during 2003-2004. Well LWPH1 is located within a sand bar of the river channel. The other four wells in the upper aquifer range from the river bank to about 200 ft away from the river channel in the order from top to bottom in the legend. Well LWPH4B is at the same location as well LWPH4A. Daily precipitation is shown as the blue bars. The bottom part of the graph shows two periods of flow in the Arkansas River during 2003-2004. The source of the flow was fresh stormwater runoff from the Pawnee River. The river was dry between the flow periods. The dissolved solids content of the alluvial aquifer water responds primarily to the influx of the freshwater recharge from the river flow events. The higher conductance of the ground water between and after the flow events derives from 1) ground-water flow into the river corridor that is affected by irrigation return flow (infiltration), 2) phreatophyte water consumption within the riparian zone, and 3) the previous influx of saline river water derived from high flows from Colorado.

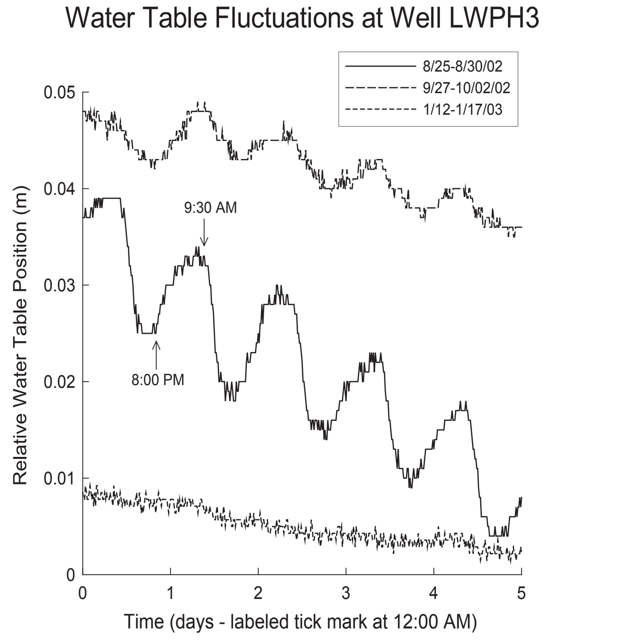


Figure 13. Diurnal fluctuations in the water table in the alluvial aquifer that result from consumption of water by phreatophytes, primarily cottonwood trees. The trees act as pumps that turn on as daylight starts in the morning and turn off as the sun sets. The diurnal fluctuations are greatest during the summer and cease during the late fall through early spring when there are no leaves on the trees.

Figure 10. River stage and water-level and specific conductance in observation well LWPH4A during and after a river flow event in the fall 2003. The water level and conductance were recorded using an In-Situ Troll 9000. The blue bars indicate daily precipitation. The highest bar represents 1.33 inches. The coincident rise of the ground-water level with the river stage demonstrates the recharge of the alluvial aquifer with river water. The conductance of the ground water varied substantially depending on the movement of the fresh river-water recharge within the aquifer. Large to small diurnal oscillations in the conductance are thought to be related to horizontal and vertical movements of ground water along the mixing interface of the freshwater recharge and existing mineralized water. Although difficult to see at the scale of the graph, there are small diurnal fluctuations in the ground-water levels. These are more apparent in Figures 11 and 12.

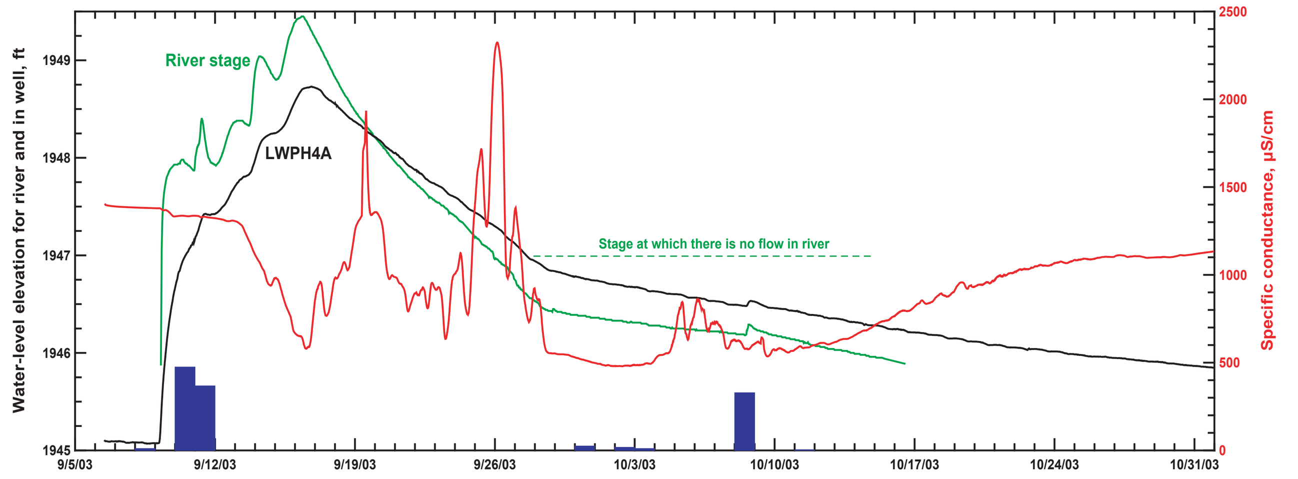


Figure 11. River stage and water-level and specific conductance in observation well LWPH4A after a river flow event in the summer 2004. The water level and conductance were recorded using an In-Situ Troll 9000. The blue bars indicate daily precipitation. The highest bar represents 2.04 inches. The river flow event was substantially greater than for Figure 10. The conductance decrease is primarily due to the freshwater influx from the river into the aquifer and not surface recharge from rainfall, as can be seen by comparing changes relative to the precipitation bars. Also, the river briefly flooded the site during the two flow peaks (see Figure 9). The ground-water salinity decreased with time after the flow event but not in a linear manner. The small diurnal oscillations in the ground-water table are related to phreatophyte water consumption (see Figure 13).

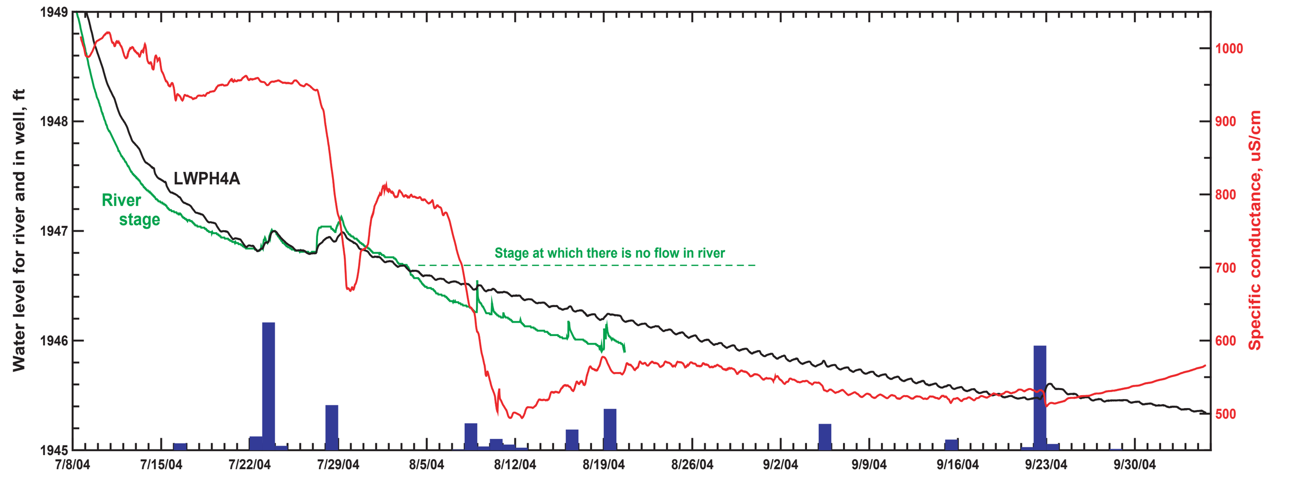
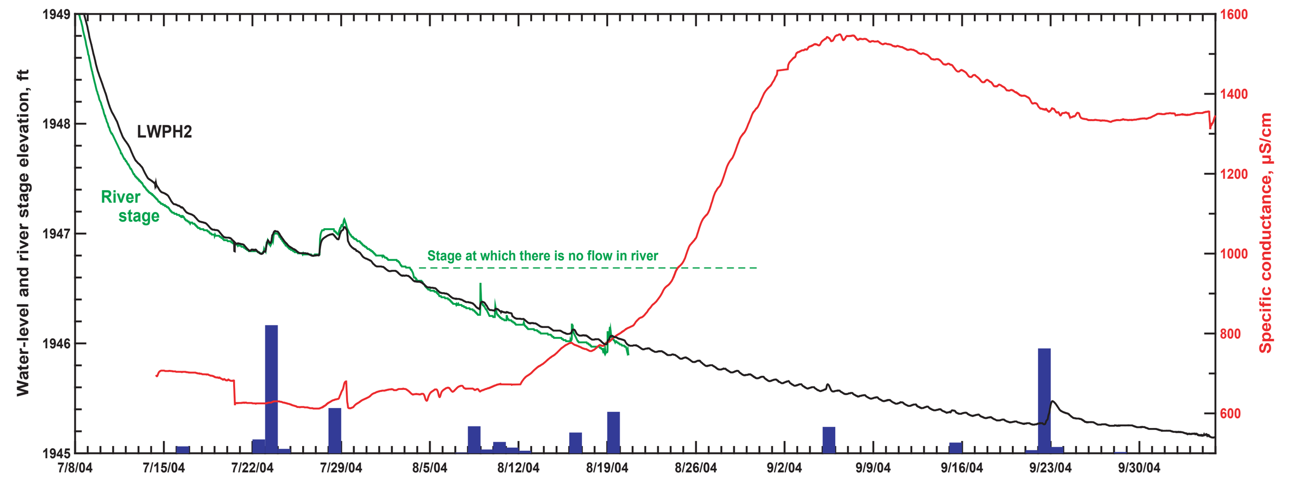


Figure 12. River stage and water-level and specific conductance in observation well LWPH2 after the same river flow event shown in Figure 11. The water level and conductance were recorded using a YSI 600SL Level Sonde. Well LWPH2 is closer to the Arkansas River channel than well LWPH4A but the ground surface is at a higher elevation at the site than at well LWPH4A and was not flooded during the flow peaks. The freshwater influx from the river had already reached the subsurface at the well by the time the conductance record starts. After the river flow event, the ground-water conductance rose substantially at well LWPH2 in comparison with the relatively low conductance of ground water at well LWPH4A. The different responses at the two locations indicates the substantial influence of heterogeneities in the alluvial aquifer system underlying the river channel and adjacent riparian zone on the stream-aquifer interactions.



Summary and Implications of Observations

Ground-water quality varies substantially in space and time in the alluvial aquifer of the middle Arkansas River.

Decadal to seasonal variations can be caused by changes in the

- source of bank storage from periods of high flows of the river and its tributaries that have different chemistry (saline water from the upper Arkansas River versus freshwater from the Pawnee River),
- climate that lead to variations in ground-water recharge and evapotranspiration in the river corridor,
- ground-water level decline from pumping that alters the relative proportions of bank storage during high river flows and baseflow following flow events,
- amount of irrigation return flow affecting ground-water inflow to the river corridor.

Weekly to daily variations can be caused by

- specific flow events from tributaries that recharge the alluvial aquifer and the resultant horizontal and vertical movement of water in the aquifer, including the relationship to the hydrostratigraphic heterogeneity,
- diurnal water-level oscillations related to ground-water consumption by phreatophytes,
- the relationship of vertical changes in water quality to the well-screen length.

Substantial variations in the quality of ground water in the shallow alluvial aquifer can occur on the order of hours to weeks, depending on the size of river flow events that recharge the aquifer and the distance from the river channel.

Substantial variations in the quality of ground water in the lower alluvial aquifer could require months to years, depending on the size and duration of river flow events that recharge the aquifer, the contrast of the chemistry of the river and ground waters, and the relative hydraulic heads in the shallow and deep alluvial aquifer and underlying High Plains aquifer.

The substantial variations in water quality with time and space have a significant bearing on the meaning of ground-water sampling in alluvial aquifers.