WATER QUALITY OF THE ARKANSAS RIVER AND ITS EFFECT ON GROUND WATER

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WATER QUALITY OF THE ARKANSAS RIVER IN SOUTHWEST KANSAS

Arkansas River water entering Kansas from Colorado is saline. The total dissolved solids concentration usually ranges from about 2,000 to 4,000 mg/L (a mg/L is essentially the same as a ppm for fresh and slightly saline water) depending on flow, and exceeds 3,000 mg/L at the average flow of the last two decades. The main dissolved constituents in the water for average flows are, in decreasing order of concentration (in mg/L), sulfate, sodium, calcium, bicarbonate, magnesium, and chloride. The mass source of the dissolved constituents in the river water is from soils and bedrock in Colorado, particularly the marine rocks of eastern Colorado. The concentration of the dissolved solids in the Arkansas River greatly increases across eastern Colorado because evaporation from the river, reservoirs, and irrigation ditches and fields and transpiration by crops and phreatophytes consume water, while the dissolved salts remain in the residual water. During many summers, most of the river water crossing the Colorado-Kansas line derives from irrigation return flows.

The dissolved solids content of Arkansas River water at the state line exceeds 4,000 mg/L during low flows (Figure 1) and reaches a maximum of about 4,200 to 4,500 mg/L at flows less than 100 cfs. The salinity generally decreases with increasing flow above 100 cfs. High flows over the last couple of decades have contained dissolved solids concentrations that exceed 1,000 mg/L, the classification divide between fresh and saline water. Thus, the dissolved solids content of river water at the state line during recent years has substantially exceeded the recommended or secondary standard of 500 mg/L for drinking water. The salinity of low flows is also high enough to cause yield reductions in certain types of crops when used for irrigation.

Sulfate is always the constituent with the highest concentration in the river water. The distribution of points on a graph of sulfate content versus discharge for river water samples (Figure 2) appears very similar to that in Figure 1. The sulfate concentration reaches a maximum of about 2,600 mg/L for flows of about 100 cfs and below. The precipitation of the mineral gypsum ($CaSO_4 \cdot 2H_2O$) limits the

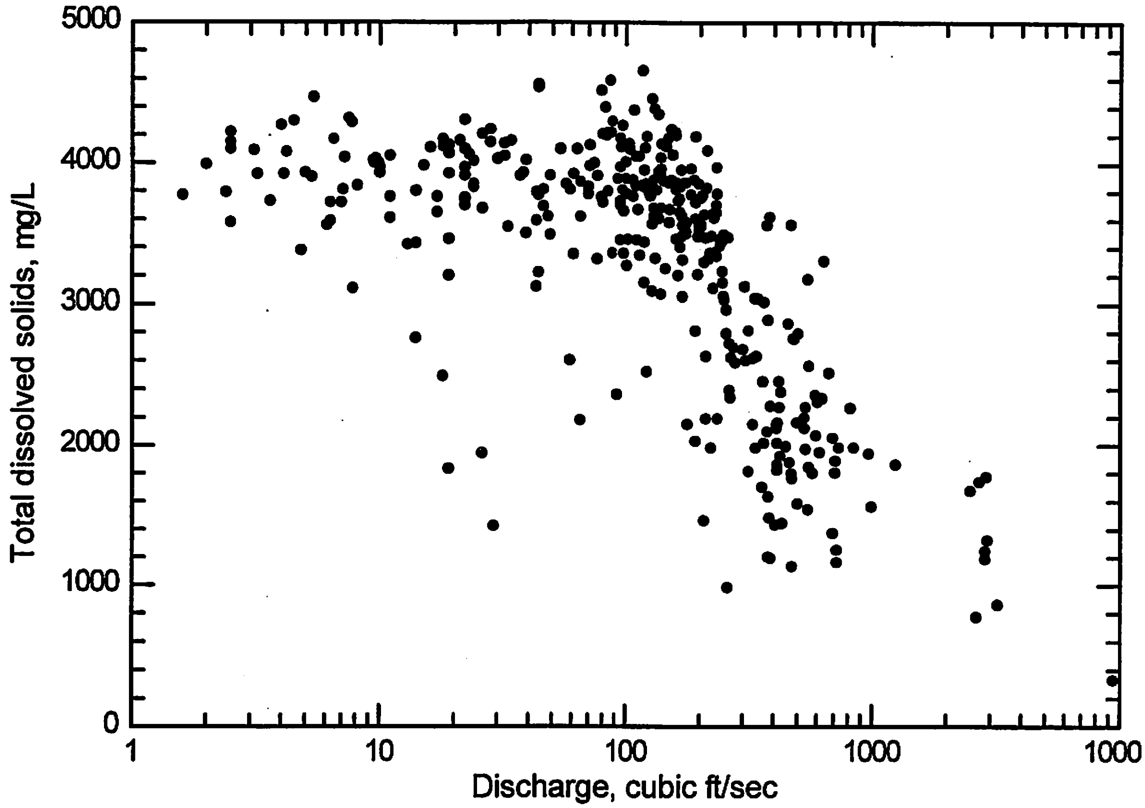

Figure 1. Variation in dissolved solids concentration with discharge in the Arkansas River near Coolidge, Kansas, 1963-1999.

concentration of sulfate from rising much higher than 2,600 mg/L for the water composition in the Arkansas River corridor. Gypsum, calcium carbonate, and minor amounts of other salts precipitate in soils and sediments when the dissolved solids content of water in soils and surface waters subject to high evapotranspiration losses increases above the solubility limits of these minerals. The sulfate concentration in the river water during the last two decades has always substantially exceeded the recommended or secondary standard for drinking water of 250 mg/L.

The solubility of the most common chloride mineral (halite or NaCl) is much greater than that of gypsum. Chloride concentration is not limited by mineral precipitation until the salt content becomes very high, such as when essentially all water is lost from soil solutions. Therefore, the chloride content in the river water does not reach a maximum as do sulfate and dissolved solids concentrations but continues to increase with decreasing flow below 100 cfs (Figure 3). This makes the chloride content a generally better measure of the degree of concentration of residual salts caused by evapotranspiration losses. The chloride concentration in the Arkansas River at the state line has nearly

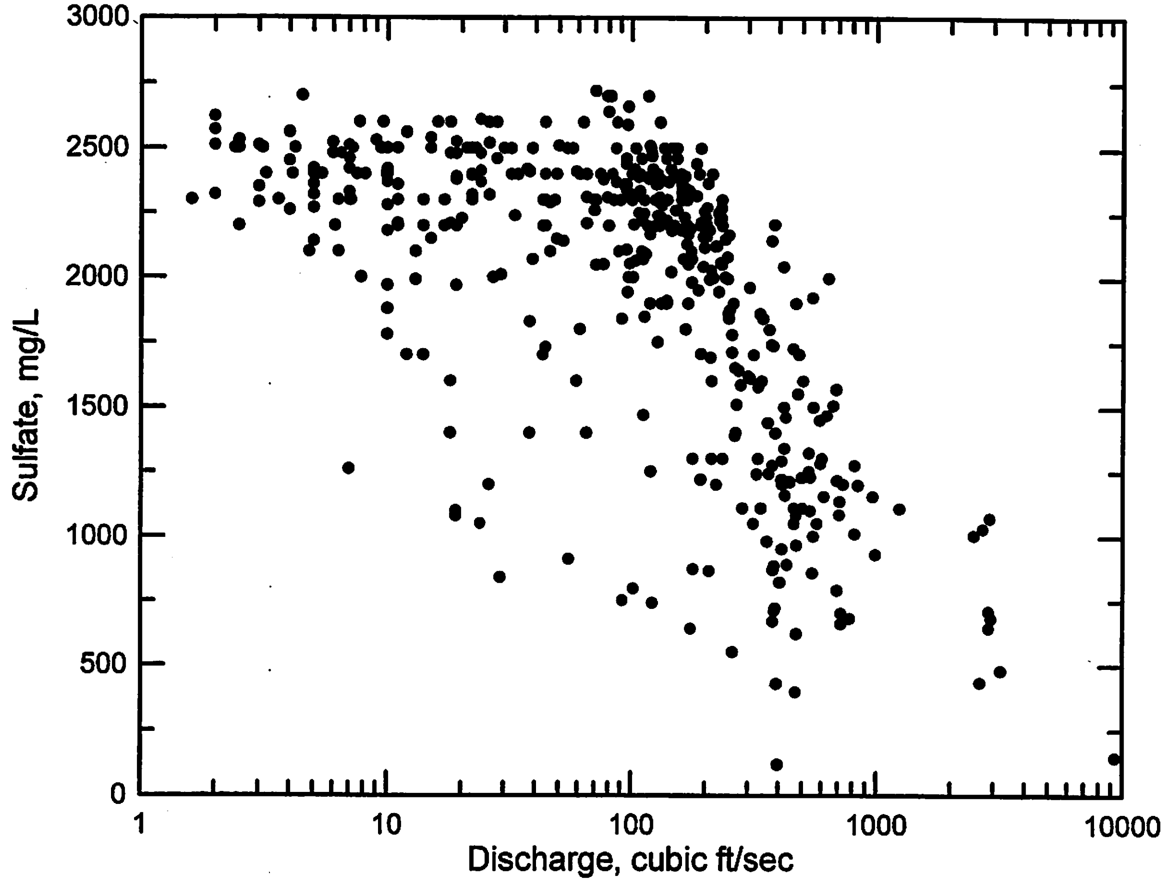

Figure 2. Variation in sulfate concentration with discharge in the Arkansas River near Coolidge, Kansas, 1963-1999.

always been below 250 mg/L, the recommended or secondary standard for drinking water for this constituent.

Many dissolved constituents in the river water are generally correlated with the salinity, i.e., the greater the dissolved solids content, the greater their concentration. These include nitrate, boron, and selenium. Nitrate concentrations in the river in southwest Kansas typically range from 1 to 3 mg/L nitrate-nitrogen. Low flows usually contain between 2 and 3 mg/L nitrate-nitrogen whereas high flows typically have concentrations <2 mg/L and commonly <1 mg/L. The nitrate contents are always substantially lower than the maximum contaminant level for drinking water of 10 mg/L as nitrate-nitrogen. Boron concentrations range from a few to several tenths of a mg/L up to nearly 1 mg/L. Although boron contents in low flows can exceed 0.75 mg/L, the recommended maximum for irrigation water use, the high salinity in the water is probably of more concern for crop health. The selenium concentration of the river water entering Kansas from Colorado is often greater than 5 µg/L (1 µg/L equals 0.001 mg/L), the chronic criterion for aquatic life support, and sometimes exceeds 20 µg/L, the acute criterion for aquatic life and the recommended limit

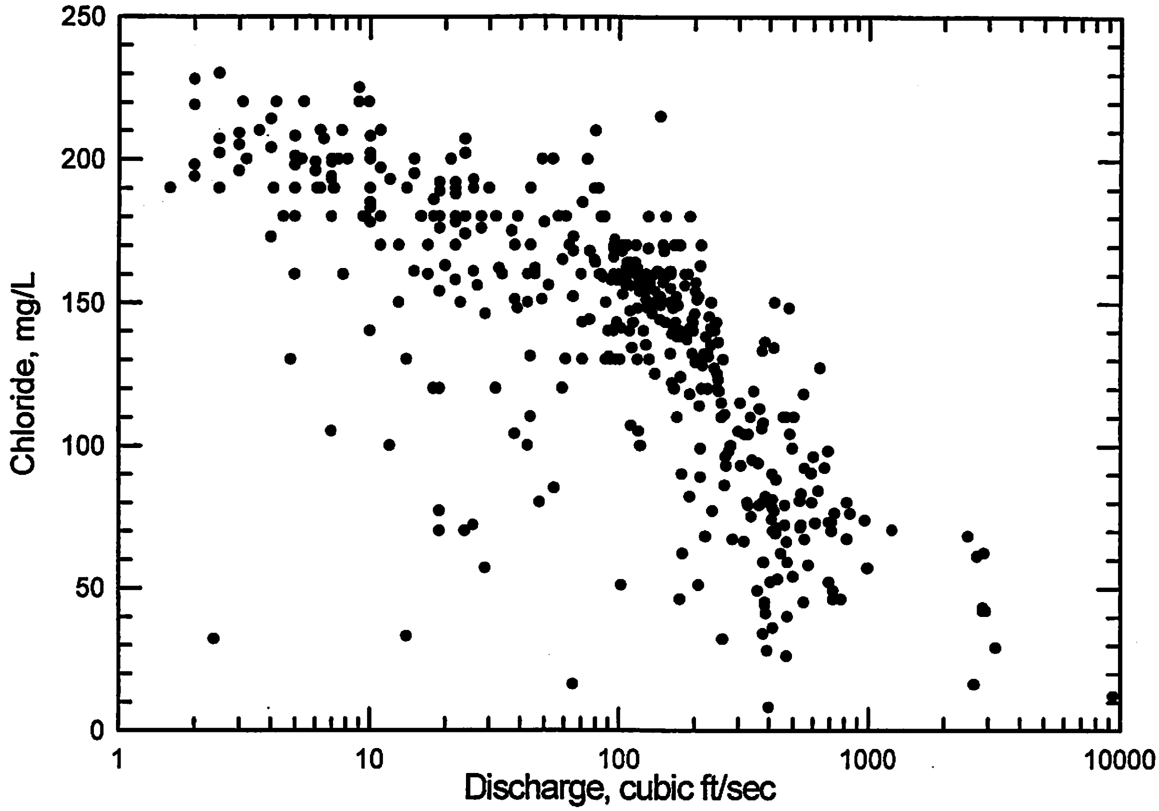

Figure 3. Variation in chloride concentration with discharge in the Arkansas River near Coolidge, Kansas, 1963-1999.

for irrigation water, in low flows. The selenium content has never been observed to exceed the maximum contaminant limit of 50 µg/L for drinking water.

WATER QUALITY OF THE ARKANSAS RIVER IN SOUTH-CENTRAL KANSAS

Natural intrusion of saltwater from Permian rocks into the High Plains aquifer in eastern Stafford, southwest Rice, and northwest to north-central Reno counties affects the quality of the Arkansas River through ground-water discharge. The saline discharge enters streams such as Rattlesnake, Peace, and Salt creeks that then flow into the Arkansas River. In some areas of southwest Rice and north-central Reno counties, the saline ground water may discharge to the Arkansas River depending on the local hydrologic conditions. The saltwater is derived from the dissolution of rock salt (halite) in the bedrock and predominantly contains dissolved sodium and chloride with smaller amounts of calcium, magnesium, bicarbonate, and sulfate. Therefore, the saline input to the Arkansas River in south-central Kansas is primarily a sodium-chloride type of water. Although there is also some contamination of Cow Creek by oil-field brine, water-softener salt in municipal wastewater discharge, and salt-plant effluent, the total percentage effect on the Arkansas River salinity is small. During years when there is no flow from the Arkansas River past Dodge City, the water quality in the Arkansas River in south-central Kansas mainly reflects the amount of saline input ultimately derived from the Permian bedrock. The saline input is substantially diluted by runoff during wet periods. During extended dry conditions, chloride concentrations in the river near Hutchinson can exceed 1,000 mg/L. The major dissolved constituents in the river water for these low-flows are, in decreasing order of concentration, chloride, sodium, bicarbonate, sulfate, calcium, and magnesium. The chloride concentration of low to moderate flows usually exceeds the recommended drinking water standard. The chloride content and salinity of lower flows is great enough to cause yield reductions to crops if it was used for irrigation.

When there are substantial flows in the Arkansas River past Dodge City, the sodium-sulfate water mixes with the sodium-chloride water in south-central Kansas and changes its chemical character. The main effect of the Arkansas River water from Colorado is to substantially increase the sulfate concentration and to dilute the chloride concentration in the mixture with south-central Kansas discharge. For example, in 1987 and 1995, high flows in the Arkansas River at the state line caused flows in the river to pass Ford County following many years of low to no flow conditions at Dodge City. In the first half of 1987 and 1995 prior to the high flow at the state line, the chloride concentration of the Arkansas River near Hutchinson was several hundred mg/L and the sulfate between 150 and 200 mg/L during lower flows. After the high flows from southwest Kansas reached the south-central part of the state, the sulfate concentration in the Arkansas River near Hutchinson rose to several hundred mg/L and the chloride content decreased to a few hundred mg/L. During 1998, the Arkansas River continued to flow through the state and raised the sulfate content in the river water near Hutchinson to over 1,000 mg/L during lower discharges from the watersheds in south-central Kansas. The chloride concentration during these conditions was near 300 mg/L.

Nitrate concentration in Arkansas River water in south-central Kansas is nearly always within the range <1-5 mg/L as nitrate-nitrogen and is, therefore, substantially lower than the maximum contaminant limit of 10 mg/L for drinking water. Typically, nitrate contents are between 1 and 4 mg/L for frequent flow conditions. Although boron concentration increases with increases in the proportion of upper Arkansas River water in the mixture, the value does not usually exceed 0.5 mg/L.

EFFECT OF ARKANSAS RIVER WATER ON GROUND-WATER QUALITY IN SOUTHWEST KANSAS

Discharge records for the Arkansas River in southwest Kansas indicate that the river has generally lost appreciable quantities of flow from the state line to Garden City since the beginning of continuos flow measurements in the 1920's. In comparison, substantial flow losses from Garden City to Dodge City began in the mid-1980's.

Annual flows of the Arkansas River entering Kansas have included a few years of large discharge interspersed with periods of intermediate and low flows. During many years from the late 1970's to the early 1990's the river has been nearly or completely dry by the time it reached Garden City or Dodge City and flow loss is nearly 100 percent of the amount entering Kansas. Flow losses for the two highest discharge years (1987 and 1998) during the last three decades have been approximately 50% of the river volume crossing the state line. The total flow loss for the years 1975-1998 is 83% of the state-line discharge.

The river water lost from the state line to Garden City leaves by a combination of evapotranspiration to the atmosphere and infiltration to the alluvial and High Plains (Ogallala) aquifers. Most of the water diverted from the river for irrigation in southwest Kansas has been consumed by evapotranspiration. Water-level and ground-water quality data indicate that appreciable amounts of diverted water have infiltrated to the aquifer underlying the irrigation canals and fields. Substantial amounts of water also have been lost by transpiration from phreatophytes, particularly tamarisk (salt cedar) and cottonwood trees, along the river and by evaporation from the surface of the broad, shallow river. The increase in the concentration of Arkansas River water from evapotranspiration is partially offset by dilution from direct precipitation and what little fresh runoff reaches the river.

Interactions between the river and the adjacent portions of the alluvial aquifer probably generated a zone of somewhat saline ground water near the river before the start of irrigation diversions in the late 1800's. As the salinity of the river water crossing the state line increased due to the development of ditch irrigation systems and shallow storage reservoirs in Colorado, the salinity of the alluvial aquifer affected by stream-aquifer interactions would have also increased. However, ground water in the High Plains aquifer remained fresh until recent years because water generally flowed in the subsurface from the High Plains aquifer to the alluvial aquifer.

Appreciable leakage from the alluvial aquifer to the underlying High Plains aquifer began when water levels in the deeper aquifer fell substantially below levels in the alluvial aquifer. The appreciable increase in ground-water withdrawals for irrigation from the High Plains aquifer during the 1970's caused water-levels to decline enough below the shallow aquifer that saline water could penetrate deeper. The leakage from the alluvial aquifer is the main cause of increased recharge from the river to the alluvial aquifer, and therefore decreased river flows from Garden City to Dodge City.

The average salinity increase in the alluvial and High Plains aquifers from loss of river water in the upper Arkansas River corridor can be estimated from calculations of the dissolved solids budget. Computations based on the concentration of the main constituent, sulfate, are representative of the salinity increase. The total sulfate mass accumulating in the Arkansas River corridor in southwest Kansas is the difference in the mass entering and leaving the system. The most important inputs are the sulfate in river water flowing across the state line and subsurface ground-water flow into the area. The major outputs are also river flow and subsurface ground-water flow. The largest mass of sulfate that enters and leaves the system is in the river water. The masses in ground-water flow into and out of the corridor area in the alluvial aquifer approximately balance and, thus, the net mass difference due to subsurface flows is not as significant.

If the mass accumulated in the river corridor is divided by the volume of the alluvial and High Plains aquifers potentially affected by the infiltration of river water from the channel and ditch diversions, an average concentration of the aquifers can be calculated. The mass/volume calculations indicate that, if all the sulfate mass added since the start of irrigation diversions had time to mechanically disperse uniformly into the sediments, the average sulfate concentration added to the aquifers in the state line to Garden City portion of the corridor would be about 900 mg/L. This concentration should be added to the estimated sulfate content of the aquifer existing before the effect of Colorado irrigation systems on the river water quality. A two-mile wide band of the alluvial aquifer along the Arkansas River from the state line to southwest Kearny County might have contained sulfate concentrations of up to several hundred mg/L in some locations during particularly dry years before the start of river diversions in Colorado. South of the Arkansas River, sulfate concentrations in the uncontaminated part of the High Plains aquifer are less than 50 mg/L. North of the Arkansas River, the aquifer just outside of the ditch-irrigated area contains water with a sulfate content generally within the range 50-200 mg/L; this range is expected to be the natural background before the impact of added salinity.

The average sulfate concentration calculated for salinity addition to both the alluvial and High Plains aquifers underlying the river from Garden City to Dodge City is appreciably smaller than that for the state-line to Garden City section. Water-level declines have not been as great along this stretch of the river and the river has been dry many of the years since the late 1970's. These factors, coupled with the presence of a lower permeability zone that underlies and slows downward migration from the alluvial aquifer to the High Plains aquifer, have restricted the high sulfate concentrations primarily to the alluvial aquifer. If the sulfate mass accumulated from river losses between Garden City and Dodge

City is divided by the volume of only the alluvial aquifer near the river, the average sulfate concentration added is between 900 and 1,000 mg/L.

The actual distribution of the added salinity is not uniform. Measured sulfate concentrations in well-water samples range widely depending on location and depth in the aquifer system. Sulfate contents for alluvial aquifer waters along the Arkansas River in Hamilton and Kearny counties are greater than 2,000 mg/L in some locations. Large areas of the aquifers in Kearny and Finney counties contain ground waters with over 1,000 mg/L sulfate and some of the wells yield waters with greater than 1,500 mg/L sulfate. The salinity of the ground waters in the upper Arkansas River corridor can be expected to generally increase with time as additional dissolved solids accumulate from river water seepage. Based on recent conditions and existing salinity, in about 50 years river water seepage has the potential to contaminate all of the High Plains aquifer underlying 500 square miles of the corridor to a sulfate concentration over 1,000 mg/L.

Although the river water recharging the aquifers is saline, it a valuable resource if viewed in terms of quantity. The recharge of the High Plains aquifer by river water seeping from the river channel and infiltrating below the ditch-irrigated areas is on a scale that is similar to planned recharge projects in the United States costing many millions of dollars. As water treatment technologies become more cost efficient, desalinization of a local supply might become competitive with distant transport of freshwater if water-levels continue to decline at substantial rates in the High Plains aquifer. However, management and protection of existing fresh ground waters in the corridor will still be important to minimize salinity impacts for municipal, agricultural, and industrial uses.

EFFECT OF ARKANSAS RIVER WATER ON GROUND-WATER QUALITY IN SOUTH-CENTRAL KANSAS

Different sections of the Arkansas River in south-central Kansas gain water from or lose water to the alluvial aquifer. During high flows, river water recharges the alluvial aquifer adjacent to the river channel. Flow losses also occur where ground-water pumping has caused declines in aquifer water levels that are below those of the alluvial aquifer adjacent to the river. The water in the alluvial aquifer adjacent to the river is saline in south-central Kansas due to both subsurface flow of saline water to the river in some sections and recharge from the river in other areas.

Long-term pumping of water from the Equus Beds area of the High Plains aquifer in southwestern Harvey and northwestern Sedgwick counties has lowered ground-water levels such that migration of saline water from the alluvial corridor of the Arkansas River is of concern. The declines are generally centered around the well field that supplies water to the City of Wichita. The U.S. Geological

Survey and U.S. Bureau of Reclamation have modeled the movement of the saline water from the alluvial aquifer towards the well field. The results show that if recent conditions continue, the saline water from the alluvial corridor could reach the well field in the future and cause salinity increases in the supply.

The chemical character of the migrating water is primarily sodium-chloride based on the present water quality in the alluvial system. If higher than average flows continue in the upper Arkansas River and substantial quantities can reach south-central Kansas, the sulfate concentration of the alluvial aquifer water between Hutchinson and Wichita could be expected to increase. However, as indicated in the section on water quality above, the influx of upper Arkansas River water has a benefit in diluting the chloride content of the river in south-central Kansas.

ACKNOWLEDGMENTS

The Kansas Water Plan has supported research studies providing information used for this paper. The collaborative work of staff in the Kansas Geological Survey, Kansas Water Office, Division of Water Resources of the Kansas Department of Agriculture, Kansas Department of Health and Environment, and Ground Water Management District Nos. 2, 3, and 5 is appreciated.