Geohydrology of Finney County, Southwestern Kansas

By WALTER R. MEYER, EDWIN D. GUTENTAG, *and* DAVID H. LOBMEYER

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GEOHYDROLOGY OF FINNEY COUNTY, SOUTHWESTERN KANSAS

By WALTER R. MEYER, EDWIN D. GUTENTAG, and DAVID H. LOBMEYER

ABSTRACT

Finney County is in southwestern Kansas and comprises an area of 1,300 square miles. The rocks studied range in age from Late Permian to Holocene. The spatial relationships of the subsurface deposits were determined from more than 1,400 sample, drillers', gamma-ray, and laterolog resistivity logs of rotary test holes. The log data were used for the following determinations: Lithology of the rock samples, topography of the pre-Pliocene surface, bedrock geology, regional structure, and geologic sections.

Unconsolidated sediments of Tertiary and Quaternary age form the principal ground-water reservoir of Finney County and attain a thickness of more than 500 feet in the southwestern part of the county. The subsurface Tertiary and Quaternary deposits have been divided at aquifer test sites into the Pliocene Ogallala Formation and the undifferentiated Pleistocene deposits. The sand and gravel beds of the Ogallala contain a greater amount of interbedded and mixed silt, clay, and caliche than do those of Pleistocene age.

Minor amounts of water, for domestic and stock purposes, are available from aquifers in the Lower Cretaceous deposits and possibly from the Upper Jurassic Morrison (?) Formation.

Recharge to the Lower Cretaceous sandstone aquifers within Finney County is from the overlying Tertiary and Quaternary deposits in the southern part of the county. Recharge to the Tertiary and Quaternary aquifers is principally from dune-sand areas, depressions in the loess, and irrigated areas. Recharge to the alluvial deposits is from the Arkansas River, local precipitation, and underflow from the dune sand.

Coefficients of permeability and transmissibility were obtained from aquifer tests at nine locations. These coefficients were used with many detailed lithologic logs to determine the movement of water through the county.

The analyses of the 1940, 1962, 1963, and 1964 water-table-contour maps indicate a constant inflow of 40.2 million gallons per day and a constant outflow of about 42.0 million gallons per day.

As the inflow and outflow are constant, the system of aquifers is considered to be a reservoir that is subject to the three phases of reservoir operation: recharge, storage, and discharge.

Discharge from the reservoir is primarily from pumping and a small amount of natural discharge. The change in storage was obtained from water-level-change maps and from long-term hydrographs.

The recharge was computed by adding the discharge components (pumping and natural discharge) and the change in storage. This was found to be approximately 2.7 inches per year.

The annual recharge ranged from 0 to 306,000 acre-feet and averaged approximately 177,000 acre-feet for the period 1955–64.

The 1963 rate of pumping was approximately 295,000 acre-feet. The pumping rate caused an overdraft on the reservoir of approximately 167,000 acre-feet. This caused an average drop in water level of 1.5 feet. The decline in the areas of intensive pumping is approximately 4 feet per year and is almost nothing in areas of no pumping.

Water quality in the county ranges from good in the undifferentiated Pliocene and Pleistocene deposits of southern Finney County, with less than 200 milligrams per liter dissolved solids, to poor in the Pleistocene and Holocene alluvium of the central part of the county, with over 3,000 milligrams per liter dissolved solids. The sodium-adsorption-ratio ranges from less than 1 for the good-quality water in southern Finney County to more than 20 for water from undifferentiated Lower Cretaceous sediments in northeastern Finney County. Water in about half the area is undesirable for domestic purposes because of dissolved-solids content or high fluoride concentrations.

All available chemical-quality data were examined, and the more recent analyses were used to make a map and section of dissolved-solids concentration, a map of fluoride concentration, and two hydrogeochemical sections. A comparison of data from recent analyses with historical data from the late 19th century and early 20th century indicates a deterioration of water quality in some shallow aquifers.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

Irrigation has been practiced for many years in Finney County, but not until the period 1954–57 were there any large increases in groundwater use. Records from the Kansas State Board of Agriculture, Division of Water Resources, show that from 1946 to 1954 the amount of water pumped for irrigation doubled. By 1956 the amount of water pumped for irrigation was three times greater than that pumped in 1946, and in 1964 it was approximately four times greater.

A study was initiated to determine the effect of this rapid expansion in irrigation acreage and the resulting increase in pumpage upon the ground-water supply of Finney County.

The objectives of this investigation were to define the geology of the water-bearing deposits and determine the areal extent of these deposits, evaluate the hydraulic characteristics of the aquifers, determine the effect of pumping on the water levels of the area, ascertain the sources of recharge and the amount of recharge from each source, and determine the chemical quality of water and its relation to the rocks and to the hydrologic continuity of the aquifers.

LOCATION AND EXTENT OF THE AREA

Finney County, in southwestern Kansas (fig. 1), includes 36 townships (1,300 sq mi) and is the second largest county in Kansas.

All of Finney County was considered in the geologic and chemical-quality sections of this report. However, the 16 townships in the northeastern panhandle section of the county had little bearing on the hydrologic study and, accordingly, are not considered in the hydrology of the report.

PREVIOUS INVESTIGATIONS

Several studies have been made of the geology and ground-water resources of southwestern Kansas. The principal studies are given below in chronological order.

Nettleton (1892) reported the results of some underflow surveys in the Platte and Arkansas River valleys which included a discussion of the water-table configuration at Garden City. Haworth (1897a) described the geology and physiography of western Kansas and included a discussion of the Arkansas River. Haworth (1897b) published the results of an investigation of the underground water of southwestern Kansas which included the southern half of Finney County. Haworth (1897c) gave a general account of the geology of underground water in western Kansas. Johnson (1902) briefly described the slope of the water table near Garden City and the early attempts at irrigation. Slichter (1902) included a hydrograph of the city well at Garden City in his classic report on the motions of underground waters. Darton

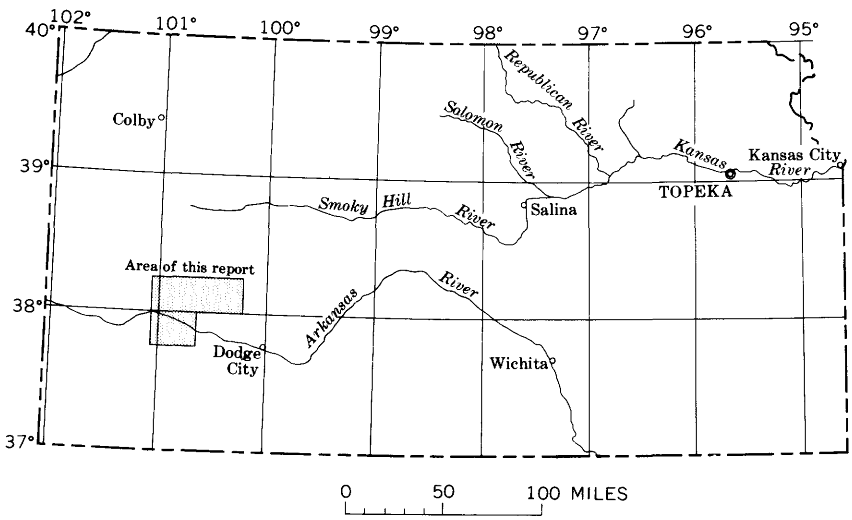

FIGURE 1.—Index map of Kansas, showing location of study area.

(1905) reported on the geology and the ground-water resources of the central Great Plains and gave a general description of the water supply of Finney County.

Slichter (1906) made an intensive investigation of the Arkansas River underflow in Finney and Kearny Counties and reported in detail on the origin and velocity of the underflow, the fluctuations of the ground-water levels, and the quality of the water. He performed aquifer tests on several pumping plants in the Arkansas Valley to determine the specific capacity of the wells and the cost of pumping. The quality and availability of water in Finney County were studied by Parker (1911). Haworth (1913) described the well waters in Kansas and discussed the ground water in the Tertiary and Quaternary rocks of western Kansas.

A preliminary reconnaissance report of the Shallow Water Basin in Finney and Scott Counties was published by Moss in 1933. Theis, Burleigh, and Waite (1935) described briefly the water-bearing formations and the availability of ground water in the entire southern High Plains. In 1940 Smith described the Tertiary and Quarternary geology of southwestern Kansas, including Finney County. Waite (in Moore and others, 1940) discussed the Shallow Water Basin in Finney and Scott Counties. A comprehensive report on Finney and Gray Counties by Latta, published in 1944, included a description of areal geology, physiography, ground-water supply, and logs of many wells and test holes drilled in Finney County. Frye and Fishel (1949) published a general report on ground water in southwestern Kansas, including Finney County.

More recent studies are by Stramel, Lane, and Hodson (1958), who studied the geology and ground-water hydrology of the Ingalls area, which included part of southeastern Finney County; the Bureau of Reclamation (Barret, 1961) published a status and inventory report of the Arkansas River basin below the John Martin Reservoir, which included Finney County; and the Kansas Water Resources Board (1962) studied the water resources of the county as part of their preliminary appraisal of water problems in the Upper Arkansas Unit. Meyer (1962) published results of a pumping test conducted on the alluvium near Holcomb in which a neutron moisture probe was used to determine the specific yield of the aquifer. Gutentag (1963) illustrated the regional continuity of the Pleistocene and Pliocene deposits.

Measurements of ground-water levels in observation wells in Finney County were first published by Meinzer and Wenzel in 1940. Publication of ground-water data was continued by the U.S. Geological Survey, and since 1956, the Finney County water levels have been published by the State Geological Survey of Kansas. The detailed bibliography of the various publications which contain water-level data for Finney County was referenced by Broeker and Winslow (1963).

WELL-NUMBERING SYSTEM

The well and test-hole numbers in this report give the location of wells and test holes according to the U.S. Bureau of Land Management system of land subdivision, as follows: Township, range, section, and position within the section. This method of well location is shown in figure 2. The first numeral indicates the township, the second indicates the range, and the third indicates the section in which the well or test hole is situated. Lowercase letters following the section number locate the well or test hole within the section. The first letter denotes the quarter section, the second letter denotes the quarter-quarter section, and the third letter denotes the quarter-quarter-quarter section. The letters are assigned in a counterclockwise direction, beginning with "a" in the northeast quarter of the section. Letters are also assigned to each quarter-quarter section and to each quarter-quarter-quarter section in the same manner. Where more than one well or test hole is in a quarter-quarter-quarter section, consecutive numbers, beginning with 1, are added to the letters. For example, 22–33–23bac indicates that a well is in the SW¼NE¼NW¼ sec. 23, T. 22 S., R. 33 W.

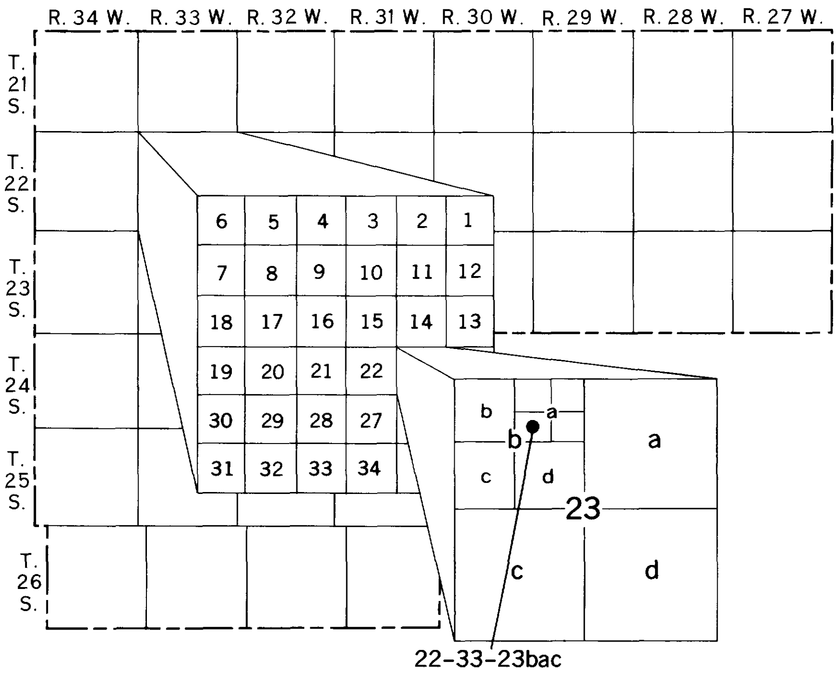

FIGURE 2.—Well-numbering system.

CLIMATE

The climate of Finney County is characterized by abundant sunshine, moderately low precipitation, low relative humidity, brisk wind movement, and a high rate of evaporation. Often the summers are hot, but the heat is moderated by good wind movement and low humidity. The winters are moderate.

Records of the Garden City Experiment Station show the average annual rainfall as 17.98 inches. The annual precipitation during the period of record 1908–63 ranged from 5.68 inches in 1956 to 36.19 inches in 1923 (fig. 39).

The average length of the growing season is 170 days. The average date of the last killing frost in the spring is April 28, and that of the first killing frost in the fall is October 15.

ACKNOWLEDGMENTS

The writers of this report express appreciation to the residents of Finney County who gave information regarding their wells and permitted test drilling on their land and the use of their land and irrigation wells for aquifer tests. Records and information were obtained through the courtesy and cooperation of the following drilling companies: Henkle & Co., Minter Drilling Co., Western Drilling Co., Swearengen Drilling Co., and Gestenslager Drilling Co., all of Garden City, Kans.; Loucks Bros., of Copeland, Kans.; and Weishaar Drilling Co., of Scott City, Kans.

Appreciation is extended to the following companies for the opportunity to obtain gamma-ray logs: Cities Service Petroleum Co., Pan-American Petroleum Corp., and Anadarko Production, all with field offices in Liberal, Kans. Appreciation is also extended to the following State and Federal agencies: The Garden City Experiment Station of Kansas State University for supplying weather records and allowing the use of their neutron meter; the Garden City office of the Division of Water Resources for the use of their application files and for their assistance in several pumping tests; and the Soil Conservation Service of the U.S. Department of Agriculture, Garden City regional office, for their aid with data from their files.

E. L. and Carrie Reavis determined the altitude of the measuring points of many wells in the county. E. A. Waddell compiled the numerous tables for this report.

The present report was reviewed by members of the U.S. Geological Survey and of the State Geological Survey of Kansas; by R. V. Smrha, chief engineer of the Division of Water Resources, Kansas State Board of Agriculture; by J. L. Mayes, chief engineer, and B. F. Latta, geologist, of the Environmental Health Services, Kansas State De-

partment of Health, and by D. F. Metzler, executive secretary of the Kansas Water Resources Board.

GEOLOGY

PHYSIOGRAPHY

Finney County lies within three major sections of the Great Plains physiographic province: the High Plains, the Dissected High Plains, and the Arkansas River Lowlands.

The High Plains section is characterized by flat to gently rolling uplands, a few shallow valleys, and many undrained depressions. The depressions are 10–20 feet deep and may be as much as 3.5 miles across. Many of these depressions retain water after a rain and become areas of ground-water recharge. The Finney basin is a broad shallow depression in the High Plains section that extends from the Arkansas River northward into Scott County (fig. 3). This asymmetrical depression is marked by a conspicuous escarpment along the east edge, but it merges with the High Plains on the west edge.

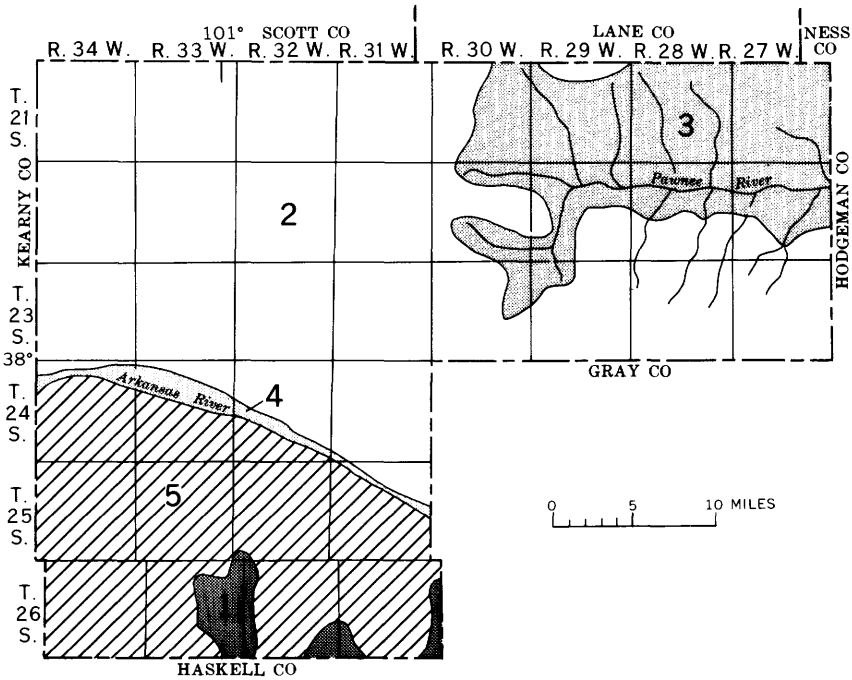

FIGURE 3.—Physiographic areas: 1, High Plains; 2, Finney basin; 3, Dissected High Plains; 4, Arkansas valley; and, 5, sandhills. (Modified from Latta, 1944, and from Schoewe, 1949.)

The Dissected High Plains section is characterized by hilly topography cut by numerous drains. Cretaceous rocks crop out along most of the larger drains. Unconsolidated deposits, which form a thin mantle on the upland, generally reflect the underlying dissected erosion surface of the bedrock.

The Arkansas River Lowlands section is subdivided, in this report, into Arkansas Valley area and sandhills. Included in the Arkansas Valley area are the flat flood plain of the river and its adjcent low (4–7 ft) terraces. Bordering the valley area on the south is a large area of mature sand dunes, most of which are covered by vegetation. Some wind action is shown, however, by a small number of blowouts from which vegetation has been removed.

The Arkansas River heads in the Rocky Mountains in central Colorado and follows an easterly course through southeastern Colorado and southwestern Kansas. It enters Finney County at a point 17 miles north of the southwest corner, flows east-southeast, and leaves the county at a point 9 miles north of the southeast corner. The average gradient of the river across the county is 7 feet per mile. Width of the Arkansas Valley ranges from 1 mile near the Gray County line to 3.5 miles near Garden City. The flood channel of the Arkansas is 300–400 feet wide. During most of the year, however, the flow of the river is small and is confined to a narrow channel 10–30 feet wide. No streams enter the Arkansas River in Finney County.

The Pawnee River heads in the northeast panhandle section of Finney County about 16 miles west of the Hodgeman County line. The Pawnee Valley ranges in width from one-fourth of a mile to more than 1 mile and has numerous short tributary valleys. During much of the year, flows are not sustained because of numerous dams across the main stream and its many tributaries.

The highest point, in the northwest corner of Finney County, has an altitude of 3,090 feet; the lowest point, where the Pawnee River leaves the county, has an altitude of 2,450 feet above mean sea level. The total relief of the area is 640 feet; locally, the relief does not exceed 300 feet. The land surface slopes toward the east at an average gradient of less than 10 feet per mile.

STRATIGRAPHIC CLASSIFICATION

A primary consideration for a geohydrologic study is the stratigraphy of the water-bearing deposits. Some stratigraphic units previously described by Latta (1944) as independent geologic entities are now considered collectively with respect to their water-bearing properties.

The oldest beds considered in this report are the Upper Permian undifferentiated red beds which make up units comparable to the Whitehorse Formation, Day Creek Dolomite, and the Big Basin Sandstone. These beds are unconformably overlain by beds tentatively correlated with the Morrison Formation of Late Jurassic age (table 1). The Early Cretaceous undifferentiated deposits unconformably overlie the Morrison(?) Formation and consist of rocks equivalent to the Cheyenne Sandstone, Kiowa Shale, and the Dakota Formation. Because of facies variations, the Lower Cretaceous deposits are not differentiated in Finney County. The Upper Cretaceous deposits consist of the following units: Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Chalk.

Tertiary and Quaternary deposits are not easily separated by age without a study of their fossils; however, in some localities these deposits are divided by their lithologic differences. The Ogallala Formation includes all the known Pliocene deposits in the county. The Pleistocene deposits are separated, on the basis of lithology, as loess, alluvium and terrace deposits, dune sand, and undifferentiated deposits. The Holocene deposits form a thin mantle of fine-grained alluvium on the flood plain of the major stream valleys and on adjacent uplands.

SURFACE GEOLOGY

The geologic map (pl. 1) was modified from the geologic map by Latta (1944) and was checked in the field. The oldest rocks exposed are in the Pawnee drainage system in northeastern Finney County and comprise units from the Upper Cretaceous Carlile Shale and the Niobrara Chalk.

Deposits of Tertiary and Quaternary age make up the rest of the surface rocks. The Pliocene Ogallala Formation crops out in small areas of northeastern Finney County. Undifferentiated Pleistocene deposits, composed mainly of sand and gravel, border the north-side bluffs of the Arkansas River east of Garden City and the major drainage areas of the Pawnee.

A Pleistocene terrace, 20–25 feet above the flood plain, forms a continuous belt along the south side of the Arkansas River. Although the surface of the terrace appears to be of late Pleistocene age, the underlying deposits are believed to range from early to late Pleistocene age. Dune sand, which masks the outer boundary of the terrace, covers most of the southern part of the county and occurs in small isolated areas on the north side of the river.

Loess is the major surficial deposit in Finney County. It mantles the older rocks over much of the area north of the Arkansas River. The loess is in part contemporaneous with the dune sand. Colluvial

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TABLE 1.—*Generalized section of geologic formations and their water-bearing characteristics*

System	Series	Stratigraphic unit	Thickness (feet)	Physical character	Water supply
Quaternary	Holocene and Pleistocene	Alluvium	0–70±	Silt, clay, and sand of Holocene age overlying sand, gravel, and cobbles of late Pleistocene age along the major stream valleys both in valley proper and in adjacent uplands.	Yields from single wells range from 800 to 1,200 gpm, and yields from battery wells range from 3,000 to 5,000 gpm in Arkansas River valley.
	Pleistocene	Dune sand	0–75±	Fine to medium quartzose sand with lesser amounts of clay, silt, and coarse sand formed into small hills and mounds by wind. Located principally along the south side of the Arkansas River.	Lies above the water table and does not yield water to wells. The dunes have a high infiltration rate and are important as areas of ground-water recharge.
		Loess	0–30±	Eolian (windblown) silt mantles much of the county and is moderately permeable.	Lies above the water table and does not yield water to wells. Serves as minor areas of ground-water recharge.
		Undifferentiated deposits	0–300±	Sand, gravel, silt, clay, and caliche underlies most of the county and is generally in contact with the Ogallala Formation where both are present.	The sand and gravel of the undifferentiated Pleistocene deposits and the Ogallala Formation are the principal water-bearing deposits in the county. Yields range from 600 to 2,500 gpm in irrigation wells.
Tertiary	Pliocene	Ogallala Formation	0–300±	Poorly sorted sand, gravel, silt, clay, and caliche; unconsolidated to tightly cemented by calcium carbonate.	

Cretaceous	Upper Cretaceous	Niobrara Chalk, Carlile Shale, Greenhorn Limestone, and Graneros Shale	0–600±	Massive cream-colored chalky limestone and gray to black clayey and chalky shale with thin limestone beds and some sandstone. Eroded out in much of southern Finney County.	Yield 2–10 gpm of water for stock and domestic wells near outcrop areas.
	Lower Cretaceous	Undifferentiate deposits	120–460±	Shale, clay, sandstone, and siltstone; interbedded and varicolored.	Yield 20–100 gpm of water to wells from sandstone aquifers.
Jurassic	Upper Jurassic	Morrison(?) Formation	50–350±	Shale, clay, sandstone, and siltstone with basal sandstone and siltstone.	Not known to yield water to wells. A potential aquifer for small to moderate yields.
Permian	Upper Permian	Undifferentiated red beds	200–500±	Shale, siltstone, sandstone, dolomite, and anhydrite; local limestone.	Not known to yield water to wells.

NOTE.—The classification and nomenclature of the stratigraphic units used in this report are those of the U.S. Geological Survey and differ somewhat from those of the State Geological Survey of Kansas.

deposits, consisting of reworked loess containing minor amounts of sand and gravel and local bedrock fragments, constitute part of the thin surficial deposits on the slopes of the minor stream valleys and in the upland draws. These deposits, where present, are included with the loess deposits.

Alluvium along the Arkansas and Pawnee Rivers represents the youngest deposit in the county. The unit shown on the geologic map (pl. 1) includes the flood-plain deposits of Holocene age, the underlying alluvium, and a low terrace deposit of late Pleistocene age. This terrace is 4–8 feet above the flood plain and is prevalent along the north side of the rivers.

SUBSURFACE GEOLOGY

The hydrology of the area is controlled primarily by the geology of water-bearing and overlying deposits. A knowledge of the physical properties and the structure of the subsurface units is essential to understand the hydrologic properties of the deposits. The methods used to obtain the needed knowledge are (1) lithologic study of the deposits, (2) determination of the bedrock surface (pre-Pliocene), (3) determination of the structural relationship, and (4) preparation of representative maps and geologic sections to illustrate the data.

LITHOLOGY

Lithologic detail derived from various types of well logs is a basic tool of the hydrologist; therefore, the quality of well logs is a major consideration in preparing a hydrologic analysis. The types of logs used to determine the lithology of the water-bearing deposits are sample logs, gamma-ray logs, laterolog resistivity logs, and drillers' logs of water-well tests and seismic shotholes.

The gamma-ray log is important for correlating and determining the continuity of the subsurface geologic formations, especially in areas of Finney County where other information is scant or lacking. The gamma-ray curve is a record of the variation in the natural gamma radiation that exists in dissimilar strata. Limestone and chalk and sand and gravel are less radioactive than clay and shale strata. The laterolog resistivity curve indicates changes in the lithology of the formation, especially in those wells drilled with high-salinity mud. Limestone and unconsolidated sandstone are highly resistive deposits as compared with silt and shale. Each gamma-ray or laterolog resistivity curve shows a series of deflections which reflect the physical characteristics of the beds penetrated by the borehole, as illustrated for a typical log in Finney County (fig. 4).

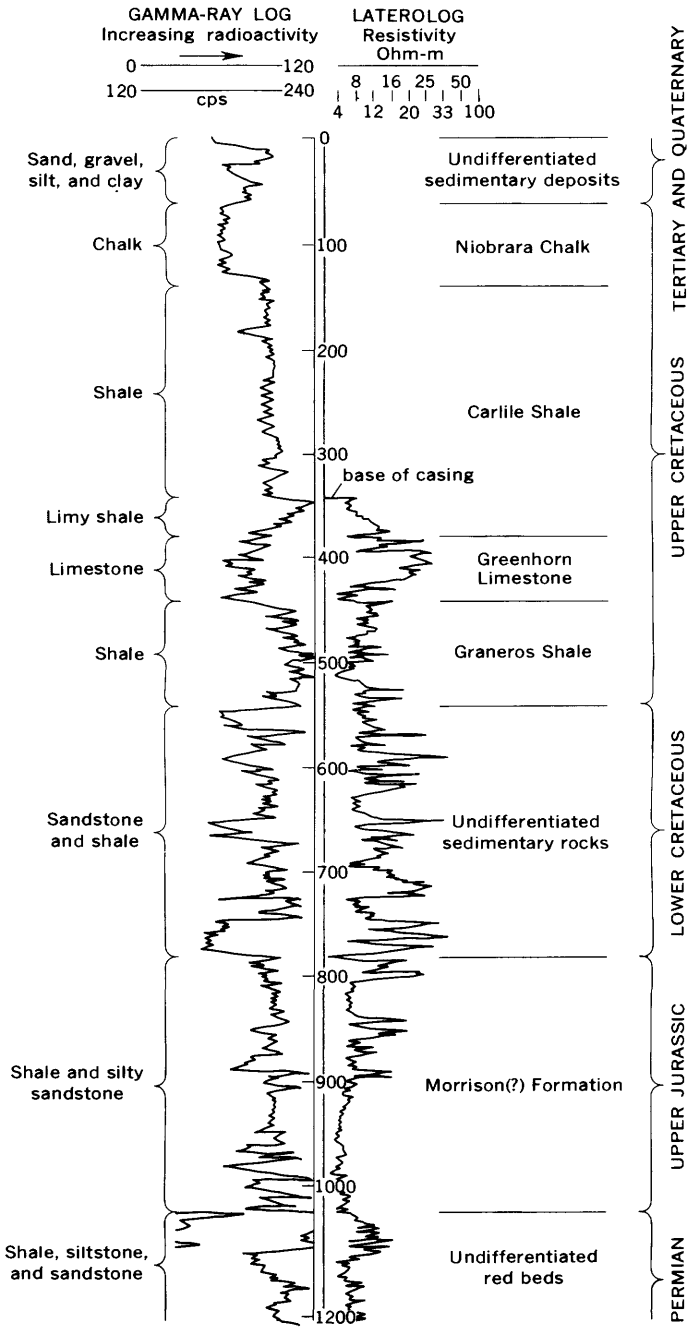


FIGURE 4.—Gamma-ray log and laterolog of the Shallow Water Refining Co. Maune "B" 1 well, center of the NE¼NE¼ sec. 36, T. 21 S., R. 34 W.

Sample logs were made from rotary-drill cuttings. When examined under the binocular microscope, these drill cuttings give an understanding of the physical framework of the deposits. Data were collected about the types of material, grain size, color, degree of roundness, and approximate sorting.

Drillers' logs of water-well tests, supplied by irrigators and water-well contractors, were used in conjunction with other data to define the lithology of the deposits. Drillers' logs of seismic shotholes were valuable in determining the pre-Pliocene surface in areas where other log data were lacking. These data, when combined with data from sample logs, gamma-ray logs, and laterologs, provided the information used to define the vertical and horizontal limits of the aquifers in Finney County.

BEDROCK SURFACE

The configuration of the bedrock surface underlying the unconsolidated Tertiary and Quaternary deposits (pl. 1) shows a pattern of relief that is quite different from that of the present land surface. Contours on the bedrock surface indicate a valley trending southward from Scott County and underlying the Finney basin, as described by Latta (1944). This valley continues southward to a low point 10–12 miles south of Garden City, where it converges with another major valley in the bedrock surface. The latter valley appears to trend southeastward from Kearny County to Haskell County.

The average slope of the bedrock surface from northwest to southeast is 11 feet per mile, as compared with the slope of the present surface in the same direction of 6 feet per mile. The slope difference shows that the bedrock surface probably has undergone greater erosion than the present surface or that an uplift occurred just prior to Pliocene deposition. The areas of greatest Tertiary and Quaternary fill are those where the slopes of the two surfaces are most divergent, such as in southwestern Finney County.

The areal extent of the bedrock formations underlying the unconsolidated deposits is shown in figure 5. All the formations are of Cretaceous age. Undifferentiated Lower Cretaceous rocks occur in the southwestern part of the county along the deepest channel in the bedrock surface. The Upper Cretaceous Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Chalk are in normal sequence, from oldest to youngest, as the altitude of the bedrock surface increases to the northeast.

The sandstone beds in the Lower Cretaceous formations constitute the principal bedrock aquifer in the county. They probably receive some recharge in southwestern Finney County, where they are in direct hydrologic connection with the saturated Tertiary and Qua-

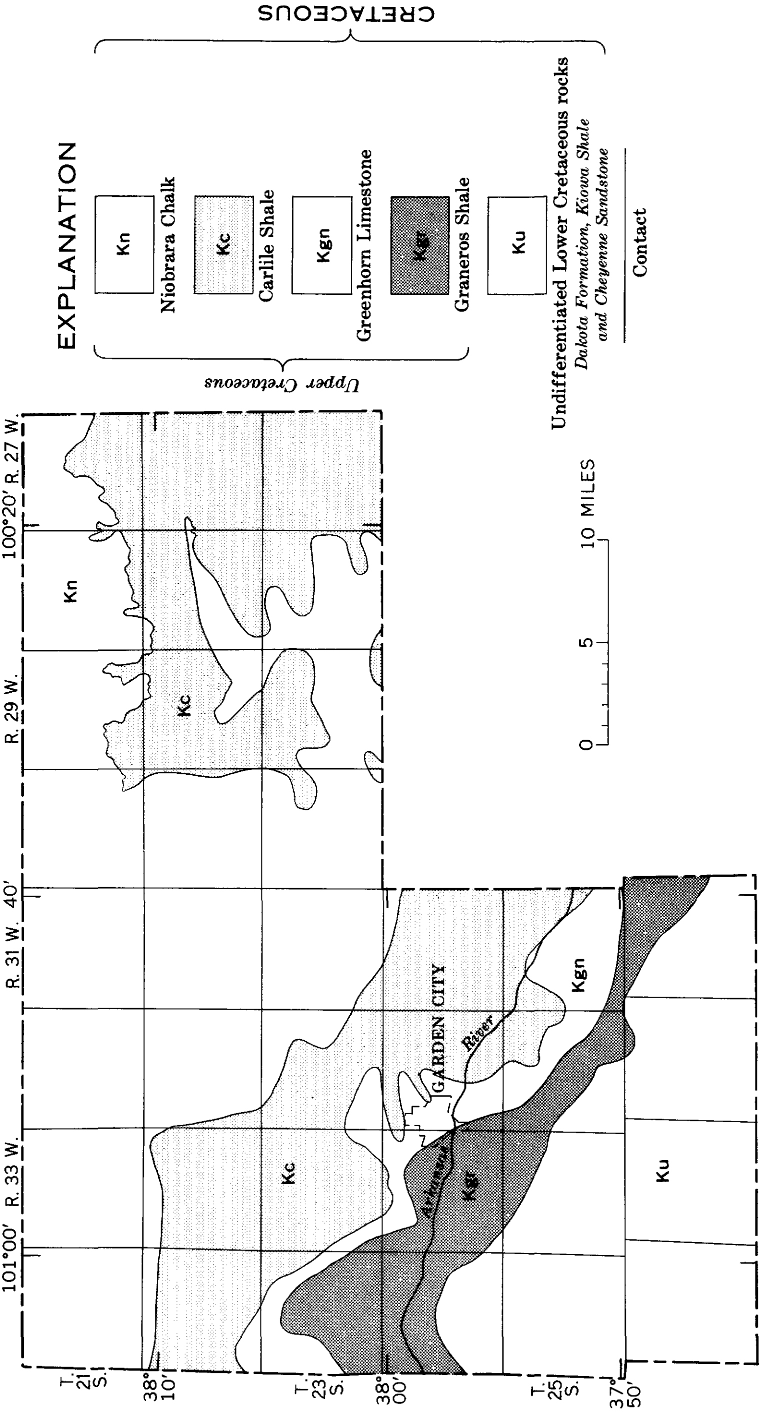


FIGURE 5.—Bedrock geology.

ternary deposits. The limestone, chalk, and shale of the Upper Cretaceous formations that underlie the Tertiary and Quaternary deposits are relatively impermeable and retard ground-water movement. Although some solution channels are present in the Niobrara Chalk, they are not believed to constitute a continuous aquifer.

STRUCTURE

A generalized structure map on the basal surface of the Greenhorn Limestone (fig. 6) was prepared for the part of Finney County where information is available. Thus, the structural map is not extended to the northeastern part of the county nor to the area south of the Arkansas River, where erosion removed the Greenhorn. The map reveals only the post-Graneros structural movements and does not include the deformation prior to the deposition of the Greenhorn Limestone. The base of the Greenhorn Limestone was chosen because the difference between the noncalcareous Graneros Shale and the limestones in the Greenhorn is clearly distinguishable on gamma-ray and resistivity logs (fig. 4). The structure map is based on 250 points obtained from gamma-ray and resistivity logs. A contour interval of 50 feet was used to minimize errors in surface altitudes.

The base of the Greenhorn Limestone displays an average northeasterly dip of 25 feet per mile from western Finney County (T. 23 S., R. 34 W.) to central Finney County (T. 21 S., R. 31 W.). The structure map suggests that the undulations of the Greenhorn structure represent gentle folding superimposed on the regional dip. The regional dip is the result of uplift of the Las Animas arch, which is southwest of Finney County. Finney County is on the easternmost flank of the regional structure. A closed-contour area in T. 22 S., R. 34 W., probably is a reflection of a deeper structural high. The dominant structural feature is a northerly plunging marginal syncline on the east border of the Los Animas arch (Lee and Merriam, 1954).

GEOLOGIC SECTIONS

The subsurface maps, the pre-Pliocene topographic map (pl. 1), the bedrock geology map (fig. 5), and the Greenhorn structure map (fig. 6) show geologic conditions in virtually horizontal planes; geologic sections show the details of stratigraphy and structure in vertical planes. In the Finney County investigation, four geologic sections were prepared to illustrate the interrelationship of the surface and subsurface geology (pl. 1). The Greenhorn structure (fig. 6) was projected on the pre-Greenhorn deposits and extended to the overlying deposits, including the Niobrara Chalk.

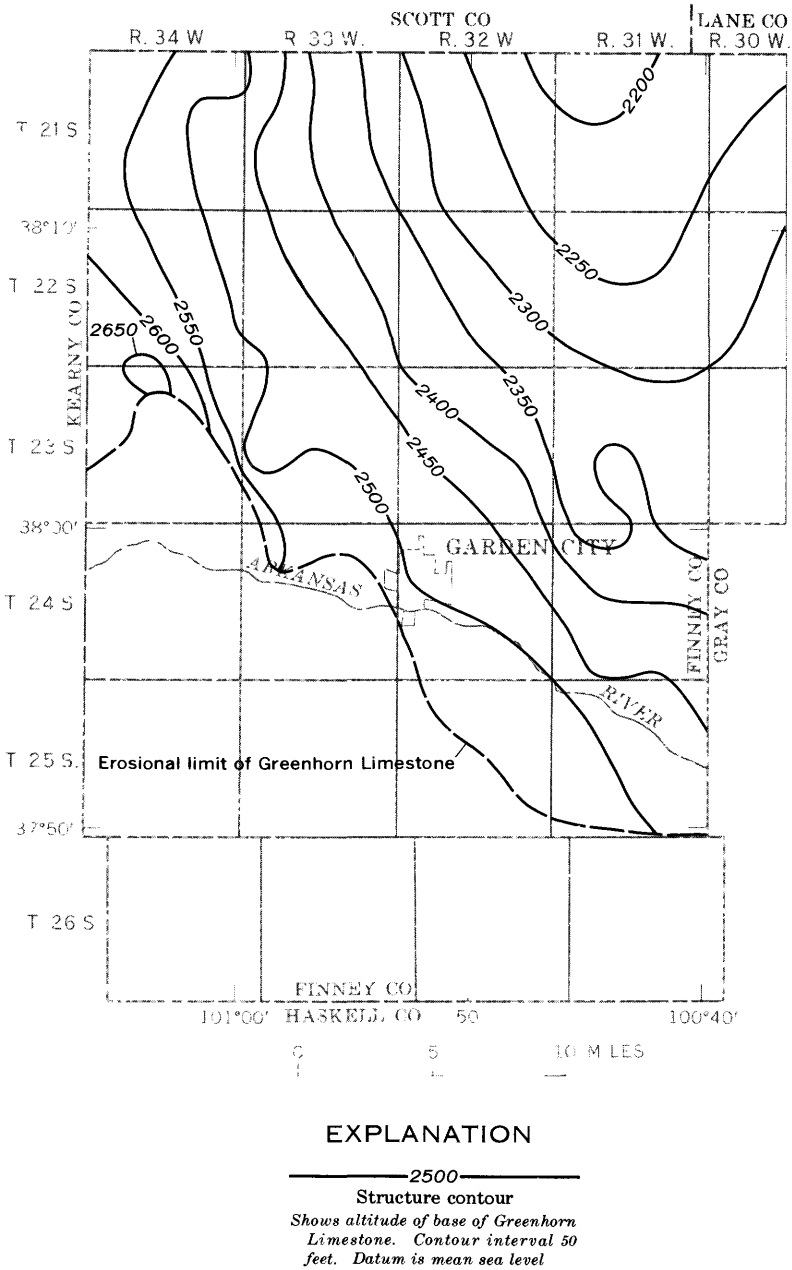


FIGURE 6.—Basal configuration of the Greenhorn Limestone in western Finney County.

The south-north geologic section *A–A′* extends from the Haskell County line to the Scott County line and coincides with the major drainage system on the pre-Tertiary and Quaternary topographic map (pl. 1). The increase in thickness of the pre-Pliocene deposits in the southern part of this geologic section illustrates greater erosion and subsequent deposition on the pre-Pliocene surface.

Geologic section *C–C′* trends south-north about 6–8 miles west of geologic section *A–A′*. This section was chosen to illustrate the bedrock high in the northwest corner of the county and to indicate the differential erosion of the resistant Niobrara Chalk and the nonresistant Carlile Shale.

The sections are very valuable in defining the unconsolidated ground-water reservoir of Finney County. For example, the south-north geologic sections, *A–A′* and *C–C′*, show a thickening of saturated deposits toward the south. The amount of water available to wells is greatest where the saturated Tertiary and Quaternary deposits are thickest.

East-west geologic section *B–B′* originates in eastern Kearny County and extends across Finney County to the southeast corner of the Finney County panhandle. This section indicates that water can easily enter Finney County from Kearny County. The area east of well 23–32–23cc illustrates a high bedrock surface and a decrease in saturated Tertiary and Quaternary deposits. Water levels are not continuous beyond well 23–31–35cc. The geologic section suggests that a limited amount of water flows into the panhandle, in northeastern Finney County.

Geologic section *D–D′* shows the subsurface geology of eastern Finney County 4–6 miles south of section *B–B′*. The structural relation between the east-west geologic sections is similar in depicting a downwarp in R. 31 W. This downwarp is an extension of the marginal syncline on the east flank of the Las Animas arch. The increased thickness of the Morrison(?) Formation on the gamma-ray log of well 24–31–29b was probably caused by deposition upon a Permian erosion surface and later by a gentle uplift or epeirogenic movement. Geologic section *D–D′* also shows that the saturated Tertiary and Quaternary deposits decrease in thickness eastward. The ground-water reservoir in Finney County, as illustrated by the geologic sections, is controlled by the thickness of the saturated Tertiary and Quaternary deposits. There is a general increase in thickness of these deposits in the central part of the county, and they thin in all directions except southeastward.

The Finney County topographic depression (Finney basin) was considered by Smith (1940) and Latta (1944) to be the result of post-Ogallala downwarping. East-west geologic section *B–B′* shows that the Finney basin between wells 23–32–21caa and 23–32–23cc is erosional and not structural. The deepest part of this bedrock-valley system is superimposed upon a structural high. The bedrock erosional high, as indicated by well 23–31–19c (center) is superimposed on a structural low. The present erosional surface reflects the bedrock erosional surface and not the structure. This geologic section illustrates that deformation followed deposition of the Niobrara Chalk (middle Late Cretaceous) and preceded deposition of the unconsolidated Ogallala Formation (Pliocene).

GEOLOGY IN RELATION TO GROUND WATER

PERMIAN SYSTEM—UPPER PERMIAN SERIES

UNDIFFERENTIATED RED BEDS

The Permian deposits consist of rocks comparable to the Whitehorse Formation, Day Creek Dolomite, and the Big Basin Sandstone. The deposition of the rocks was controlled by the Hugoton embayment, to the south. The outcrop pattern, illustrated by Merriam (1957, fig. 6), indicates that successively older beds crop out away from the center of the basin.

Character.—The undifferentiated red beds consist typically of dark-red to orange-red silty shale, siltstone, fine-grained sandstone, and shale. Beds of fine-grained dense dolomite, anhydrite, or gypsum occur in these deposits. The contact between the undiffereniated red beds and the overlying Upper Jurassic Morrison(?) Formation can be placed with accuracy by use of gamma-ray logs. The greater radioactivity of the red beds (fig. 4) is the criterion for the separation of the undifferentiated red beds and the Morrison(?) Formation.

Distribution and thickness.—Deposits of undifferentiated red beds underlie all of Finney County (pl. 1). These deposits thicken southward toward the center of the Hugoton embayment. The thickness, interpreted on gamma-ray logs, ranges from 200 feet in northeastern Finney County to 500 feet in southwestern Finney County.

Water supply.—No wells obtain water from the undifferentiated red beds in the county. Water from the red beds is believed to be highly mineralized and of poor quality for most uses.

JURASSIC SYSTEM—UPPER JURASSIC SERIES

MORRISON(?) FORMATION

Deposits believed to correlate with the Morrison(?) Formation have been identified in the subsurface of Finney County. Data based on lithology and stratigraphic position derived mainly from gamma-ray logs were used to differentiate the Morrison(?) Formation. A query is used to designate the Morrison(?) Formation because the rocks have not been directly correlated with paleontologically dated Morrison deposits in other areas.

Character.—Samples from the interval correlated with the Morrison(?) Formation were available from wells 23–33–5aa and 25–33–1bd. In these wells the predominant lithologic unit is a dark-gray noncalcareous to calcareous sandy shale; some shale beds are red or green. A distinctive feature is the fine- to medium-grained silty sandstone at the base of the formation. The contact between the Morrison(?) Formation and the underlying Permian red beds is easily determined on gamma-ray logs (fig. 4) because of the greater radioactivity of the red beds near the contact. The upper contact of the Morrison(?) Formation with the undifferentiated Lower Cretaceous deposits is less definite than the lower contact. The upper contact is evident where the Lower Cretaceous sandstone directly overlies the Morrison(?) shale, but the contact is indefinite where the Morrison(?) shale is overlain by Lower Cretaceous shale.

Distribution and thickness.—These deposits thicken slightly toward the east, as shown by geologic section *B–B′* (pl. 1). The eastward thickening may represent deposition in an old valley system which later had the Cretaceous marginal syncline superimposed upon it. Geologic section *D–D′* (pl. 1) also illustrates the thickening of the Morrison in the vicinity of the structural downwarp. Geologic sections *A–A′* and *C–C′* show the Morrison thickens toward the north. The thickness ranges from 50 feet in southern Finney County to 350 feet in northern Finney County and averages 182 feet (for 115 wells).

Water supply.—No wells obtain water from the Morrison(?) Formation. Sandstones in the Morrison are considered to be potential aquifers for domestic and stock uses.

CRETACEOUS SYSTEM—LOWER CRETACEOUS SERIES

UNDIFFERENTIATED LOWER CRETACEOUS DEPOSITS

The formations below the Upper Cretaceous Graneros Shale and above the Morrison(?) Formation are in many localities, variable in lithology both horizontally and vertically. Therefore, the Lower Cretaceous deposits are treated in this report as undifferentiated. These undifferentiated deposits are equivalent to the Cheyenne Sandstone, the Kiowa Shale, and the Dakota Formation, which have been differentiated in the subsurface elsewhere in southwestern Kansas (Fader and others, 1964).

Character.—The undifferentiated Lower Cretaceous deposits in many parts of Finney County consist of two sandstone units. The lower unit consists of gray to tan very fine grained to medium-grained silty lenticular sandstone. The sandstone is commonly interbedded with gray and red calcareous siltstones. The lower sandstone unit is in the stratigraphic position of the Cheyenne Sandstone, but its vertical limit has not been determined. The distinguishable lower contact between the basal sandstone unit of undifferentiated deposits and the shales in the underlying Morrison(?) Formation on the gamma-ray logs is shown in figure 4. However, in other areas of the county, the basal deposits consist of gray calcareous sandy siltstones that are not easily distinguished from the Morrison(?) shales.

An upper sandstone unit is persistent throughout much of Finney County. This unit generally consists of very fine grained to medium-grained calcareous sandstone. Layers of gray to black calcareous siltstone containing lignite and pyrite are interbedded with the sandstone beds. The upper sandstone unit is in the stratigraphic position of the Dakota Formation. The contact of the Upper Cretaceous Graneros Shale and the upper sandstone unit of undifferentiated Lower Cretaceous deposits is shown on the gamma-ray logs (fig. 4) as an abrupt lithologic change from shale to sandstone.

The interval between the upper and lower sandstone units is not distince in Finney County; accordingly, the sandstones cannot be separated. Blue-black shale, typical of the subsurface Kiowa Shale, is interbedded between sandstone beds in both the upper and lower sandstone units; therefore, it cannot be used as a stratigraphic marker. The time interval corresponding to shale deposition of the Kiowa Shale in other areas was probably represented in Finney County by a period of sandstone deposition.

Distribution and thickness.—The undifferentiated Lower Cretaceous deposits underlie all of Finney County, as shown by the geologic sections (pl. 1). In southern Finney County, post-Cretaceous erosion removed all Upper Cretaceous sediments and eroded into the Lower Cretaceous deposits. This is illustrated in figure 5.

The thickness of the undifferentiated deposits, where not affected by erosion, ranges from 120 to 460 feet and averages 272 feet (for 113 wells). The variation in thickness is probably the result of deposition upon the eroded surface of the Morrison(?) Formation. The Lower Cretaceous deposits are thickest where the underlying Morrison(?) is thin. The composite thickness of the two formations does not vary greatly over the area.

Water supply.—The sandstone beds of the Lower Cretaceous deposits are a potential source of water for household and stock uses throughout the county. In most of the area, however, adequate supplies are obtainable from the unconsolidated deposits at shallow depths.

When the unconsolidated deposits are thin and mostly drained, as in northeastern Finney County, water is generally available in the Lower Cretaceous sandstones.

CRETACEOUS SYSTEM—UPPER CRETACEOUS SERIES

The Upper Cretaceous deposits, although of geologic importance, are of little value as aquifiers in Finney County; accordingly, only the subsurface occurrences of these deposits are discussed. For detailed information concerning these formations at the outcrops and their stratigraphy, the reader is referred to Latta (1944).

GRANEROS SHALE

In the subsurface of Finney County, the Graneros Shale consists of dark-gray to black calcareous shale that contains thin limestone and bentonite streaks. Beds of gray to black noncalecareous shale are interbedded with the calcareous shale. The term Graneros, as used in this report, refers to the shale interval separating a sandstone unit believed to be Lower Cretaceous from an overlying shaly limestone assigned to the Greenhorn Limestone. The upper contact of the Graneros Shale with the Greenhorn Limestone is sharp and distinct on the gamma-ray logs (fig. 4). The lower contact of the Graneros with the sandstone in the undifferentiated Lower Cretaceous is also sharp on the gamma-ray logs.

The Graneros Shale underlies Finney County, except in the area south of the Arkansas River, where post-Cretaceous erosion has removed it. The Graneros subcrop pattern is shown in figure 5. The thickness of the Graneros ranges from 55 to 110 feet and averages 79 feet (for 89 wells).

No wells are known to obtain water from the Graneros Shale. The Graneros acts as a confining bed for water in the underlying Lower Cretaceous sandstone beds.

GREENHORN LIMESTONE

The Greenhorn Limestone consists of a dark-gray shaly limestone interbedded with dark-gray calcareous shale in most parts of the county. In other parts of the county the Greenhorn consists of a dark-gray calcareous shale containing thin limestone streaks. The upper contact of the Greenhorn with the Carlile Shale is shown by the representative gamma-ray log (fig. 4) as a gradational contact 40 feet below the base of the surface casing. Much of the deflection in gamma-ray intensity of the Carlile Shale shown in figure 4 results from a dampening effect of the cemented surface casing. The limestone and limy shale units in the basal Carlile are difficult to differentiate from the limestone and limy shale units in the Greenhorn; accordingly, the contact is queried. In some places in Finney County the contact is more easily determined between a limy shale of the Carlile and a limestone in the Greenhorn. The deflection on the gamma-ray logs is extremely sharp between the Greenhorn and the Graneros and was used to prepare the structure map (fig. 6).

The distribution of the Greenhorn in Finney County is governed also by postdepositional erosion (fig. 5). The thickness of the Greenhorn ranges from 45 to 75 feet and averages about 62 feet (for 83 wells).

The Greenhorn is not an aquifer and does not yield water to wells in Finney County.

CARLILE SHALE

The Carlile Shale, the oldest rock formation exposed in Finney County, is shown on the geologic map (pl. 1). The Carlile outcrops in the country were discussed by Latta (1944) and by Hattin (1962). In the subsurface the Carlile consists of an upper, dark-gray to blue-black noncalcareous shale that is interbedded with calcareous silty very fine grained sandstone in some places. The lower unit consists of dark-gray to black chalky shale. The upper contact of the Carlile with the Niobrara Chalk is abrupt and distinctive, as shown by the gamma-ray log (fig. 4). In wells where the Carlile Shale is directly overlain by unconsolidated Tertiary and Quaternary deposits, the contact shown on the gamma-ray logs is also sharp and distinctive because of the difference in lithology.

The thickness of the Carlile, where not affected by post-Cretaceous erosion, ranges from 209 to 330 feet and averages about 251 feet (for 55 wells). The bedrock geology map (fig. 5) shows the extensive Carlile subcrop pattern north of the Arkansas River.

Latta (1944) reported that the Carlile Shale yielded small quantities of water for domestic purposes from the silty sandstone in the upper part of the formation in the panhandle of northeastern Finney County. In most places the Carlile does not yield adequate supplies of ground water for domestic and stock purposes.

NIOBRARA CHALK

The Niobrara Chalk is exposed along the Pawnee drainage in northeastern Finney County (pl. 1). The Niobrara stratigraphy at the outcrops was fully discussed by Latta (1944). The Niobrara in Finney County can be divided into two units. The lower unit consists of white to yellow massive chalky limestone, and the upper unit consists of yellow chalk and light- to dark-gray beds of chalky shale. The upper contact of the Niobrara Chalk with the unconsolidated Tertiary and Quaternary deposits, as indicated in the typical gamma-ray curve (fig. 4), is generally distinct; however, where calcareous beds in the unconsolidated deposits overlie the Niobrara Chalk, the contact is difficult to differentiate without samples.

The Niobrara subcrop area is extensive in the northern part of the county (fig. 5). The thickness of the Niobrara is variable because of post-Cretaceous erosion and ranges from 0 to 200 feet. The lower unit of the Niobrara forms a resistant bed, as shown in geologic sections *A–A′* and *C–C′* (pl. 1), in the northwestern part of the county. The Niobrara is shown as the uppermost unit of the structural downfolds on geologic sections *B–B′* and *A–A′*, where the lower limestone unit represents a resistant bedrock hill.

The lower limestone unit of the Niobrara Chalk is not a major water-bearing unit. However, fracture and solution openings in the unit do yield small quantities of water for domestic and stock use in areas where adequate supplies are not available from the Tertiary and Quaternary deposits.

TERTIARY AND QUATERNARY SYSTEMS

The unconsolidated deposits of Tertiary and Quaternary age are the major water-bearing sediments and are the source of virtually all water supplies in the county. Tertiary and Quaternary rocks underlie the surface over the greatest part of the mapped area (pl. 1). These deposits are either correlated at the outcrops with Pliocene Ogallala Formation or assigned a Pleistocene age. The surficial deposits are divided into the undifferentiated deposits, loess, and dune sand of Pleistocene age and the alluvium of Pleistocene and Holocene age.

Observations of the Tertiary and Quaternary deposits in the subsurface, made by the examinations of numerous samples under the binocular miscroscope and the interpretation of several hundred drillers' logs, indicate to the authors that the individual beds or lenses of sand, gravel, silt, and clay are not continuous over wide areas. On the contrary, the individual beds pinch out or grade, almost imperceptibly, both laterally and vertically, into finer or coarser material of another bed or lense. However, if the mixture of materials were designated as to its major constituent, certain gross lithologic groupings or units would be evident. Units composed mostly of sand and gravel form aquifers in which water movement is unrestricted; units composed mostly of silts form aquitards in which water movement is retarded but not prevented; and units composed mostly of clay form aquicludes in which water movement is virtually prevented.

In Finney County the Tertiary and Quaternary deposits are not separated in the subsurface except in localities where detailed lithologic studies of the water-bearing deposits are available from the aquifer test sites. An example of this type of analysis is shown by the geologic section (fig. 15) of the Raymond Morris pumping test site (well 24–32–25bda1). At this site the basal unit of the undifferentiated Pleistocene deposits consists of fine to very coarse subangular to rounded sand and very fine to medium angular to subrounded gravel with streaks of tan limy silt. The sand and gravel is predominantly arkosic. The Pliocene-Pleistocene boundary is placed at the base of the arkosic sand and gravel. The Pleistocene sand and gravel unit overlies tan sandy limy silt that is interbedded with tannish-white caliche. The lower, fine-grained unit is considered to belong to the Pliocene Ogallala Formation. The aquifers in the Ogallala are below the silt and caliche bed.

Aquifers of different ages exhibit different properties (aquifer constants) dependent mainly upon lithologic conditions at the time of deposition. Data from aquifer tests show that the Pleistocene and Holocene alluvium and the undifferentiated Pleistocene deposits have greater permeabilities than the Ogallala Formation. Wells that tap multiple aquifers in the undifferentiated Pleistocene deposits and the Ogallala Formation have average permeabilities that vary between the values for the individual aquifers.

The thickness of the Tertiary and Quaternary deposits is shown in figure 7. This map was prepared by using approximately 1,000 control points. The greatest thickness of unconsolidated deposits occurs over topographic lows on the bedrock surface; the least thickness occurs over bedrock highs. The maximum thickness, 500 feet or more, occurs in the southwestern part of the county. The deposits thin in the north, where the thickness ranges from 100 to 200 feet. The Finney topographic basin and the marginal syncline are also indicated by this map. Closed contours are mainly the result of different rates in slope between the two surfaces.

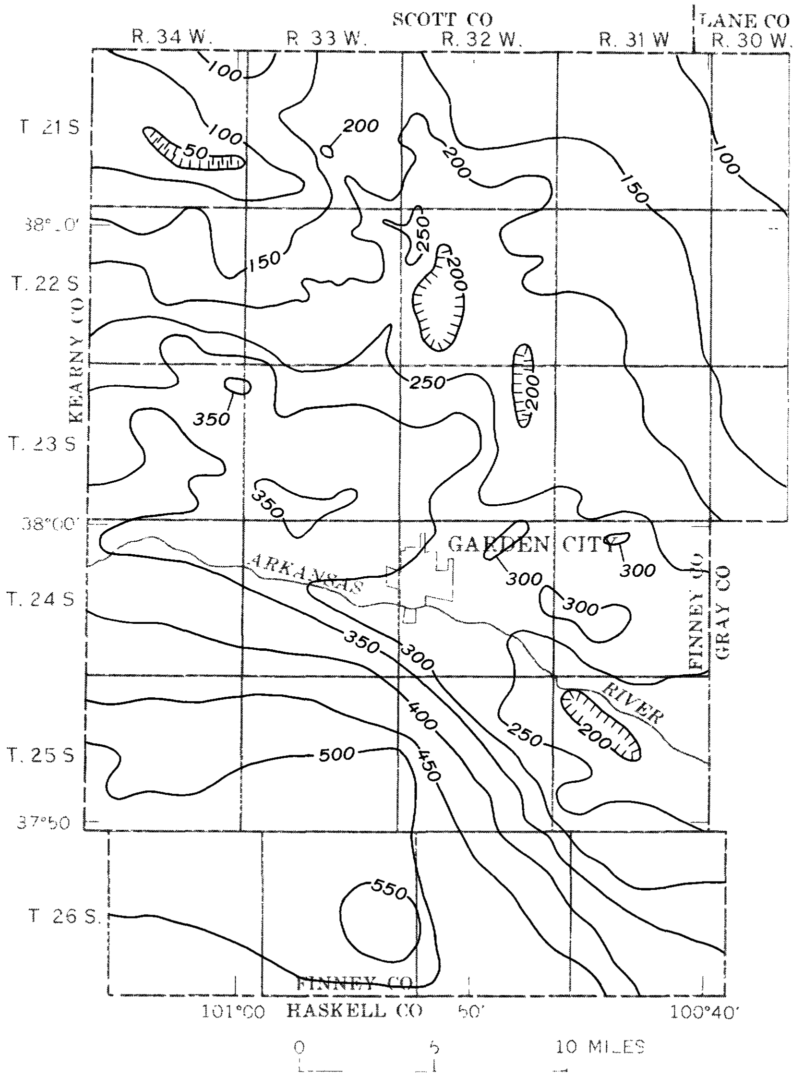
PLIOCENE SERIES

OGALLALA FORMATION

In Finney County all deposits above the Cretaceous bedrock and below the Pleistocene deposits are correlated with the Pliocene Ogallala Formation. Divisions of the Ogallala that are elsewhere applied (Frye and others, 1956) are not distinguished in this report.

The Ogallala was deposited upon the Cretaceous erosional surface by eastward- and southeastward-flowing streams. The load source for

373-262 O—70——3



EXPLANATION

500
Line of equal thickness of Quaternary and Tertiary deposits
Interval 50 feet

FIGURE 7.—Thickness of Tertiary and Quaternary deposits in western Finney County.

the streams was the erosional debris of the Rocky Mountains and the exposed sedimentary rocks of southeastern Colorado and western Kansas. The Ogallala was deposited as alluvial valley fills which overlapped laterally from the axes of the main valleys upon the valley sides. This type of sedimentation by shifting meandering streams caused the Ogallala sediments to be a heterogeneous assortment of aluvial sediments. Beds within the Ogallala can be correlated with confidence over short distances only.

Character.—The Ogallala Formation in the subsurface of Finney County consists of tan, reddish-tan, and yellow sediments. The deposits contain individual and admixed layers of stream-deposited silt, clay, sand, and gravel. Caliche and "mortar beds" (caliche-cemented sand and gravel) occur at several horizons throughout the formation. The layering of different materials is the significant feature observed during drilling and collecting of samples from the Ogallala. Beds of uniformly sized sand are rare, as the sorting is extremely poor. Gravel layers generally are interbedded with lenses of sand, silt, and clay. The poorly sorted gravel beds at or near the base of the formation contain abundant phenoclasts of reworked local materials. South of the Arkansas River the gravel contains a large percentage of reworked angular to subangular fragments of Lower Cretaceous sandstone and ironstone associated with subangular to subrounded quartz, showing the close correlation between the lithology of the gravel and the underlying deposits. North of the Arkansas River the dominant phenoclasts are composed of reworked Upper Cretaceous limestone and chalk. The ease of penetration of the formation by the rotary drill, as well as the association of typical alluvial material, in most places, precluded misidentification of the reworked material as bedrock.

Distribution and thickness.—The Ogallala Formation was penetrated beneath younger deposits in most of the northern part of the county, except in the Finney basin. In the sandhills area south of the Arkansas River, the areal extent of the Ogallala is not definitely known, owing to lack of detailed well information. Because of the similarity in lithology, the contact between the Ogallala Formation and the overlying Pleistocene deposits was difficult to determine from drillers' logs, gamma-ray logs, and some test-hole logs. The thickness of the Ogallala ranges from 0 to an estimated 300 feet.

Water supply.—The Ogallala Formation is one of the principal aquifers in Finney County. Sand and gravel beds in the Ogallala—because of admixed clays and silts—do not yield as much water in most places as do comparable thicknesses of lower Pleistocene sand and gravel.

Sites for large-capacity wells are generally selected after several test holes have been drilled. Lateral variations in the permeability of the deposits are so great that several test holes may be needed within a quarter section to locate a suitable site for a well.

Wells are generally perforated opposite all water-bearing zones; hence, the yield from the Ogallala in multiple-aquifer wells is not easily determined. Yields of wells screened in only the Ogallala Formation range from a few gallons a minute, for domestic and stock wells, to 1,250 gpm in well 24–32–25bda1.

PLEISTOCENE AND HOLOCENE SERIES

UNDIFFERENTIATED PLEISTOCENE DEPOSITS

Overlying the Ogallala Formation in Finney County are sand, gravel, silt, and clay deposits of Pleistocene age. These deposits are judged to be equivalents of the lower Pleistocene deposits in Grant and Stanton Counties, Kans. (Fader and others, 1964). Broad shallow valleys cut into or through the Ogallala Formation were filled and overtopped by early Pleistocene sediments. A heterogeneous mixture of coarse-grained channel deposits and fine-grained stream or lake deposits resulted from the ensuing sequence of streams that meandered across the alluvial plain. A typical example of the valley cutting and redeposition is the Finney basin. There, these deposits have subtle differences in lithology from those in the Ogallala Formation. Just as in other parts of southwestern Kansas, the distinctive granitic-arkosic gravel lithofacies of the undifferentiated Pleistocene deposits can be differentiated in many wells (Gutentag, 1963). However, a study of the subsurface contact between the Ogallala and the Pleistocene throughout the area was not within the scope of this investigation.

A small isolated deposit of the lower Pleistocene marker bed, the Pearlette Ash, is in the SW¼SE¼ sec. 16, T. 21 S., R. 30 W., along a tributary of the Pawnee River. However, the ash was not found in the subsurface samples.

The terrace 20–25 feet above the flood plain south of the Arkansas River, is in most localities, an erosional surface of late Pleistocene age. The terrace (surface) is underlain by deposits ranging in age from early to late Pleistocene. The minimum age of the deposits upon which the terrace was developed is indicated by the occurrence of late Pleistocene vertebrate fossils in gravel pits south of Garden City (Latta, 1944). This gravel material was deposted in a valley that was cut into the lower Pleistocene deposits east of Garden City and into very early upper Pleistocene deposits west of Garden City, where the old valley crossed the Finney topographic basin.

Character.—The fine materials in the undifferentiated lower Pleistocene deposits consist primarily of tan to reddish-brown calcareous silt, sandy silt, and clayey silt, which are interbedded in some places with gray to almost white caliche beds. Fossiliferous blue clayey silt and silty clay are present in these fine-grained deposits in parts of the county. North of the Arkansas River, the fossiliferous blue silt and clay are associated with the subsurface Pleistocene deposits in the Finney topographic basin.

Fine to very coarse subangular to subrounded gravel and coarse sand containing fine to medium sand interbedded with thin silt streaks make up most of the undifferentiated deposits. In most places the coarse-grained deposits are not indurated with caliche, as are those in the Ogallala. The gravel and coarse sand deposits contain phenoclasts of granite, pink feldspar (orthoclase), quartz, quartzite, and rock fragments from other igneous and metamorphic rocks. Minor amounts of water-worn pebbles of caliche and chalcedony are in the gravel and sand. In parts of the county, minor amounts of local-source material are associated with the normal granitic-arkosic gravel lithofacies.

The fine-sand beds in the undifferentiated Pleistocene deposits cannot be distinguished from those of the Ogallala Formation; however, these fine-sand beds are near the top of the formation, above the lithologically distinctive basal gravel. Deposits underlying the terrace, which is 20–25 feet above the flood plain south of the Arkansas River, consist mostly of unconsolidated fine sand to cobbles. Sand and gravel beds are composed mainly of subrounded to rounded quartz and contain some feldspar and dark minerals. Phenoclasts of quartz, feldspar, and granite are the major constituents; smaller amounts of igneous and metamorphic rock are also present. Reworked caliche and "mortar beds" are minor constituents.

Distribution and thickness.—Undifferentiated deposits of Pleistocene age were penetrated beneath younger sediments throughout much of the area. The exact thickness of these deposits has not been determined throughout the county; however, it ranges from 0 to 300 feet in areas where detailed geologic data are available.

Water supply.—Much of the water pumped in the county is from aquifers in the undifferentiated Pleistocene deposits. Most irrigation wells screened in both Pleistocene and Ogallala deposits receive the larger part of their yield from the undifferentiated Pleistocene deposits. Wells perforated in only the Pleistocene deposits are reported to yield as much as 2,500 gpm.

LOESS

A mantle of loess overlies many of the older deposits in Finney County (pl. 1). The loess is composed predominantly of silt-sized particles deposited primarily by wind. The term "loess" is used in this report to designate the eolian silt on the uplands, where it has not been moved appreciably by agencies of erosion other than the wind. Colluvial slope veneers, which represent downward creep of loess from higher levels, are included with the loess. Some water-deposited loess-like silts, reworked from upslope loess deposits, are included with the primarily wind deposited loess.

Sources and origin of loess in the High Plains of Nebraska and Kansas were discussed by Frye and Leonard (1951) and by Lugn (1962). Smith (1940) considered the loess of southwestern Kansas to be of late Pleistocene age. The presence of dune sand over both terrace alluvium and partially weathered loess in Finney County suggests that the sand was deposited during or after the later stages of loess deposition. Therefore, the loess does not postdate the dune sand; rather, it is in part contemporaneous with the dune deposits. Loess of one or more late Pleistocene ages occurs in Finney County, but for purposes of this report the loess deposits are considered as a unit.

Character.—The parent loess material consists of a pale-yellowish-brown calcareous porous silt loam. A number of soils have developed from the parent loess principally because of variations in relief. Relief affects the amount of water that infiltrates into the soil and the amount of soil removed by erosion. On the steeper slopes, less precipitation infiltrates the soil, and more soil is removed by erosion than on the more gentle slopes. Some of the runoff from the steeper slopes infiltrates the soils on the more gentle slopes. As a consequence, soils on the more sloping land show little profile development and are generally calcareous at or near the surface, whereas soils on the nearly level uplands show distinct profile development, and the depth to calcareous material in these soils ranges from 1 to 2 feet.

Distribution and thickness.—Loess covers much of Finney County north of the Arkansas River, and minor amounts occur south of the river. Harner, Agell, Lobmeyer, and Jantz (1965) reported that loess-derived soils cover 548,157 acres, or 65.8 percent of Finney County.

The thickness of the loess and loess-derived soils ranges from 5 to 30 feet and averages about 12 feet for the county.

Water supply.—The loess deposits in Finney County are above the water table and are not water-bearing materials. However, recharge through the loess to the water table does occur. The infiltration rate of the loess soils, reported by Harner, Agell, Lobmeyer, and Jantz (1965), ranges from 0.1 to 0.8 inch per hour, and the average rate is about 0.3 inch per hour. This infiltration rate is lower than that for the dune sand and accounts for a greater runoff in the loess area. Except in the Finney County panhandle, most of the runoff is retained within the county, as it is ponded in depressions from which the water ultimately percolates into the soil or evaporates. The field capacity [1] of loess is high; it ranges from 26 to 28.5 percent by weight (Meyer and others, 1953). Field capacity indicates the level of soil moisture above which downward percolation is most likely to occur. The amount of water needed to restore the moisture deficit created in the loess during the growing season after long intervals between rains is about two to three times that for dune sand. Most loess soils require a large amount of water to restore them to field capacity, and the infiltration rate is somewhat lower than that in the dune sands; therefore, ground-water recharge in an area mantled by loess would be considerably less than in an equivalent area mantled by dune sand.

Most irrigation in Finney County is in the loess area, and the amount of water applied to these soils by irrigation and rainfall is as much as two to three times that applied by rainfall to the loess soils under dry-land farming. Therefore, on the irrigated soils the amount of water available for movement by deep percolation is considerably greater. The irrigated areas are considered to be major areas of recharge as compared with dry-land farming areas.

DUNE SAND

Dune sand of late Pleistocene age is exposed principally south of the Arkansas River, although small isolated areas are found north of the river (pl. 1). The sand has been accumulated by wind action to form hills as much as 60 feet high. The major part of the dune area is fairly well stabilized by grass and low-shrub vegetation. Sand bluestem and sand sagebrush are the predominant types of natural flora.

Character.—The dune sand is composed predominantly of fine to medium subrounded to well-rounded slightly frosted quartz sand. Minor amounts of clay, silt, and very fine and coarse sands are also included. The sand in the dunes is characteristically crossbeded and is white or reddish brown.

Simonett (1960) suggested that the possible sources of dune sand are (1) the terrace deposits below the dune sand, (2) the exposed terrace deposits near the Arkansas River, and (3) the alluvium along the Arkansas River. Locally, it is difficult to separate the dune sand from the sand in the underlying older alluvial deposits.

Distribution and thickness.—Harner, Agell, Lobmeyer, and Jantz (1965) reported that dune-derived soils and active dunes cover an area of 156,700 acres, or 18.8 percent of the county.

[1] The moisture content of soil in the field 2 or 3 days after a thorough wetting of the soil profile by rain or irrigation water, expressed in percent moisture by weight.

The areas of actively moving dunes and blowouts are not extensive; they total only 1,185 acres.

The thickness of dune sand in most areas ranges from 20 to 35 feet. Most test holes were drilled in the depressions between sandhills and did not penetrate the maximum thickness of the dune sand, which is believed to be about 75 feet.

Water supply.—The dune sand is above the water table and is not a water-bearing deposit. But, because it has a relatively high permeability, it provides an area of potential recharge from precipitation. The field capacity of the dune sand is low—approximately 6 percent by weight. Owing to this factor, the amount of water needed to restore the soil-moisture deficit is not great, even in the summer growing season after long intervals between rains.

The infiltration rate of dune sand is reported to be greater than 0.8 inch per hour (Harner and others, 1965). The high infiltration rate and the low amount of water required to restore the moisture deficit account for a greater depth of penetration of precipitation in the dune sand than in the upland loess-covered areas. In periods of copious precipitation, considerable amounts of water can move by deep percolation to recharge the ground-water supply.

ALLUVIUM

Alluvium of Pleistocene and Holocene age underlies the flood plain of the Arkansas and Pawnee Rivers (pl. 1). The Holocene deposits consist of a thin mantle (5–10 ft) of clay, silt, and fine sand. The underlying deposits of late Pleistocene age consist of coarse sand, gravel, and cobbles, and of thin beds of silty clay.

Character.—The alluvium along the Arkansas River consists of poorly sorted stream deposits which range from clay to cobbles. The fine-grained alluvial deposits contain silt and clay beds that represent the flood-plain environment. These gray to brown silt and clay beds contain an invertebrate fauna. The coarse-grained alluvial deposits consist of sand and gravel, which represent the channel facies of the alluvium. The alluvial sands consist of fine to coarse quartz fragments and minor amounts of feldspar and dark minerals. Gravel composes most of the alluvium and ranges from fine to very coarse, but it is mostly fine to medium with large amounts of interbedded sand. The gravel is subangular to rounded, with well-rounded larger phenoclasts of granite, feldspar, quartz, and fragments of igneous and metamorphic rocks.

The alluvium in the Pawnee Valley consists of silt and clay underlain by coarse sand and gravel. The gravel is subangular to rounded, with well-rounded larger phenoclasts of feldspar, quartz, granite, and fragments of other igneous and metamorphic rocks.

Distribution and thickness.—The width of the alluvium of the Arkansas Valley ranges from 1 mile at a point 5 miles upstream from the Gray County line to about 3 miles near Holcomb and averages about 2 miles. The thickness of the alluvium differs in various parts of the valley but averages about 40 feet.

The width of the Pawnee Valley flood plain, underlain by alluvium, is ¼–1 mile. Latta (1944) reported the thickness of the alluvium in the Pawnee Valley to range from a few feet to about 30 feet.

Water supply.—The sand and gravel of the alluvium and the saturated material in the terrace deposits are recharged principally by the Arkansas River, by local precipitation, and by underflow from the dune sand.

These alluvial deposits are the most permeable water-bearing deposits in Finney County. Yields from single irrigation wells range from 800 to 1,200 gpm, and yields from battery wells range from 3,000 to 5,000 gpm.

HYDROLOGY

THE GROUND-WATER SYSTEM

The unconsolidated Pliocene and Pleistocene deposits of Finney County contain a number of interconnected aquifers. In this report, these aquifers and the interbedded and overlying beds of silt and sandy silt are considered to be a single ground-water reservoir in which ground water is stored until discharged either naturally or by pumping. The extent of the aquifers has been discussed under "Geology." The geologic sections (pl. 1) and the discussion of the Tertiary and Quaternary deposits (p. 24) define areal and depth limits of the reservoir. That part of the county east of R. 31 W., where the unconsolidated aquifers are discontinuous, was not considered in the hydrologic analysis of the ground-water reservoir. The surface area of the reservoir, as defined in this report, is 552,960 acres.

Under natural conditions the water table was near equilibrium and the quantity of water stored in this reservoir was relatively constant, varying slightly in response to changes in annual precipitation, streamflow, and vegetation. However, the development of a number of wells and the pumping of large quantities of water for irrigation and other uses have disturbed the natural equilibrium of the reservoir and resulted in lowering of the water table in some areas. The principal objective of this investigation was to study the effects of pumping on the reservoir and to develop tools and techniques to aid the evaluation of effects caused by the anticipated increase in ground-water use.

The understanding of the operation of a ground-water reservoir requires a knowledge of a number of factors, summarized as follows:

$$\text{Recharge} = \text{change in storage} + \text{discharge.}$$

Although each of these factors may consist of several components, the relation between them is simple and direct. When recharge exceeds discharge, the quantity of water in storage increases and the water table rises. Conversely, as currently applies to Finney County, when discharge exceeds the recharge, the quantity of water stored decreases and the water table declines.

Recharge, storage, and discharge of water from the Finney County ground-water reservoir were studied in detail to determine the gross effects on water availability caused by development of irrigation supplies. The storage coefficient and the permeability of the aquifers were determined by a series of aquifer tests. (For summary, see p. 49 and table 2.)

Discharge from the reservoir was separated into natural and artificial (pumpage) components. The natural discharge includes outflow through the aquifers to adjacent counties and a small amount of water discharged to the Arkansas River in eastern Finney County.

The amount of water in storage was computed by multiplying the volume of saturated sediments by the storage coefficient. Changes in the amount of water stored as a result of changes in the water table were determined from analyses of water-level change maps for various periods of time.

The recharge from streams, precipitation, return flow from irrigation, and inflow through the aquifers was the most difficult factor to evaluate. For this reason, a number of different approaches to the problem were used.

HYDROLOGIC OBSERVATIONS

HYDRAULIC PROPERTIES

To make quantitative predictions involving projected development, the values of the hydraulic constants of the aquifer must be known. Knowledge of the values of these constants, their distribution in space, the areal extent of the aquifers, and the hydrologic boundaries controlling flow on the perimeter of the reservoir enable one to make predictions of the hydraulic behavior of an underground reservoir for any postulated pattern of water withdrawal.

The fundamental constants needed are the coefficients of transmissibility (T), storage (S), and leakage (p'). The coefficient of transmissibility is expressed in gallons per day per foot (discharge per unit normal width per unit hydraulic gradient) and indicates the ability of the aquifer to transmit water. The storage coefficent for confined flow is defined as the volume of water that a unit decline of head releases from storage in a vertical prism in the aquifer unit cross section. For unconfined flow, the storage coefficient is sensibly equal to the specific yield (effective porosity of the material at the position of the water table). The coefficient of leakage characterizes the ability of the semiconfining bed to transmit water vertically—up or down—and is defined as the quantity of flow that crosses a unit area of the semiconfining bed per unit hydraulic gradient.

The assumption that these coefficients are constant throughout the aquifer and that they remain so with time is common to most known formulas describing the potential distribution in ground-water reservoirs. If this assumption were true, the coefficients could be determined from one pumping test; however, in practice, coefficients differ, reflecting differences in geologic conditions, such as thickness and the heterogeneous anisotropic nature of the sediments.

AQUIFER TESTS AND ANALYSES

As part of this investigation, nine aquifer tests were made, and the test data and analyses are summarized in table 2. Three of the pumped wells were screened in one aquifer; the other six wells were screened in more than one aquifer. Five of the aquifer tests are presented in detail to show the types of analyses made, and the results of the other four aquifer tests are summarized to avoid duplication of routine analysis.

TABLE 2.—*Summary of Finney County aquifer tests*

Well	Transmissibility (gpd per ft)	Storage coefficient	Thickness (feet)	Permeability (gpd per sq ft)	Geologic (units)	Aquifer description
21-33-2ac1	62,000	0.00063	42	1,500	Pleistocene	Single aquifer.
24-34-1ddb1	140,000	.14	53	2,600	Pleistocene and Holocene alluvium.	Do.
21-32-8ab1	*84,000	*.0014	64	*1,300	Pleistocene	Do.
26-32-31cc	90,000	.22	138	650	Pleistocene and Pliocene.	Multiple aquifer.
24-32-25bda1	29,000	.00062	90	320	Pliocene	Do.
22-31-32db1	67,000	.048	61	1,100	Pleistocene and Pliocene.	Do.
24-32-16ab	72,000	.0017	115	620	do	Do.
24-33-7ba	40,000	.00057	56	710	do	Do.
26-33-12ca	140,000	.0012	153	920	do	Do.

*Approximation only, owing to change from artesian to water-table conditions during test. (See also p. 39 and 40.)

GROSS TEST

The test made on well 21–33–2ac1 (owned by Ralph Gross) indicated that artesian conditions prevailed. The pumped well is reported to be 125 feet deep and the static water level was 38.1 feet below land surface. The lithology in the area is as follows: Silt and sandy silt with limy clay, 0–74 feet; sand and gravel, 74–151 feet; silt and interbedded sand, 151–174 feet; and shale, 174–180 feet. The well was pumped at an average rate of 1,080 gpm for approximately 4 days. Two observation wells were installed, 200 and 400 feet south of the pumped well. A continuous record of water levels in the observation wells was obtained by using electrical water-sensing devices and water-level recorders. The time-drawdown plots made from test data conformed very closely to the Theis nonequilibrium type curve.

Figure 8 shows the curves of drawdown versus time derived from the water-level measurements made in each of the observation wells. Although both curves match the Theis nonequilibrium type curve (fig. 8), the analysis shows a somewhat different value for the coefficients T and S. Actually, the results are close, as the calculated transmissibility was 62,000 gpd per ft at 200 feet, and was 75,000 gpd per ft at 400 feet. Part of this difference may be the result of partial penetration of the observation well at 400 feet. Because of this, results calculated from the well 200 feet from the pumped well were believed to be the more representative of the aquifer.

The tests indicate that the aquifer at this location is artesian and that there is no evidence of leakage. The storage coefficient calculated from drawdowns measured at 200 feet is 0.00063 and at 400 feet is 0.00052, both of which are typical of artesian aquifers.

SCHOPF TEST

A pumping test was completed on well 24–34–1ddb1 at the Ora Schopf farm. The pumped well is 70 feet deep, and its bottom 50 feet is screened in the alluvium. The well was pumped for about 6⅓ days. Five observation wells were installed, at 10 feet, 50 feet, 100 feet, 200 feet, and 450 feet, in a line east from the pumped well. The data were analyzed by the Thiem method (1906) for calculating transmissibility and by Jacob's intercept method (Ferris and others, 1962, p. 92) for calculating coefficient of storage. The drawdown-distance plot is shown in figure 9.

Neutron access tubes were installed 1 foot from each observation well. Before the test began, moisture contents were determined above, and at intervals of 1 foot below, the water table. During the test, moisture contents were determined at various times, and the water level

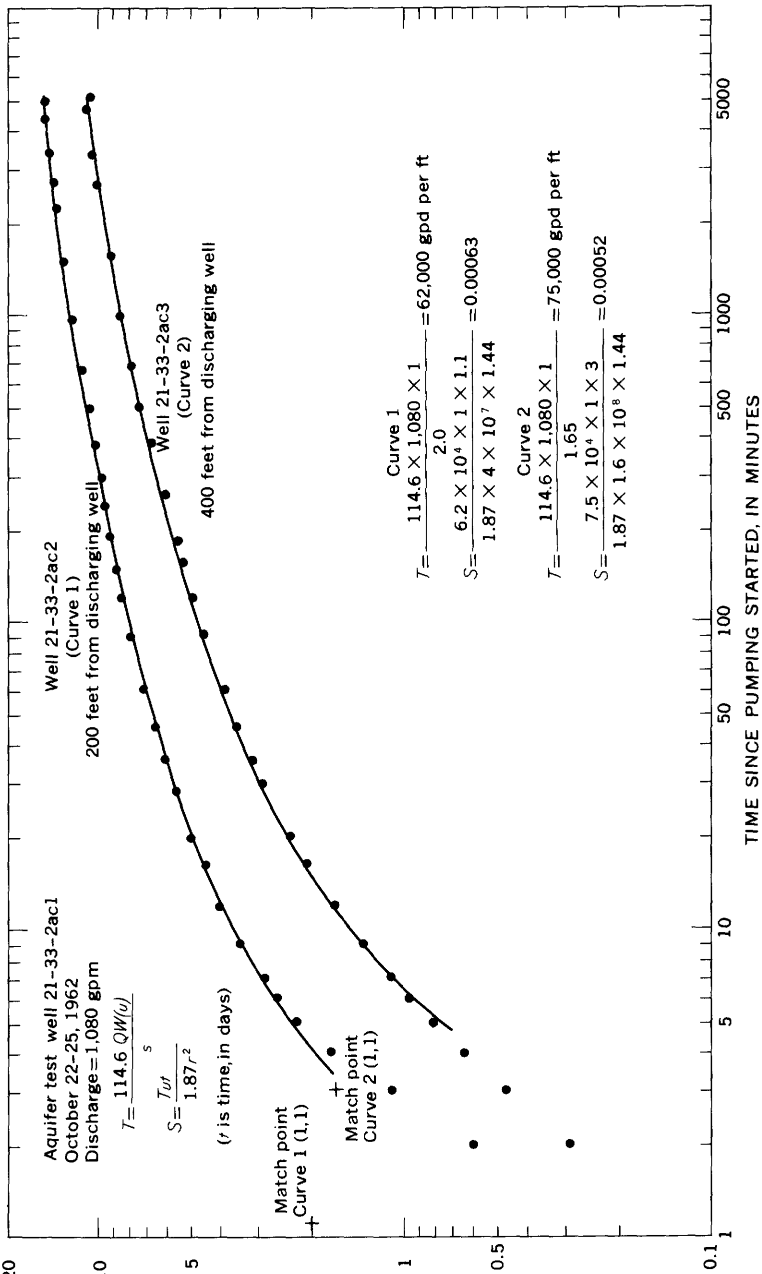


FIGURE 8.—Drawdown of water levels in observation wells 21–33–2ac2 and 21–33–2ac3 plotted against time, in minutes, since pumping started.

was noted to decline at a faster rate than the water-bearing material dewatered. This condition was most evident in the wells nearest the pumped well. In the observation well 10 feet from the pumped well, the water level declined 7 feet during the first day of pumping, but only the top 3 feet of water-bearing material had approached complete drainage. At a depth of 1½ feet below the static water table, 65 minutes elapsed before measurable drainage began. Drainage then progressed rapidly and in the next 45 minutes was 65 percent of the value obtained at 24 hours. Figure 10 shows the rate of drainage of the top 3 feet of saturated section (18–19 ft. below land surface) 10 feet radially from the pumped well. Similar delayed drainage was noted in all the neutron access wells, although the magnitude was not as great. The storage coefficient determined by the neutron meter was 0.20, which is comparable to the value of 0.19 determined from analyses of drawdown observed in wells at 10 and 100 feet from the pumped well (Meyer, 1962).

All methods of analysis for determining the coefficient of transmissibility indicate a figure of 140,000 gpd per ft. The neutron probe showed the storage coefficient to be 0.20 at 10 feet from the well. The value obtained for S in an analysis of drawdowns in which all observation wells were considered was 0.14. The latter value is an average value of drained and partially drained material after pumping for

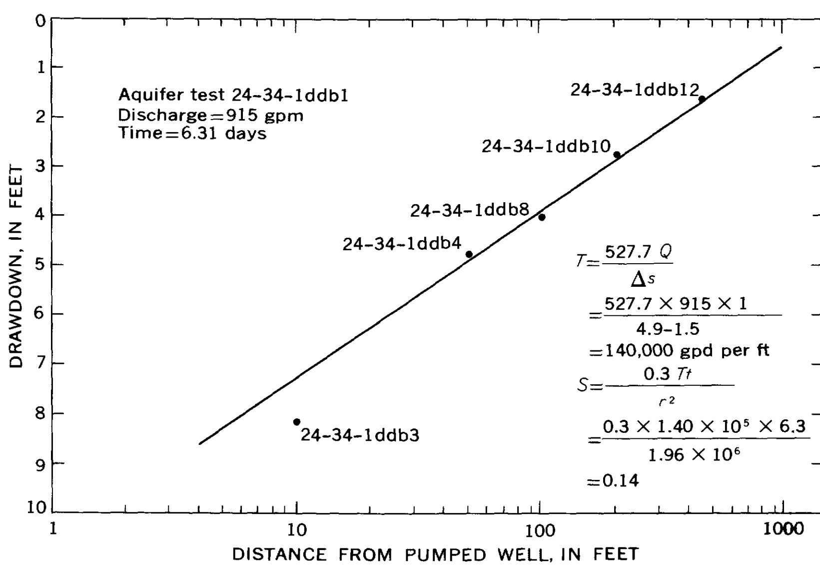


FIGURE 9.—Drawdown of water levels in observation wells 6 days after pumping started in aquifer test 24–34–1ddb1.

152 hours. If the test had been run for a long period of time (60 days or more), the coefficient of storage should have approached or exceeded the value obtained by the neutron meter. A coefficient of 0.20 is considered to be more representative for the long-term computations. (See p. 58. Similar evidence was simulated by Stallman (1965) in an electric analog.

BARNETT TEST

Well 21–32–8ab1, operated by C. L. Barnett, was used as the pumped well in completing an aquifer test at this location. The well was drilled through the Pleistocene deposits to a depth of 155 feet and was terminated in shale. Interbedded silt and clay beds extend from the soil zone to 65 feet. The sand and gravel aquifer is continuous from 66 feet below land surface. The well was pumped continuously for 3 weeks at an average rate of 2,230 gpm. Shortly after pumping started, the water level declined below the top of the aquifer, causing a change from artesian to water-table conditions. The rate of recovery of the water table was measured in two observation wells, one located 200 feet north and the other 400 feet south of the pumped well. The Theis

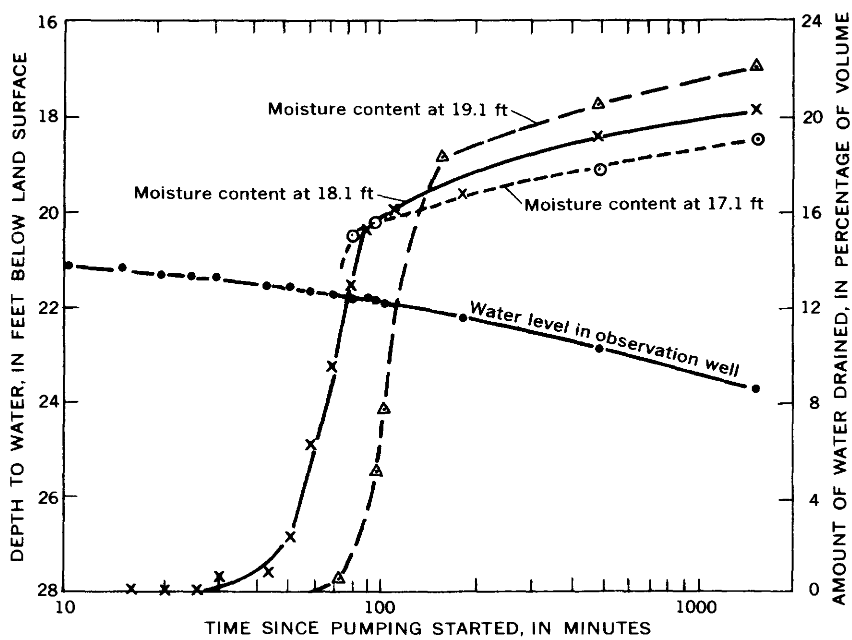


FIGURE 10.—Depth to water in observation well 22–34–1ddb1 and amount of water drained at depths of 17.1, 18,1, and 19.1 feet, as determined by neutron moisture probe in access tubing 10 feet from pumped well. (From Meyer, 1962.)

recovery method was used to analyze the data. The recovery plots (fig. 11) show a change in slope which would normally indicate heterogeneous conditions. In this test the change in slope of well 21–32–8ab2 was interpreted to indicate that part of the cone of depression was operating under unconfined conditions. The rate of recovery was moderate in the unconfined part of the cone in the immediate vicinity of the pumped well. The rate of recovery in the rest of the cone, under confined conditions, was more rapid. Figure 12 illustrates the generalized shape of the cone of depression.

At the end of 3 weeks pumping, or at the beginning of the recovery test, the observation well 200 feet away from the pumped well had approximately 1 foot of artesian head, indicating that only a small part of the cone of influence was operating under unconfined conditions. Quantitative determinations of coefficients by use of available analytical equations are dubious for tests that include a change from artesian to water-table conditions; therefore, values for this test are only approximate.

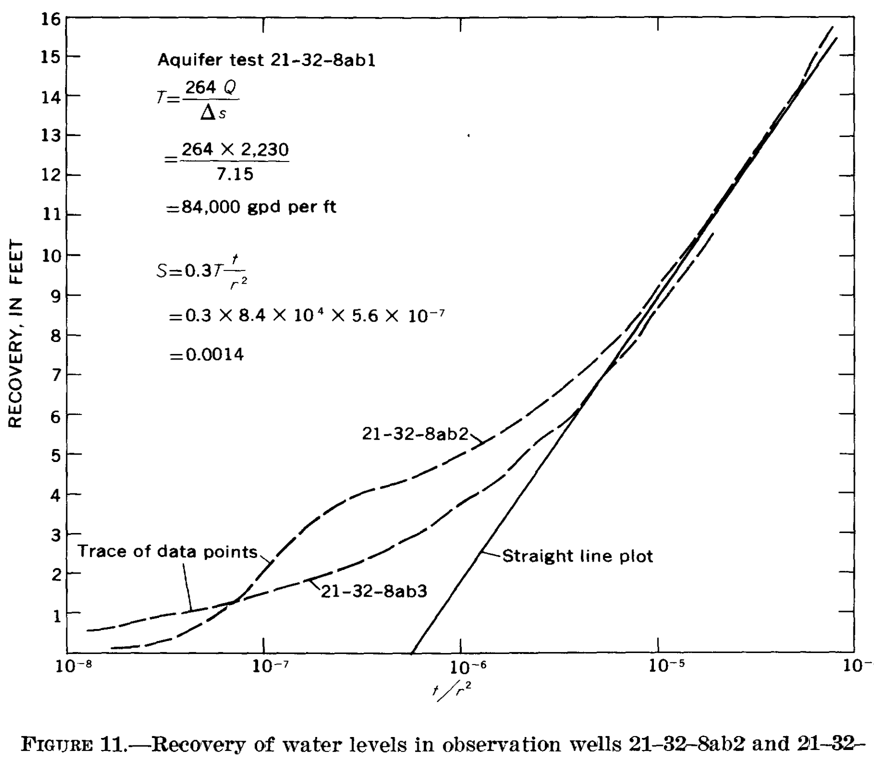


FIGURE 11.—Recovery of water levels in observation wells 21–32–8ab2 and 21–32–8ab3 plotted against t/r^2 since pumping stopped in well 21–32–8ab1. t is time, in days, since pumping stopped; r is distance, in feet, from pumped well.

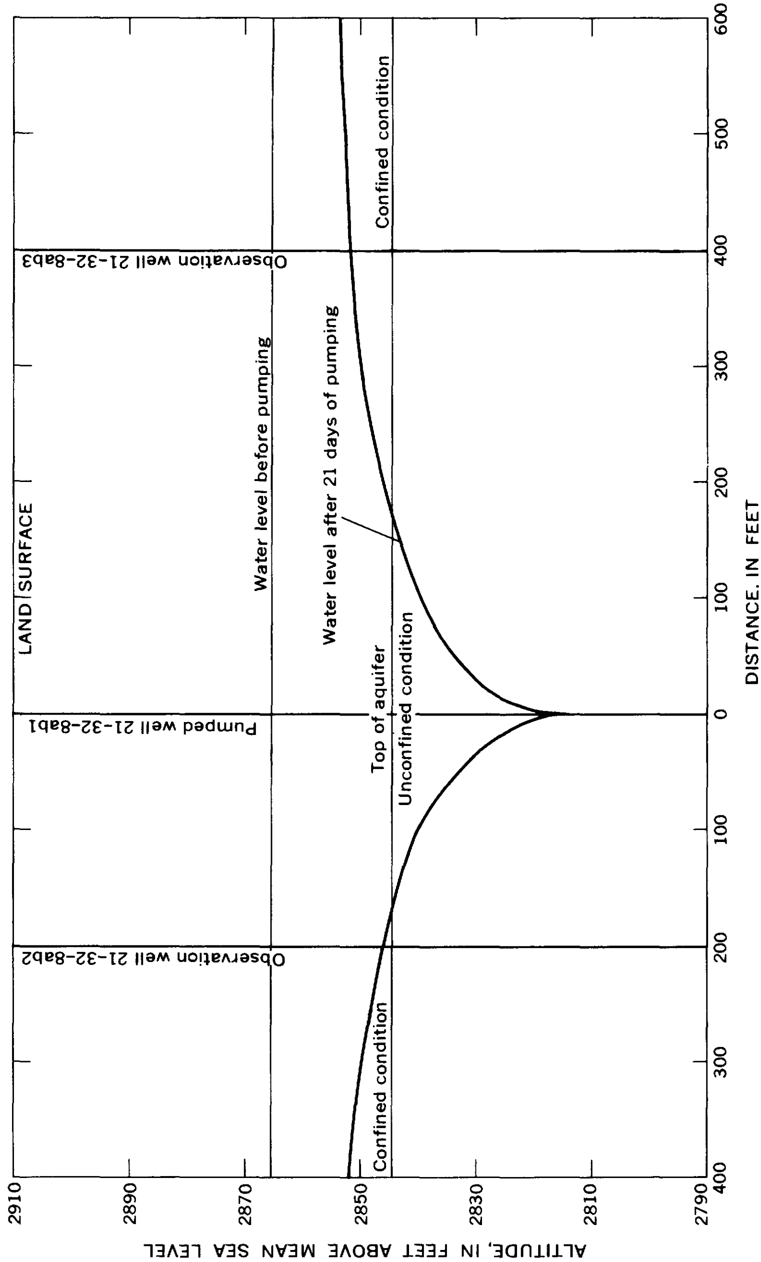


FIGURE 12.—Shape of the cone of depression and the top of the aquifer at well 21–32–8ab1.

SNODGRASS TEST

Another aquifer test was completed using well 26–32–31cc, which is owned by Cecil Snodgrass. The log of the pumped well indicates that two major aquifers of Tertiary and Quaternary age are penetrated by the pumped well. The upper aquifer of sand and gravel is between the depths of 115 and 254 feet below the land surface. From the depth 254 feet to 305 feet is a layer of silt that is an aquitard. The lower aquifer consists of sand and gravel from 305 feet to the bottom of the well, at 334 feet. The upper aquifer is unconfined, and the lower aquifer is confined. The well was pumped continuously from April 5 to June 15, 1963, at an average rate of 1,095 gpm. The observation well (26–33–36dd1) was 625 feet from the pumped well and was screened in the upper, or major, aquifer. The pumped well was screened in both aquifers. Figure 13 shows the plotted drawdown data obtained in the observation well. The part of the curve from 18,000 minutes to 82,000 minutes was used to make the analysis. The transmissibility of 90,000 gpd per ft and the storage coefficient of 0.22 obtained indicate an effective water-table condition. This part of the curve was chosen for analysis because during this time an equilibrium condition is judged to have existed between the two aquifers. The lower aquifer was assumed to have reached a steady-state leaky-artesian condition, and virtually all the water was being supplied by the unconfined aquifer. Thus, the above conditions produced the expected curvature shown by the drawdown plot in figure 13.

To test the existence of leaky-artesian conditions, an additional observation well (26–33–36dd2) was installed 625 feet from the pumped well and was screened in the artesian (lower) aquifer. Another test was made, and a record of the drawdown in each aquifer was obtained. The well was pumped continuously from April 24 to May 29, 1964. The pumping rate varied from 994 gpm to 1,108 gpm. Figure 14 shows the graph of time versus drawdown for the upper and lower aquifers. After 10 days (14,400 min) of pumping, the lower aquifer had reached a steady-state condition, as no further drawdown occurred until the pumping rate inceased from 993 gpm to 1,066 gpm, when another equilibrium condition was reached, and no further decline resulted. The logarithmic rate of drawdown in the upper aquifer increased after 10 days. At this time and for the rest of the test, the upper aquifer supplied virtually all water entering the pumped well.

The drawdown recorded in the upper aquifer reflects, in part, the artesian-head decline of the lower aquifer because part of the water is supplied by the lower aquifer. This causes a rather rapid decline for the first 80 minutes on the drawdown curve (fig. 13). The relatively flat section of the drawdown curve, from 100 to 1,440 minutes, is

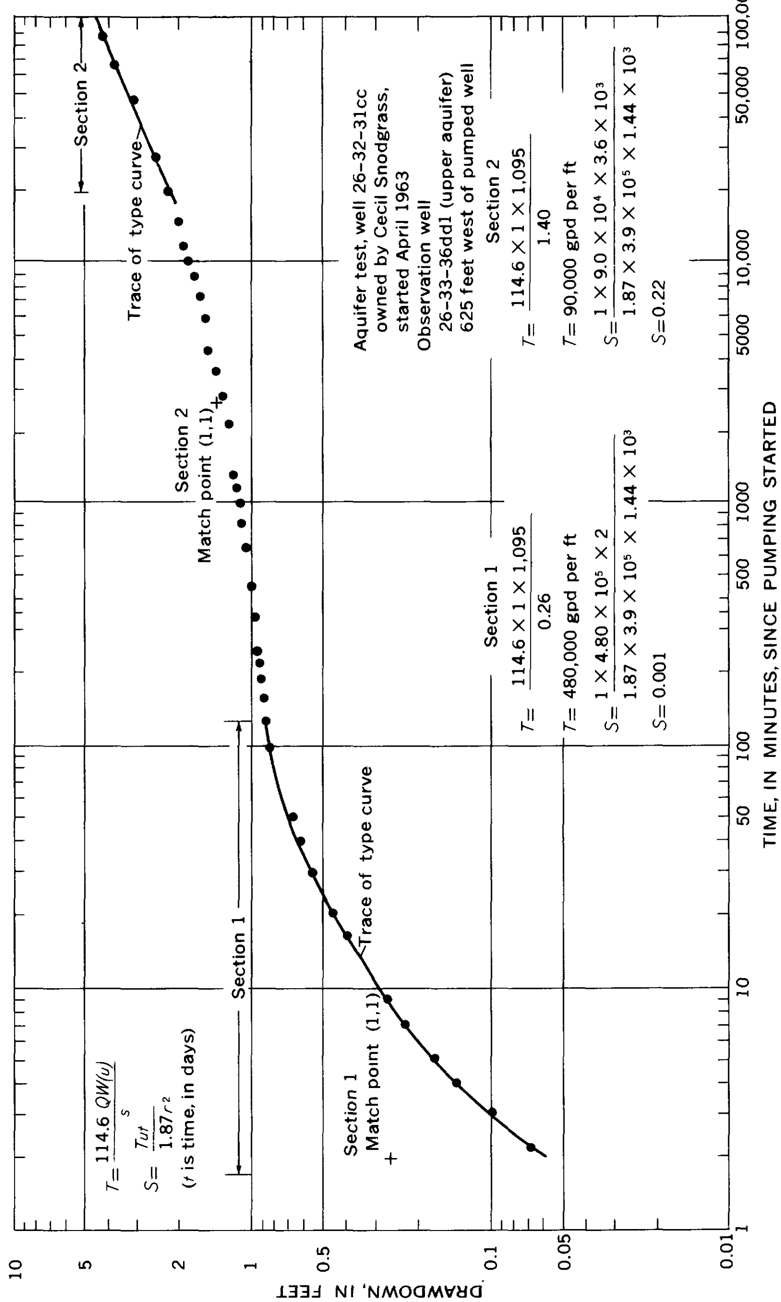


FIGURE 13.—Drawdown in observation well 26–33–46dd1 (screened in upper aquifer) plotted against time, in minutes, since pumping started.

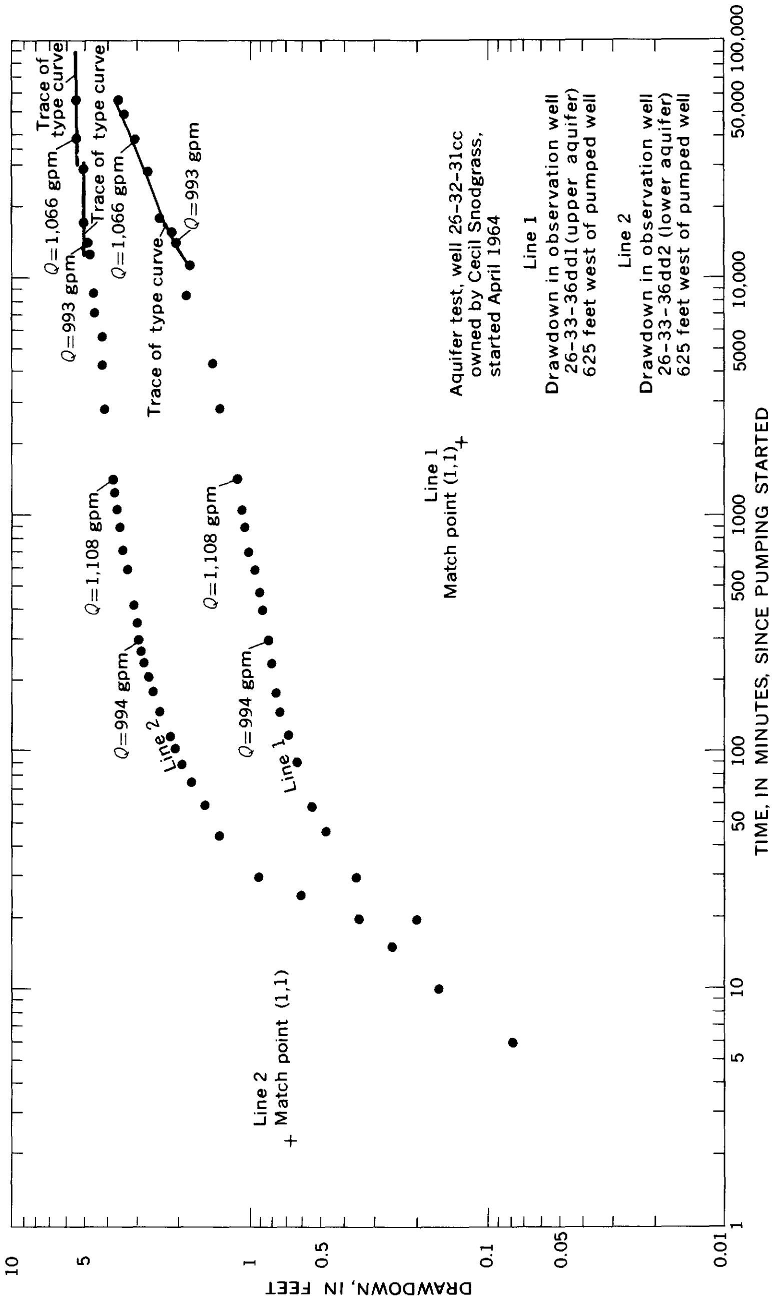


FIGURE 14.—Drawdown in observation well 26-33-36dd1 (screened in upper aquifer) and well 26-33-36dd2 (screened in lower aquifer) plotted against time since pumping started.

caused by a combination of delayed drainage from the unconfined aquifer and vertical-flow components between the water table and the pumping well. The section of the curve from 1,440 minutes to 20,160 minutes shows a gradual increase in the amount of vertical downward leakage until the leakage is sufficient to supply the amount of water pumped from the confined aquifer. The remaining part of the curve shows the drawdown where steady-state leaky-artesian conditions exist in the confined aquifer.

If the early part of the curve (fig. 13) were used to find the hydraulic constants, a transmissibility of 480,000 gpd per ft and a storage coefficient of 1.0×10^{-3} would be obtained for the upper aquifer. These values indicate that the results from pumping tests of relatively short duration in multiaquifer wells must be evaluated carefully.

MORRIS TEST

Well 24–32–25bda1, owned by Raymond Morris, was used as the pumped well for an aquifer test where four aquifers were present. For convenience in discussing this test, the four aquifers will be identified as A, B, C, and D, from the uppermost aquifer downward. The lithology at the location is given in figure 15. The pumped well was drilled to a depth of 256 feet and was perforated in aquifers C and D (fig. 15). Observation wells were installed at 20 feet, 150 feet, 450 feet and 750 feet south of the pumped well. At each of the above-mentioned distances, four wells were installed, each one screened in only one of the four aquifers. Figure 16 shows the shape of the cone of depression in each of the aquifers after 8 days of pumping compared with the static water level prior to pumping. The well was pumped at an average rate of 1,260 gpm. Because the water levels are at the same elevation in aquifers C and D at a distance of 450 feet, they can be considered to be operating as a single aquifer at this location. All the water entered the well from the two lower aquifers; however, part of the water was supplied by downward leakage from the upper aquifers. By use of the nonsteady leaky-artesian analysis (Hantush and Jacob, 1955) of the time-drawdown plot of the two lower aquifers at 450 feet (fig. 17), the transmissibility of these aquifers (C and D) is computed to be 29,000 gpd per ft, the storage coefficient is 0.00062, and the coefficient of leakage is 0.28 gpd per sq ft per ft.

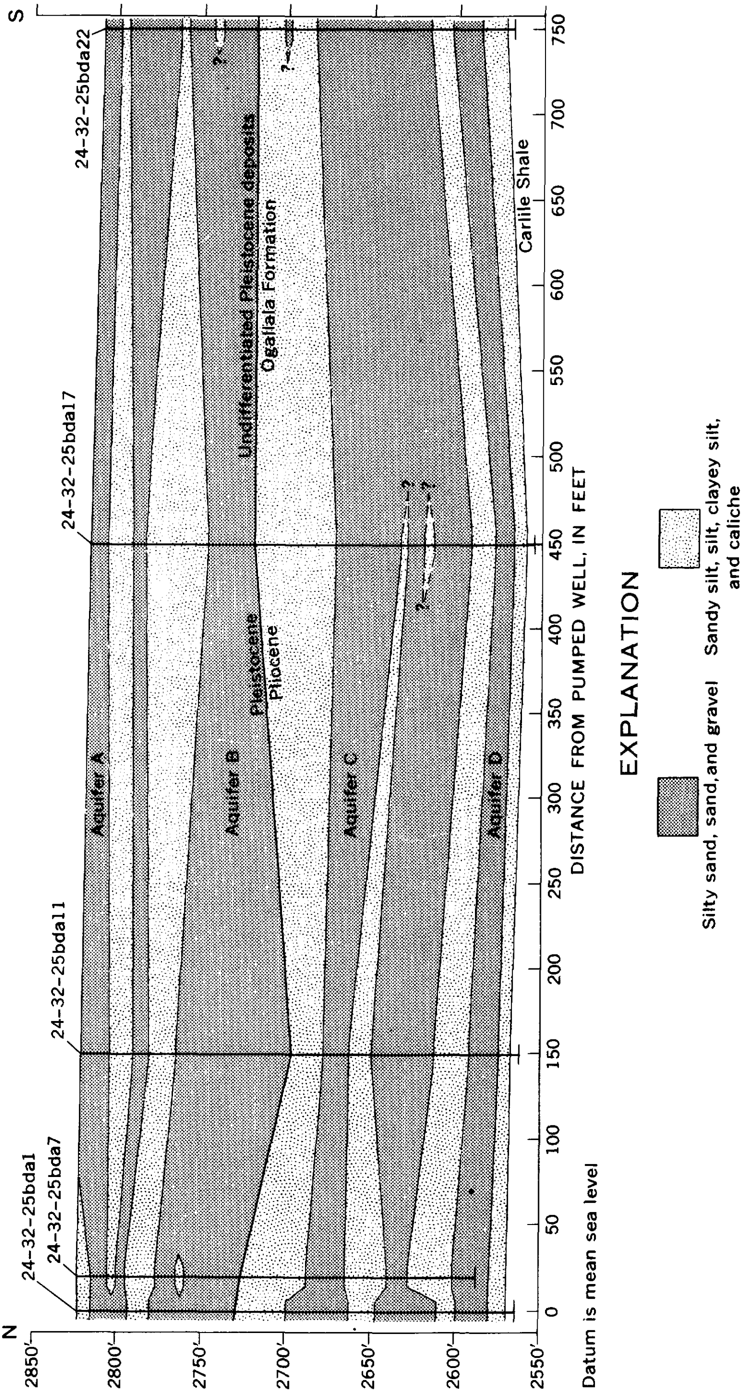


FIGURE 15.—Geologic setting at the site of aquifer test 24-32-25bda1.

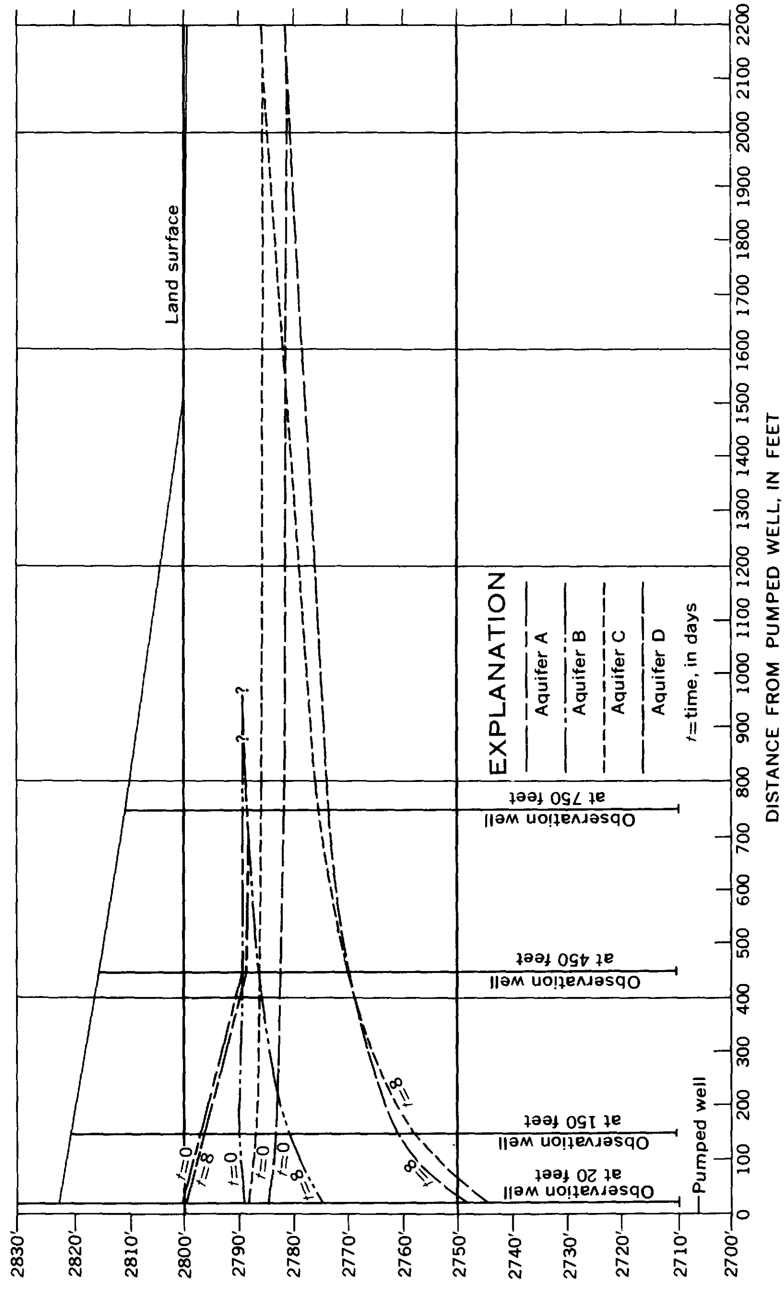


FIGURE 16.—Water levels at aquifer test well 24-32-25bda1 after 8 days of pumping compared with static water levels prior to pumping.

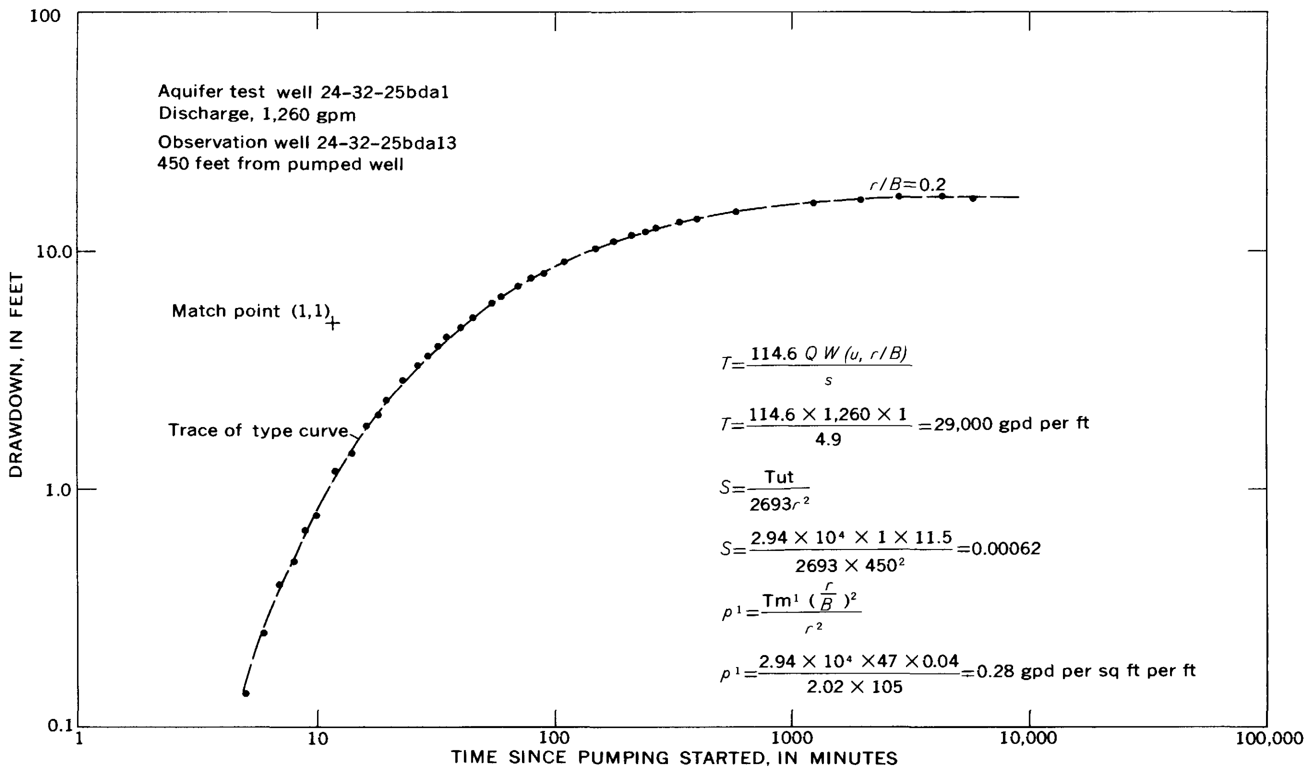


FIGURE 17.—Drawdown in observation well 24–32–25bda13 plotted against time, in minutes, since pumping started.

The quantity of leakage may be determined by using the following formula:

$$Q=\frac{T}{B^2}A\Delta h,$$

where Q is the amount of leakage through a vertical column of the semiconfining bed, A is the basal area through which leakage occurred, B is the leakage factor, in feet, and Δh is the difference between the average altitudes of the water levels in aquifers B and C. The amount of leakage was found to be 160,000 gpd, or approximately 9.0 percent of the water pumped from the well.

SUMMARY OF TESTS

The summary of aquifer test data (table 2) shows a correlation between geologic units and permeabilities. In the aquifer test of well 24–34–1ddb1 (Schopf test), the well was screened in a single aquifer of Pleistocene and Holocene age (alluvium) and the permeability was 2,600 gpd per sq ft. In aquifer test 21–33–2ac1 (Gross test), the well was screened in a single aquifer of Pleistocene age (undifferentiated Pleistocene deposits) and the permeability was 1,500 gpd per sq ft. In the aquifer test of well 21–32–8ab1 (Barnett test), the well was screened in a single aquifer (undifferentiated Pleistocene deposits) and the permeability was 1,300 gpd per sq ft. In aquifer test 24–32–25bda1 (Morris test), two aquifers of Pliocene age (Ogallala Formation) were screened, and the permeability was 320 gpd per sq ft.

All the other pumping tests were made in multiple aquifers with various amounts of Pleistocene and Pliocene deposits. The permeabilities obtained from these tests were 620–1,100 gpd per sq ft. In general, the higher permeabilities were found to occur where the Pleistocene deposits are thicker than the Pliocene deposits.

GROUND-WATER FLOW INTO AND OUT OF THE RESERVOIR

Ground water enters Finney County from Kearny County on the west and from Scott County on the north and flows southeastward, almost parallel to the Arkansas River. Ground water flows from Finney County into Gray County on the east and into Haskell County on the south and discharges from aquifers into the Arkansas River. Ground-water flow is dependent upon transmissibility, the hydraulic gradient, and the length of the perimeter through which the flow occurs. The flow may be computed by the formula:

$$Q=TIL,$$

where

Q = flow, in gallons per day;
T = transmissibility, in gallons per day per foot;
I = hydraulic gradient, in feet per mile; and
L = length of the perimeter on county border through which ground water is flowing, in miles.

The permeabilities obtained from pumping tests were applied through drillers' logs to determine transmissibilities of the aquifers at various locations. The above equation was used with calculated transmissibilities and water-level maps for computing the rate of inflow to, and outflow from, the county.

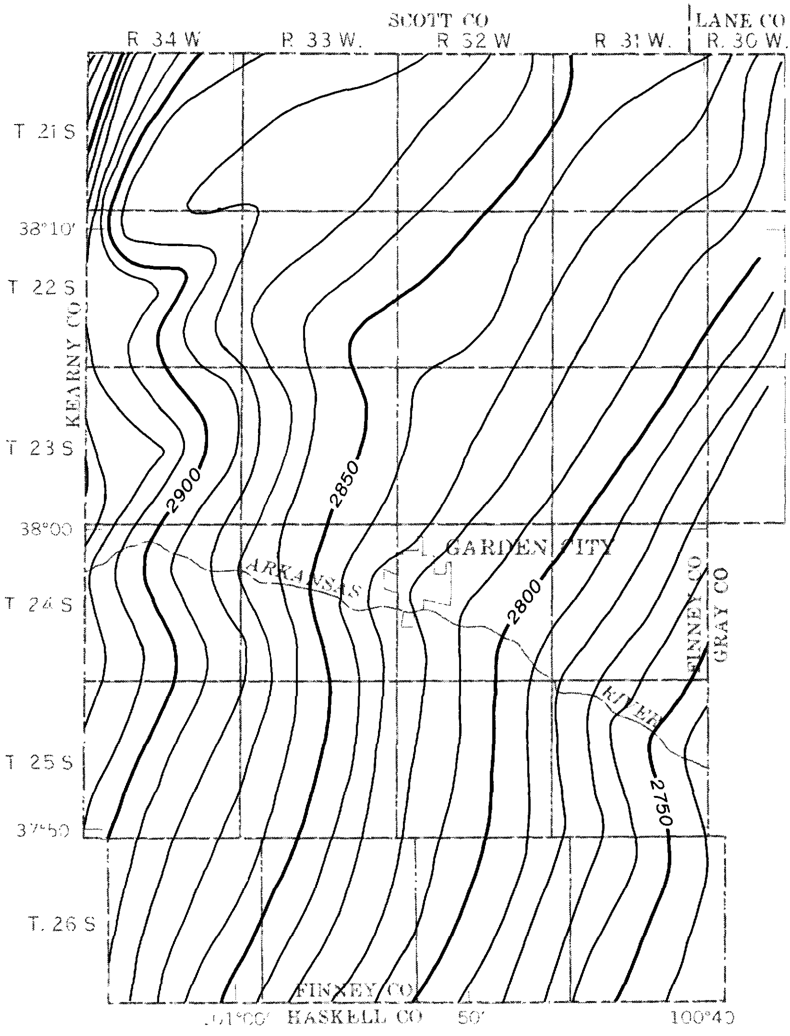
By using the 1940 water level map (Latta, 1944; fig. 18), inflow from the west was calculated to be approximately 36,400,000 gpd, or 41,000 acre-feet per year. In addition, approximately 3,800,000 gpd, or 4,000 acre-feet per year, flows into Finney County from Scott County. Thus, total inflow is approximately 40 mgd (million gallons per day), or 45,000 acre-feet per year, or the equivalent of 0.98 inch per year over the area considered.

This same type of analysis was made on each of the water-level maps: 1940 (fig. 18), February 1962 (fig. 19), September 1962 (fig. 20), February 1963 (fig. 21), and March 1964 (fig. 22). During the period 1940–63, some change in direction of ground-water flow occurred in parts of the county. By September 1962 some ground water was moving toward the large shallow cones of depression rather than southeastward across the county. As the depressions refilled, the flow resumed its normal southeast direction.

The computed discharge from the county was the same for each water-level map: 42 mgd, or 47,000 acre-feet per year. Thus, the net outflow of ground water from the reservoir in the county is about 2,000 acre-feet per year.

FLOW TO AND FROM THE ARKANSAS RIVER

The only sustained surface-water flow entering Finney County is that of the Arkansas River. The river is in hydraulic continuity with the reservoir, as indicated by the water-level maps shown in figures 18–22. Table 3 shows annual streamflow, in acre-feet, at Syracuse and Garden City, Kans., the total diversion between these two cities, and the net gain or loss in flow between the two measuring stations. It is noteworthy that the river showed a net loss between these points from 1922 to 1947 with the exception of two extremely wet years, 1922–23 and 1928–29, when gains were reported. From 1947–48 to 1953–54, the river has shown a net gain between these two measuring points.

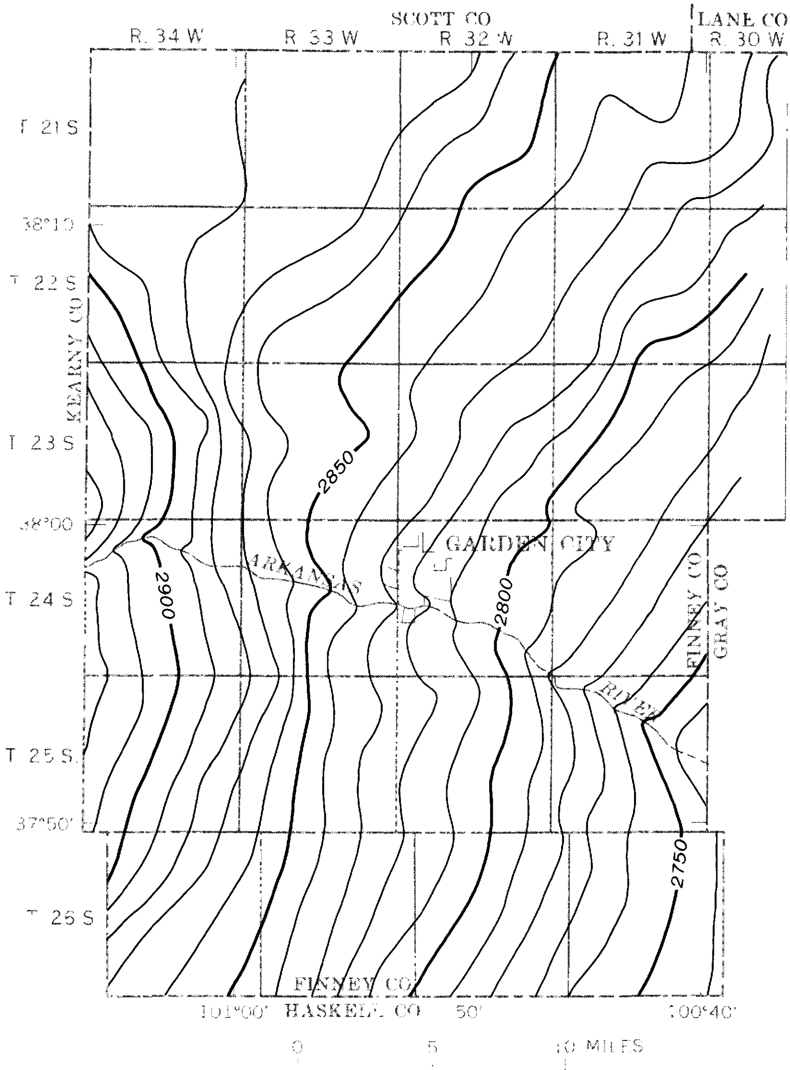


EXPLANATION

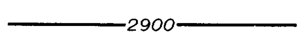
2900

Water-level contours
Show altitude of water level. Contour interval 10 feet. Datum is mean sea level

FIGURE 18.—Water level in western Finney County, spring 1940 (Latta, 1944).



EXPLANATION



Water-level contours

Show altitude of water level. Contour interval 10 feet. Datum is mean sea level

FIGURE 19.—Water level, western Finney County, February 1962.

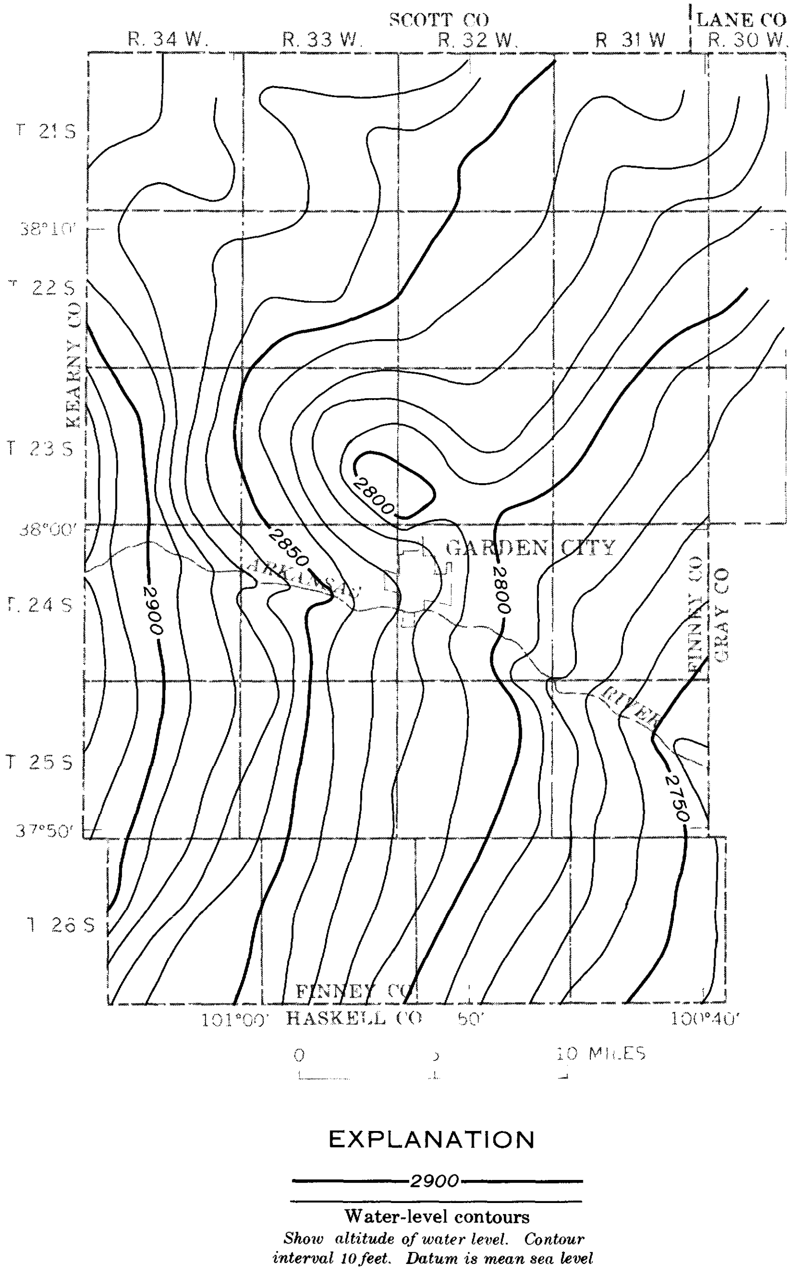
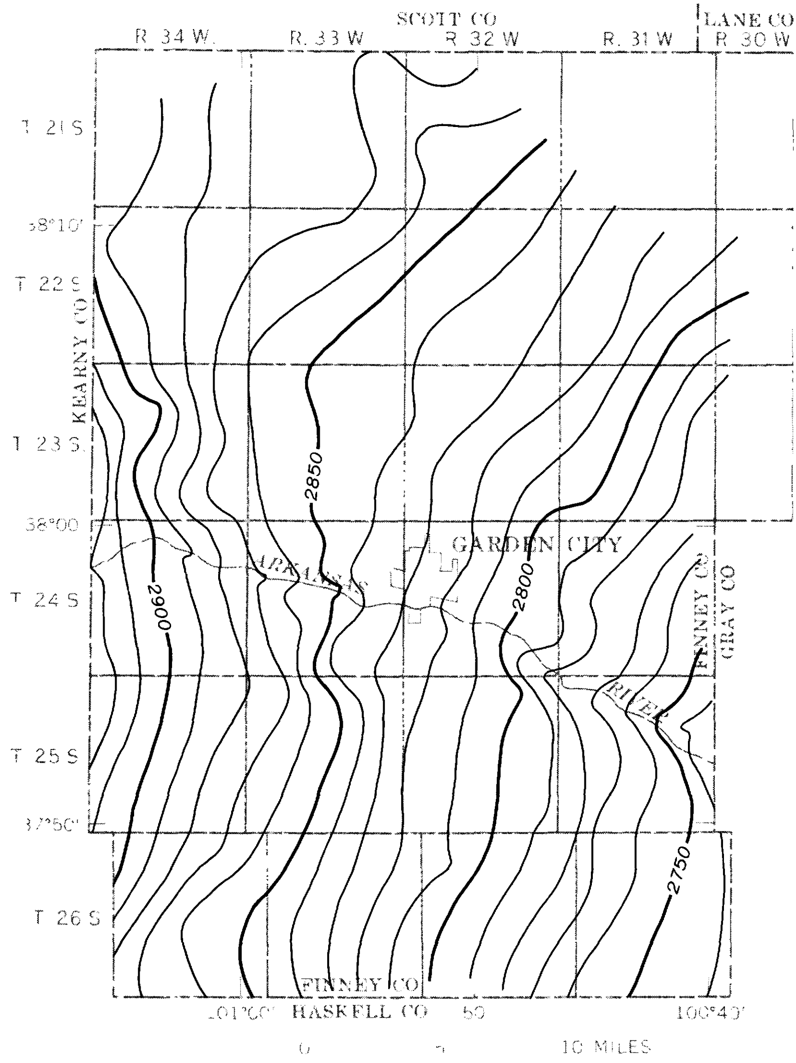


FIGURE 20.—Water level, western Finney County, September 1962.



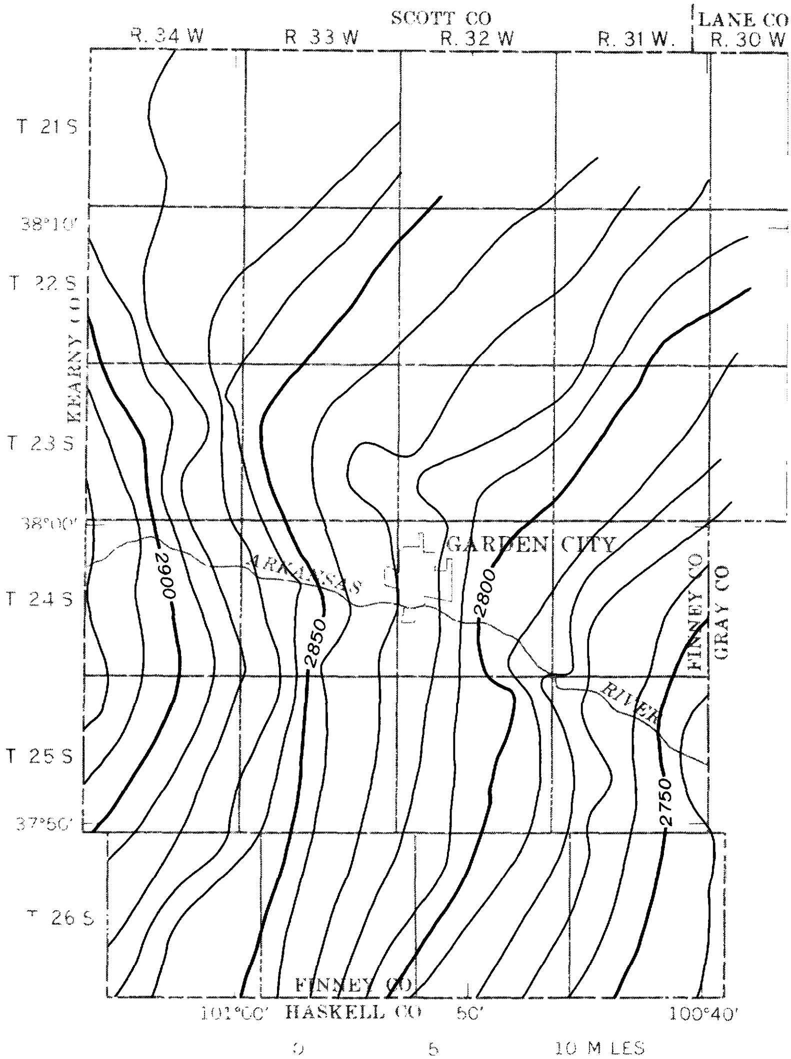
EXPLANATION

2900

Water-level contours

Show altitude of water level. Contour interval 10 feet. Datum is mean sea level

FIGURE 21.—Water level, western Finney County, February 1963.



EXPLANATION

——— *2900* ———

Water-level contours

Show altitude of water level. Contour interval 10 feet. Datum is mean sea level

FIGURE 22.—Water level, western Finney County, March 1964.

TABLE 3.—*Annual discharge of Arkansas River at Syracuse and Garden City, Kans.*

[Diversion of water by canals; loss or gain of stream flow between Syracuse and Garden City for the 41-year period from October 1, 1922, to October 1, 1963 (Latta, 1944, p. 78)]

Water Year (Oct. 1-Sept. 31)	Flow of Arkansas River (acre-ft)		Loss (−) or gain (+) between Syracuse and Garden City			
			Change (acre-ft)	Diversion into canals (acre-ft)	Change exclusive of diversion (net gain or loss)	
	At Syracuse	At Garden City			Acre-feet	Percent of discharge at Syracuse
1922–23	630,000	484,000	−146,000	−97,310	−48,690	−7.72
1923–24	526,000	506,000	−20,000	−50,160	+30,160	+5.72
1924–25	263,000	111,000	−152,000	−82,560	−69,440	−26.4
1925–26	106,000	12,600	−93,400	−77,820	−15,580	−14.7
1926–27	256,000	204,000	−152,000	−103,600	−48,400	−13.6
1927–28	310,000	236,000	−74,000	−66,660	−7,340	−2.36
1928–29	214,000	133,000	−81,000	−105,900	+24,900	+11.6
1929–30	152,000	42,600	−109,400	−95,110	−14,290	−9.4
1930–31	221,000	120,000	−101,000	−73,370	−27,630	−12.5
1931–32	64,100	11,700	−52,400	−42,800	−9,600	−15.0
1932–33	160,000	50,000	−110,000	−86,300	−23,700	−14.8
1933–34	68,900	11,960	−56,940	−42,200	−14,740	−21.4
1934–35	221,600	81,720	−139,880	−79,800	−60,080	−27.1
1935–36	323,800	199,400	−124,400	−93,900	−30,500	−9.45
1936–37	117,500	37,290	−80,210	−67,200	−13,010	−11.1
1937–38	199,200	32,940	−166,260	−124,100	−42,160	−21.9
1938–39	80,800	21,550	−59,250	−58,600	−650	−8.0
1939–40	24,880	1,340	−23,540	−14,600	−8,940	−35.9
Totals, 1922–40	3,938,780	2,297,100	−1,741,680	−1,361,990	[1] −379,690	
1940–41	234,500	93,920	−140,580	−110,000	−30,580	−13.0
1941–42	1,412,000	1,223,000	−189,000	−110,300	−78,700	−5.6
1942–43	238,000	176,900	−61,100	−52,000	−9,100	−3.8
1943–44	299,300	193,500	−105,800	−53,200	−52,600	−17.6
1944–45	155,400	58,470	−96,930	−51,200	−45,730	−30.5
1945–46	129,000	39,420	−89,580	−74,800	−14,780	−11.4
1946–47	407,000	306,500	−100,500	−93,000	−7,500	−1.8
1947–48	184,200	75,780	−108,420	−137,000	+28,580	+15.5
1948–49	282,800	223,500	−59,300	−91,400	+32,100	+11.4
1949–50	194,900	139,400	−55,500	−81,300	+25,800	+13.3
1950–51	330,220	315,150	−15,070	−58,410	+43,340	+13.1
1951–52	113,490	86,490	−27,000	−54,660	+27,660	+24.2
1952–53	92,680	29,647	−63,033	−65,480	+2,447	+2.6
1953–54	92,760	36,808	−55,952	−56,140	+188	+0.196
1954–55	133,100	51,790	−81,310	−78,920	−2,390	−1.80
1955–56	96,380	26,449	−69,931	−65,450	−4,481	−4.62
1956–57	161,700	60,786	−100,914	−98,470	−2,444	−1.51
1957–58	168,100	128,740	−39,360	−69,490	+30,130	+24.0
1958–59	184,400	69,390	−115,010	−119,270	+4,260	+2.32
1959–60	136,700	108,054	−28,646	−51,800	+23,154	+17.0
1960–61	93,530	20,898	−72,632	−64,780	−7,852	−8.5
1961–62	131,800	53,640	−78,160	−73,210	−4,950	−3.8
1962–63	60,950	13,520	−47,430	−44,900	−2,530	−4.72
Total, 1940–63	5,332,910	3,531,752	−1,801,158	−1,755,180	[2] −45,978	

[1] Average net loss for 1922–40 is 379,690÷18, or 21,000 acre-feet.
[2] Average net loss for 1940–63 is 46,000÷23, or 2,000 acre-feet.

Figure 23 shows the net gain or loss of the Arkansas River between Syracuse and Garden City, a hydrograph of well 24–33–9aaa approximately 1½ miles north of the Arkansas River, the accumulated departure from mean annual precipitation, and the annual pumpage.

The hydraulic connection between the river and the ground water is indicated by the hydrograph of Finney County well 24–33–9aaa (fig. 23) and the net loss or gain curve. A definite relation is evident between gain or loss from the river and the ground-water stage. Note that when the water level reached a stage of about 7 feet below the land surface (January 1948), the river gained water from the aquifer. This was due in part to above-average precipitation for a series of years and recharge was greater than pumpage, causing an increase in ground water held in storage. The ground-water peak was rapidly dissipated after 1951, as the hydrograph indicates. The decline in water level was caused by the rapid expansion of pumping and by below-average precipitation. As drought conditions and expansion of irrigation continued, the water level continued to decline rapidly. When the water level in well 24–33–9aaa reached 13 feet below the surface (August 1954), the hydraulic gradient from the river reversed, causing the river to again supply water to the ground-water reservoir.

In 1957 and 1958 precipitation was above normal, and once again the river received water from the ground-water reservoir. Note on the hydrograph the change in hydraulic gradient when the water level was at 14 feet below land surface (or approximately 7 ft lower than the reversal point in 1948). This indicates that, with the expansion of pumping, a new level was established that triggers the reversal of flow into or out out the river. The water level fell to a depth of 14 feet during the summer of 1961, and once again the river supplied water to the underground reservoir.

A small amount of ground water is discharged into the channel of the Arkansas River downstream from Garden City and moves out of the county as surface flow. Flow-duration curves based on daily observations of discharge are available (Furness, 1959) for gaging stations at Syracuse, Garden City, and Dodge City, Kans. These curves (fig. 24) show that total runoff to the Arkansas River increases from Garden City to Dodge City. Interpretation of the mean average-yield curves (fig. 25) prepared by Furness (1960) indicates that the increase in flow of the Arkansas River is approximately 0.005 cfs per sq mi (cubic feet per second per square mile) of the total drainage area per year between the west and east county lines, or approximately 300 acre-feet per year. Mean average yield is identical with mean annual runoff and includes both surface- and ground-water contributions to streamflow. No perennial tributaries feed into the Arkansas River in Finney County.

By summation of yearly net gains and losses in the 23-year period considered in this analysis, 1940–63, the seepage loss of the river from Syracuse to Garden City, Kans., was about 46,000 acre-feet (table 3,

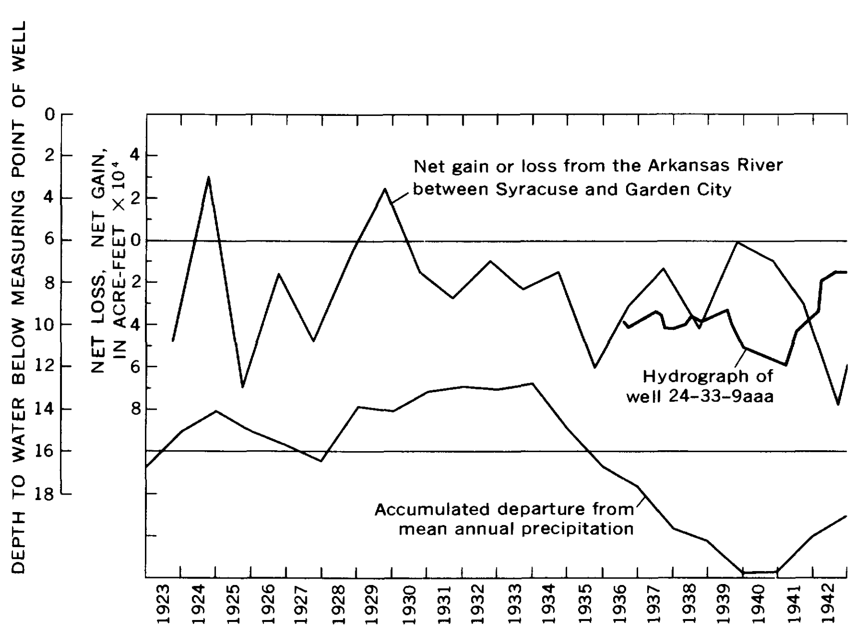
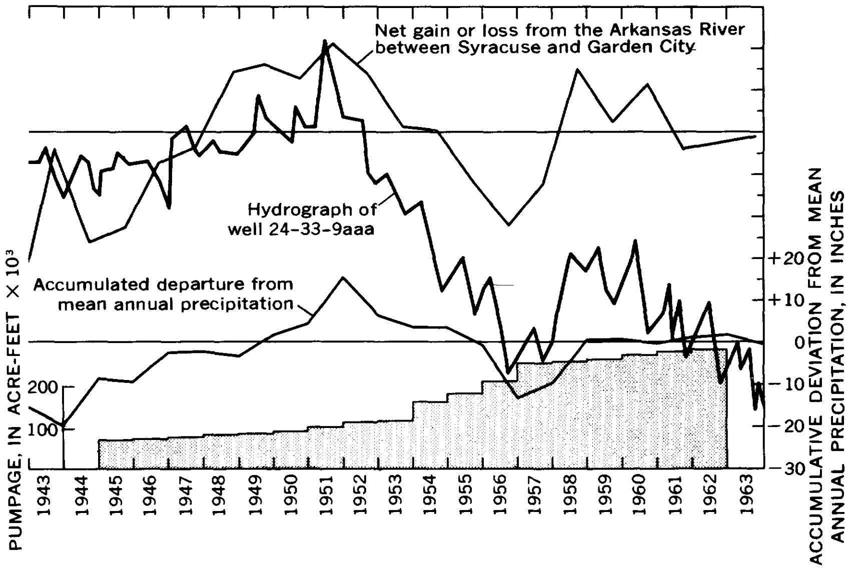


FIGURE 23.—Relation of net gain or loss from the Arkansas River to hydrograph precipitation, and

col. 6). This would be an average of 2,000 acre-feet per year. Because the Arkansas River gains and loses flow in about equal proportions as it passes through Hamilton and Kearny Counties, most of the 2,000-acre-feet loss is believed to be directly contributed to the ground-water reservoir within Finney County. This loss would be reduced by about a 300-acre-feet-per-year gain in flow of the river east of Garden City. Thus, the average net loss from the Arkansas River within Finney County would be 1,700 acre-feet per year.

RESERVOIR STORAGE FEATURES

The amount of ground water in temporary storage in Finney County can be computed from the map of saturated thickness (fig. 26). The volume of saturated material, in acre-feet, multiplied by the storage coefficient is the acre-feet of water in storage. The pumping tests at wells 24–34–1ddb1 and 26–32–31cc indicate storage coefficients for the sand and gravel of 0.14 and 0.22 (table 2). Several tests with the neutron meter indicate a storage coefficient of 0.20. Consequently, a value of $S=0.2$ was used for sand and gravel. However, it is not



of Finney County well 24–33–9aaa, to accumulated departure from mean annual to pumpage since 1945.

definitely known how much water the fine-grained material (silt and sandy silt) between and above the aquifers will yield. Measurements made with the neutron probe indicate that the total porosity of the saturated fine-grained material is about 0.36 at the Morris pumping-test site (24–32–25bda1). Similar fine-grained material, which is above the water table and is not saturated, shows a moisture content of 0.17 at this site, indicating that the effective porosity of the fine-grained material at this locality is 0.19 or 0.20. The effective porosity of silty clay or clay beds would be much less than that of the coarser material and might be less than 0.05. The time necessary to drain this material is not known. A conservative figure of 0.15 was used as the average storage coefficient for the saturated material, without regard to lithology or delayed yield in computing total ground-water storage. Using $S=0.15$, the amount of ground water stored in western Finney County is calculated to be $0.15 \times 129{,}875{,}840$ (volume of saturated material, in acre-ft), or approximately 20,000,000 acre-feet.

Water levels were measured in 115 key wells in February 1962, September 1962, February 1963, and March 1964, and maps of water-

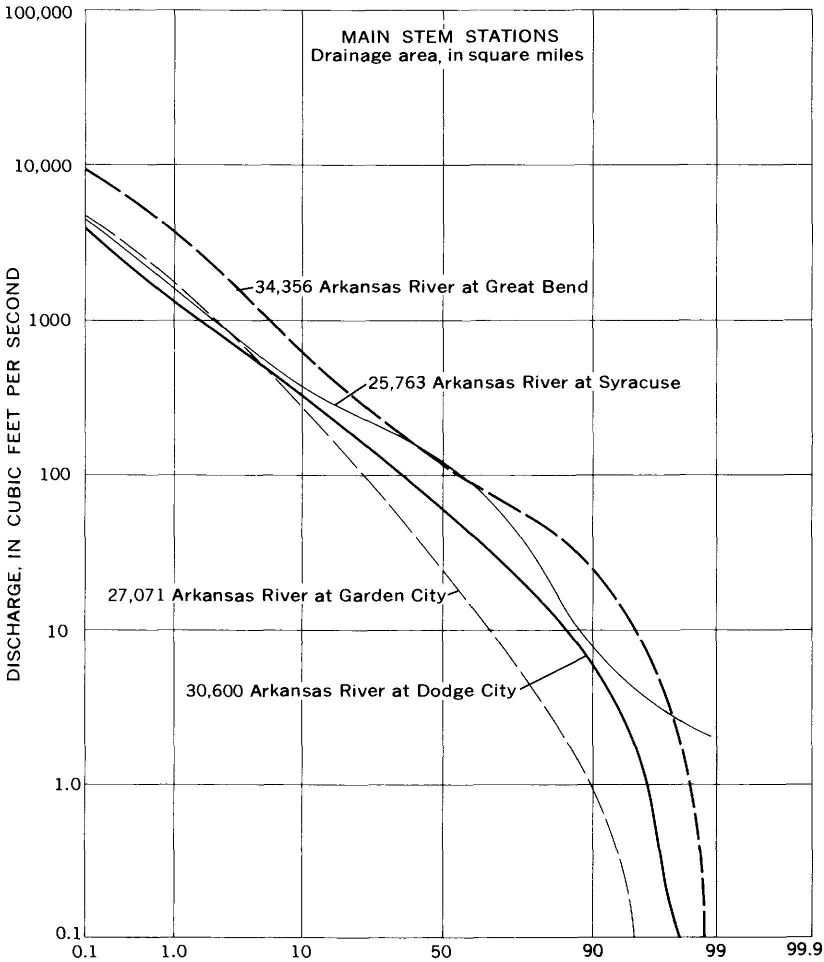


FIGURE 24.—Daily flow-duration curves at Syracuse, Garden City, Dodge City, and Great Bend, Kans. (Modified from Furness, 1959.)

level altitudes were prepared from their measurements. By comparing these water-level maps with the 1940 water-level map (Latta, 1944), change maps were constructed. Water-level-change maps were prepared for the following time intervals: spring 1940–February 1962 (fig. 27), spring 1940–September 1962 (fig. 28), spring 1940–February 1963 (fig. 29), and spring 1940–March 1964 (fig. 30).

Water-level changes that occurred between the spring of 1940 and February 1962 are shown in figure 27. Two small areas had water-level changes of more than 20 feet. One area is in the center of T.

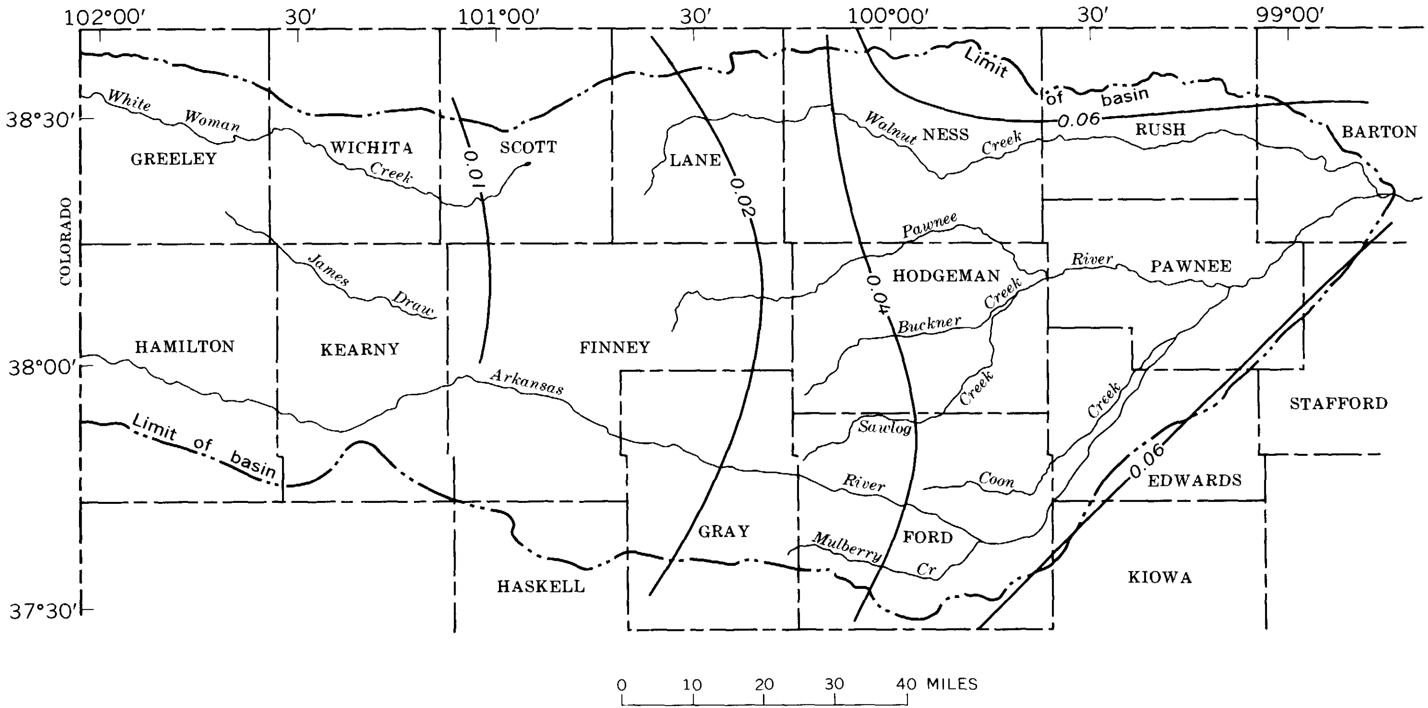
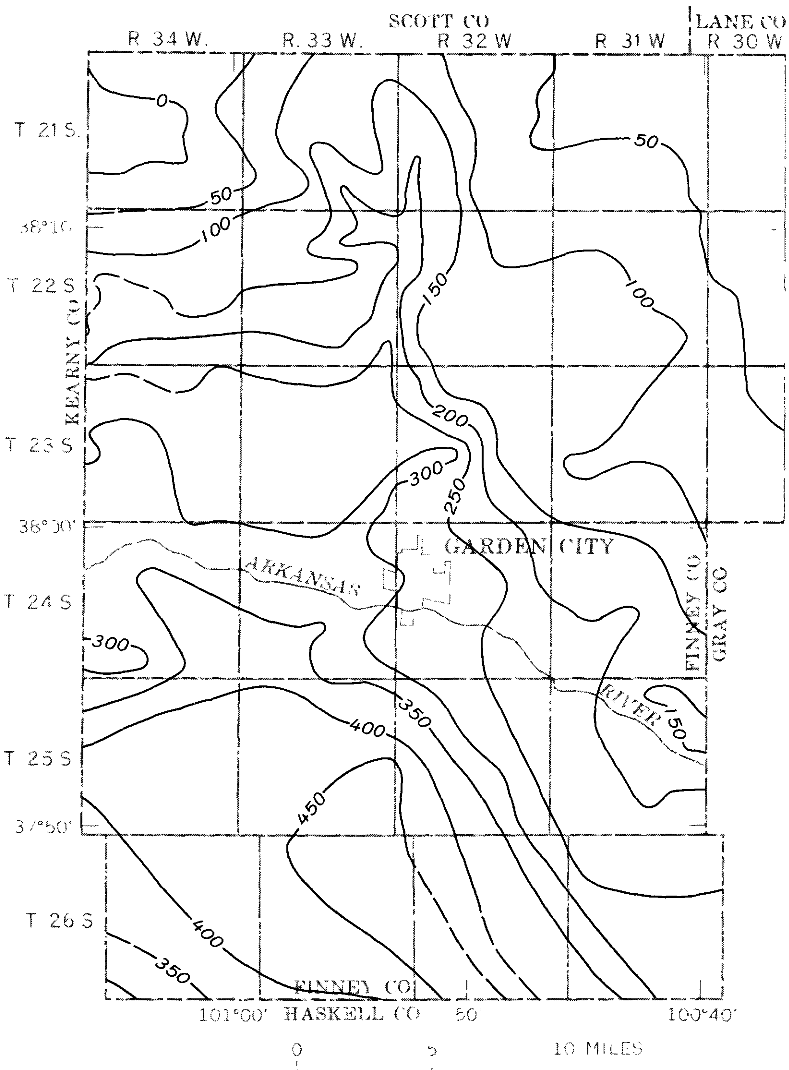


FIGURE 25.—Mean surface-water yields of the Upper Arkansas Unit, western Kansas. (Modified from Furness, 1960.) Quantities, in cubic feet per second per square mile, are estimated on the basis of adjusted streamflow records for the years 1921–56.



EXPLANATION

———— 200 — — — —

Line of equal saturated thickness of Quaternary and Tertiary deposits

Dashed where approximately located. Interval 50 feet

FIGURE 26.—Saturated thickness of Tertiary and Quaternary deposits in western Finney County.

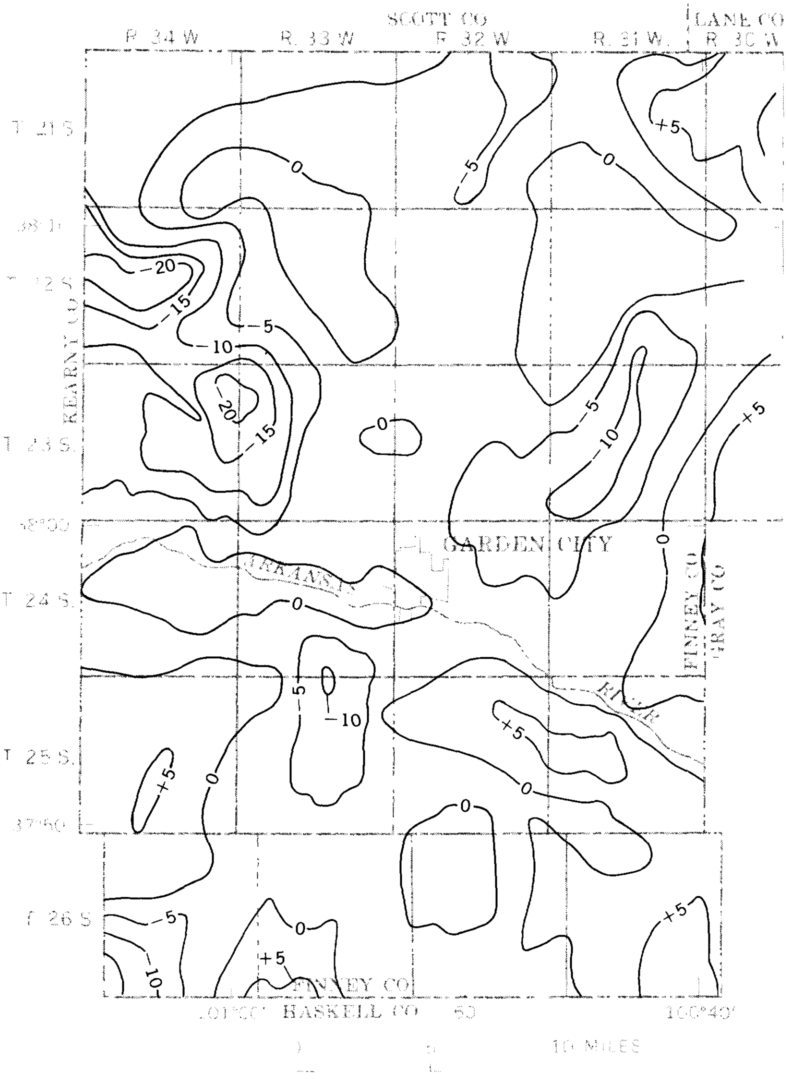
22 S., R. 34 W., and the other is in sec. 12, T. 23 S., R. 34 W., and sec. 7, T. 23 S., R. 33 W. The decline in the first area cited was caused by the dissipation of a ground-water mound that was in the area in the spring of 1940, as shown in figure 18. The decline in the second area was the result of a dense concentration of wells in the two sections or, possibly, the result of late-season pumping.

The areas where irrigation is not practiced show either no change or a slight rise in water levels. This is particularly noticeable in the area south of the Arkansas River and in the northeast corner of the ground-water reservoir (T. 22 S., R. 31 W.). The small area of decline in the southwest corner may reflect pumping in Haskell and northeastern Grant Counties.

The water-level-change map for the period 1940–September 1962 (fig. 28) shows that the center of the cone of depression was in T. 23 S., R. 33 W., where the maximum decline was 50 feet. The decline reflects, in part, the piezometric-head loss of the confined aquifers. The piezometric head recovers rapidly after pumping ceases. Much of the recharge to the lower aquifer is supplied by from above, as indicated by the aquifer test on well 24–32–25bda1. The water-level change as of February 1963 is shown in figure 29. The large depression shown on the September 1962 change map (and probably caused by pumping during the 3 months prior to measurement of water levels) was no longer present. The rapid filling of the depression indicates that the change in September 1962 was primarily a lowering of the piezometric head in an artesian or a leaky-artesian aquifer. The small change in February may represent the water withdrawn from storage on a long-term basis. The water-level change as of March 1964 (fig. 30) showed a deepening in the major cones of depression.

The sequence-of-change maps (figs. 27–30) indicate that the cone of depression is expanding laterally and that the lowering of water levels is about 4 feet per year in the area of greatest pumpage. The magnitude of this change can be seen in table 4. The area circumscribed by successive lines of water-level change in square miles and in percent of total reservoir area, is shown for each change map. The increase in the area circumscribed by minus lines provides clear evidence of the water-level decline.

The area of decline for each water-change line was converted to volume of material dewatered, in acre-feet, by multiplying the average vertical interval between lines (2.5, 7.5, 12.5, and so forth) by 640 (acres per sq. mi.). This volume was then converted to acre-feet of water removed from storage by multiplying by the storage coefficient. A storage coefficient of 0.20 was used because the dewatered material was predominantly coarse sand and gravel, and water-table conditions



EXPLANATION

———— 5 ————
Lines of equal water-level change
Showing rise (+) and decline (−). Interval 5 feet

FIGURE 27.—Water-level change from spring 1940 to February 1962, western Finney County.

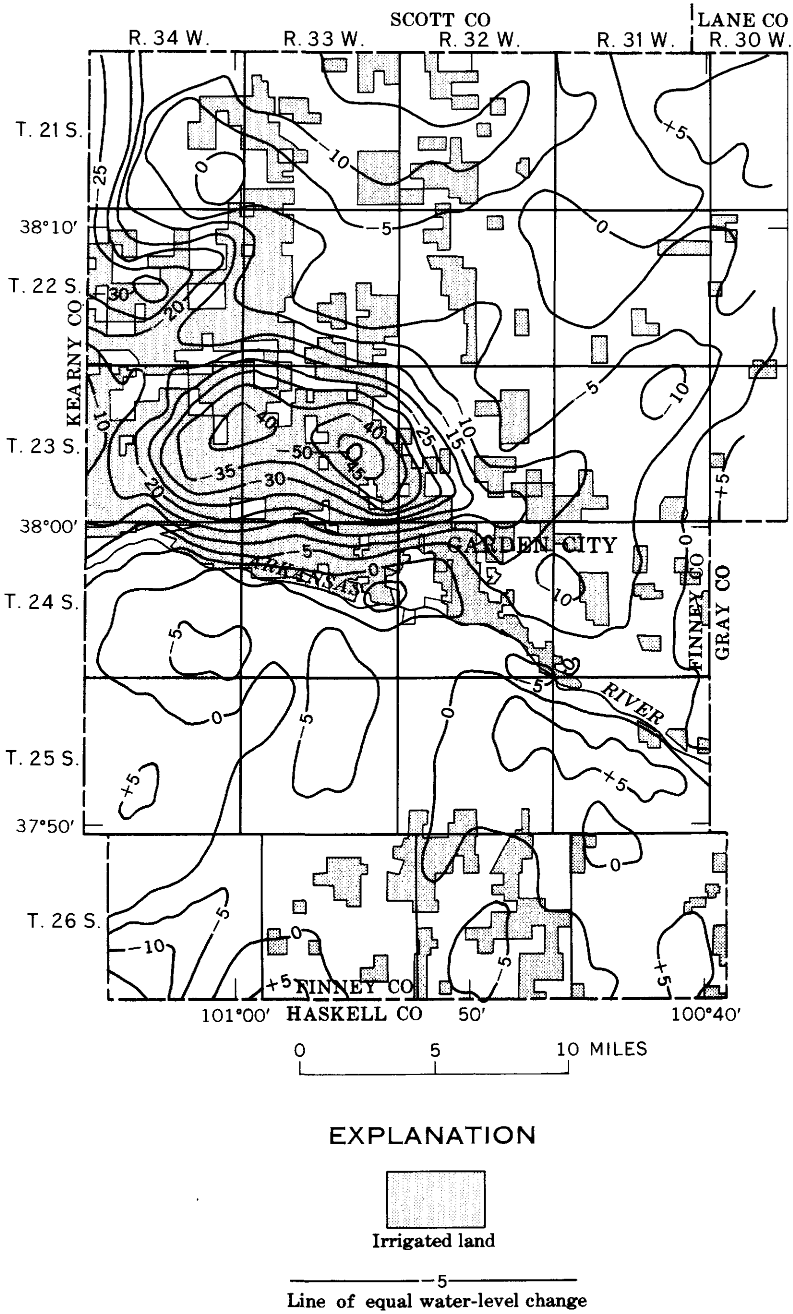
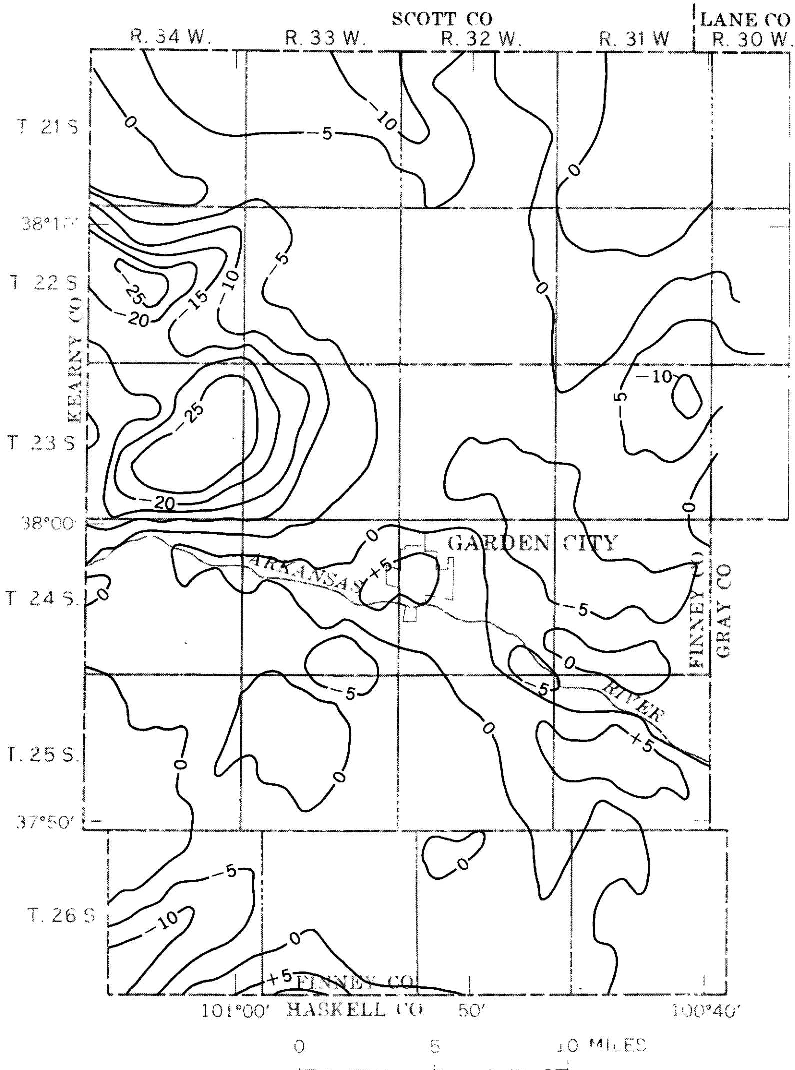


FIGURE 28.—Water-level change from spring 1940 to September 1962, western Finney County.



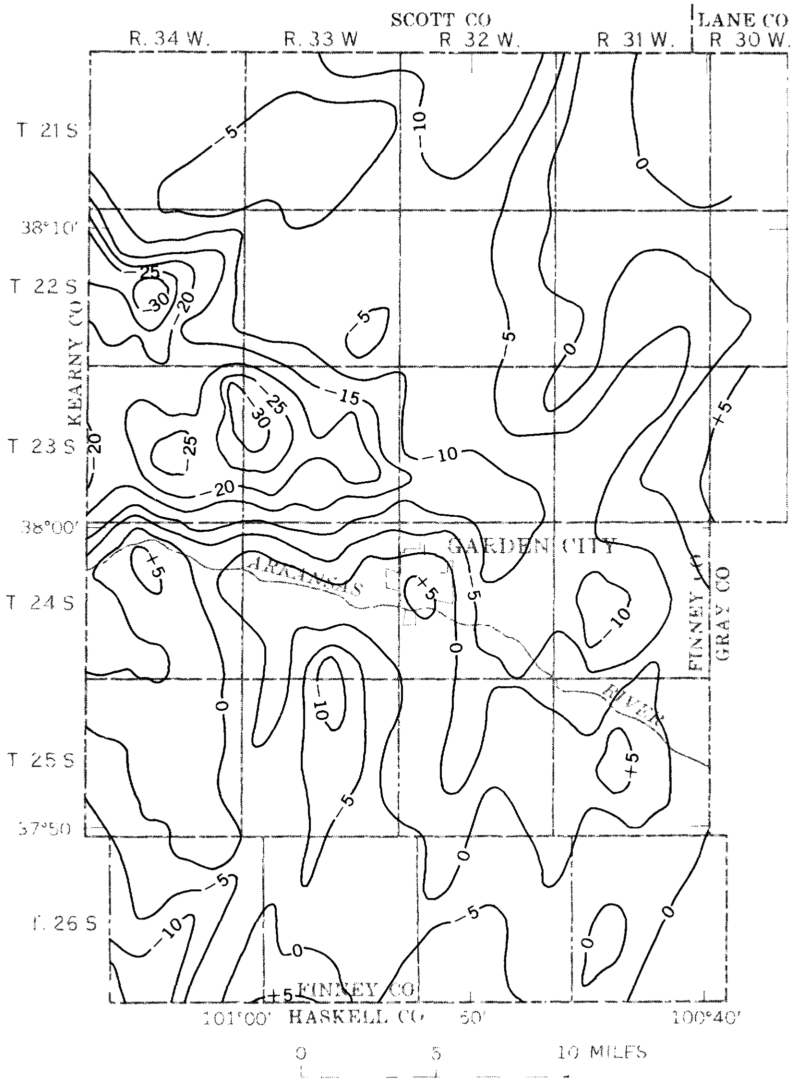
EXPLANATION

—5—

Line of equal water-level change

Showing rise (+) and decline (−). Interval 5 feet

FIGURE 29.—Water-level change from spring 1940 to February, 1963, western Finney County.



EXPLANATION

—5—
Line of equal water-level change
Showing rise (+) and decline (−). Interval 5 feet

FIGURE 30.—Water-level change from spring 1940 to March 1964, western Finney County.

TABLE 4.—*Area circumscribed by lines showing the water-level changes*

Contour interval	1940–Feb. 1962		1940–Sept. 1962		1940–Feb. 1963		1940–March 1964	
	Square miles	Percent of total	Square miles	Percent of total	Square miles	Percent of total	Square miles	Percent of total
+10 to +15					1.0			
+5 to +10	25	2.9	25.0	2.9	16.0	1.9	7.0	0.8
0 to +5	269	31.0	182.0	21.0	194.0	22.3	199.0	22.8
0 to −5	379	43.5	306.0	35.2	440.0	50.5	290.0	33.3
−5 to −10	138	15.9	158.0	18.1	126.0	14.5	223.0	25.6
−10 to −15	38	4.4	89.0	9.2	38.0	4.4	74.0	8.4
−15 to −20	14	1.6	33.0	3.8	24.0	2.8	37.0	4.3
−20 to −25	7	.8	26.0	3.0	16.0	1.9	27.0	3.1
−25 to −30			22.0	2.5	14.0	1.7	11.0	1.3
−30 to −35			14.0	1.6			4.0	.4
−35 to −40			15.0	1.7				
−40 to −45			8.0	.9				
−45 to −50			2.0	.2				
−50 to −55			.32	.0				
Net change in volume of water, in acre-feet	225,000		(1)		400,000		565,000	

[1] Not computed, as changes are due to the drop in piezometric head, and an *S* of 0.20 would be in error.

were assumed to exist in all wells at the time measurements were made. The wells had been shut off a sufficient time to allow the piezometric surface and the water-table to coincide.

Unfortunately, water-level measurements prior to February 1962 in the wells used for the change maps are not available. The Division of Water Resources of the Kansas State Board of Agriculture had maintained continuous hydrographs since 1940 of five wells in the county (fig. 31). All the hydrographs show a net rise in water level from 1940 to 1951, which indicates that during this period recharge not only supplied all the water pumped but also increased the amount of water stored in the ground-water reservoir.

If the changes in water level between 1940 and 1964 in the five wells are averaged and are assumed to represent the average change in reservoir water level, the change in ground-water storage and the storage coefficient can be computed. If the change in storage determined by this method corresponds to that obtained from the change map, it should then be possible to compute the yearly change in storage for any year of record by use of the hydrographs.

The average net water-table change, in feet, from 1940 to February 1964 was calculated from the five hydrographs (fig. 31). The average change, in feet, for water levels in the wells for this period follows:

Well	24-32-3dac	21-32-19bbd	24-33-9aaa	25-33-13dac	25-31-13cda
Feb. 1940	71.4	23.5	11.1	76.7	4.4
Feb. 1964	77.9	28.3	18.7	78.2	5.1
Change (ft)	−6.5	−4.8	−7.6	−1.5	−0.7

NOTE.—Total change, −21.1 ft; average change, −4.22 ft.

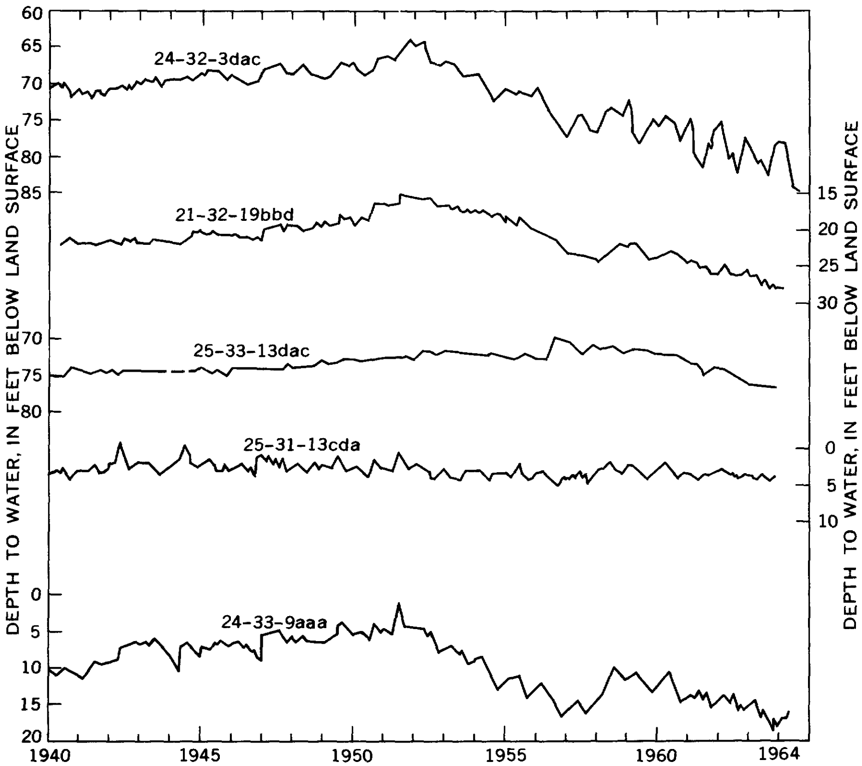


FIGURE 31.—Water levels in wells.

The change in storage for the period 1940–February 1964 can be determined by multiplying the area of the ground-water reservoir by the average water-level change. The product is the volume of material dewatered, which, in turn, is multiplied by the storage coefficient 0.20 to obtain the change in storage.

Change in storage.—(552,960×4.2×0.20) = 460,000 acre-feet (1940–Feb. 1964). The latter estimate is in reasonably close agreement with the value of 565,000 acre-feet obtained by analysis of the change map (table 4). Therefore, it seems reasonable to estimate storage changes by using the average water levels observed in the five wells of long record (fig. 31).

PUMPAGE

Estimates of pumpage were obtained from the appropriation files of the Division of Water Resources, Kansas State Board of Agriculture. In 1940 the annual pumpage was reported to be 71,000 acre-feet. The pumpage increased approximately four times by 1963, when the amount pumped from the ground-water reservoir was 295,000 acre-feet.

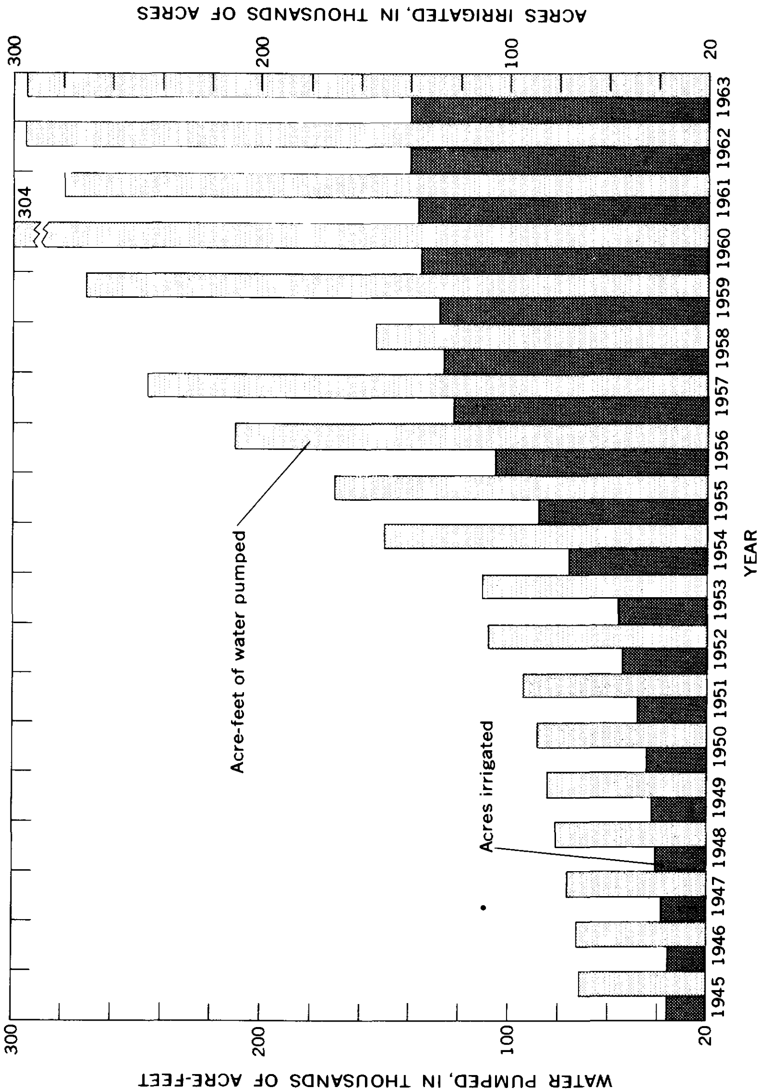


FIGURE 32.—Irrigated acres and pumpage, by years, 1945–63.

Figure 32 shows the yearly pumpage, in acre-feet, and the number of acres irrigated each year. The rate of irrigation expansion was gradual until 1953. From 1953 to 1956 the pumpage doubled. Since 1956 the rate of increase in pumping has been slower.

In most places the appropriation for water granted by the Division of Water Resources is 2 acre-feet per acre. The amount of water applied during the period 1945–57 was not measured, and the pumpage estimate is based on the appropriation of 2 acre-feet per year. Since 1958 the water users have been requested to report the acre-feet of water used each year. Table 5, showing reported pumpage for 1958–62, indicates that in most years wells are withdrawing all the water that has been appropriated. Locations of the irrigation wells (as of 1965) are shown in plate 2. The depth to water under nonpumping conditions ranges from 15 feet to more than 100 feet. Figure 33 shows the variations in depth to water throughout the county.

RETURN FLOW FROM IRRIGATION WATER

The exact contribution to the reservoir of return flow from irrigated fields, canals, and ditches could not be calculated, owing to the absence of field data. Approximately 25 percent of the applied water is estimated to return to the reservoir. Some supporting data are available in this area to justify the estimate. Figure 34 illustrates a ground-water mound that developed under the Farmers Ditch at the west edge of sec. 31, T. 23 S., R. 33 W., from March 29 to April 25, 1962.

A flow of 182 cfs was recorded April 18, 1962, at the Kansas State Division of Water Resources gage on the Farmers Ditch in sec. 4, T. 24 S., R. 34 W. The discharge was measured again at the west side of sec. 36, T. 23 S., R. 34 W. (2.75 miles east of the gage), and was recorded at 163.5 cfs. At the east side of sec. 31, T. 23 S., R. 33 W., the discharge was 153.4 cfs. There were no diversions in this 5-mile stretch. This difference in discharge, 28.6 cfs, would amount to a 15 percent seepage loss from the canal. The loss is probably higher than an aver-

TABLE 5.—*Water use as reported by water users in Finney County, Kans.*

[Data (unpublished) obtained from the Division of Water Resources, Kansas State Board of Agriculture]

Year	Water applied (acre-ft)	Number of acres irrigated	Acre-feet per acre
1958	3,748	3,073	1.22
1959	99,800	47,502	2.10
1960	112,812	50,004	2.26
1961	90,534	44,679	2.03
1962	141,189	66,601	2.12

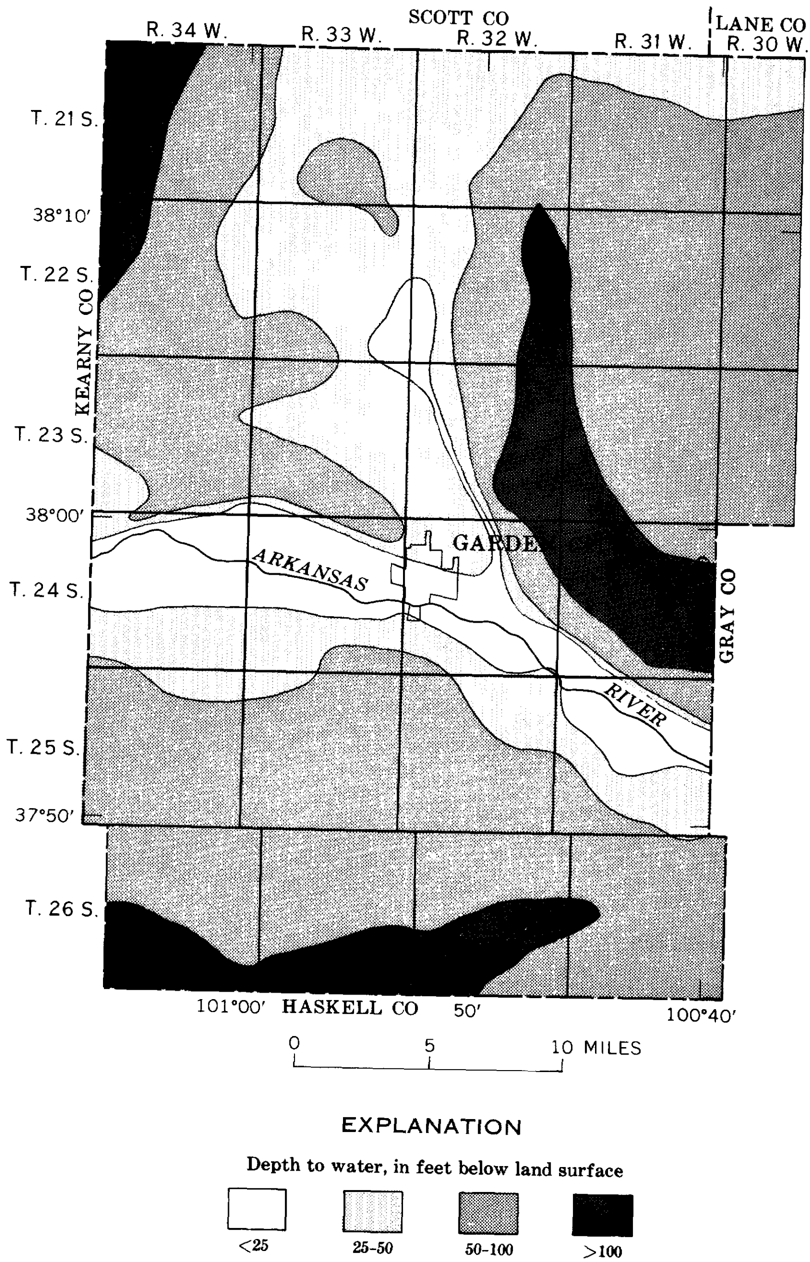


FIGURE 33.—Depth to water, February 1962, western Finney County.

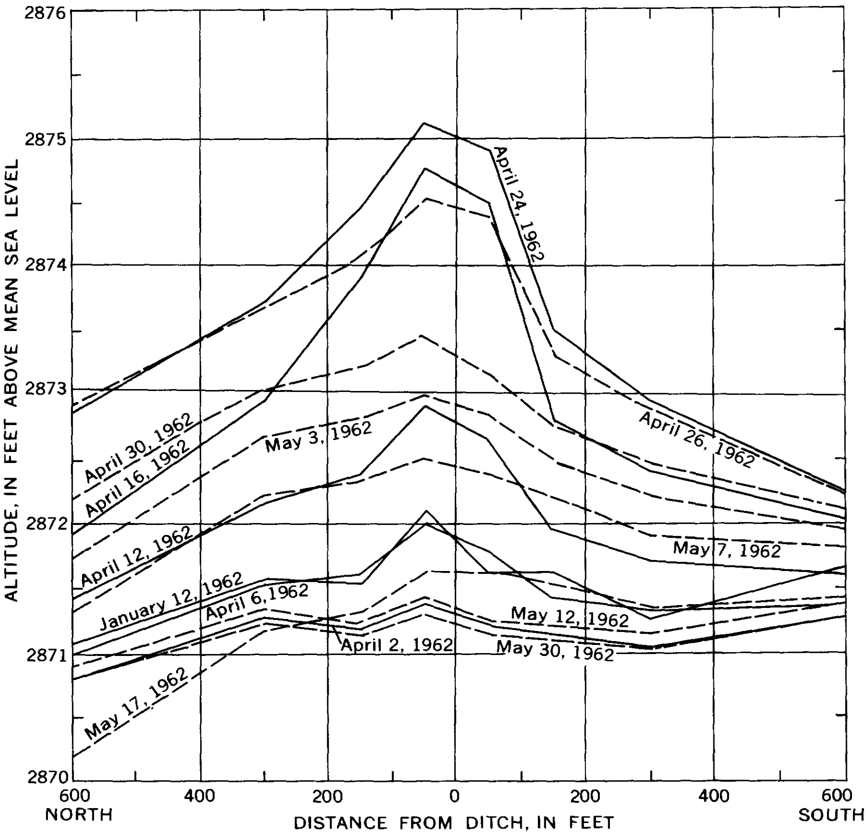


FIGURE 34.—Development and dissipation of ground-water mound under Farmers Ditch at west edge of sec. 31, T. 23 S., R. 33 W. (Water was turned into the ditch March 29, 1962, and turned out of the ditch April 25, 1962.)

age canal loss because this section of ditch is composed of a series of cuts and fills that enable the ditch to supply water to the upland bench above the Arkansas River. Ditch-loss studies conducted at the Garden City Experiment Station showed that losses of 10 percent occurred in a quarter-mile length of a farm supply ditch (W. R. Meyer, U.S. Dept. Agriculture, unpub. data, 1954).

Experiments on irrigation efficiencies showed that, in this area, deep-percolation losses (those penetrating more than 6 ft) in a well-drained system are frequently 20 percent or more (Meyer and others, 1953). With this fact in mind, it seems reasonable to assume that 15 percent of the water applied to irrigated fields could return to the ground-water reservoir, and that another 10 percent would return from ditch leakage.

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Of the total pumpage—3,530,000 acre-feet (table 6)—25 percent, or 882,000 acre-feet, returned to the ground-water reservoir, and an additional 219,000 acre-feet returned from surface water. This would be a total contribution of about 1,100,000 acre-feet for the 24-year period, or an average annual contribution of approximately 45,700 acre-feet, which is equivalent to 1.00 inch over the area.

RECHARGE FROM PRECIPITATION WITHIN THE COUNTY

To estimate the amount of recharge from precipitation, the rise in water level for observation well 21–32–19bbd was used for the years 1940–52. This well was chosen from the five wells available that have long-term hydrographs (fig. 31) because it is located where the effects of the river are negligible and the effects of pumping were minimal. During this period, no irrigated areas or canals were within 4 miles. After 1951 several wells were drilled in the vicinity of this well, so it is no longer usable as a valid observation well. The sediments in the vicinity of this well are predominantly sand and gravel; therefore, the storage coefficient was considered to be approximately 0.2. The rise in water level during this period was 7.0 feet, and, computed with a storage coefficient of 0.2, this rise would be the equivalent of 1.40 feet of water added over the 12-year period, or 0.117 foot per year, or 1.4 inches over the area.

INTERPRETATION

The chief response of the ground-water reservoir to pumping is a lowering of the water level. Movement of water induced by pumping also affects the chemical quality and temperature of the water pumped, but these latter effects have, to date, been so small that they are not readily observable and, therefore, are not considered to be significant. The magnitude of the lowering of water is dependent both on the amount of water pumped and on the manner in which natural recharge and discharge is affected by pumping. Superimposed on these factors is the variable natural recharge of the aquifers from precipitation.

TABLE 6.—*Summary of data computed from change-in-water-level maps and pumpage for the given time periods*

Period in which water-level change occurred	Water pumped from storage (acre-ft)	Total pumpage (acre-ft)	Percent of pumpage supplied from storage
Spring 1940–February 1962	225, 000	2, 940, 000	7. 6
1940–February 1963	400, 000	3, 230, 000	12. 4
1940–March 1964	565, 000	3, 530, 000	16. 0
February 1962–February 1963	173, 059	294, 000	58. 8
February 1963–March 1964	167, 117	[1] 295, 000	56. 7

[1] Estimated.

Analysis of observed water levels in Finney County, therefore, reflects the recharge and discharge conditions as they are related to development of ground water.

WATER BALANCE

The most encompassing outlook can be obtained by computing the areal recharge from the equation of water balance, as shown on page 34.

Total recharge = change in storage + pumpage + (ground-water outflow − inflow) + seepage loss.

All elements except total recharge were observed or estimated and are described in this report. Data from the period 1940–64 can be used in the water-balance equation for computing total recharge.

The net gain in flow of ground water across Finney County averaged 2,000 acre-feet per year (p. 50). Therefore, the calculated net ground-water gain for the 24-year period selected was about 48,000 acre-feet.

From analysis of streamflow records (p. 50–58), the net gain in ground water due to seepage from the Arkansas River was about 1,700 acre-feet per year, or 41,000 acre-feet for the 24-year period.

Observed pumpage and change in storage are given in table 6. Observed values of the components on the right side of the water-balance equation are summarized as follows:

Data for 1940–64	*Water (acre-ft)*
Change in storage	−565,000
Pumpage	+3,530,000
Outflow minus inflow	+48,000
Seepage from Arkansas River	−41,000
Recharge from precipitation and irrigation return	+2,972,000

Thus, the average recharge indicated by the water-balance equation for the 24-year period was about 124,000 acre-feet per year. This is equivalent to 0.224 foot, or 2.70 inches, of water a year over the area.

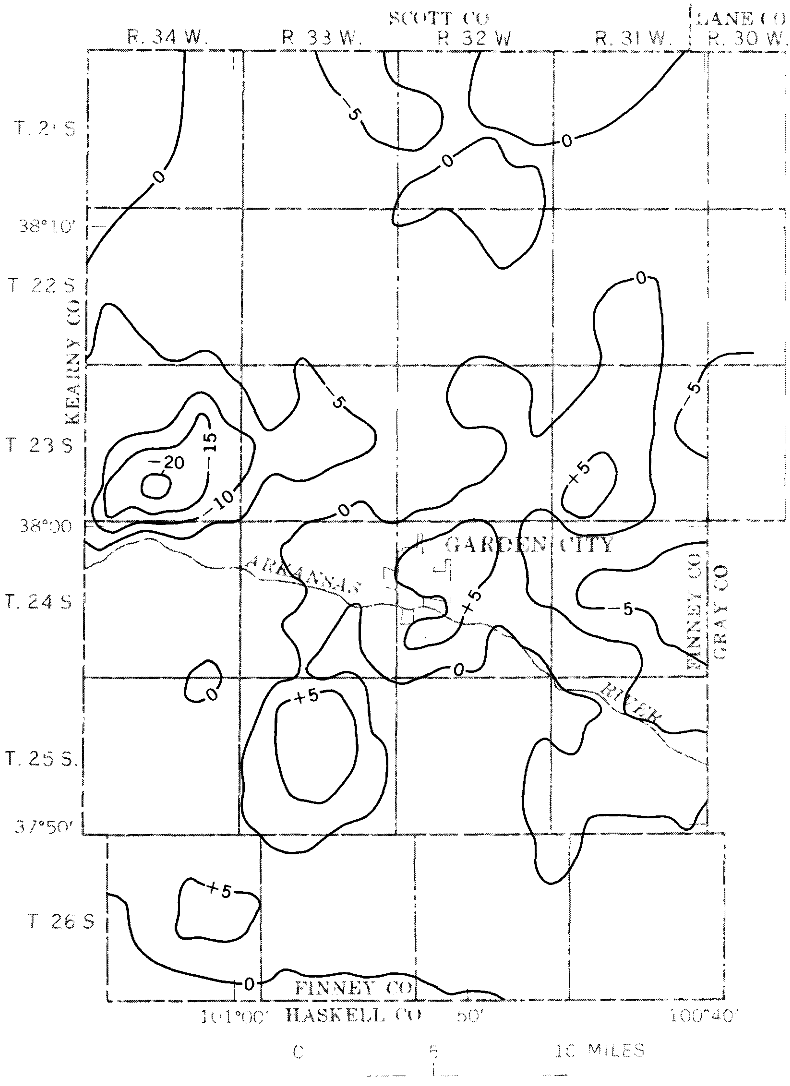
If the ground-water system were considered to be under near-equilibrium flow before pumping began, the components in the water-balance equation would be as follows:

Components	*Acre-feet per year*
Change in storage	0
Pumpage	0
Outflow minus inflow	+2,000
Seepage from Arkansas River	−1,700
Total recharge	+300

Historic records of streamflow for the period 1922–30, however, indicate a seepage loss of 21,000 acre-feet per year. The long-term average recharge to the reservoir was apparently less than 0.5 inch per year, instead of the 2.7 inches per year indicated by the data of 1940–64. Thus, the rate of 2.7 inches per year probably reflects an additional recharge resulting from recycled ground water from irrigation and an accompanying increase in effective recharge from precipitation on the irrigated land. The change in land use—from growth of native grass to production of agricultural crops—is a factor that would tend to decrease consumptive use and to increase recharge. Some recharge temporarily held in storage is withdrawn from the reservoir by evaporation and plant use. As the water table is lowered by pumping, the evapotranspiration losses are reduced, and the effective recharge to the aquifer is increased. Thus, at least four factors probably had a role in increasing recharge during the 1940–64 period: increased precipitation, return flow, change in land-use practices, and evapotranspiration control.

Table 6 shows the relation between pumpage and change in storage for selected periods. In the 2 years, 1962–64, the water in storage was reduced more than it had been in the previous 22 years. The yearly change map for February 1962–February 1963 (fig. 35) shows that the change in storage was 58.7 percent of the pumpage in 1962. A similar analysis of the change map for February 1963–March 1964 (fig. 36) shows that the change in storage was 56.7 percent of the pumpage in 1963. Inasmuch as the rapid expansion in pumping occurred between 1954 and 1957, recharge must have been considerably in excess of normal for a period of years since 1940, and the resulting increased recharge was sufficient to temporarily supply all the water pumped by wells and, also, to increase the amount of water stored in the ground-water reservoir.

The change in storage computed from water-level maps of 1940 (fig. 18) and 1964 (fig. 22) corresponds closely to the change in storage computed from the five hydrographs in figure 31. Thus, the water levels indicated in figure 31 can be applied for estimating the annual change in storage, from which the annual contribution to the reservoir by variable recharge can be computed. The yearly recharge, as determined from the five hydrographs in figure 31 for the years 1962 and 1963, is higher than the recharge computed by using the change maps for these years (table 7). This discrepancy occurs because the observation wells are outside the area of concentrated pumpage and do not accurately reflect the total change. In the authors' opinion, these wells have accurately reflected the change in storage prior to 1962 and,



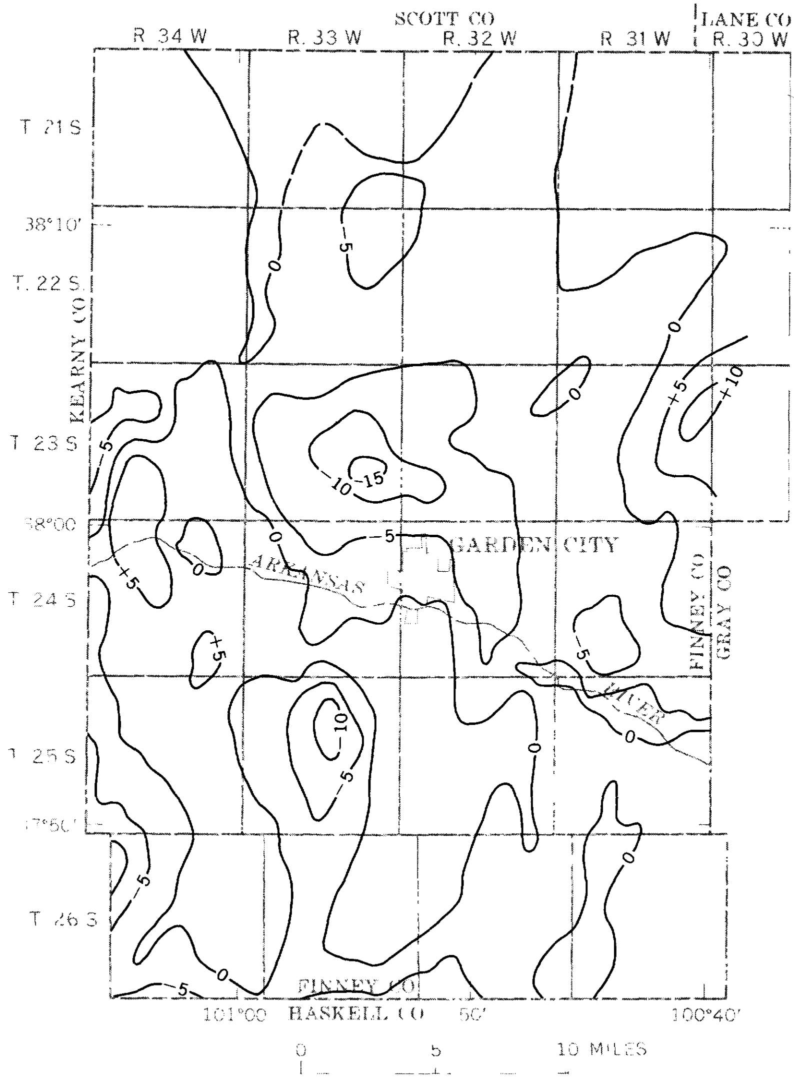
EXPLANATION

—— 5 ——

Line of equal water-level change

Showing rise (+) and decline (−). Interval 5 feet

FIGURE 35.—Water-level change, February 1962–February 1963, western Finney County.



EXPLANATION

—5—

Line of equal water-level change

Showing rise (+) and decline (−). Interval 5 feet
Dashed where approximately located.

FIGURE 36.—Water-level change, February 1963–March 1964, western Finney County.

therefore, can be used to calculate yearly recharge for the period 1940–62.

Table 8 shows the yearly change in each well and the average yearly change for the five wells for the period 1940–63. The computed yearly recharge contribution is given in table 7. The period 1941–51 is characterized by a recharge rate in excess of the discharge from the system, as llustrated in figure 37. A ground-water mound developed over the entire area. The accumulated recharge and accumulated pumpage are plotted in figure 38, and an increase is shown in the amount of water stored in the reservoir area until 1951. The rapid increase in pumpage and the drought period of 1952–54 removed the excess water in storage by 1955. Since 1951 the discharge from the reservoir has been greater than the recharge. Figure 37 indicates that during the early part of the period prior to 1952, increased recharge very nearly kept pace with pumpage; during the later part, when

TABLE 7.—*Annual precipitation and recharge*

Year	Annual precipitation (in.)	Water applied (acre-ft)	Recharge, in acre-feet				
			1	2	3	4	5
1940	18.42	85,200	51,000	112,000	47,500	82,500	
1941	26.30	181,200	180,000	194,000	186,900	194,000	
1942	21.96	181,800	122,000	151,000	136,800	146,000	
1943	14.71	123,200	11,000	78,500	23,400	50,800	
1944	29.39	124,200	188,000	225,000	194,200	214,000	
1945	16.96	122,400	57,000	101,000	49,100	75,600	
1946	24.78	146,800	160,000	179,000	152,000	168,500	
1947	18.16	169,000	56,000	113,000	86,300	100,600	
1948	17.19	218,500	90,000	103,000	99,800	102,200	
1949	22.90	176,100	142,000	160,000	144,900	155,000	
1950	20.55	169,800	167,000	137,000	114,500	127,300	
1951	29.62	154,200	186,000	228,000	211,900	224,100	
1952	8.30	163,700	−40,000	14,400	−30,700	−10,100	
1953	15.25	177,100	10,000	83,900	56,600	70,300	
1954	10.88	207,100	2,000	40,200	20,900	29,300	
1955	20.76	255,900	106,000	139,000	159,900	151,200	
1956	5.68	276,500	5,000	−11,800	−4,600	−10,100	
1957	21.36	343,500	305,000	145,000	210,700	179,700	
1958	28.37	227,500	197,000	215,000	234,000	228,600	
1959	18.07	389,300	250,000	112,000	195,400	154,700	
1960	16.89	354,800	103,000	100,000	164,500	132,900	
1961	19.39	344,800	233,000	125,000	188,500	158,200	
1962	18.64	367,200	204,000	118,000	191,000	155,500	121,600
1963	15.88	340,000	180,000	90,200	144,400	117,200	127,600
Totals		5,299,800	2,965,000	2,952,400	2,977,900	2,998,000	[1] 2,965,000

[1] Accumulated pumpage 1940–64 less change in storage (from table 6).

RECHARGE BASIS

[R, recharge; P, annual precipitation; C, constant, as defined]

1. From long-term hydrographs.
2. $R=(P-6.86 \text{ in.})\ C$, where $C=10{,}000$ acre-ft per in.
3. $R=25$ percent applied water $+(P-12.90 \text{ in.})\ C$, where $C=11{,}100$ acre-ft per in.
4. $R=50$ percent applied water $+(P-18.00 \text{ in.})\ C$, where $C=11{,}600$ acre-ft per in.
5. From water-level-change maps, except total, which is estimated as accumulated pumpage for 1940–64 (from table 6) less change in storage (from table 6).

TABLE 8.—*Changes in water level, in feet, in five observation wells*

Year	Observation wells: 24-32-3dac, Depth to water	24-32-3dac, Change in water level	25-31-13cda, Depth to water	25-31-13cda, Change in water level	25-33-13dac, Depth to water	25-33-13dac, Change in water level	21-32-19bbd, Depth to water	21-32-19bbd, Change in water level	24-33-9aaa, Depth to water	24-33-9aaa, Change in water level	Total yearly changes in water level in five wells	Average yearly change
Feb. 1940	70.2		3.4		75.2		22.5		10.7			
1940-41	71.4	−1.2	3.1	+0.3	74.7	+0.5	22.4	+0.1	11.5	−0.8	−1.1	−0.22
1941-42	70.4	+1.0	1.9	+1.2	74.6	+.1	22.1	+.3	9.1	+2.4	+5.0	+1.00
1942-43	69.7	+.7	2.3	−.4	74.6	0	22.1	0	7.1	+2.0	+2.3	+.46
1943-44	69.4	+.3	2.4	−.1	74.6	0	22.1	0	10.0	−2.9	−2.7	−.54
1944-45	68.5	+.9	2.0	+.4	74.5	+.1	20.8	+1.3	7.5	+2.5	+5.2	+1.04
1945-46	69.1	−.6	2.6	−.6	74.2	+.3	21.1	−.3	6.9	+.6	−.6	−.12
1946-47	68.1	+1.0	1.8	+.8	74.1	+.1	20.0	+1.1	5.9	+1.0	+4.0	+.80
1947-48	68.0	+.1	2.6	−.8	73.9	+.2	19.9	+.1	6.4	−.5	−.9	−.18
1948-49	68.8	−.8	2.6	0	73.3	+.6	19.3	+.6	6.4	0	+.4	+.08
1949-50	67.9	+.9	2.8	−.2	73.1	+.2	18.7	+.6	5.5	+.9	+2.4	+.48
1950-51	66.5	+1.4	2.8	0	72.6	+.5	17.3	+1.4	5.4	+.1	+3.4	+.68
1951-52	64.6	+1.9	2.7	+.1	72.3	+.3	15.5	+1.8	4.9	+.5	+4.6	+.92
1952-53	67.3	−2.7	3.2	−.5	72.0	+.3	16.7	−1.2	7.6	−2.7	−6.8	−1.36
1953-54	69.6	−2.3	3.3	−.1	72.2	−.2	17.4	−.7	8.9	−1.3	−4.6	−.92
1954-55	71.1	−1.5	3.5	−.2	72.6	−.4	18.6	−1.2	12.3	−3.4	−6.7	−1.34
1955-56	71.6	−.5	3.8	−.3	72.8	−.2	20.3	−1.7	12.8	−.5	−3.2	−.64
1956-57	76.2	−4.6	4.2	−.4	70.7	+2.1	23.0	−2.7	16.5	−3.7	−9.3	−1.86
1957-58	75.0	+1.2	3.3	+.9	71.5	−.8	23.7	−.7	14.3	+2.2	+2.8	+.56
1958-59	77.0	−2.0	3.0	+.3	71.8	−.3	21.9	+1.8	11.8	+2.5	+2.3	+.46
1959-60	75.2	+1.8	2.8	+.2	72.1	−.3	23.9	−2.0	12.4	−.6	−.9	−.18
1960-61	76.6	−1.4	3.9	−1.1	73.7	−1.6	24.3	−.4	14.5	−2.1	−6.6	−1.32
1961-62	76.4	+.2	3.5	+.4	74.5	−.8	25.8	−1.5	14.8	−.3	−2.0	−.40
1962-63	76.6	−.2	4.2	−.7	76.3	−1.8	26.3	−.5	17.7	−2.9	−6.1	−1.22
1963-64	77.9	−1.3	4.1	+.1	76.7	−.4	27.3	−1.0	18.3	−.6	−3.2	−.64

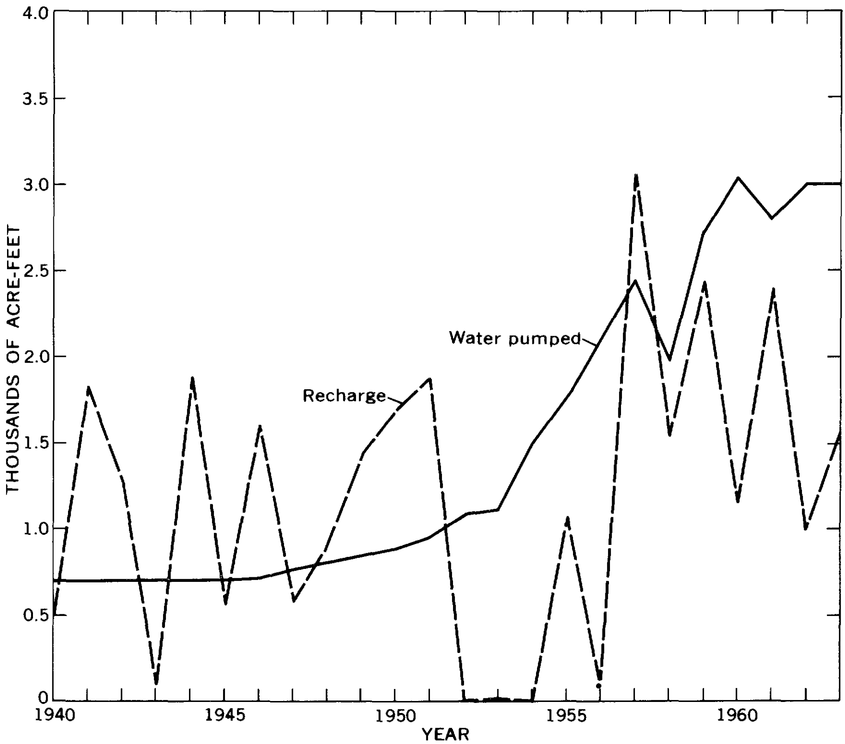


FIGURE 37.—Relation of annual recharge to annual pumpage.

pumping rates were relatively large, the increased recharge became a smaller proportion of discharge. Such a trend can be expected because of two principal factors:

1. The period 1940–51 was marked by precipitation rates significantly above average, and the resulting increased recharge was more than enough to offset pumpage (fig. 37).
2. The possible increase in average rate of recharge by return flow from irrigation is limited to about 25 percent of applied water, and other recharge effects like those due to land management are also limited. As the pumpage is increased, these limits combine to produce a maximum in the ratio of storage change to pumpage.

Assuming all recharge effects to be negligible, the theoretical maximum for the ratio of change in storage to pumpage is 100 percent—that is, all water pumped is obtained from storage. If return flow from applied ground water accounts for the increased recharge in long-term operationg of the reservoir, about 70–75 percent of the pumpage will be obtained from storage. If we consider that part of the return is ob-

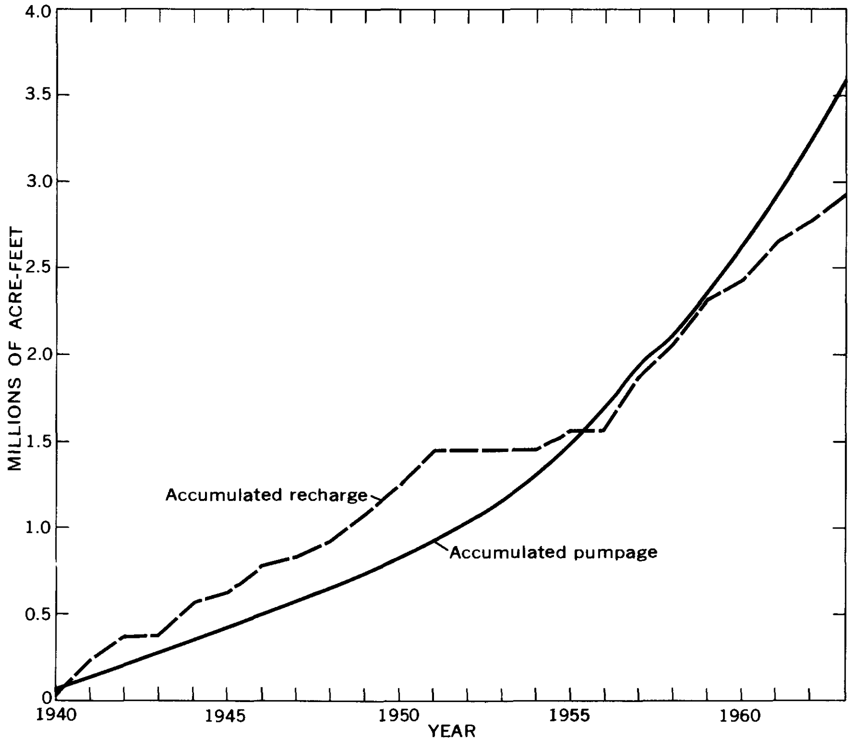


FIGURE 38.—Relation of accumulated recharge to accumulated pumpage.

tained from applied surface water, then approximately 50–60 percent of the pumpage will be from storage. Thus, one may conclude that land management, evapotranspiration control, and precipitation effects may have increased the total recharge during the period 1950–64 by about 25 percent of the pumpage.

RELATION OF EFFECTIVE RECHARGE TO PRECIPITATION

Average annual precipitation observed at the Garden City Experiment Station is 17.98 inches per year for the period 1908–64. Precipitation is highly variable, ranging from 5.68 to 36.19 inches per year. Figure 39 shows the yearly precipitation at the Garden City Experiment Station. The average annual precipitation from 1908 to 1939 was 17.07 inches, and from 1940 to 1964 it was 18.77 inches. The average precipitation rate was 1.7 inches per year greater during the period used for analyzing storage change than it was during the 31 years prior. If the precipitation record of 1908–64 at Garden City reflects more closely the long-term precipitation than does the 1940–64 record, one

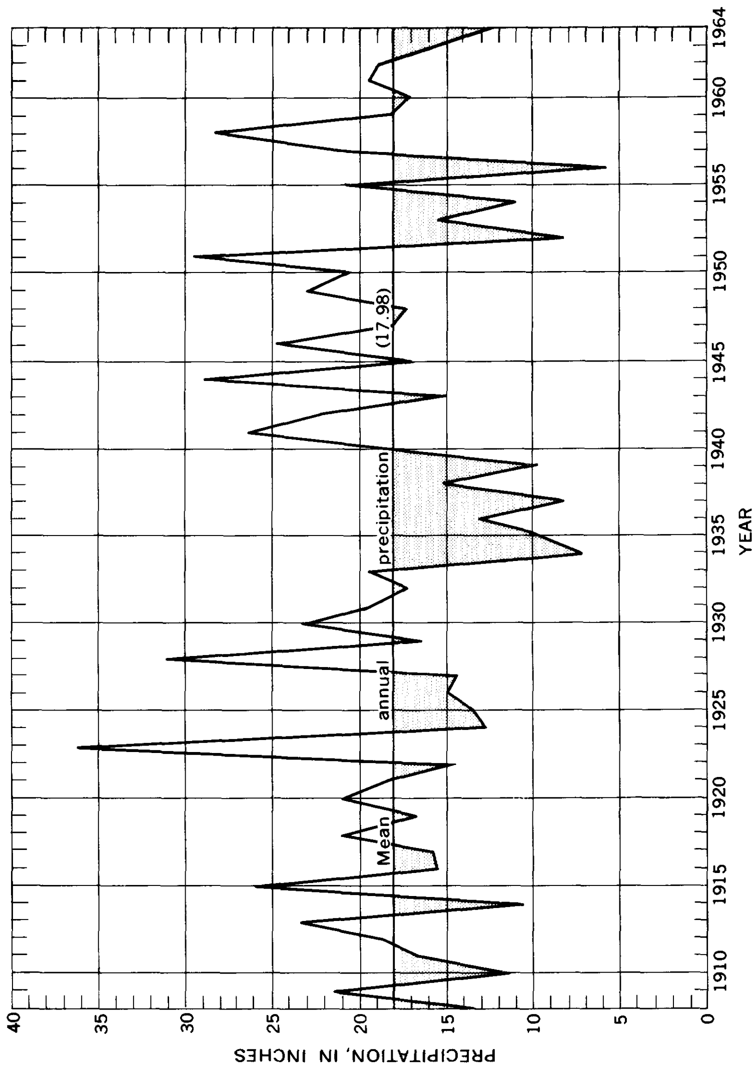


FIGURE 39.—Annual precipitation recorded at Garden City Experiment Station.

would expect a definite increase in recharge from precipitation after 1940. To determine whether recharge and precipitation (table 7) are related, estimates of recharge from water levels in the five wells shown in figure 31 were plotted versus annual precipitation (fig. 40). The data for 1957–63 generally fall well above the mean line drawn through all the data points. The water-level changes on which recharge computations are based are believed to yield progressively less accurate values of recharge as pumping is spread laterally through the aquifers. Note, for example, the points plotted in figure 40 in bold symbols. These were obtained from water-level-change maps of 1962–63 and 1963–64 (figs. 35, 36). The water-level-change maps for those 2 years indicate a computed recharge of about 60 percent of that indicated by the five hydrographs.

The mean line drawn through the points in figure 40 has a slope of 10,000 acre-feet per inch and intercepts a value of zero annual recharge at 6.86 inches per year. This means, literally, that each inch of precipitation above an annual rate of 6.86 inches contributed 10,000 acre-feet of water to storage in the Finney County reservoir. Because 1 inch of water applied over the reservoir area would be equivalent to 46,000 acre-feet, this analysis indicates that possibly as much as 22 percent of the annual precipitation above 6.86 inches (fig. 40) recharges the aquifer.

The preceding analysis of figure 40 is based on the assumption that all recharge noted for the period 1940–64 was derived from above-normal precipitation during that period. However, such an assumption does not appear to be compatible with the data on ground-water inflow and outflow. The net ground-water flow from the reservoir, which remained constant during the period 1940–64, indicated an average annual recharge from natural influences of 2,000 acre-feet, or approximately 0.05 inch per year over the area. Thus, on a long-term basis, the natural recharge from precipitation must be less than 0.05 inch per year, or nearly zero. Water stored in the soil when precipitation is above normal is believed to be discharged largely by evapotranspiration when precipitation is below normal.

The latter viewpoint can be used to estimate the magnitude of manmade effects on recharge, such as return flow from irrigation, land management practice, and evapotranspiration control. In essence, the magnitude of the total of these effects was assumed to be zero in the analysis of figure 40. The annual recharge estimates plotted were obtained by adjusting observed storage changes by an amount equal to the annual pumpage. An additional adjustment of the storage-change data can be made to account for man's influence on recharge. Return flow was estimated (p. 71) to be 25 percent of applied water. Figure 41

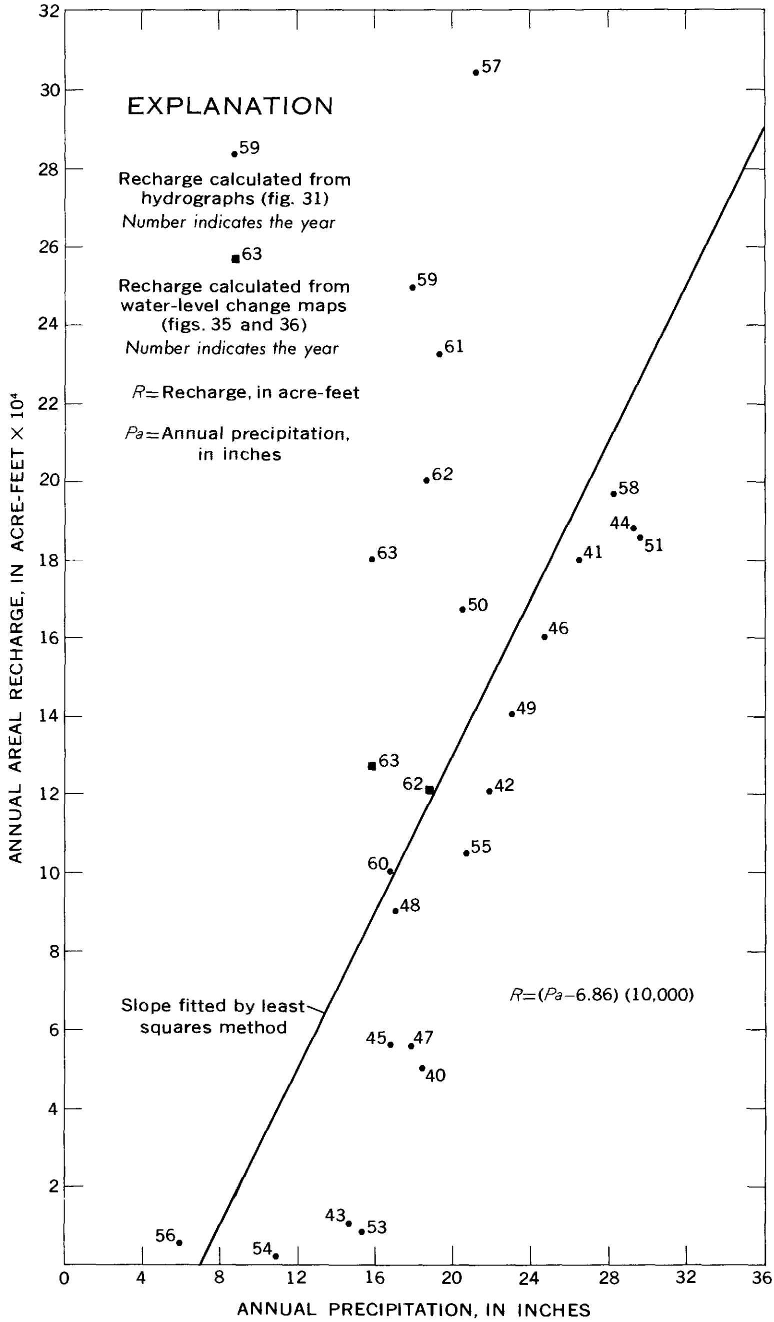


FIGURE 40.—Relation of areal recharge and annual precipitation.

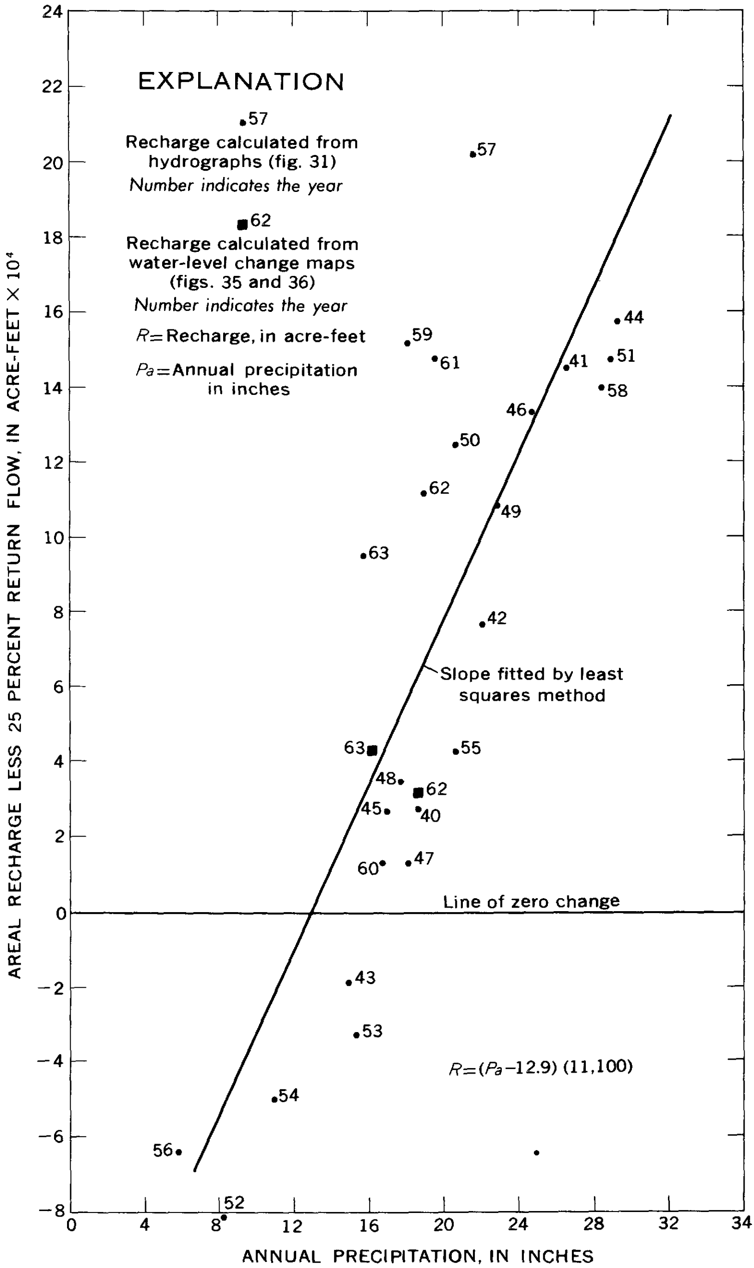


FIGURE 41.—Relation of areal recharge less 25 percent of applied water to annual precipitation.

shows the areal recharge less 25 percent of applied water plotted versus the annual precipitation. The slope of the mean line through the data is nearly the same as the slope in figure 40. However, the intercept with zero net recharge is at 12.9 inches annual precipitation. A similar graph (fig. 42) was constructed by assuming that manmade

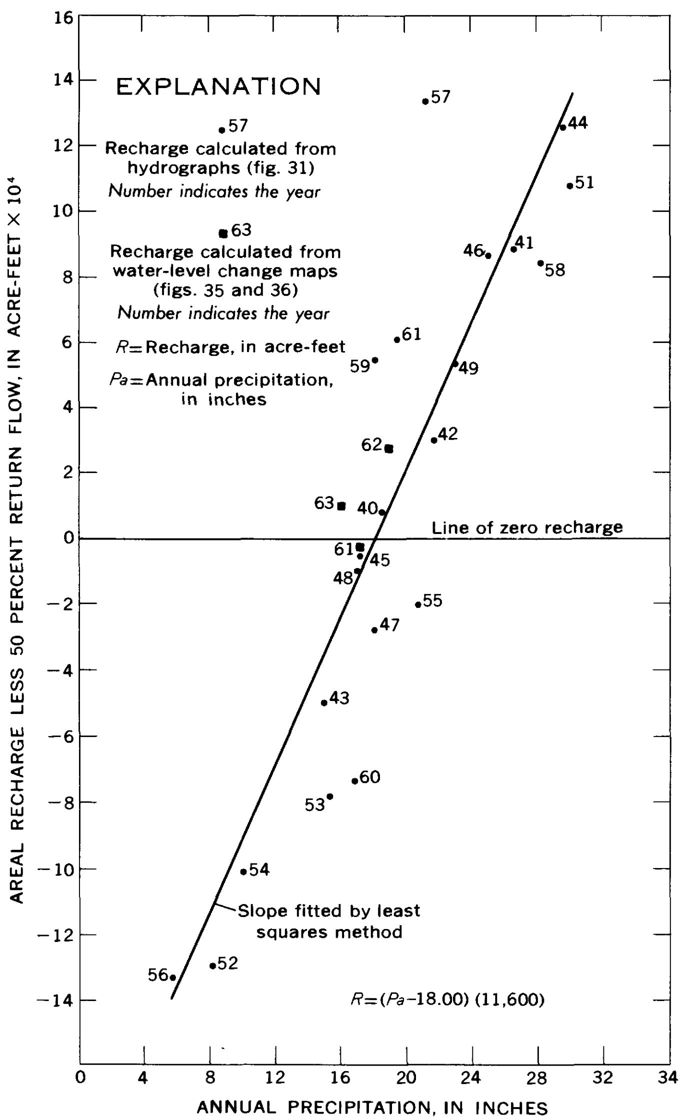


FIGURE 42.—Relation of areal recharge less 50 percent of applied water to annual precipitation.

recharge effects are 50 percent of the applied water. The intercept with zero recharge in the latter graph is at 18 inches annual precipitation.

A graph of the intercepts versus the corresponding annual precipitation derived from figures 40–42 is shown in figure 43. The effects on recharge due to man's activity (return flow, land management, and evapotranspiration control) can be found by extrapolation between the points plotted in figure 43. Recharge effects should average zero at the annual average precipitation rate of 17.98. In figure 43 this rate coincides with 50 percent applied water. Thus, the total effect of man's development of the reservoir, or recharge, probably is to increase recharge by approximately 50 percent of applied water, including both ground- and surface-water irrigation.

Considerable data scatter is to be expected in the figures 40–42 because the factors controlling recharge are highly variable. Conditions producing the fluctuations in water levels in the five observation wells are not uniformly representative of reservoir conditions each year because each well can be affected to varying degrees by nearby

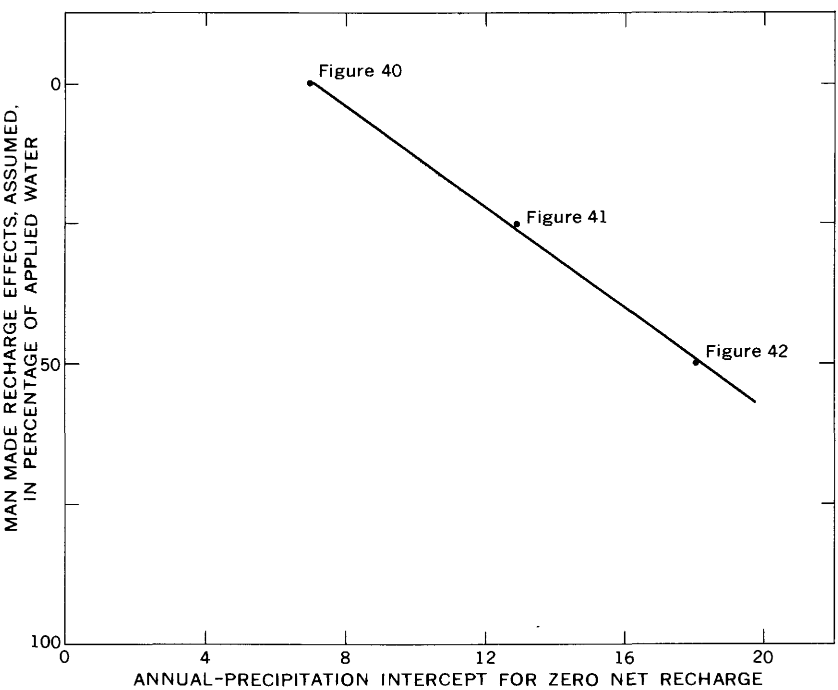


FIGURE 43.—Relation of manmade recharge effects and annual precipitation intercept for zero net recharge.

pumping. Antecedent conditioning of the unsaturated zone by precipitation produces variable recharge conditions for any given annual precipitation rate, as would the duration and frequency of storms. Detailed analysis of water-level fluctuations versus precipitation indicated that such antecedent effects may be significant for 3 of the years studied. Because there is considerable scatter in the relation between recharge and other variables, it does not seem possible to define, either separately or by trends, the recharge effects due to return flow, land management, and evapotranspiration control. The data analyzed show only that about 50 percent of the applied water is recycled through the reservoir. Should future management practice include the use of lined distribution canals and ditches, the percentage of recycled water might be smaller.

EFFECT OF PUMPING

The altitude of the water table in Finney County is the result of a number of variables including pumpage, subsurface inflow, local recharge, and flow of surface water to the aquifers. The amount of ground water pumped is the only reservoir variable directly controlled by man in the county. The relation is simple and direct: when pumpage exceeds recharge, the water table declines. Average decline of the water level in the reservoir can be computed as follows:

$$\text{Average drawdown of reservoir (1963), in feet} = \frac{\text{Pumpage less recharge, in acre-feet}}{\left(\text{Specific yield of drained material}\right)\left(\text{Area of reservoir, in acres}\right)},$$

$$= \frac{295{,}000-128{,}000}{(0.2)(552{,}960)},$$

$$= 1.5 \text{ feet},$$

where

pumpage is in acre-feet, from figure 32;
total recharge is in acre-feet;
pumpage less the change in storage, from table 6;
specific yield of the drained material is 0.2, as stated on page 63;
area of reservoir is in acres, as stated on page 33.

The amount of drawdown given above is an average for the entire reservoir in 1963. Larger declines will occur in pumped areas, and rises or minor lowering will occur where is no pumping.

Low flow in the Arkansas River is not large enough to act as a significant boundary for added recharge to the reservoir, as water levels continue to decline in response to pumping. Nor is there any apparent source of water capable of sustaining high water levels in the face

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of continued pumping at current rates. Water levels may rise some years when precipitation is significantly above normal, but on the average, in time, storage in the reservoir will be reduced in an amount equivalent to about 60 percent of the pumpage. (See p. 82.) Thus, for each year the average water-table declines due to pumping can be estimated as

$$s=\frac{0.60Q}{552{,}960\times 0.2}=5.4\times 10^{-6}Q,$$

where s is in feet per year, and Q is the total pumpage, in acre-feet per year. For example, in 1963 the pumpage was 2.95×10^{5}, and

$$s=5.4\times 10^{-6}\times 2.95\times 10^{5}=1.6 \text{ feet}$$

of water-level decline due to pumping only.

SUMMARY OF HYDROLOGY

The group of interconnected aquifers in Finney County can be considered as a ground-water reservoir and to be subject to three phases of reservoir operation. These phases are recharge (addition of water), storage (retention of water), and discharge (diversion of water).

The permeabilities of the Tertiary and Quaternary aquifers in Finney County are as follows: Pleistocene and Holocene alluvium, 2,600 gpd per sq ft; undifferentiated Pleistocene deposits, average 1,500 gpd per sq ft; and the Pliocene Ogallala Formation, 320 gpd per sq ft. Wells that were perforated in both Pliocene and undifferentiated Pleistocene aquifers had permeabilities ranging from 620 gpd per sq ft to 1,100 gpd per sq ft. The higher permeabilities occurred where the undifferentiated Pleistocene aquifer is predominant.

The net recharge to ground water from streams in the county averaged 1,700 acre-feet per year. The net underground flow of water from the county was 2,000 acre-feet per year. Pumpage for irrigation accounted for the greatest discharge and ranged from 70,000 acre-feet in 1940 to 295,000 acre-feet in 1963.

The total storage in the reservoir was computed to be 20,000,000 acre-feet, which is about 70 times the present annual pumpage. The water-level change maps indicate that storage was reduced by only 7.6 percent of pumpage from 1940 to February 1962, and 16.0 percent of pumpage came from a reduction of storage from 1940 to March 1964. Yearly change maps for the irrigation seasons of 1962 and 1963 show that approximately 58 percent of the water pumped in those years came from a reduction in storage. Before pumpage became a significant discharge item in the reservoir, the average recharge from precipitation to the aquifers probably was virtually nil. The return flow from applied water, the possible increase in infiltration rate as a result of tillage, an increased soil moisture due to irrigation, and perhaps a small reduction of evapotranspiration from ground water all combined to increase effective recharge as irrigation was expanded. Observations of the change of water stored in the aquifer, of pumpage, and of precipitation during the period 1940–64 indicate that the recharge rate has increased by approximately 40 percent of applied water, owing to man's use of the land and the water system. Thus, only about 60 percent of the pumpage is being consumed, and 40 percent is recycled through the reservoir. As pumping continues, this recycling will probably deteriorate the quality of the water obtainable.

CHEMICAL QUALITY OF WATER

ORIGIN OF CONSTITUENTS

Much of the dissolved matter in water originates from solution of the rocks through which the water has moved. However, some dissolved matter, especially in water in the rocks of Cretaceous age, originated from sea water that either was the medium of deposition or entered during a later inundation of the sediments. The Tertiary and Quaternary sediments are composed of fragments of many varieties of older rocks that could be a source of any of the common chemical constituents in ground water.

Rainfall, some of which eventually becomes ground water, contains a number of gases dissolved from the air and some solids from dust in the air. Dust from other areas, where surface rocks are much different, often settles in Finney County. The influence of dust on the quality of water in Finney County is not known.

Surface pollution from human and animal wastes has a major influence on water quality where the wells are improperly sealed or where the aquifer is shallow and the surface rocks are very permeable.

Analyses of specific conductance, chloride, and total hardness in water from 200 wells were used to determine quality trends. Chemical analyses of 75 selected water samples were made in the Environmental Health Services Laboratory, Kansas State Department of Health.

ANALYSES OF CHEMICAL CONSTITUENTS

Silica (SiO_2).—Silica is dissolved by weathering of silicate minerals. It contributes to encrustation in steam boilers and on turbine blades. The range in concentration of silica in Finney County is from 8.0 mg/l (milligrams per liter) from 21–27–16bb, a 640-foot well in the Lower Cretaceous, where weathering is unlikely, to 42 mg/l from 22–31–32db, a 234-foot well in arkosic Tertiary and Quaternary sediments. The average concentration is 20 mg/l.

Iron (Fe).—Iron is present in most sediments in a form not readily soluble in water with a pH (a measure of acidity and alkalinity) value greater than 7.0. Results of field pH measurements indicate that the pH values of all ground water in Finney County exceed 7.0. Some iron might be dissolved from an oxidized well casing, however, which would prevent determining the true condition in the aquifer. The samples having a very high iron content probably contained iron in a suspended form at the time of analysis.

A high concentration of iron imparts a bad taste to drinking water and tends to stain laundry and plumbing fixtures. Four water samples collected in Finney County contained no iron. The highest iron content determined was 6.9 mg/l for a sample from 22–28–25cc, a well in the Lower Cretaceous. This high iron content is apparently caused by oxidation of the casing.

Calcium (Ca).—Calcium is one of the elements causing hardness in water. Tertiary and Quaternary sediments as well as the Upper Cretaceous limestones and shales contain large amounts of calcium carbonate ($CaCO_3$). Water containing carbon dioxide from the air and from biological activity dissolves calcium carbonate to form calcium and bicarbonate ions. Another major source of calcium is gypsum ($CaSO_4 \cdot 2H_2O$). It is somewhat more soluble than calcium carbonate and is present in shales and in some soils of the area. Airborne dust is also a possible source of calcium.

The lowest concentration of calcium ions in Finney County ground water is 6.4 mg/l in 23–27–4ab, a well in the Lower Cretaceous, where ion exchange has radically altered the composition of the water. The highest concentration is 386 mg/l in 24–33–12cb (from a sample collected in 1940), a well in the alluvium where concentration of solids by evaporation has been the main influence on composition of the water.

Magnesium (Mg).—Magnesium is similar to calcium in many respects. However, magnesium salts are more soluble than their calcium analogs and therefore tend to remain in solution. Magnesium, like calcium, is a source of hardness in water. Most sources of calcium also contain some magnesium. The dark minerals contained in Tertiary and Quaternary sediments could supply magnesium in small amounts as a product of weathering.

The wells in Finney County having the lowest and highest calcium concentrations also have the lowest and highest magnesium concentrations. The variation of magnesium concentration is 2–165 mg/l.

Sodium (Na).—Most rocks contain at least a small amount of sodium. Marine Cretaceous shales and nonmarine sandstones that have been invaded by sea water contain large amounts of sodium. The red Permian sediments contain evaporite beds that have large amounts of sodium chloride (NaCl) and influence the quality of water in the overlying Mesozoic sediments. Rainfall in Finney County probably contains at least a trace of sodium. Sodium is not a common constituent in unconsolidated sediments, but a small amount could find its way into the water from weathering of sodium-bearing minerals and from ion exchange, where calcium displaces sodium in clay minerals. An excessive concentration of sodium in relation to calcium and magnesium may be detrimental to soil structure and plant growth.

The lowest concentration of sodium is 1.6 mg/l in 24–32–19cd, a well in terrace gravel south of the Arkansas River; the highest is 492 mg/l in 24–33–14cac, a well in the alluvium north of the Arkansas River.

Potassium (K).—Potassium is almost as abundant in sediments as sodium but generally is not present in a soluble form and is more readily absorbed by sediments. Therefore, concentrations of potassium in water are lower than those of sodium. Although chemically similar to sodium in some respects, potassium in the concentrations present in Finney County is beneficial rather than harmful to plants.

The lowest concentration of potassium is 3.2 mg/l in the relatively low dissolved-solids water in 26–32–31cc, a well in Pliocene and undifferentiated Pleistocene deposits; the highest is 24 mg/l in water in the Pleistocene and Holocene alluvium.

Bicarbonate (HCO_3).—The bicarbonate ion is formed mainly by the dissolution of carbonate sediments by water containing carbon dioxide from the air and the soil. All sediments in Finney County, except the surface layers of some soils and some of the Mesozoic sandstone at depth, contain easily detectable amounts of calcium carbonate. The presence of large amounts of bicarbonate in irrigation water tends to induce precipitation of the calcium and magnesium, leaving a high ratio of sodium ions to calcium and magnesium ions that may be detrimental to soil structure and plant growth.

The lowest concentration of bicarbonate ions in ground water sampled in Finney County was 134 mg/l in water from the 92-foot level of 24–32–19ca3, a well in unconsolidated sediments, where the predominant ions are calcium and bicarbonate; the highest was 522 mg/l in 22–28–25cc, a well in the Lower Cretaceous, where sodium and sulfate predominate.

Sulfate (SO_4).—Sulfate in ground water is derived from the solution of sulfate minerals, generally gypsum, and the oxidation of sulfide minerals. Unconsolidated sediments apparently contain a small amount of gypsum, probably in the finer fractions. Some sulfate originates with the oxidation of pyrite in the dark clays and silts in the subsurface Tertiary and Quaternary deposits in many areas of Finney County. Much of the sulfate in ground water may be leached from dust deposited on the surface by duststorms which originate in areas of gypsiferous soils.

The presence of sulfate in irrigation water is desirable, especially in water that has a high dissolved-solids content. It improves soil structure, and, because it is soluble (1,500 mg/l as calcium sulfate in pure water and much more in the presence of some other salts), it can be flushed through the soil so that there is no salt build up.

Concentrations of sulfate in ground water of Finney County range from 6.8 mg/l in 25–31–15dc, a 24.5-foot well in the alluvium south of the Arkansas River, to 2,028 mg/l in 24–33–14cac, a 40-foot well in the alluvium north of the river.

Chloride (Cl).—Most sediments contain at least a small amount of chloride. Mesozoic sediments of marine origin and sandstones that have been flooded with salt water at some time contain enough sodium chloride to have a noticeable effect upon water that contacts them. Some chloride is dissolved from Tertiary and Quaternary sediments, for in the areas where water apparently is moving downward, the chloride-ion concentration increases with depth. The concentration of chloride ion in the county has little effect on water quality, as it is low compared with the concentrations of other constitutents.

The lowest concentration of chloride in ground water sampled in Finney County is 2.5 mg/l in wells (26–33–9aa and 26–31–30aa) in Pliocene and undifferentiated Pleistocene deposits in the sandy area south of the Arkansas River. The maximum chloride concentration of 282 mg/l occurs in water from a well (22–28–25cc), in undifferentiated Lower Cretaceous deposits.

Fluoride (F)—Fluoride is a minor constituent in most igneous rocks and can be derived from this source. Cretaceous sediments contain beds of bentonite formed from the weathering of volcanic ash that might have contained fluoride minerals. The Ogallala Formation is known to contain ash and bentonite beds in other areas and probably contains at least a small amount of these materials in Finney County. Volcanic ash of Pleistocene age has been identified in Finney County. Traces of fluorite and other fluoride minerals in the clastics of igneous origin that constitute the major part of the coarse fractions of the Tertiary and Quaternary sediments could also be a source of fluoride in ground water.

Calcium fluoride (CaF) is slightly soluble in pure water, 8.7 mg/l fluoride at 25°C. Fluoride is easily absorbed by sediments. These factors, as well as its low availability, keep the concentration of fluoride to within safe limits for most of the drinking water in this area.

Concentrations of 1.0–1.5 mg/l fluoride in drinking water can be an aid in preventing tooth decay. Over 1.5 mg/l may cause mottling of tooth enamel in children drinking such water. Some authorities infer that concentrations over 4.0 mg/l fluoride may have an effect upon bone structure.

The lowest concentration of fluoride in water sampled in Finney County is 0.2 mg/l in 26–31–15dc, a well in the Pleistocene and Holocene alluvium south of the Arkansas River; the highest is 6.5 mg/l in water from 23–27–4ab, a well in the Lower Cretaceous.

Nitrate (NO_3).—Various nitrogen compounds are components of precipitation from thunder showers, are present in animal and human wastes, and are products of decay of animal and vegetable proteins. Legumes take nitrogen from the atmosphere and fix it in the soil as nitrate. Nitrate from these natural sources may eventually find its way into ground water. Chemical fertilizers containing nitrogen compounds can also add large amounts of nitrate to the ground water when heavy fertilization is accompanied by leaching.

An examination of the wells yielding water with a high nitrate content in Finney County indicates organic pollution from animal wastes either through an improperly sealed well or by percolation through permeable sediments in the vicinity of the well. Chemical fertilizers apparently have no influence on the nitrate concentration in ground water at present, but their use is increasing, and a noticeable rise in nitrate concentration could occur. The concentration of nitrate in ground water sampled in Finney County ranges from 0 mg/l, in well 21–32–20cb, to 53 mg/l in well 21–31–3c. Both wells are in Pliocene and undifferentiated Pleistocene deposits. A concentration of less than 44 mg/l nitrate is the recommended limit (U.S. Public Health Service, 1962) above which water should not be used for feeding babies because of the danger of methemoglobinemia, which causes cyanosis (blue coloration of the skin). Water from one well (21–31–3c) is above the limit, and several more wells yield water with a nitrate concentration near the upper limit. Concentrations of over 20 mg/l nitrate may be indicative of organic pollution.

Dissolved solids.—Values reported for dissolved solids are calculated and are the sum of determined constituents.

Because of salinity problems in Finney County, the dissolved-solids value is the best analysis figure to use in comparing irrigation waters. A high concentration of dissolved solids is detrimental to plant growth because an increase in salinity decreases the osmotic pressure gradient, and the plant absorbs less water. High salinity levels may have other detrimental effects on plants. Some species of plants are more tolerant than others to saline water.

The lowest concentration of dissolved solids in ground water of Finney County is 178 mg/l in 26–32–31bc, a well in Pliocene and undifferentiated Pleistocene deposits; the highest is 3,197 mg/l in 24–33–12cb, a well in the Pleistocene and Holocene alluvium north of the Arkansas River.

Hardness as $CaCO_3$.—Hardness is expressed as an equivalent quantity of calcium carbonate ($CaCO_3$) for convenience in comparing waters of different composition. The ions that ordinarily cause hardness in water are calcium and magnesium. Hardness causes the formation of scale in tea kettles, water heaters, steam boilers, and other applications where water is heated. It also increases the amount of soap necessary for cleaning purposes. Calcium and magnesium ions react with ordinary soluble-sodium soaps to form insoluble soaps that precipitate as a sticky curd. The sum, in milliequivalents per liter, of calcium and magnesium is converted to calcium carbonate (by multiplying by 50) and is reported as hardness.

Hardness caused by carbonates and bicarbonates of calcium and magnesium can be largely eliminated by boiling the water, which causes the precipitation of calcium and magnesium carbonate. The remaining hardness is called noncarbonate hardness, or, sometimes, permanent hardness. It is calculated by subtracting milliequivalents per liter carbonate and bicarbonate from milliequivalents per liter calcium and magnesium and converting the result to milligrams per liter calcium carbonate.

Most of the ground water in Finney County is very hard (more than 180 mg/l total hardness). The lowest calcium magnesium hardness in ground water of Finney County is 24 mg/l in the most recent sample from well 23–27–4ab, where the source is the Lower Cretaceous. This sample contained zero noncarbonate hardness. The highest calcium magnesium hardness was 1,641 mg/l in water collected in 1940 from 24–23–12cb, a well in the Pleistocene and Holocene alluvium of the Arkansas River. The water also contained the highest noncarbonate hardness, 1,425 mg/l.

Specific conductance (micromhos at 25°C).—Specific conductance is the reciprocal of the resistance, in micro-ohms, of a 1-centimeter cube of water and is an indication of dissolved-solids content. The ratio of specific conductance to dissolved solids in Finney County ranges from 0.57 for water low in dissolved solids to 0.78 for water containing more than 3,000 mg/l dissolved solids. As the conductance of a water sample is relatively easy to determine, an estimate of the suitability of water for irrigation can be made quickly.

The lowest specific conductance in ground water of Finney County is 340 micromhos per centimeter for a sample from a depth of 104 feet in 25–33–1dc2; the highest is 4,300 micromhos per centimeter for the sample from 24–33–14cac, a well in the alluvium.

pH.—The negative logarithm to the base of 10 of the hydrogen ion concentration (pH) for pure water is 7. Minerals added to pure water can change the pH to either below 7 for acid substances or above 7 for basic substances. Some impure water can have a pH of 7 because of a balance between acid and basic substances. When calcium bicarbonate, which is the salt of an acid tending to ionize only slightly, and a base, which ionizes to a much greater extent, are present in water, the pH tends to be slightly above 7. Dissolved carbon dioxide (CO_2) forms the slightly ionized acid, carbonic acid (H_2CO_3), in the water. The presence of this acid with a salt of the same acid forms a buffered system what keeps the pH between 7 and 8. This system is operative in most, or possibly all, of the ground water in Finney County.

A correlation with depth of source is evident with water from the deeper wells having the highest pH. The highest pH value is 8.0 for water from 24–32–25bda, a well in Pliocene and undifferentiated Pleistocene deposits; the lowest is 7.2 for 24–32–22db, a well in Pleistocene and Holocene alluvium, and 24–32–36ba, another well in the same formation.

SPATIAL DISTRIBUTION OF CHEMICAL CONSTITUENTS

The quality of water is markedly different from one area of the county to another, and in some areas it also differs greatly with depth. Concentrations of fluoride range from 0.2 mg/l in water from Tertiary and Quaternary sediments at the south edge of the county to 6.5 mg/l in water from the Lower Cretaceous in northeastern Finney County. Total-solids concentrations range from less than 200 mg/l in southern areas to over 3,000 mg/l in some wells in the alluvium in the central part of the county. Calcium bicarbonate water normally contained the lowest concentrations of total dissolved solids. As the concentration of solids becomes higher, the water changes to a magnesium sodium sulfate water in Tertiary and Quaternary sediments and to a sodium bicarbonate sulfate water in the bedrock aquifers.

The highest concentration of dissolved solids in ground water is generally associated with a high water table and with undrained depressions, or both. Under these conditions, salts accumulate especially in fine- to medium-textured soils (Harner and others, 1965). Surface accumulations of the least soluble salts, including calcium carbonate and calcium sulfate are sometimes removed by wind action. Flushing of the more soluble salts from the soil by rainwater causes relative enrichment of the ground water in magnesium, sodium, sulfate, and chloride ions. At high concentrations, sodium may be adsorbed preferentially by exchange minerals in the soil (Carroll, 1962), leaving magnesium as the dominant cation.

Sodium is generally the dominant cation in water from unconsolidated aquifers in irrigated areas and in the Arkansas River valley, where it has not accumulated in the soil. Although water in the sandstone aquifers seems to have been affected by cation exchange reactions, water from the limestone cavities does not.

RANGE OF FLUORIDE CONCENTRATION

Fluoride content is a primary consideration in water for domestic use in Finney County. The range in concentration of this constitutent is shown in figure 44, a map of fluoride concentration in possible domestic supplies of water in Finney County. Water for possible domestic supplies does not include that having a dissolved-solids concentration greater than 1,000 mg/l unless a better quality supply is not available.

The fluoride concentration varies in proportion to total solids except in the band of high-fluoride water that extends from the Scott-Finney County line southeastward to the Gray-Finney County line. The band

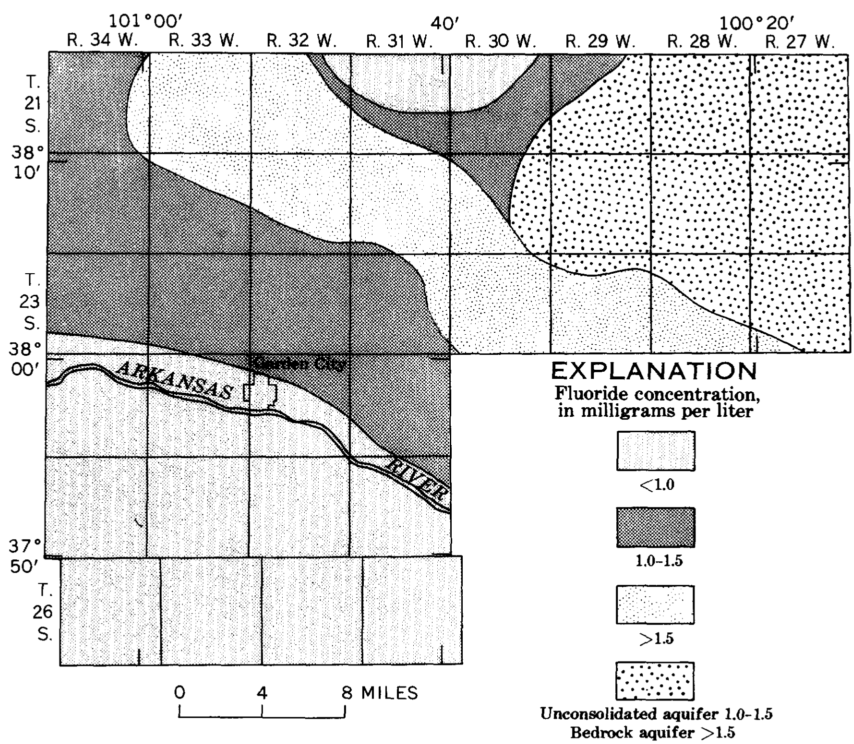

FIGURE 44.—Fluoride concentration in domestic water supplies.

follows, in general, the flow lines of the water-level maps (figs. 18–22) of the area and appears to originate in an area that has a high water-table and undrained depressions. The high concentration of fluoride is probably related to other water-quality changes taking place in that area. This water contains from two to three times the concentration of fluoride in water flowing into that area from Scott County (Waite, 1947, table 15).

The large area of variable fluoride content in northeastern Finney County does not have continuous Tertiary and Quaternary aquifers. Water from the Tertiary and Quarternary aquifer in that area has a fluoride content of less than 1.5 mg/l, whereas the Lower Cretaceous, which is used where a good supply from unconsolidated aquifers is not available, yields water having a very high fluoride content (as much as 6.5 mg/l in well 23–27–4ab).

RANGE IN DISSOLVED SOLIDS

The practices used in irrigation in the various parts of Finney County depend to a great extent upon the total solids content of the water used. The physiological effect of water with high dissolved solids discourages its use for domestic purposes.

The areal distribution of dissolved-solids concentrations is shown in figure 45. The general relation of dissolved-solids concentrations to geologic formations in the subsurface is shown in figure 46.

An analysis of water from Lower Cretaceous rocks was not available near the section, so a value was projected from northeastern Finney County. A gradient in downdip dissolved-solids change was assumed, based upon regional dip and distance from the recharge area. To show the vertical changes more clearly, the lowest concentration class on the map (0–300 mg/l) is separated into two classes (0–200 mg/l and 200–300 mg/l) on the section.

Flow-direction arrows in figure 46 show the minor north-south and vertical components of movement. The major component of flow is to the east, so that the actual horizontal distance along flow lines between changes-in-concentration classes is, in some places, more than five times as great as the distances shown on the section. The location of the section was selected because of available data.

Water in Tertiary and Quaternary aquifers of northern Finney County has a concentration of total solids approximately twice in that water in the southern part of the county. In the sandy, southern section, less material is available for solution, and the water penetrates to the water table rapidly; thus, less concentration occurs by evaporation than in the loess-covered, northern section. The water table in northern Finney County is higher, at present, than in the southern

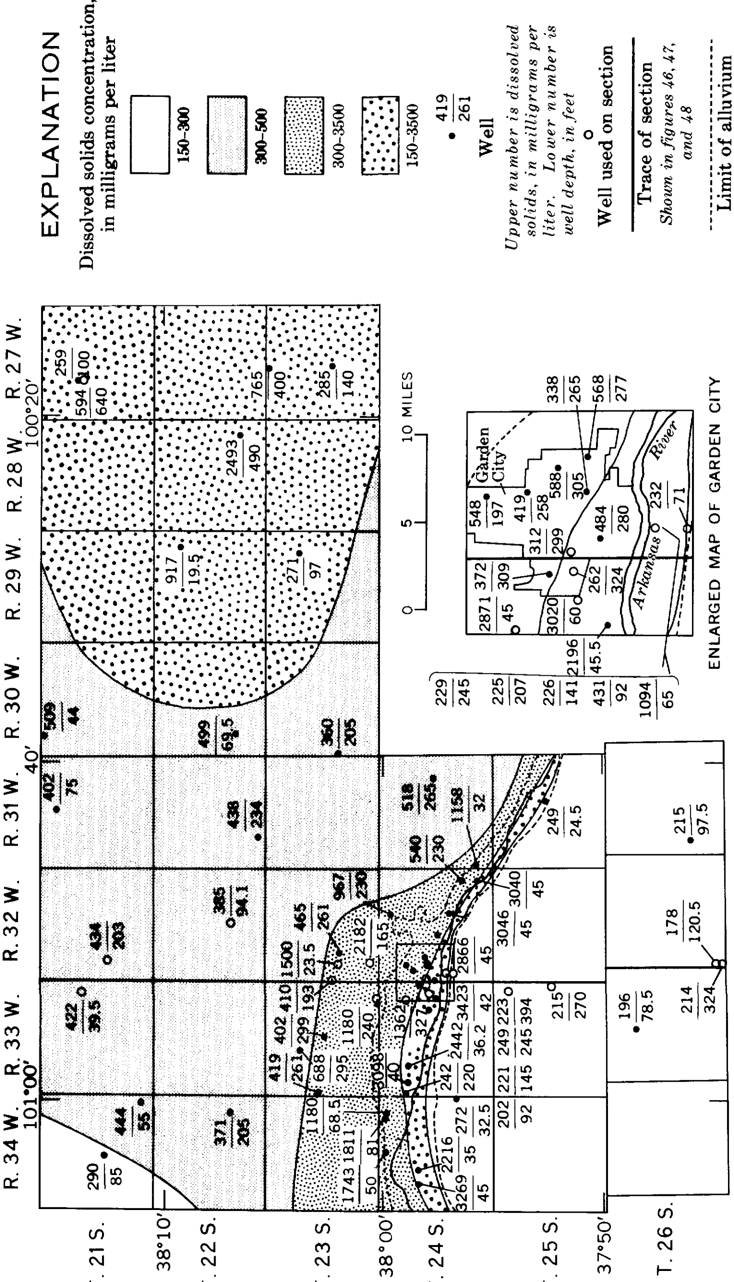

FIGURE 45.—Concentration of dissolved solids in water.

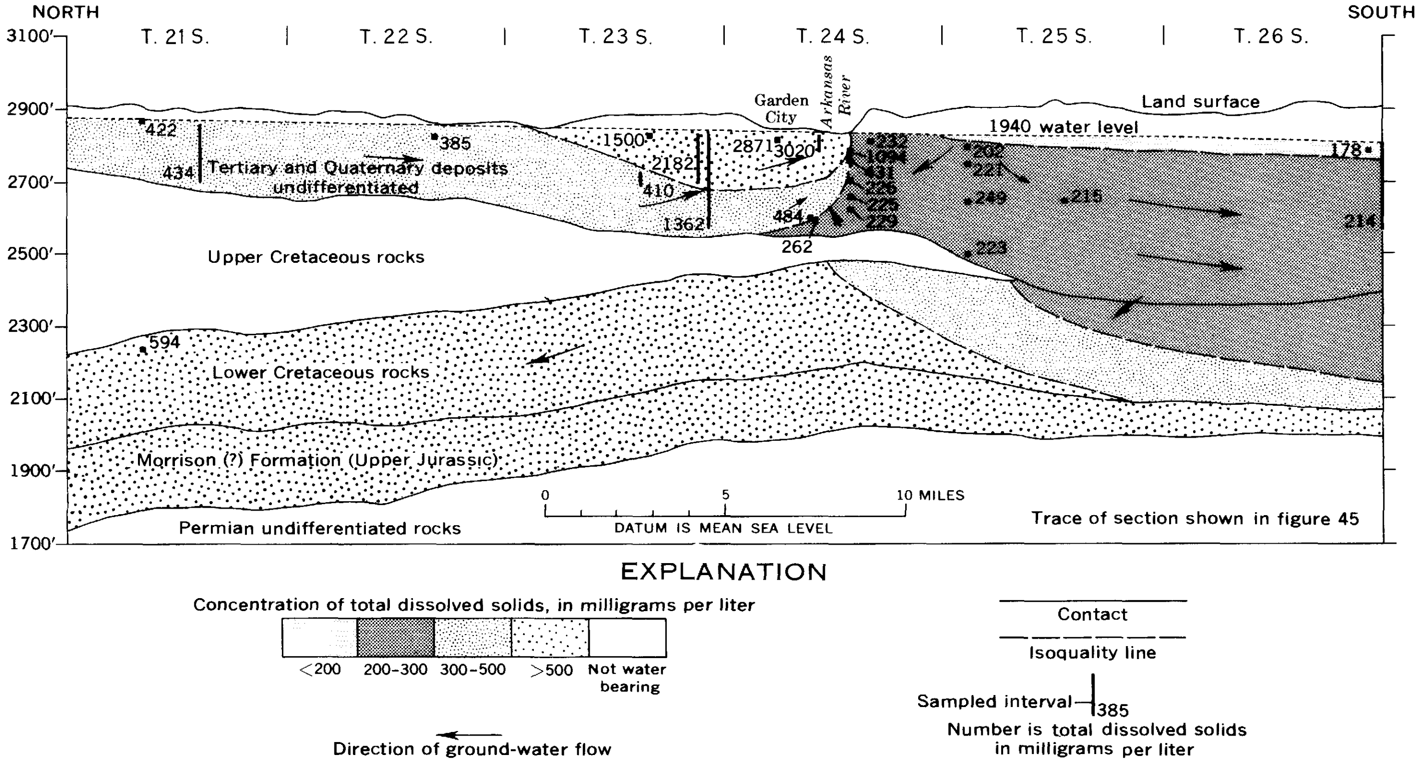

FIGURE 46.—North-south section, showing total dissolved solids in ground water.

section and has been at or near the surface in many places during periods of extremely large amounts of rainfall (such as the summer of 1951). Local accumulations of salts are at the surface because of this condition. Small areas of extremely poor quality water in the area north of the Arkansas River are probably numerous because of local depressions where water stands and evaporates. Total solids show a general increase downgradient from areas that are predominantly recharge areas. The downgradient increase in total solids is accentuated in the Mesozoic formations by the flushing of water from upgradient areas (fig. 46).

In the shallow alluvium along the Arkansas River, the rate of increase in dissolved solids is accelerated by evaporation. The river should act, under normal conditions, as a sort of sewer to drain off water highly charged with dissolved solids. The wide band of poor quality water near the surface in Pliocene and undifferentiated Pleistocene deposits north and west of Garden City may be the result of a concentration of ditch irrigation using poor-quality surface water. The east end of the belt is extended by a small north-south valley, where, at times of high water level, evaporation increases total solids.

HYDROCHEMICAL FACIES

To show that changes in composition accompany an increase in concentration of total solids, sections were constructed showing cation facies (fig. 47) and anion facies (fig. 48), shown on the same base as the dissolved-solids section (fig. 46). The values used in the construction of the sections are percentages based on milliequivalents per liter converted from milligrams per liter through use of the conversion factors in Hem (1959, p. 32). To further illustrate the changes in composition, the percentages were plotted on a modified Piper diagram (fig. 49).

For most of the area, ion exchange is relatively unimportant. The only place that it predominates as an influence on water quality is in the Lower Cretaceous. The cation ratios used were changed from the sodium potassium versus calcium magnesium, used by Back (1960), to sodium potassium magnesium versus calcium. This method emphasizes the changes due to evaporation. Ranges for ratios were selected to show natural water-quality divisions within the report area.

A comparison of the cation- and anion-facies sections with the dissolved-solids section shows the change from calcium bicarbonate facies to sodium magnesium sulfate facies that accompanies the increase in concentration of total solids. The change with distance downdip and increased total solids in the Mesozoic aquifers is toward a sodium bicarbonate facies, as the main mechanisms are ion exchange and solution of new material.

CLASSIFICATION OF WATER FOR IRRIGATION

Factors to consider when classifying water for irrigation are the ratio of sodium to calcium and magnesium and the total-solids concentration. These factors are used in figure 50, a nomogram for determining sodium-adsorption-ratio, and in figure 51, a diagram for classification of water used for irrigation. These illustrations are based on Agricultural Handbook 60, U.S. Department of Agriculture (U.S. Salinity Laboratory Staff, 1954).

The SAR (sodium-adsorption-ratio) is determined by plotting, in figure 50, the concentration of sodium, in milliequivalents per liter, on the left scale (*A*), and the concentration of calcium plus magnesium, in milliequivalents per liter, on the right scale (*B*). A line connecting these two points intersects the sodium-adsorption-ratio scale (*C*) at the sodium-adsorption-ratio of the water. The SAR may also be calculated with the following formula:

$$SAR = \frac{Na^{+1}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}},$$

using the same units of concentration as in figure 50. This formula was used to obtain the SAR for water from well 24–33–7db1 because the concentration of calcium plus magnesium exceeded the largest figure on the right scale (*B*) of the nomogram. Analyses made prior to 1962, which include the potassium as equivalent sodium, can be used by considering the potassium as negligible.

When the SAR and the electrical conductivity are known, an estimate of the suitability of water for irrigation can be determined graphically from figure 51. An approximation of the electrical conductivity can be obtained by dividing the dissolved solids, in milligrams per liter, by 0.64.

Four analyses were selected to show the ranges in suitability of water in Finney County for irrigation. The analysis of water from well 26–32–31cc is typical of water from the sandy area in southern Finney County. Well 22–34–25ab is in the loess-covered area in northern Finney County and is typical for that area. Both of these analyses show a low sodium hazard (S1) and moderate salinity hazard (C2). They can be used for irrigation where a moderate amount of leaching occurs. Crops that tolerate moderate amounts of salt, such as potatoes, corn, wheat, oats, and alfalfa, can be irrigated with this water without special practices.

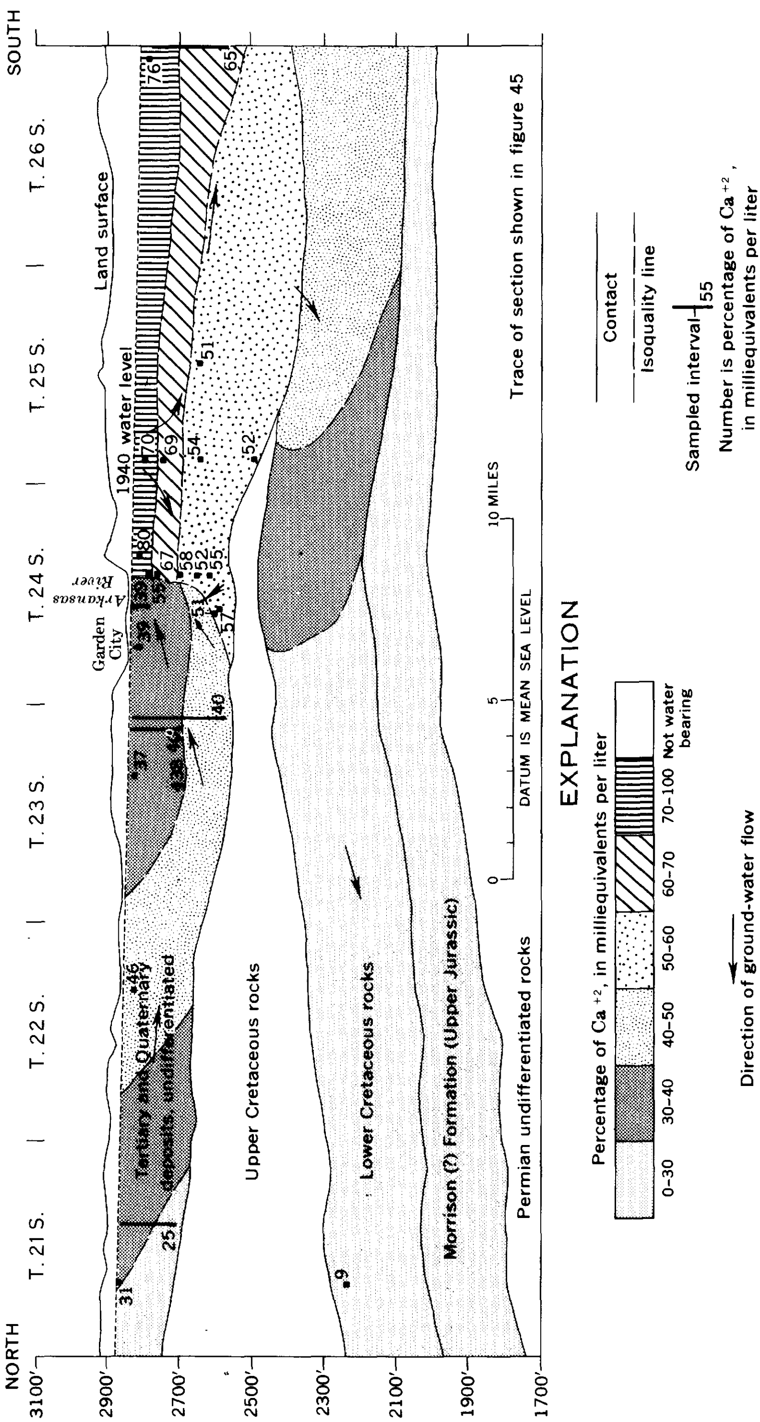

FIGURE 47.—North-south section, showing cation facies (here, the percentage of calcium) in ground water.

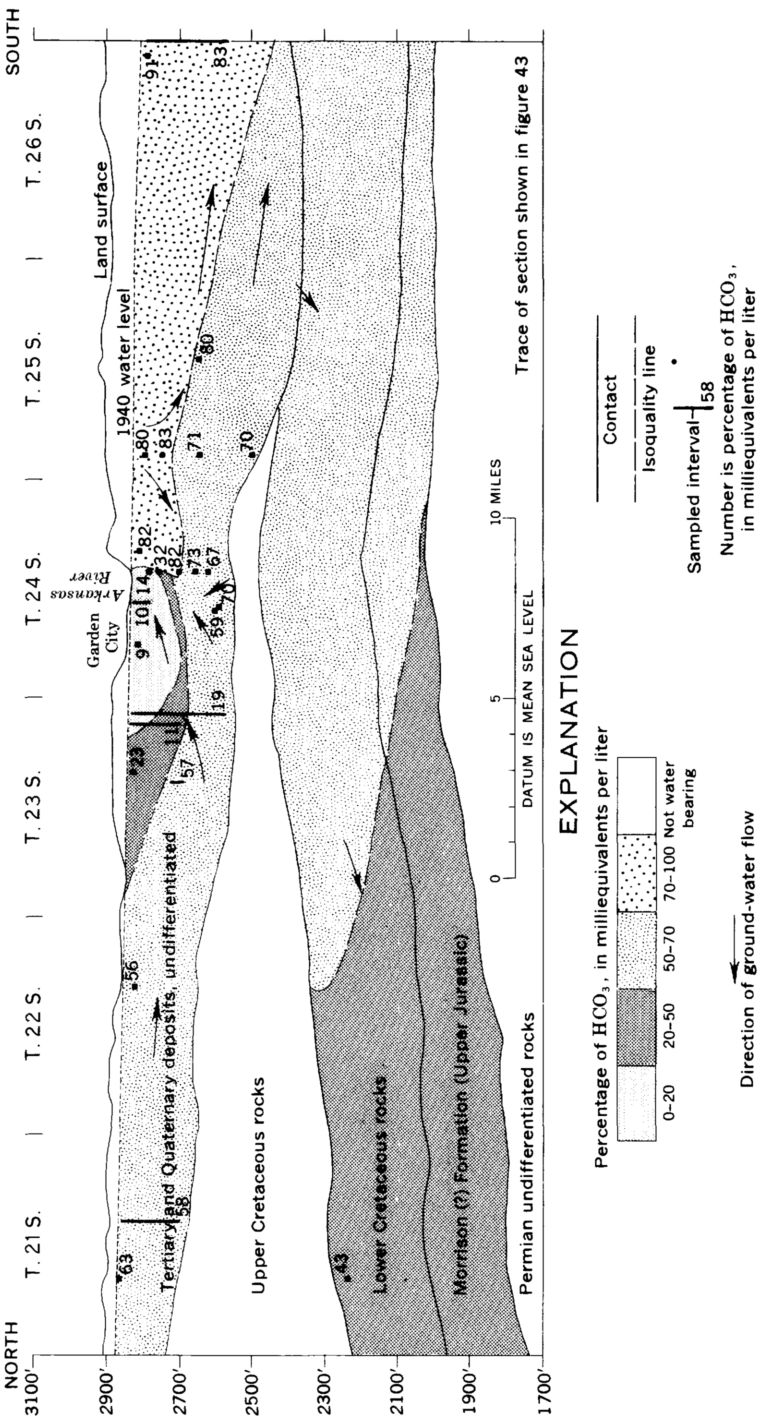

FIGURE 48.—North-south section, showing anion facies (here, the percentage of HCO_3) in ground water.

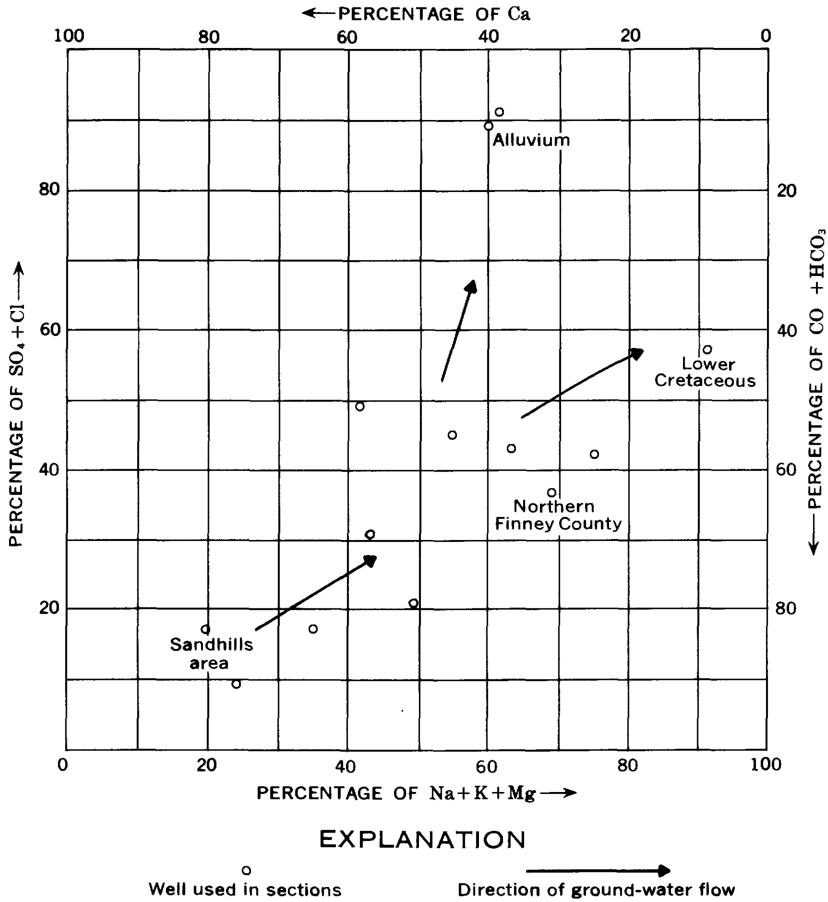

FIGURE 49.—Hydrochemical facies classification.

The analyses of water from 24–33–7db, a well in the alluvium, and 23–27–4ab, a well in the Lower Cretaceous, represent water that is unsatisfactory for irrigation unless special practices are followed. The water from well 24–33–7db has a moderate sodium hazard (S2) and a very high salinity hazard (C4). This type of water is being used successfully on well-drained coarse-textured soils. Its use requires that a large excess of water be applied to prevent salt buildup in the soil. Water from well 23–27–4ab has a very high sodium hazard (S4) and a high salinity hazard (C3). This water can be used for irrigation on well-drained coarse-textured soil if gypsum is added. The fine-textured soil in the vicinity of the well would not perform satisfactorily under intensive irrigation with water from well 23–27–4ab.

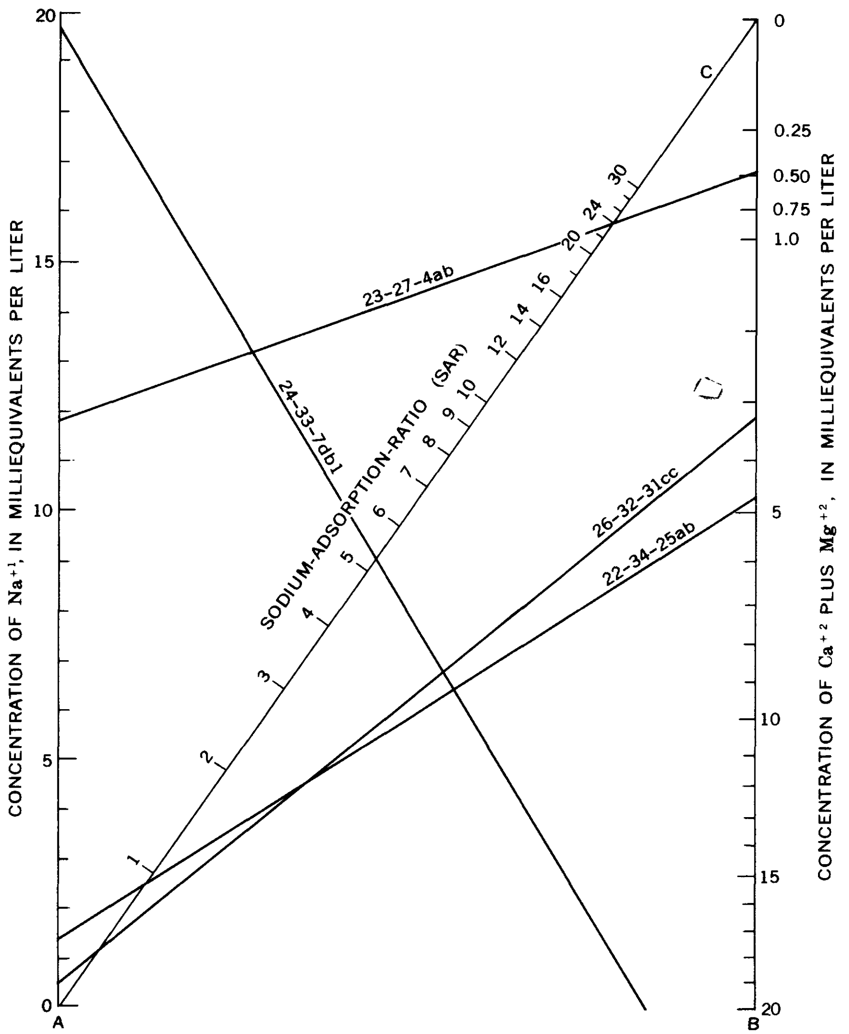

FIGURE 50.—Nomogram for determining the sodium-adsorption-ratio of water.

CHANGE IN WATER QUALITY WITH TIME

Parker (1911) and Slichter (1906) showed analyses made from 1898 to 1907 of well water in the Garden City area. Methods used to analyze the water samples at that time were somewhat different from those used today, and the depth of sampling generally was not given. Thus, the analyses may not be strictly comparable to more recent analyses. There appears to have been an increase of dissolved-solids content of as

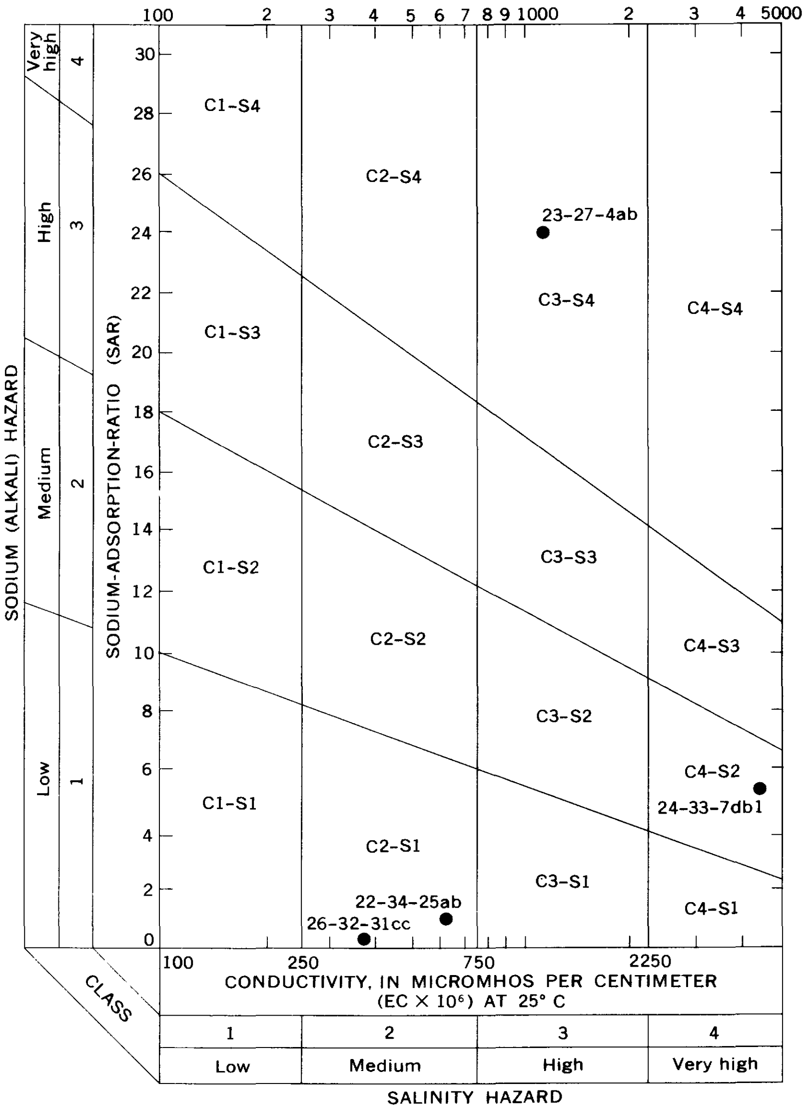

FIGURE 51.—Diagram for classification of water for irrigation, with typical analyses plotted to show the range in suitability of water for irrigation.

much as 100 percent in water from shallow alluvial aquifers since that time. Their analyses indicate that the same general relationships of dissolved solids to depth and location were present at that time as now. Slichter stated that the high concentrations of dissolved solids near the ground surface in the Arkansas River valley were due to evaporation.

Between 1940 and the present 1960–64 period, the change in the dissolved-solids content in water sampled from the same or from adjacent wells was not consistent. The apparent changes might be attributed to variations in sampling date during the year, to seasonal changes in evapotranspiration, and to slight changes in the depth at which the water was sampled.

The long-term trend will probably be a deterioration of quality, especially in the deeper aquifers. Recent pumping has lowered the head of the lower aquifer (Pliocene and undifferentiated Pleistocene deposits) so that poor-quality water from the upper aquifer can move into the lower aquifer in the area near the Arkansas River.

CONCLUSIONS

The geology and areal extent of the water-bearing deposits were studied to define the ground-water reservoir in Finney County. The water-bearing rocks range in age from Early Cretaceous to Holocene. The principal aquifers are of Pliocene and Pleistocene age. The subsurface occurrence of the aquifers is governed by a major southeast-trending bedrock valley which is filled by Tertiary and Quaternary deposits. The northerly plunging marginal syncline on the east border of the Los Animas arch is the dominant structural feature. The surficial Finney County topographic depression (Finney basin) is west of the marginal syncline and is the result of erosion.

The unconsolidated deposits of Tertiary and Quaternary age are the major water-bearing sediments and are the source of virtually all water supplies in the county. They can be considered as the ground-water reservoir of Finney County. The subsurface Tertiary and Quaternary deposits have been separated only at localities where detailed lithologic studies of the water-bearing deposits are available from the aquifer test sites. The aquifers in the Pliocene Ogallala Formation consist of poorly sorted gravel and sand beds that contain reworked Cretaceous material and are generally cemented by caliche. The gravel and sand aquifers in the undifferentiated Pleistocene deposits are well sorted and contain a characteristic grantic-arkosic gravel lithofacies.

The Pleistocene and Holocene alluvium of the Arkansas Valley contains a channel facies consisting of fine to very coarse arkosic gravel with large amounts of interbedded sand and comprises the most permeable Tertiary and Quaternary deposits in the county.

Discharge of ground water by pumpage increased from 71,000 acre-feet in 1940 to 295,000 acre-feet in 1963. Natural discharge remained relatively constant at 42 mgd, or 48,000 acre-feet per year.

Recharge from precipitation and irrigation return is approximately 2.7 inches per year, or 124,000 acre-feet per year. In addition, approximately 45,000 acre-feet per year of ground water moves into the county from adjacent areas to the west and the north.

The quantity of ground water in storage in Finney County is approximately 20,000,000 acre-feet. The excess of discharge over recharge, due mostly to pumping, results in withdrawal of water from storage. The current reduction in ground-water storage is lowering the water table at a rate of approximately 1.5 feet per year. In areas of heavy pumpage, the water-level decline is as much as 4 feet per year.

Most of the dissolved solids in water from Finney County are derived from rocks through which the water has moved. Water moving downgradient in Tertiary and Quaternary deposits shows an increase in all the more soluble constituents. A greater increase in soluble constituents occurs in limited areas with a high water table, as a result of concentration by evaporation. Water in Mesozoic formations increases in dissolved solids because of the leaching of soluble material from the formation.

Most of the ground water in Finney County is suitable for domestic supplies. Water in the Pleistocene and Holocene alluvium, in the upper part of the Tertiary and Quaternary aquifer adjacent to the north side of the valley, and in the Lower Cretaceous rocks may be undesirable for domestic supplies because of high dissolved-solids concentrations. High fluoride concentration makes the water in the Tertiary and Quaternary rocks in a band 6–12 miles wide from northwestern to east-central Finney County and in the Lower Cretaceous rocks undesirable for domestic use. Some of the water in the Arkansas River valley alluvium also contains excessive fluoride.

The use of water from the Pleistocene and Holocene alluvium and the upper part of the Tertiary and Quaternary aquifer adjacent to the north side of the Arkansas Valley for irrigation generally requires special practices to prevent salt build up in the soil. The other aquifers in Finney County, except the Lower Cretaceous rocks, yield water of good to excellent quality for irrigation.

The kinds of dissolved constituents and the concentration of these constituents have not been changed radically by man's activities. Irrigation has caused a general increase in dissolved solids in water in shallow aquifers that originally yielded water of poor quality. Deterioration in quality of ground water will probably continue with continued irrigation.

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