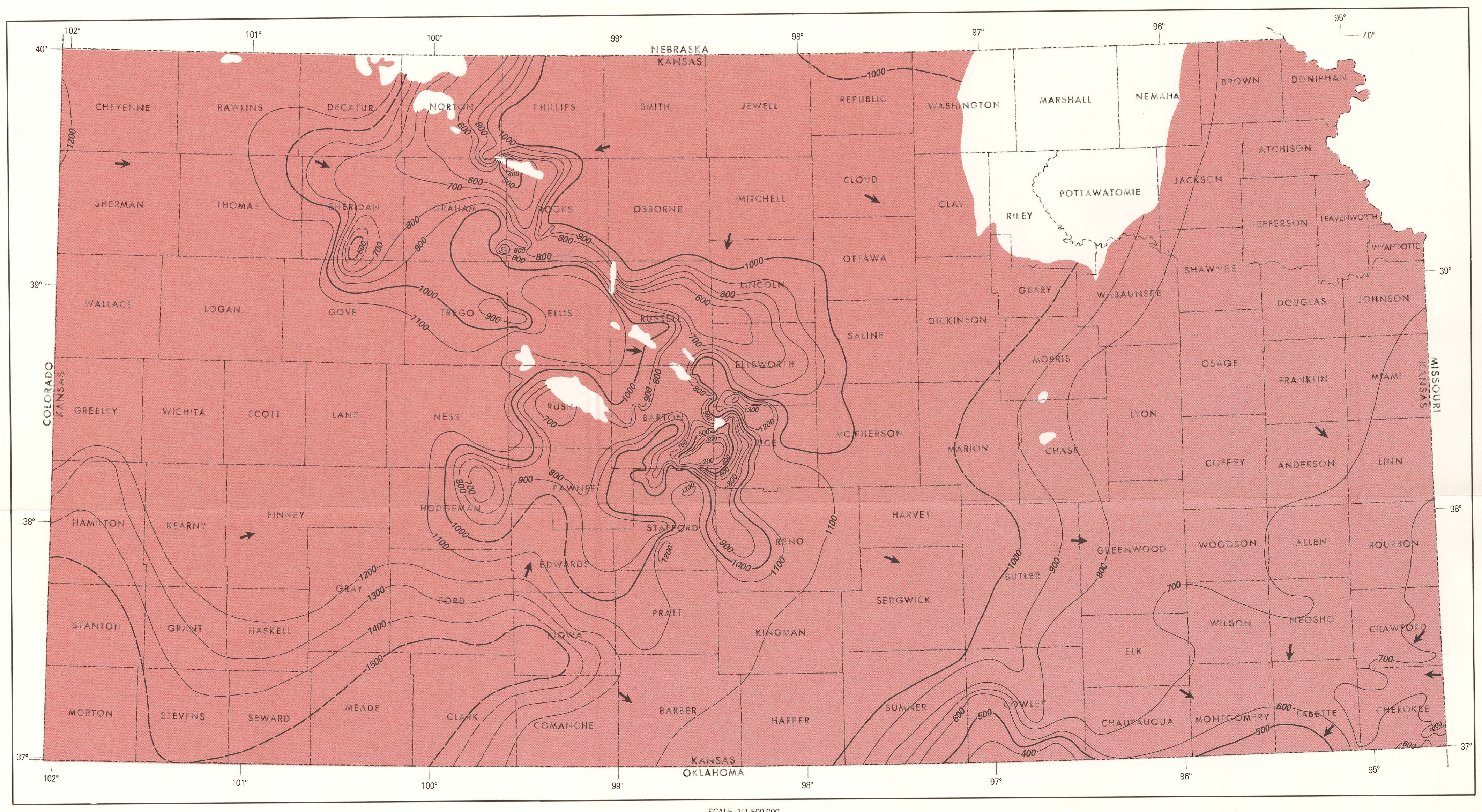

FIGURE 9.—Geohydrologic map showing equivalent freshwater heads in lower part of lower aquifer unit.

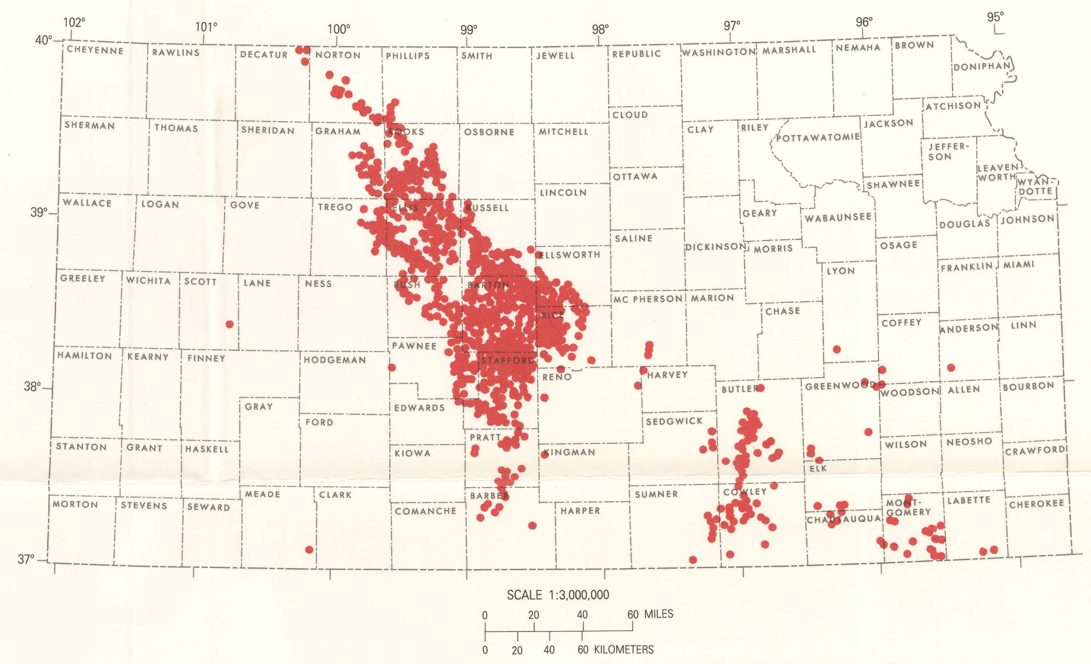

FIGURE 10.—Map showing areal distribution of oil and gas wells drilled into lower part of lower aquifer unit (modified from Newell and others, 1987).

HYDROLOGIC CHARACTERISTICS

For discussion of hydrologic characteristics, the lower aquifer unit of the Western Interior Plains aquifer system was divided into lower and upper parts; the lower part consists of rocks in the extensive Arbuckle Group, and the upper part consists of rocks that overlie the Arbuckle up to and including the Hunton Formation (table 1).

Equivalent Freshwater Heads

The petroleum industry is frequently the most common source of hydrologic data from deep saline-water systems, and pressure data from drill-stem tests are a common form of the data. In determining fluid levels and probable direction of fluid flow in a variable-density aquifer, hydrologists most often convert the pressure data from drill-stem tests to equivalent freshwater heads (Jorgensen and others, 1982). Equivalent freshwater heads are a measure of the altitude to which freshwater would rise in a tightly cased well fully penetrating the top of an aquifer. The direction of fluid flow is not always orthogonal (at right angles) to the equivalent freshwater-head contours in variable-density aquifers; however, direction of flow can be determined by using the Darcy equation in three dimensions and pressure and density terms (Jorgensen and others, 1982).

On the basis of about 260 records of wells and drill-stem tests, equivalent freshwater heads in the lower part of the lower aquifer unit range from about 1,900 feet above sea level in southwestern Kansas to less than 200 feet above sea level in central Kansas (fig. 9). Distortion of the equivalent freshwater-head contours in central Kansas reflects the extensive development of oil and gas reservoirs in this area (fig. 10).

Equivalent freshwater heads in the upper part of the lower aquifer unit were based on about 190 records of drill-stem tests (fig. 11). The distorted equivalent freshwater-head contours also reflect the distribution of oil and gas development in the south-central part of the State (fig. 12). Equivalent freshwater heads in the upper part of the aquifer unit range from about 2,200 feet above sea level in the southwest to about 200 feet above sea level in south-central Kansas.

Because of their limited extent and relatively poor hydraulic connection to the regional ground-water flow system, oil and gas reservoirs are affected greatly by development, and thus, drill-stem tests in areas of oil and gas development do not reflect predevelopment conditions. To visualize what fluid levels may have been before the extensive oil and gas development, the many available drill-stem-test data from the lower part of the lower aquifer unit were screened in search of those records that contained the highest values of equivalent freshwater head, regardless of date, and that did not reflect the obvious effects of oil and gas development (D.G. Jorgensen, U.S. Geological Survey, oral commun., 1987). The resulting interpretation (fig. 13) shows that predevelopment fluid levels in the lower part of the lower aquifer unit range from about 1,500 feet above sea level in southwestern Kansas to about 700 feet above sea level in southeastern Kansas.

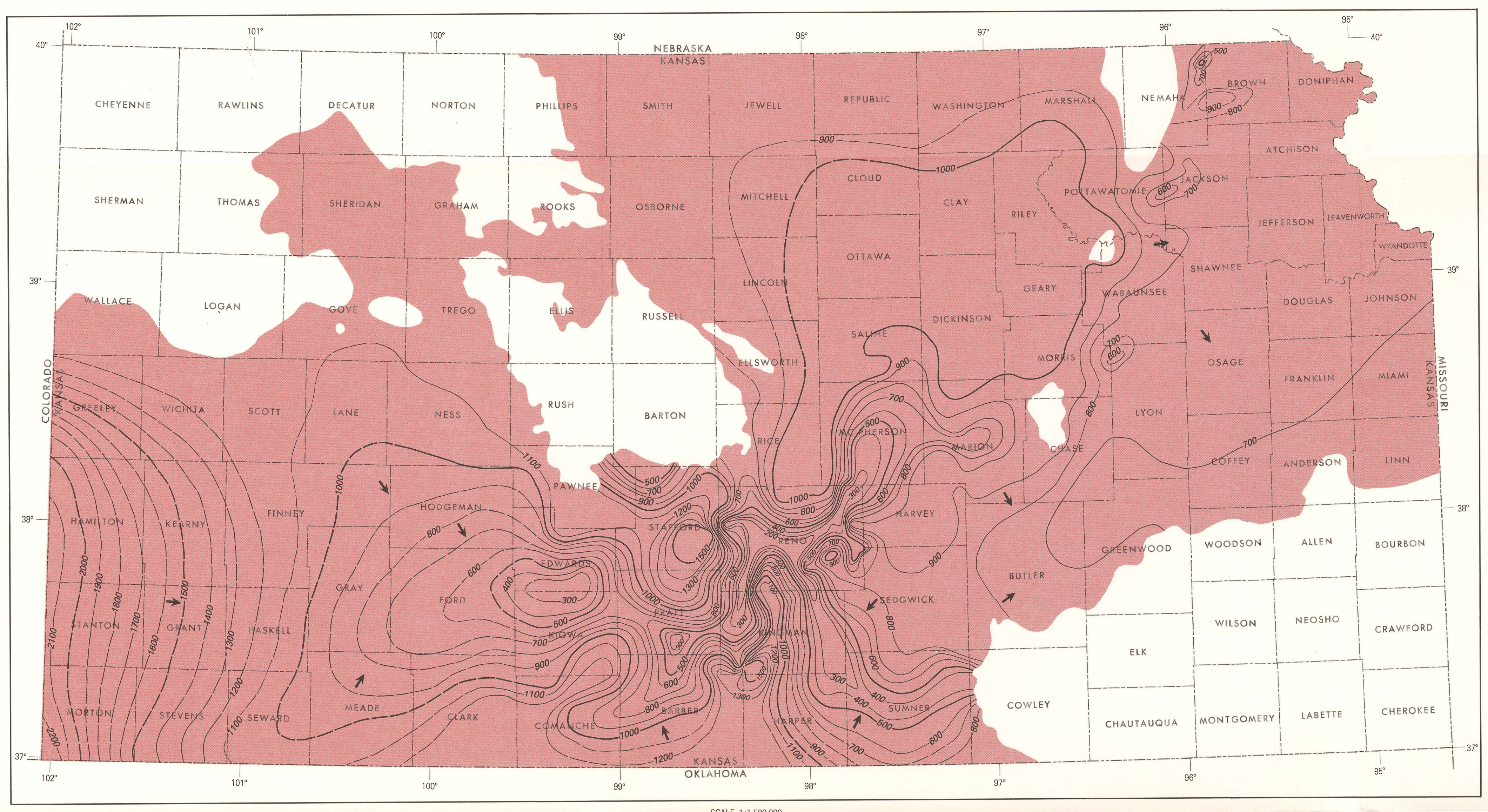

FIGURE 11.—Geohydrologic map showing equivalent freshwater heads in upper part of lower aquifer unit.

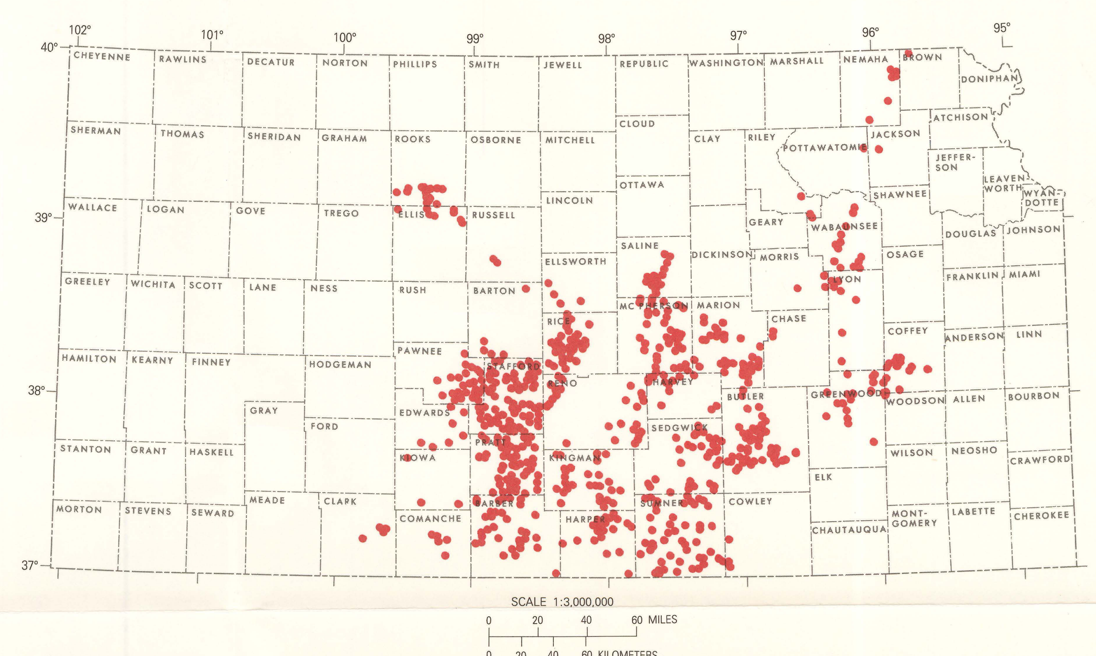

FIGURE 12.—Map showing areal distribution of oil and gas wells drilled into upper part of lower aquifer unit (modified from Newell and others, 1987).

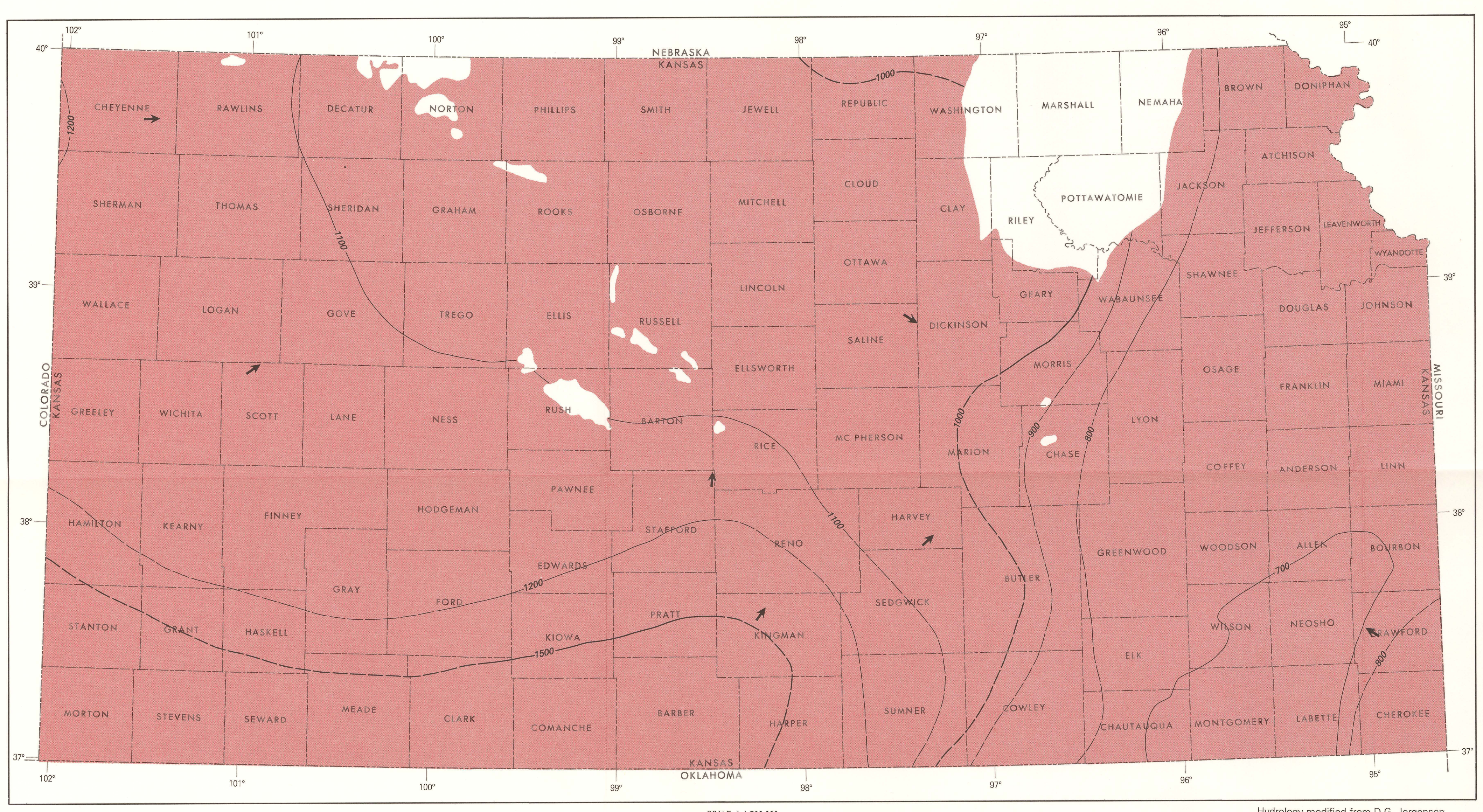

FIGURE 13.—Geohydrologic map showing predevelopment equivalent freshwater heads in lower part of lower aquifer unit.

Regional Flow

The lower aquifer unit in the Western Interior Plains aquifer system is part of two separate, laterally adjacent flow systems with opposite directions of ground-water movement and distinctly different water quality. Throughout most of the State, the unit contains generally eastward-flowing saline water; in the area of southeastern Kansas that corresponds to the Ozark Plateaus aquifer system, the unit contains generally westward-flowing freshwater. The boundary between the two flow systems, which is often called the transition zone, is an indistinctly defined area about 25 miles wide that contains water of mixed type (Jorgensen and others, in press).

In an aquifer that contains water of constant density (freshwater, for example), flow can be assumed to be orthogonal to the contours of the potentiometric surface; however with aquifers that contain water of variable density, such as the lower aquifer unit of the Western Interior Plains aquifer system, this is not always the case, and the directions of regional flow can only be implied. Although a potentiometric surface does not exist for a variable-density aquifer, it is, nevertheless, assumed in this report that water flows approximately orthogonally to the equivalent freshwater-head contours. Vertical flow can also exist between aquifers or surface-water units if a potential gradient exists, assuming hydraulic connection. This condition occurs in southeast Kansas in the transition zone where water discharges upward from the Western Interior Plains aquifer system to streams or to the near-surface water table.

Implied directions of regional flow in the lower part of the lower aquifer unit show movement from southwestern Missouri into southeastern Kansas and then into Oklahoma (fig. 9). Regional flow in the rest of Kansas generally moves from west-northwest to south-southeast, except in the central part of the State where oil and gas development has disrupted the regional-flow pattern. Components of flow in the upper part of the lower aquifer unit are thought to be from west-northwest to south-southeast throughout the State (fig. 11). Implied directions of predevelopment regional flow, as shown in figure 13, are from southwest Missouri into southeast Kansas, from the south-southwest to the north-northeast direction in southwestern Kansas, and from the west-northwest to the south-southeast in the rest of the State.

Ground-Water Availability

In the lower and upper parts of the lower aquifer unit, water is under confined conditions. A confined aquifer is a water-bearing, permeable, geologic unit capable of transmitting significant quantities of water under ordinary hydraulic gradients and is overlain by a geologic unit that may be saturated with water but is less permeable (Freeze and Cherry, 1979).

Properties of rock that indicate its ability to yield water include transmissivity and storage coefficient. Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient; it equals the hydraulic conductivity multiplied by aquifer thickness. Storage coefficient (dimensionless) is the volume of water an aquifer releases or takes into storage per unit area per unit change in hydraulic head (Lohman and others, 1972). As estimated by Spruill (1987), transmissivity values for the lower part of the lower aquifer unit in southeastern Kansas ranged from 400 to 1,070 $[(ft^3/d)/ft^2]$ ft, and storage coefficients ranged from 3×10^{-4} to 7×10^{-4} (Spruill, 1987).

Freshwater for domestic, public, and industrial supplies is withdrawn from the lower aquifer unit and stratigraphically equivalent units only in southeastern Kansas and only from the lower part of the aquifer unit. Wells drilled into the lower part of the lower aquifer unit generally range between 500 to 1,800 feet deep in southeastern Kansas (Bevans and others, 1985). Here, wells commonly yield 30 to 150 gal/min, although well yields in some areas may exceed 500 gal/min (Bevan and others, 1985).

In the rest of the State, wells in the lower and upper parts of the lower aquifer unit are primarily oil and gas wells or wells used to inject the briny water that is produced during oil and gas operations into the lower aquifer unit. Carr and others (1986) estimated that an average of 20 barrels of brine for each barrel of oil, or a total of about 1,170 million barrels of brine, was produced during oil production in 1980. Most of the brine produced during oil production was returned by injection into the lower aquifer unit at a rate that ranged from 100 to 150,000 barrels per day (3–4,375 gal/min) during 1984 (Carr and others, 1986).

Discharge from the lower part of the lower aquifer unit is principally by well pumpage for public and industrial supplies in southeastern Kansas. Bevans and others (1985) reported that 14 Mgal/d was withdrawn from this area during 1983 and that water levels declined as much as 200 feet locally on the basis of predevelopment and 1980 potentiometric-surface maps (Macfarlane and others, 1981). Withdrawal of brine during the production of oil and gas from the lower aquifer unit accounts for the major discharge component in other parts of the State. Carr and others (1986) estimated that 1,018 million barrels of briny water was withdrawn from the upper part of the lower aquifer unit and that 152 million barrels was withdrawn from the lower part.

Because the lower aquifer unit is deeply buried, natural recharge to the unit originates mostly in outcrop areas in the Ozark region of Missouri. Some interchange of water with the overlying upper aquifer unit in the Western Interior Plains aquifer system occurs where the aquifer units are in direct contact. From 1942 to 1986, the lower part of the lower aquifer unit has became a major zone for disposal of fluids produced during oil and gas drilling operations. By 1980, about 889 million barrels per year of briny water was being injected into the lower part of the unit, mainly in uplift areas in the central part of the State (Carr and others, 1986). The effects of fluid injection have not been determined, but the cumulative volume of briny water added to the lower aquifer unit could cause notable changes in pressure and chemical composition of the aquifer fluids.

GEOHYDROLOGIC SYSTEMS IN KANSAS—GEOHYDROLOGY OF THE LOWER AQUIFER UNIT IN THE WESTERN INTERIOR PLAINS AQUIFER SYSTEM

By
L.J. Combs, C.V. Hansen, and R.J. Wolf

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