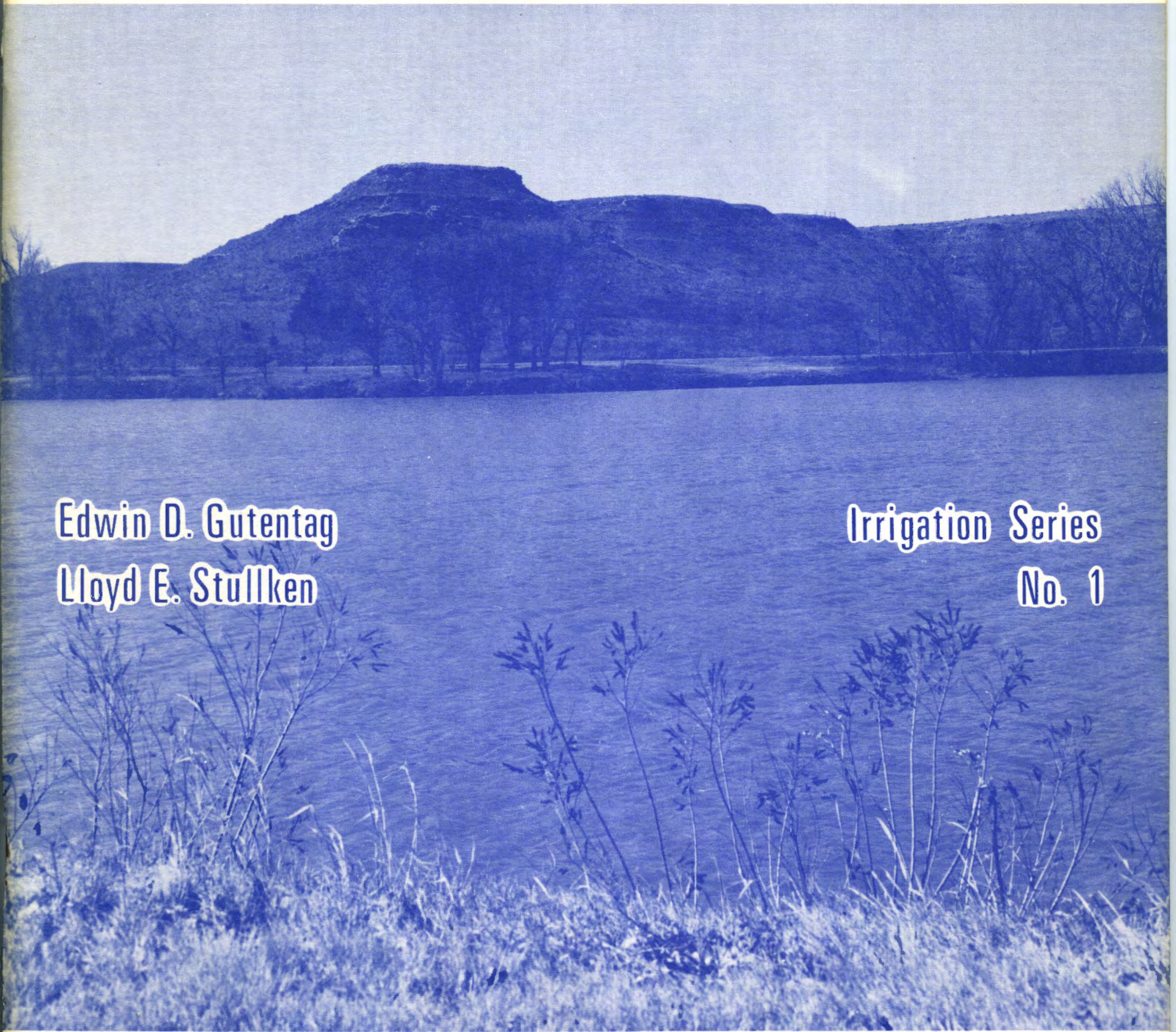
# Ground–Water Resources of
# LANE AND SCOTT COUNTIES
## Western Kansas



Edwin D. Gutentag
Lloyd E. Stullken

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The University of Kansas
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# Ground-Water Resources of Lane and Scott Counties, Western Kansas

By

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*Prepared by the Kansas Geological Survey*
*and the U.S. Geological Survey*

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# Ground-Water Resources of Lane and Scott Counties, Western Kansas

## SUMMARY

Lane and Scott Counties comprise an area of 1,444 square miles (3,740 $km^2$).[1] Much of the area is underlain by saturated sand and gravel of Pliocene age (Ogallala Formation) and Pleistocene age (undifferentiated deposits) that form a major unconsolidated aquifer. The main body of the aquifer comprises about 34 percent of Lane County and about 81 percent of Scott County. A chalk aquifer, consisting of fractures and solution openings in the Niobrara Chalk of Late Cretaceous age, is being developed for irrigation in southeastern Scott County. A sandstone aquifer, consisting of Upper Jurassic and Lower Cretaceous rocks that underlie both counties, is a potential source of ground water.

Yields of wells in the unconsolidated aquifer range from 100 to 1,700 gallons per minute (6.3 to 110 l/s). Yields from 500 to 1,000 gallons per minute (32 to 63 l/s) are available from wells that tap fractures and solution openings in the chalk aquifer. The sandstone aquifer is tightly cemented in many places and wells in it may not yield sufficient water for irrigation.

The unconsolidated aquifer constitutes a ground-water reservoir in which inflow, outflow, and change in storage occur. These components of the ground-water flow system comprise many individual parameters that are difficult to separate. Estimates based on data for Scott County indicate that inflow to the ground-water reservoir was about 23,000 acre-feet (28 $hm^3$) in 1971 and 33,000 acre-feet (41 $hm^3$) in 1972. Outflow from the reservoir was about 124,000 acre-feet (153 $hm^3$) in 1971 and 80,000 acre-feet (99 $hm^3$) in 1972. The change in ground-water storage in Scott County, therefore, amounted to 101,000 acre-feet (125 $hm^3$) in 1971 and 47,000 acre-feet (58 $hm^3$) in 1972. Differences between the two years are attributed to pumpage in a dry growing season in 1971 and a wet growing season in 1972. Data are not available to permit similar estimates for Lane County.

In seven aquifer tests made for this study, the transmissivity of the unconsolidated aquifer ranged from 2,960 to 9,900 feet squared per day (275 to 920 $m^2$/day); the storage coefficient ranged from 0.001 to 0.25. Transmissivity values determined from aquifer and specific-capacity tests and estimated from logs of test holes were used in preparation of a map showing the areal distribution of transmissivity. The unconsolidated aquifer has a specific yield generally between 0.14 and 0.18. In the buried south-trending bedrock trough in central Scott County, where the water occurs under confined or semiconfined conditions, the specific yield probably ranges from 0.01 to 0.15. In Lane and Scott Counties, between 4 and 6 million acre-feet (4,900 and 7,400 $hm^3$) of water is estimated to have been in storage in January 1973. Assuming that only 70 percent of the total volume of water is recoverable by wells, between 2.8 and 4.3 million acre-feet (3,500 and 5,200 $hm^3$) of water is available for pumping.

Subsurface movement of water is predominantly in an easterly direction under a hydraulic gradient of about 10 feet per mile (1.9 m/km). The gradient is relatively flat in the vicinity of the buried bedrock trough in central Scott County, which probably reflects the higher transmissivity of the material that fills the trough.

Results of chemical analyses of water samples from typical wells in the three aquifers indicate that the concentration of dissolved fluoride and dissolved nitrate locally approaches or exceeds the limits recommended by the Kansas Department of Health and Environment for drinking water. Water in the unconsolidated and chalk aquifers generally is a calcium bicarbonate type and is suitable for most domestic,

[1] A conversion table of English/metric units and abbreviations is given on page 36.

stock, and irrigation uses except where fluoride or nitrate concentrations are high. Water from the sandstone aquifer is a sodium bicarbonate type and is unsuitable for many uses.

Irrigation has been practiced in Scott County since about 1650 when the Taos Indians diverted water from Ladder Creek to irrigate crops. Pumping of ground water for irrigation began in 1888. By 1922, about 5,000 acres (2,020 $hm^2$) were irrigated in Scott County by ground water, but irrigated acreage then declined to a low of 1,020 acres (410 $hm^2$) in 1932. In 1945, a total of 129 wells supplied 18,400 acre-feet (23 $hm^3$) of water to irrigate 21,000 acres (8,500 $hm^2$). Irrigation development in Lane County in 1949 was less than 500 acres (200 $hm^2$) irrigated by 3 irrigation wells. By 1972, about 100,000 acres (40,470 $hm^2$) were irrigated by ground water in Scott County and about 20,000 acres (8,090 $hm^2$) in Lane County.

As of January 1973, there were 164 large-capacity wells (more than 100 gpm) in Lane County and 717 large-capacity wells in Scott County. Analysis of the power used to pump water for irrigation indicates a total pumpage of 180,000 acre-feet (220 $hm^3$) in 1971 and 120,000 acre-feet (150 $hm^3$) in 1972. The greater amount pumped in 1971 and the lesser amount pumped in 1972 are attributed to below-normal and above-normal precipitation during the April-to-September growing season in respective years. The 1971 (dry year) gas-energy input for irrigation pumpage was 0.12 percent of the total natural gas produced in southwestern Kansas, which is equivalent to the production of about 6 typical gas wells. In 1972 (wet year), the gas-energy input for irrigation pumpage was 0.08 percent of the total natural gas production in southwestern Kansas, or the production of about 4.5 typical gas wells.

Water-level declines in the unconsolidated aquifer for the period from 1940-48 to 1973 ranged from less than 10 feet (3 m) to about 50 feet (15 m). Part of the decline in the south-trending trough represents a decline in artesian head, and part represents dewatering of the aquifer. Annual water-level measurements indicate that declines in 46 observation wells in Scott County averaged 1.15 feet per year (0.35 m/yr) during 1966-74. Assuming that the specific yield is about 15 percent for materials under unconfined conditions in most of the county and about 1 percent for materials under semiconfined and confined conditions in the central part, the annual reduction of ground-water storage in Scott County is estimated to be about 57,000 acre-feet (70 $hm^3$) for the period 1966-74. This value is in agreement with the figures of 101,000 acre-feet (125 $hm^3$) in 1971 to 47,000 acre-feet (58 $hm^3$) in 1972 determined from the ground-water inventory of Scott County.

Depletion of ground water in storage in the unconsolidated aquifer is indicated by a 10- to 60-percent reduction in saturated thickness since 1940-48. In the area of the south-trending trough, the saturated thickness has been reduced about 11 percent.

The potential yield of the unconsolidated aquifer at a specific site can be estimated if the saturated thickness and effective thickness (water-yielding part of the saturated thickness) values are known. Potential yield to wells in the main body of the unconsolidated aquifer in the study area ranges from about 250 to 2,000 gallons per minute (16 to 126 l/s).

The upsurge in prices for grain in 1973 from long-term averages probably will result in an increase in irrigation in Lane and Scott Counties. Irrigation is an insurance against drought. The installation of new wells and increased ground-water withdrawals will accentuate the rate of depletion and the problem of mutual interference among wells. Because the average annual pumpage exceeds the average annual inflow to the ground-water reservoir, the mining of water in storage will continue to lower water levels and reduce well yields.

The newly formed Ground-Water Management District will have the responsibility to efficiently manage the ground-water reservoir. Some of the alternatives that should be considered to conserve the ground-water supply are: re-use of water from tail-water recovery pits, improving irrigation efficiency, most efficient cropping for the least amount of water applied, limiting further ground-water development in areas where saturated deposits are thin and where significant water-level declines have occurred, regulating well spacing to minimize the effects of mutual well interference, and weather modification and importation of water to supplement ground-water supplies.

## INTRODUCTION

This study of the ground-water resources of Lane and Scott Counties began in 1971 as a cooperative program between the Kansas Geological Survey and the U.S. Geological Survey. Support in the study was provided by the Division of Water Resources of the Kansas State Board of Agriculture and the Division of Environment of the Kansas Department of Health and Environment. The objectives in this study were to (1) determine the availability and amount of ground water in the area, (2) determine the chemical quality of the water and its suitability for various uses, (3) document the extent of development of the ground-water resource and the effects of that development, and (4) describe the future outlook for irrigation in the area.

Data for this report were obtained chiefly in 1971 and 1972; additional data were available from previous investigations by Waite (1947), Prescott (1951), and Bradley and Johnson (1957). Field work for this study consisted of locating all large-capacity wells; collecting discharge and power-consumption data; drilling test holes to determine lithology, hydraulic conductivity, and depth to bedrock; conducting aquifer tests to determine aquifer properties; and collecting water samples for chemical analysis. Data from the investigations are published in Stullken and others (1974).

Lane and Scott Counties are located in western Kansas about midway between the north and south borders. Lane County covers an area of 720 square miles (1,865 km$^2$) and Scott County an area of 724 square miles (1,875 km$^2$).

Lane and Scott Counties are in the High Plains section of the Great Plains physiographic province except for a small area in the eastern edge of Lane cates the township, the second number indicates the County that is included in the Smoky Hills Upland section (Frye and Swineford, 1949). The upland plain slopes gradually eastward from an altitude of 3,170 feet (966 m) near the northwest corner of Scott County to 2,480 feet (756 m) in southeastern Lane County where Hackberry Creek enters Ness County. The High Plains section is characterized by flat to gently rolling uplands, a few shallow valleys, and many undrained depressions.

## WELL-NUMBERING SYSTEM

The well numbers in this report give the location of wells according to the Bureau of Land Management system of land subdivision. This method of well location is shown in figure 1. The first number indirange, and the third indicates the section in which the well is situated. Letters following the section number locate the well within the section. The first letter denotes the quarter section or 160-acre (65 hm$^2$) tract; the second letter, the quarter-quarter section or 40-acre (16 hm$^2$) tract; the third letter, the quarter-quarter-quarter section or 10-acre (4 hm$^2$) tract. These tracts are designated a, b, c, and d in a counterclockwise direction beginning in the northeast quadrant. Where more than one well is in a quarter-quarter-quarter section, consecutive numbers are added to the letter. For example, 19-32W-30bab2 indicates that this is the second well inventoried in the NW¼NE¼ NW¼ sec. 30, T.19 S., R.32 W.

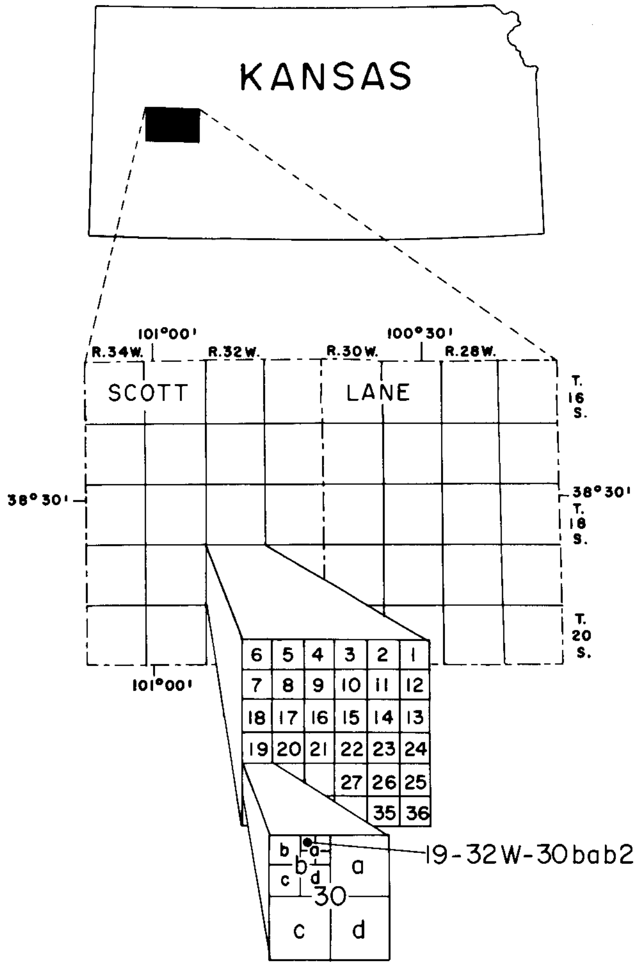


FIG. 1.—Location of report area and system of numbering wells and test holes in Kansas.

## GEOHYDROLOGY

### Description of the Rocks

The oldest rocks underlying Lane and Scott Counties that are a potential source of ground water to wells are the undifferentiated rocks of Late Jurassic age (table 1). The stratigraphic relation of these rocks and the overlying geologic units is shown on figure 2. Upper Jurassic rocks are at depths ranging from 850 to 1,600 feet (259 to 488 m) below land surface, and consist primarily of variegated shale. A fine-grained silty sandstone at the base of the formation may contain a small quantity of ground water, but the unit has not been tested by wells. Rocks underlying the Jurassic unit are of Permian age, and consist primarily of thick shale and some sandstone that contain very highly mineralized water.

Undifferentiated rocks of Early Cretaceous age unconformably overlie the Upper Jurassic rocks at depths ranging from 530 to 1,060 feet (162 to 323 m) below land surface. The Lower Cretaceous rocks can be divided into three units in most of Lane and Scott

TABLE 1.—Generalized section of geologic units.[1]

| System | Series | Geologic unit | Thickness, in feet[2] | Physical character | Water supply |
|---|---|---|---|---|---|
| QUATERNARY | Pleistocene | Loess and dune sand | 0-40 | Silt and fine sand, mostly eolian. Mantles most of the upland and masks much of the valley walls. | Most of the deposits are above water table. Where saturated, locally yield 5 to 10 gpm to wells.[3] |
| | | Alluvium | 0-50 | Stream-laid deposits ranging from sand and gravel to silt and clay. Occurs along principal stream valleys. | Generally above the water table. Where saturated, locally yields about 250 gpm to irrigation wells. |
| | | Undifferentiated deposits | 0-200 Median 23 | Medium to very coarse sand and gravel interbedded with clay, silt, fine sand, and caliche. These deposits are in contact with the Upper Cretaceous rocks where the Ogallala Formation is absent. | Principal aquifer in the south-trending bedrock trough in Scott County. Yields to irrigation wells range from 250 to 1,500 gpm. |
| TERTIARY | Pliocene | Ogallala Formation | 0-215 Median 110 | Sand, gravel, silt, clay, and caliche, commonly unconsolidated. Locally cemented by calcium carbonate (lime) or silica (opal) into mortar beds. Also contains thin freshwater limestone beds. | Principal aquifer in the area. Yields to irrigation wells range from 100 to 1,700 gpm. |
| CRETACEOUS | Upper Cretaceous | Niobrara Chalk | 0-410 Median 100 | Upper unit (Smoky Hill Chalk Member) consists of yellow to orange-yellow chalk and light- to dark-gray beds of chalky shale that locally weathers to ochre-yellow. Lower unit (Fort Hays Limestone Member) consists of a white to yellow massive chalky limestone; contains thin beds of dark-gray to brownish-gray chalky shale. | Yields as much as 1,000 gpm to wells in southeastern Scott County where the rocks have been fractured. |
| | | Carlile Shale | 200-295 Median 245 | Upper part consists of a dark-gray to blue-black noncalcareous to slightly calcareous shale that locally is interbedded with calcareous silty very fine sandstone. Lower part consists of very calcareous dark-gray shale and thin interbedded limestone. | Sandstone in upper part may yield 5 to 10 gpm to wells. |
| | | Greenhorn Limestone | 70-160 Median 105 | Alternating light- to dark-gray thin-bedded chalky limestone and calcareous shale. Contains thin layers of bentonite. | Not known to yield significant amounts of water to wells. |
| | | Graneros Shale | 25-60 Median 40 | Dark-gray calcareous shale interbedded with black noncalcareous shale. Contains thin beds of bentonite, gray limestone, and fine-grained silty sandstone. | Not known to yield significant amounts of water to wells. |

| | | | | | |
|---|---|---|---|---|---|
| | Lower Cretaceous | Undifferentiated rocks | 300-680 Median 480 | Upper unit (Dakota Formation)—brown to gray fine- to medium-grained sandstone interbedded with gray sandy shale and varicolored shale. Middle unit (Kiowa Formation)—dark-gray to black shale interbedded with tan and gray sandstone. Lower unit (Cheyenne Sandstone)—gray and brown fine- to medium-grained sandstone interbedded with dark-gray shale. | Yields of 30 to 300 gpm may be available to wells completed in sandstone beds. Yields of more than 1,000 gpm are reported from wells in counties farther south, but no irrigation wells tap these rocks within the report area. Water may be more mineralized in lower unit than in upper. |
| JURASSIC | Upper Jurassic | Undifferentiated rocks | 0-200 Median 70 | Gray, noncalcareous shale, interbedded with gray-green and blue-green calcareous shale. Contains fine-grained silty sandstone, and thin limestone beds. | The sandstone beds, although untested, may be a potential aquifer. Water may be mineralized. |

[1] The classification and nomenclature of the rock units used in this report are those of the Kansas Geological Survey and differ somewhat from those of the U.S. Geological Survey.

[2] Thickness in feet × .3048 equals thickness in meters.

[3] Yield in gpm (gallons per minute) × .06309 equals l/s (liters per second).

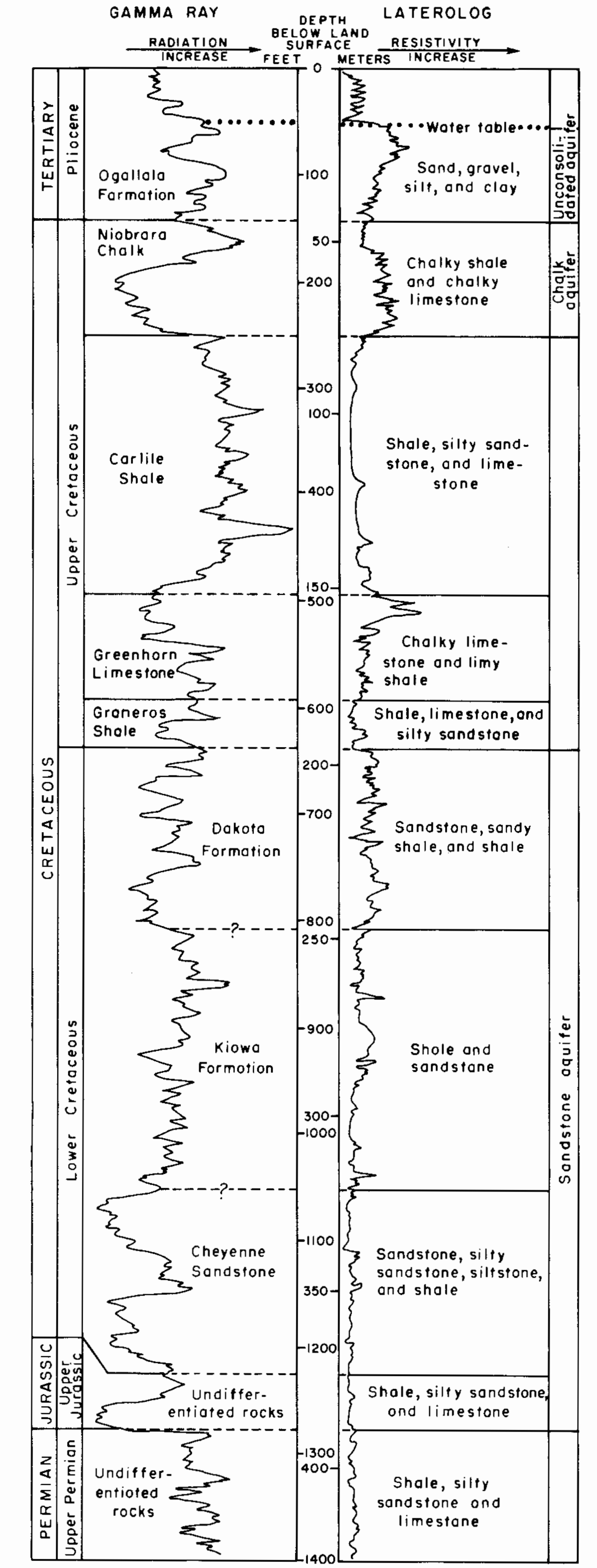


FIG. 2.—Generalized gamma-ray log and laterolog (focused resistivity) of typical gas and oil test, Lane and Scott Counties.

Counties. The lower unit, considered to be the Cheyenne Sandstone, consists mainly of lenticular sandstone interbedded with siltstone and mudstone (shale). Locally, the unit consists of silty sandstone.

The middle unit of the Lower Cretaceous rocks, which generally correlates with the Kiowa Formation, consists of shale interbedded with sandstone. Precise separation of the Kiowa is difficult because similar dark-colored shales also occur in the units above and below.

The upper unit, equivalent in part to the Dakota Formation, consists of sandstone interbedded with shale and sandy shale containing lignite and pyrite. This unit is persistent throughout much of Lane and Scott Counties. Sandstones in the Lower Cretaceous and Upper Jurassic rocks form one of the three aquifers underlying Lane and Scott Counties.

Consolidated rocks of Late Cretaceous age include the Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Chalk. The aggregate thickness of these rocks is about 500 feet (152 m). The Carlile Shale, exposed locally in the area drained by Hackberry Creek (Prescott, 1951), probably underlies the alluvium of Hackberry Creek. The bedrock surface in the rest of Lane and Scott Counties is on the Niobrara Chalk. The Fort Hays Limestone Member of the Niobrara Chalk, exposed in the Hackberry Creek drainage, probably forms part of the buried bedrock surface in southern Lane County. In Scott County and in northern Lane County, the bedrock surface is formed on the Smoky Hill Chalk Member of the Niobrara Chalk (Waite, 1947; and Prescott, 1951). This member is exposed in numerous drainages throughout the two-county area. Because of fractures and solution openings, the Niobrara Chalk is a significant aquifer in Lane and Scott Counties.

Unconsolidated deposits of sand, gravel, silt, clay, and caliche comprise rocks of Pliocene and Pleistocene age in Lane and Scott Counties. The Ogallala Formation (Pliocene), consisting chiefly of alluvial deposits, is the principal aquifer throughout the two-county area. Alluvial deposits that comprise most of the rocks of Pleistocene age can be distinguished from Pliocene deposits (Gutentag, 1963) by lithologic differences and by their relative stratigraphic positions. These undifferentiated Pleistocene deposits are the principal aquifer in the south-trending bedrock trough south of Scott City (Waite, 1947).

## Geologic Structure

A generalized structure map of the top of the Greenhorn Limestone is shown on figure 3. The top of the Greenhorn Limestone has an average northeasterly dip of 11 feet per mile (2.1 m/km) resulting from uplift of the Las Animas arch (Lee and Merriam, 1954) southwest of the study area. The contours on the structure map show undulations of the Greenhorn Limestone that indicate local folding superimposed on the regional dip. Dominant structural features associated with the folding are a northward-plunging syncline in eastern Scott County, a northward-plunging anticline in western Lane County, and a northward-plunging syncline in eastern Lane County. Deformation of the Greenhorn probably occurred during post-Cretaceous and pre-Pleistocene time (Lee and Merriam, 1954; and Russell, 1929).

## Configuration of Bedrock Surface

Significant features on a map showing the configuration of the bedrock surface (pl. 1) are (1) a general slope from west to east, (2) a conspicuous south-trending trough in central Scott County, (3) a prominent bedrock high north of Dry Lake, (4) tributary valleys, and (5) badland topography developed on the land surface where the bedrock is exposed.

The bedrock surface depicted on plate 1 slopes easterly across the two-county area at an average rate of 9 feet per mile (1.7 m/km), but with large local departures from average, and some local reversals in direction. The bedrock surface in western Scott County slopes eastward at about 15 feet per mile (2.8 m/km), which is comparable to the slope in adjacent Wichita and Greeley Counties (S. E. Slagle, personal commun., 1974). The bedrock surface slopes at an average rate of 7 feet per mile (1.3 m/km) across eastern Scott County and Lane County. The land surface, however, slopes eastward across the two-county area at an average rate of 11.5 feet per mile (2.2 m/km). The difference in slope of the bedrock and land surfaces generally results in a thickening of the unconsolidated deposits across western Scott County and a thinning from central Scott County to eastern Lane County where the bedrock is exposed.

A conspicuous south-trending trough, about 3 to 6 miles (5 to 10 km) in width, extends from northern Scott County to the Finney County line at right angles to the general direction of slope of the bedrock surface. This trough is the northern continuation of a major bedrock channel in Finney County (Gutentag and others, 1972). A lack of gradient throughout the trough may be the result of minor structural deformation in this area not evident on the map showing the configuration of the top of the underlying Greenhorn Limestone (fig. 3).

A prominent bedrock high north of Dry Lake is on the west edge of a resistant erosional remnant that coincides with a plunging syncline, as shown by the structural map of the Greenhorn Limestone (fig. 3).

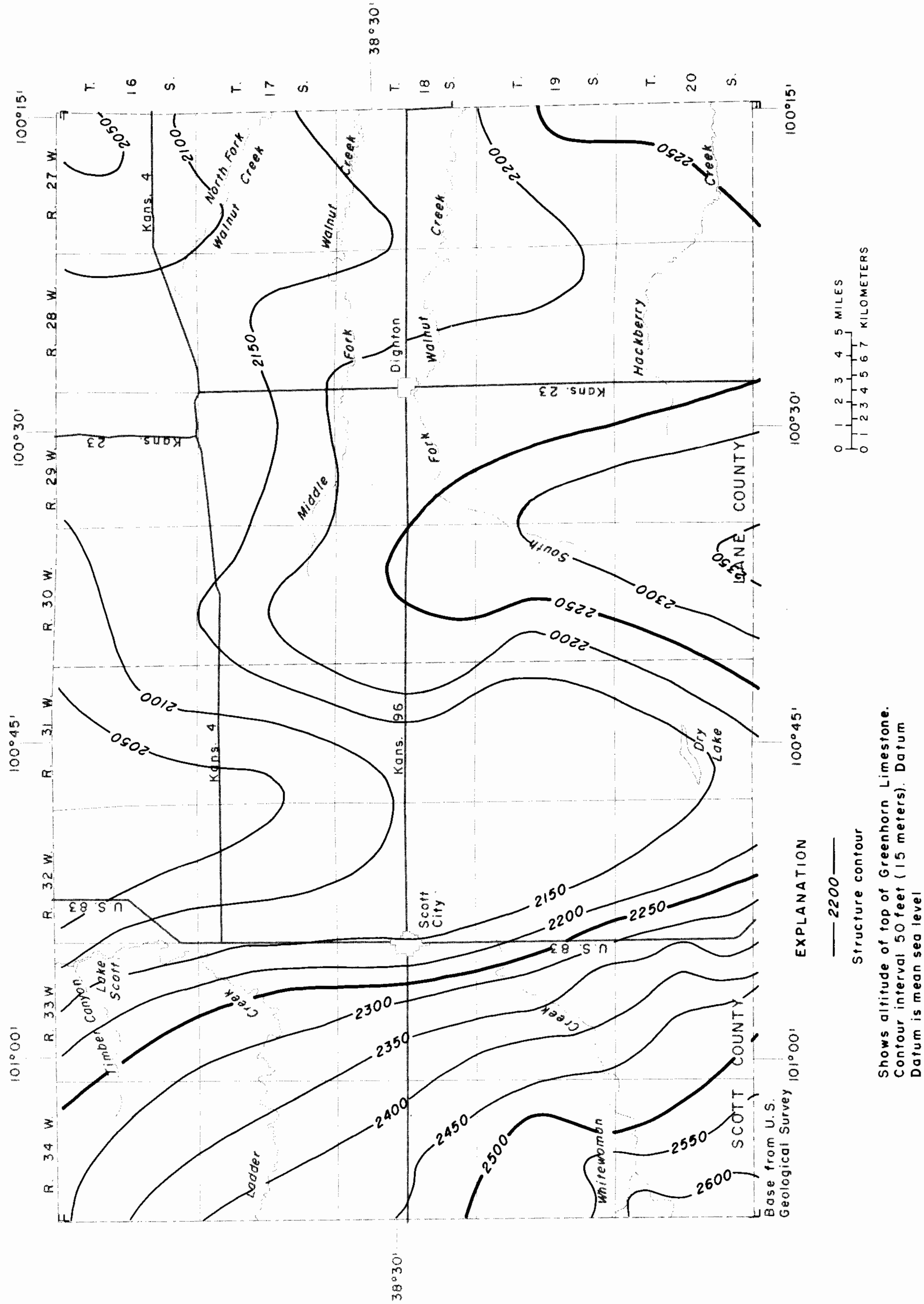


FIG. 3.—Configuration of the top of the Greenhorn Limestone.

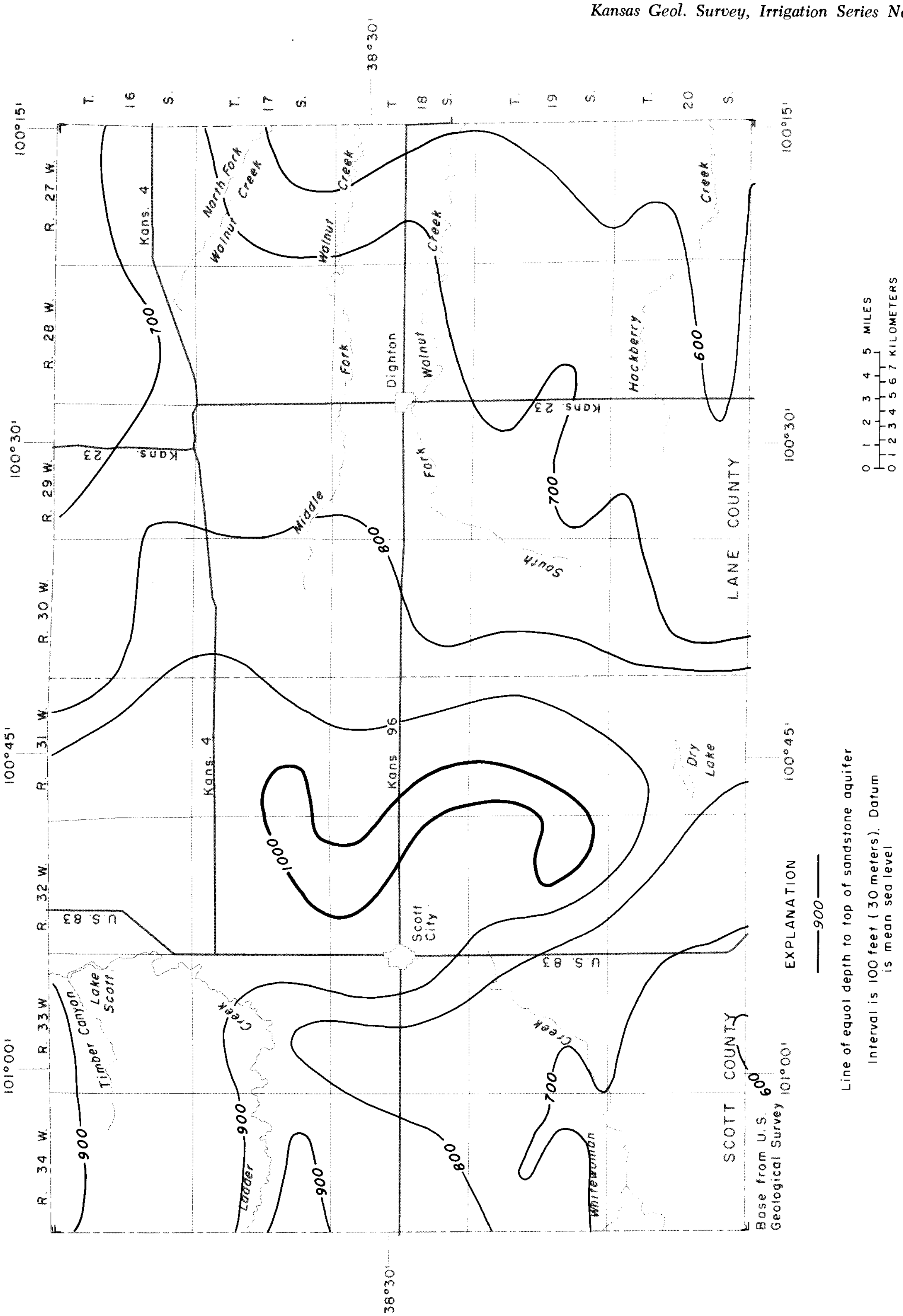


FIG. 4.—Depth to the top of the sandstone aquifer.

This remnant is evidently the result of differential erosion of less resistant rocks at the margin of the plunging syncline.

The significance of the tributary valleys is exemplified by the southeastward-trending valleys in T.19 S., R.33 W. and T.20 S., R.33 W.; which are tributary to the major south-trending trough. These buried tributary valleys are filled with coarse-grained deposits that yield large quantities of water to wells. The water-yielding deposits are almost fully developed with respect to their irrigation potential. The development of irrigation wells near Dighton indicates that a northeastward-trending valley contains similar coarse-grained deposits.

The bedrock formations are exposed in northern and southeastern Lane County allowing visual inspection of the bedrock configuration. The complex contours in this area represent the bedrock surface where it is visible; whereas, the generalized contours represent an interpretation of the bedrock surface based on logs of test holes and wells. A very intricately sculptured bedrock surface would be revealed if the unconsolidated deposits were stripped off.

The configuration of the present land surface in Lane and Scott Counties, in part, reflects features of the bedrock configuration. The elongate north-south surface depression that includes the Whitewoman Basin in south-central Scott County, known locally as the "Scott-Finney depression", overlies the south-trending trough in the bedrock. The bedrock high in southeastern Scott County is reflected by topographic highs at the surface.

## Sandstone Aquifer

The sandstone aquifer is defined here to include all rocks of Late Jurassic and Early Cretaceous age in Lane and Scott Counties. The depth to the top of the sandstone aquifer (fig. 4) ranges from 530 feet (162 m) in eastern Lane County to 1,060 feet (323 m) in central Scott County. The thickness of the sandstone aquifer (fig. 5) ranges from 430 feet (131 m) in southwestern Scott County to 710 feet (216 m) in southwestern Lane County.

Only the major sandstone beds in the sandstone aquifer contain significant amounts of recoverable water. As an example, the generalized gamma-ray log and laterolog in figure 2 shows the total thickness of the aquifer to be 635 feet (194 m), but only about 170 feet (52 m) is sandstone. Locally the sandstone beds are silty or tightly cemented, and in such localities wells in the aquifer yield sufficient water only for domestic or stock supplies. In some counties to the south and east, ground water in sufficient quantities for irrigation is obtained from loosely cemented sandstone beds of equivalent age. Yields of as much as 1,000 gpm (63 l/s) have been obtained from the sandstone aquifer by irrigation wells in the panhandle area of Finney County and in Hodgeman County.

Geophysical logs, especially the laterolog resistivity curves, may be used to indicate the relative degree of mineralization of fluids contained in the formations penetrated by the borehole. When resistivities of sandstone beds are similar to those of shale, the formational water generally is relatively highly mineralized. For example, sandstone beds shown in figure 2 indicate more highly mineralized water in all beds below the middle of the Kiowa Formation (decrease in resistivity) than that in the Dakota Formation. Therefore, the ranges of thickness on figure 5 should be used only as a general guide because part or perhaps all the water in the sandstone aquifer may be too highly mineralized for most uses. Test drilling and collection of water samples for chemical analysis are important in determining whether the sandstone aquifer contains water of usable quantity and satisfactory quality at a specific site.

## Chalk Aquifer

The chalk aquifer is defined as that part of the Niobrara Chalk that contains saturated fractures and solution openings. The occurrence of fractures and solution openings is very irregular, making it difficult to predict whether water will be found. One well drilled in limestone or chalk may penetrate water-filled fractures or solution openings and have an adequate yield. Another well, drilled only a few feet from the first, may not penetrate any fractures or solution openings and will yield little or no water. In drilling for water in an area underlain by limestone or chalk, it commonly is necessary to drill several test holes to locate a well that will yield enough water for the intended use.

In Scott County, six irrigation wells located on the erosional bedrock high in T.19 S., R.31 W. are producing from fractures and solution openings in chalk of the Smoky Hill Chalk Member (upper unit of the Niobrara Chalk). These wells are located near the center of the syncline in Scott County shown on figure 3, but there is no evidence that this particular geologic structure controls the location of fractures and solution openings. It is probable that other wells could be drilled into the same fracture system elsewhere in the county. Because the fractures and some solution cavities are thought to be a result of weathering processes before the rocks were covered by younger unconsolidated deposits, test drilling prob-

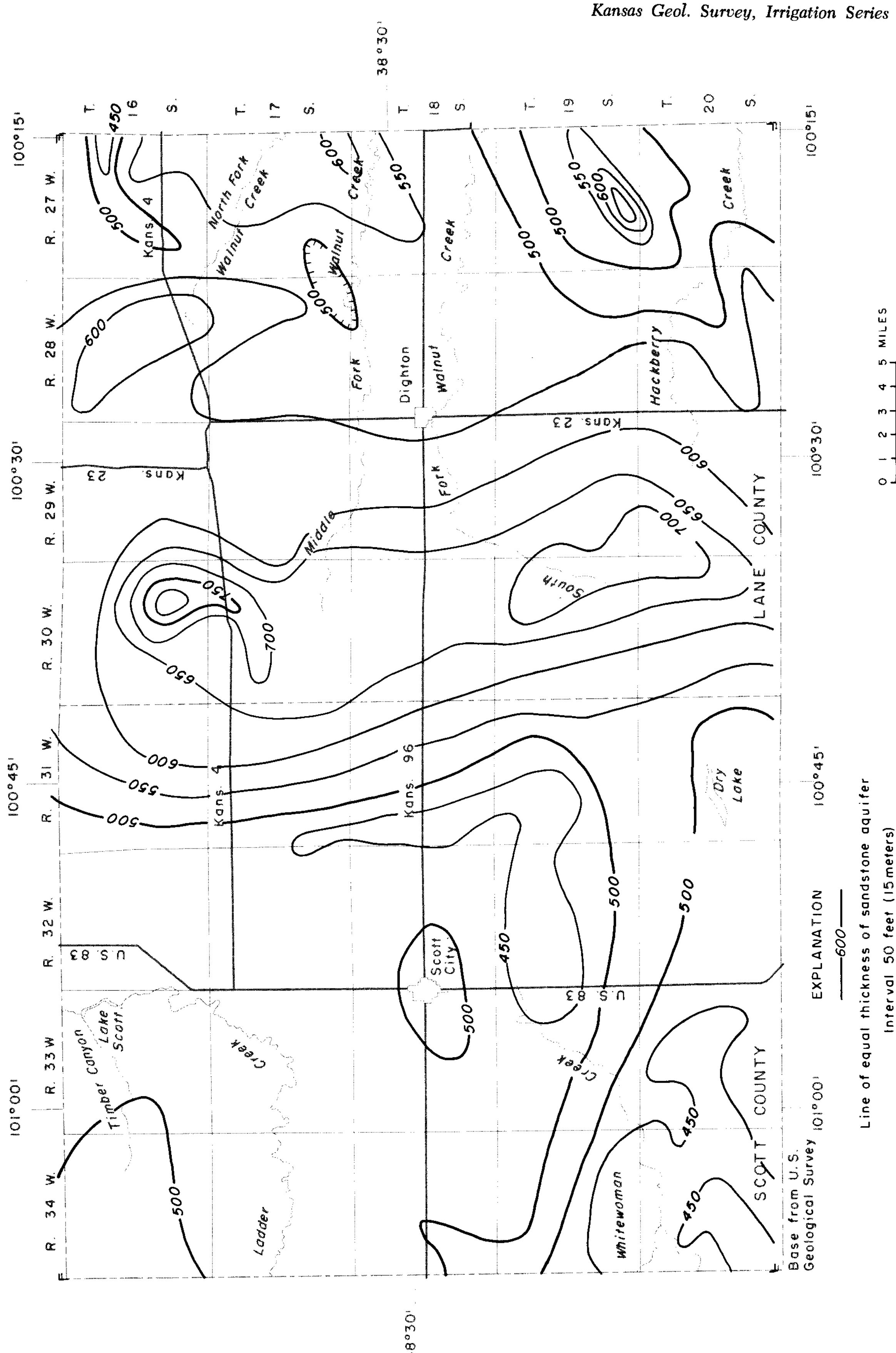


Fig. 5.—Thickness of the sandstone aquifer.

ably could be limited to the yellow or orange weathered chalk.

In the neighboring part of northwestern Finney County about 40 irrigation wells produce water, at least in part, from fractures and solution openings in chalky limestone of the Fort Hays Limestone Member (lower unit of the Niobrara Chalk). In this area the Fort Hays is the uppermost bedrock formation beneath the unconsolidated deposits. Water-well contractors report two major fracture and solution-opening zones in the Fort Hays Limestone Member. These zones lie approximately at 20 feet (6 m) and 40 feet (12 m) above the contact between the Fort Hays Limestone Member and the Carlile Shale. It is possible that saturated fractures and solution openings such as found in the Fort Hays Limestone Member in Finney County also may be found in southern Lane County.

The water in the chalk aquifer in Scott and Finney Counties is derived from the overlying unconsolidated deposits. In T.19 S., R.31 W., Scott County, percolating water is transmitted from the land surface through the unsaturated deposits to the fractures and solution openings in the Smoky Hill Chalk Member. In other areas (i.e., Finney County) the chalk aquifer is in direct hydraulic connection with the saturated unconsolidated deposits.

Wells in the chalk aquifer in Scott County may yield 500 to 1,000 gpm (32 to 63 l/s) and in northwestern Finney County 500 to 2,500 gpm (32 to 106 l/s).

### Unconsolidated Aquifer

Unconsolidated deposits of Pliocene and Pleistocene age are the principal source of water supply in the study area and are defined here as the unconsolidated aquifer. In Lane County and in much of Scott County, the Ogallala Formation of Pliocene age comprises the major part of the unconsolidated aquifer (See tables 2 and 3 in Stullken and others, 1974, for records of wells and logs of test holes).

The Ogallala Formation in the subsurface of Lane and Scott Counties consists of a heterogeneous assortment of alluvial sediments. Individual beds of silt, clay, sand, gravel, or caliche within the Ogallala can be correlated with confidence over only short distances. The formation ranges in thickness from a few feet near areas where bedrock crops out to as much as 215 feet (66 m) in central Scott County. Yields to irrigation wells range from 100 to 1,700 gpm (6.3 to 107 l/s).

Alluvial deposits of Pleistocene age overlie the Ogallala Formation in much of Lane and Scott Counties. The undifferentiated Pleistocene deposits are the principal aquifer where they fill the south-trending trough in the bedrock in central Scott County. The deposits, which consist of medium to very coarse sand and gravel interbedded with numerous layers of tan silt and clay, range in thickness from a few feet to as much as 200 feet (61 m) in the southern part of the trough. Yields to irrigation wells range from 250 to 1,500 gpm (16 to 95 l/s).

## UNCONSOLIDATED AQUIFER SYSTEM

The unconsolidated aquifer in Lane and Scott Counties is considered to be a single ground-water reservoir in which ground water is stored until it is discharged either naturally or by wells. All storage in the reservoir originated as precipitation either on the area or on contiguous areas upgradient on the water table. Inflow to the reservoir equals outflow plus or minus any change in storage in the reservoir. The major components of this general equation are discussed in the following sections.

### Inflow to the Ground-Water Reservoir

#### PRECIPITATION

Precipitation on the land surface within the area contributes inflow to the ground-water reservoir, principally during the growing season, in differing amounts dependent on duration and intensity of the rainfall, vegetation, and soil conditions. In irrigated areas, soil moisture for crop use commonly is maintained by irrigation. Therefore, precipitation that is in excess of the amount required to overcome soil-moisture deficiencies can percolate to the water table. In nonirrigated areas, precipitation supplies all of the soil moisture utilized by vegetation, and excess moisture for percolation to the water table is available only during periods of abnormally high rainfall. For this report, estimates of inflow from precipitation are based on the assumption that 10 percent of the precipitation on irrigated land during the growing season and 1 percent of the precipitation on nonirrigated land during the growing season percolates to the ground-water reservoir of Lane and Scott Counties. The inflow from precipitation during 1971 (a dry year) is estimated to have been 14,000 acre-feet (17 $hm^3$) in Scott County and 3,000 acre-feet (4 $hm^3$) in Lane County. During 1972 (a wet year), the inflow from precipitation is estimated to have been 24,000 acre-feet (30 $hm^3$) in Scott County and 6,000 acre-feet (7 $hm^3$) in Lane County.

#### SEEPAGE OF IRRIGATION WATER

Some of the water withdrawn from the ground-water reservoir and applied for irrigation is "lost" to deep percolation (percolation below the root zone). Using figures experimentally derived by Meyer and others (1953) for irrigated land in Finney County, about 20 percent of the irrigation water applied to irrigated land in Lane and Scott Counties is assumed to be returned to the ground-water reservoir. Using pumpage figures developed in the section on annual withdrawals, seepage from irrigation water applied in 1971 was about 30,000 acre-feet (37 $hm^3$) in Scott County and 6,000 acre-feet (7 $hm^3$) in Lane County. Seepage from irrigation water in 1972 was about 19,000 acre-feet (23 $hm^3$) in Scott County and 5,000 acre-feet (6 $hm^3$) in Lane County. The lesser amount in 1972 is attributed to lesser application of irrigation water in a wet year.

#### SUBSURFACE INFLOW

Ground-water movement into the area occurs primarily along the Scott-Wichita County line. Net movement along the Finney-Scott line was almost zero in January 1973. The flow is computed by summing flow through incremental sections of the saturated deposits along the total section. Flow through each section is determined by multiplying the average hydraulic conductivity by the hydraulic gradient and by the area in each section. If water-table contours are not parallel to the section, a further adjustment is made for nonperpendicular flow.

Gross values computed from those used for incremental sections along the Scott-Wichita County line are: a total saturated area of 5,834,400 square feet (542,000 $m^2$), a weighted mean hydraulic gradient of 0.0029, and a weighted mean hydraulic conductivity value of 64 ft/day (19 m/day). Using these values, which are discussed later in this report, subsurface inflow to Lane and Scott Counties is estimated to be about 9,000 acre-ft/yr (11 $hm^3$/yr).

#### STREAMFLOW LOSSES

An infrequent source of recharge to the ground-water reservoir in the counties is the infiltration of water from ephemeral stream channels during periods of flow. Streamflow in Lane and Scott Counties is primarily a function of the frequency and amount of precipitation that runs off from summer storms. All streams entering the two counties and those in the interior area are ephemeral (normally dry). Drainage from western Scott County flows toward the "Scott-Finney depression" in the central part of the county. All the streams dissipate in or near the depression except Ladder Creek.

Whitewoman Creek begins about 20 miles (32 km) west of the Colorado-Kansas State line and terminates in a closed basin (Whitewoman Basin) south of Scott City. A streamflow gage (Station No. 07138650) was established in 1966 on Whitewoman Creek in Wichita County, 20 miles (32 km) west of the Scott County line. The average annual discharge during 5 years of record at this site was 964 acre-feet (1.2 $hm^3$). Slagle and Weakly (personal commun., 1974) speculate that, if the average annual flow recorded at the gaging station occurred in one rise, infiltration into the channel bed would reduce the flow to zero before reaching Scott County. Only extreme flows on rare occasions or small flows resulting from runoff of local storms would reach Scott County and debouch into Whitewoman Basin. Ground-water recharge in Scott County from infiltration of streamflow that originated outside the county is considered too small and indeterminate on an annual basis to be designated as part of the ground-water inventory. Infiltration of streamflow that originates within the county is considered to be included with the estimate of inflow from precipitation.

### Outflow from the Ground-Water Reservoir

#### WITHDRAWALS BY WELLS

By far the largest outflow from the ground-water reservoir in Lane and Scott Counties is the withdrawal of water for irrigation. Detailed information about the distribution of wells and the amount of water pumped is given later in this report. The annual pumpage ranged from 120,000 acre-feet (150 $hm^3$) during a wet year in 1972 to 180,000 acre-feet (220 $hm^3$) during a dry year in 1971.

#### SUBSURFACE OUTFLOW

Subsurface outflow is toward the south and east. An estimated 1,000 to 3,000 acre-feet (1.2 to 3.7 $hm^3$) of ground water flows out of the main body of the unconsolidated aquifer each year by underflow into adjacent areas where saturated deposits are less than 10 feet (3 m) thick. Fractures and solution cavities similar to those described in the section on chalk aquifer also are presumed to conduct water from the main body of the unconsolidated aquifer.

#### STREAMFLOW GAINS

Streams are the natural drains of the ground-water reservoir. The streams that intersect the water table and discharge water from the reservoir are Ladder Creek, the North, Middle, and South Forks of Walnut Creek, Hackberry Creek, and numerous small tributaries of the Smoky Hill River that drain the northern part of the area.

Ladder Creek is an ephemeral stream partly incised into the Ogallala Formation where it enters Scott County. At a point 6 miles (10 km) north-northwest of Scott City, Ladder Creek turns northward. Twelve miles (19 km) north of Scott City, the stream cuts into the bedrock where it gains flow from many springs and seeps at the base of the Ogallala Formation. A dam across the stream utilizes the deep valley to capture flow from streams and springs to produce Lake Scott.

Discharge measurements made during the summer and winter of 1951-52 (Bradley and Johnson, 1957) document perennial flow in Ladder Creek at a point 22 miles (35 km) west of the Scott-Wichita County line. The 1951-52 measurements indicate a base inflow at the west Scott County line of 7 $ft^3/s$ (0.2 $m^3/s$); whereas, the present base inflow is zero. The 1951-52 measurements also document a base flow of 13 $ft^3/s$ (0.4 $m^3/s$) at the north Scott County line and at the stream gaging station (Station No. 06859500) 10 miles (16 km) further downstream. By assuming that the base flow at the north county line and at the gaging station are equal to any gains in discharge, and by using 1972 fall and winter records at the gaging station (Water resources data for Kansas, part 1. Surface water records, 1972), the base flow of Ladder Creek at the north Scott County line is determined to be about 3 $ft^3/s$ (0.08 $m^3/s$). This represents an annual reduction in ground-water contribution of about 2,000 acre-feet (2.5 $hm^3$) in Scott County alone, and a reduction of about 7,000 acre-feet (8.6 $hm^3$) through the entire upstream drainage (Scott and Wichita Counties). This reduction in base flow (ground-water contribution) is attributed to the extensive pumpage of ground water for irrigation.

The annual base flow of Ladder Creek at the north boundary of Scott County in 1972 was about 2,000 acre-feet (2.5 $hm^3$). None of the other streams have significant perennial flow, although they receive water from numerous springs and seeps at the base of the Ogallala Formation.

## EVAPOTRANSPIRATION

Water may be discharged from the ground-water reservoir by evapotranspiration, which is the combined process of evaporation and of transpiration by plants. Considerable amounts of water can be lost by this process in areas where the water table is near the land surface. In Lane and Scott Counties, however, evapotranspiration directly from the ground-water reservoir is considered negligible because the water table is well below the root zone nearly everywhere in the area.

## INVENTORY SUMMARY

A ground-water budget for Scott County is given below. Data are inadequate to prepare a similar budget for Lane County.

*Ground-water Budget for Scott County*

| | Acre-feet per year[1] 1971 (Dry year) | 1972 (Wet year) |
|---|---|---|
| Inflow to the ground-water reservoir: | | |
| Precipitation | | |
| Irrigated land | 11,000 | 19,000 |
| Nonirrigated land | 3,000 | 5,000 |
| Subsurface Inflow[2] | 9,000 | 9,000 |
| Total | 23,000 | 33,000 |
| Outflow from the ground-water reservoir: | | |
| Net withdrawals by wells[3] | 120,000 | 76,000 |
| Subsurface outflow[2] | 2,000 | 2,000 |
| Streamflow gains[2] | 2,000 | 2,000 |
| Total | 124,000 | 80,000 |
| Change in storage: | | |
| Calculated from above figures | −101,000 | −47,000 |
| Average water-level change | −1.87 ft | −.54 ft |
| Changes in storage determined using average water-level change and a specific yield of 15 percent (for comparison purposes here only) | −106,000 | −31,000 |

[1] Acre-feet per year times $1.233 \times 10^{-3}$ equals cubic hectometers per year.
[2] A constant value selected from previously given ranges.
[3] Total pumpage less return by seepage from irrigation.

As shown by the water budget of Scott County, inflow to the ground-water reservoir in the county from precipitation and subsurface flow was 23,000 and 33,000 acre-feet (28 and 41 $hm^3$) in 1971 and 1972 respectively. In addition to inflow from precipitation and subsurface flow, a part of the total water applied for irrigation returned to the reservoir by percolation. Because irrigation water is applied to the soil to supply adequate moisture for plant growth, more supplemental water is required during a dry growing season than is required during a wet growing season. As discussed in the section on Seepage of Irrigation Water, it is assumed that 20 percent of withdrawal by wells subsequently returns to the ground-water reservoir. The total amount of water pumped for irrigation in Scott County, as discussed in the section on Annual Withdrawals, was 150,000 acre-feet (185 $hm^3$) in 1971 and 95,000 acre-feet (117 $hm^3$) in 1972. The part of the total water pumped that returns to the reservoir in Scott County is estimated to be 30,000 acre-feet (37 $hm^3$) in 1971 and 19,000 acre-feet (23 $hm^3$) in 1972. As indicated in the water budget for Scott County, the effect of seepage from irrigation would reduce the amount of water withdrawn from storage to 120,000 acre-feet (148 $hm^3$) in 1971 and 76,000 acre-feet (94 $hm^3$) in 1972.

If the seepage of irrigation water is added to the inflow given in the budget for Scott County, the total water contributed to the reservoir would be 53,000 acre-feet (65 $hm^3$) in 1971 and 52,000 acre-feet (64 $hm^3$) in 1972. Thus, it would appear that the amount of water contributed to the reservoir from inflow and seepage remains relatively constant from year to year when there is little change in irrigated acreage.

## Aquifer Properties

A geologic unit containing sufficient saturated permeable material to yield significant quantities of water to wells and springs is known as an aquifer. The principal hydraulic properties of aquifers are their ability to store and to transmit water. The ability to store water is expressed by the storage coefficient, and the ability to transmit water is expressed by the transmissivity.

The storage coefficient (S) is a measure of the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. If the water in the aquifer is unconfined, the storage coefficient is virtually equal to the specific yield. The specific yield is defined as the ratio of (1) the volume of water that the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil.

Transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under unit hydraulic gradient. Hydraulic conductivity (K) is defined as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Hydraulic conductivity, as used in this study, is transmissivity divided by the thickness of water-yielding material. The effective thickness is that part of the saturated aquifer material that yields most of the water to wells (i.e., loose sand and gravel).

The specific capacity of a well is the rate of discharge from a well divided by the drawdown (difference between pumping level and static level) of the water level within the well; it varies slowly with duration of discharge. The duration of specific-capacity tests, reported in this study, ranged from 2 to 6 hours. Specific capacity is a measure of overall well performance, and is roughly proportional to transmissivity.

The transmissivity and the storage coefficient can be determined by several types of aquifer-test analyses of the effect of a discharging well on water levels in the pumped well and in nearby observation wells. During this investigation seven aquifer tests were made to determine the hydraulic properties of the aquifer. Data from the tests are tabulated in the summary of aquifer tests (table 2). Values determined by these tests pertain only to the water-yielding material for the duration of the test. Storage coefficients computed from a test of short duration generally are much less than specific yield values.

Storage coefficients of 0.05 to 0.30 indicate unconfined (water-table) conditions; 0.001 to 0.05 indicate semiconfined conditions (Ferris and others, 1962). As indicated by table 2, the storage coefficients show values in the unconfined (water-table) range at wells 18-28W-18aac, 18-34W-23ccd, and 20-33W-18abc. Although the value for the storage coefficient at 17-27W-28acc indicates semiconfined conditions, the geology at the test site indicates that the aquifer should be unconfined (see log in Stullken and others, 1974). If the aquifer test had been conducted for a longer period of time, the resulting storage coefficient probably would have been in the unconfined range. The storage coefficient at 17-30W-20bbc indicates localized semiconfined conditions at the aquifer test site. Confined to semiconfined conditions are indicated by the storage coefficients of wells 20-32W-20adb and 20-33W-26caa.

The apparent radius of influence of a pumping well, as used in this report, is the greatest distance at which a drawdown of 1 foot (0.3 m) would occur on the cone of depression. This apparent radius, noted on table 2, is a theoretical value calculated for the duration of the test. Distances range from 200 feet (61 m) where the aquifer is unconfined to 5,500 feet (1,700 m) where the aquifer is confined. The apparent radius of influence varies at any site with the rate and duration of pumpage, areal variations of hydraulic conductivity, storage coefficient, and homogeneity of the aquifer.

The results of the seven aquifer tests made in this study represent the range of short-term operation conditions in the unconsolidated aquifer. Two of the tests are described fully because they are considered representative of the aquifer under operative field conditions.

The aquifer test using well 20-33W-18abc (owned by Harold Williams) was conducted for 30,000 minutes (20.8 days) from April 6 to 27, 1972. The well discharge for the test was 625 gpm (39.4 l/s). At the test site the aquifer consists of sand and gravel in the Ogallala Formation. Observation well 20-33W-18abc2 was drilled at a distance of 80 feet (24.4 m) from the pumped well (see log of well in Stullken and others, 1974), and observation well 20-33W-18abc3 was drilled 160 feet (49 m) from the pumped well. The static water level in the pumped well and the two observation wells was about 103 feet (31 m) below the land surface at the start of the test. The initial saturated thickness at the pumped well and the two observation wells was about 60 feet (18 m).

A continuous record of water levels in the obser-

TABLE 2.—Summary of aquifer tests.

| Well number | Trans-missivity (ft² per day) | Storage co-efficient | Hydraulic con-ductivity (ft per day) | Depth to water (feet) | Effec-tive thick-ness (feet) | Satu-rated thick-ness (feet) | Well depth (feet) | Average dis-charge (gpm) | Specific capacity (gpm per ft drawdown) | Duration of test (min) | Apparent radius of influence (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17-27-28acc | 2,440 | 0.032 | 70 | 90 | 35 | 35 | 126 | 140 | 12 | 7,000 | 600 |
| 17-30W-20bbc | 3,500 | .01 | 55 | 101 | 38 | 60 | 165 | 600 | 15 | 2,400 | 1,300 |
| 18-28W-18acc | 5,700 | [1] | 130 | 60 | 44 | 44 | 104 | 625 | 38 | 20,300 | [1] |
| 18-34W-23ccd | 2,960 | .18 | 179 | 117 | 17 | 17 | 140 | 150 | 17 | 3,600 | 200 |
| 20-32W-20adb | 3,200 | .001 | 44 | 92 | 72 | 89 | [2]190 | 455 | 12 | 5,700 | 5,500 |
| 20-33W-18abc | 6,000 | .14 | 104 | 103 | 60 | 80 | 164 | 625 | 32 | 30,000 | 1,300 |
| 20-33W-26caa | 9,900 | .001 | 309 | 92 | 32 | 70 | 144 | 440 | 31 | 6,700 | 5,200 |

[1] Indefinite because of deviations from theoretical assumptions.
[2] Estimated.

vation wells was obtained using electrical water-sensing devices coupled to water-level recorders. Figure 6 shows the curve of drawdown versus time derived from water-level measurements in observation well 20-33W-18abc3 160 feet (49 m) east of the pumped well. Drawdown data were matched to the Theis nonequilibrium type curve (Theis, 1935; and Jacob, 1944). Data from 3 to 1,000 minutes in the test are considered unreliable for use in the analysis because the contribution of water by gravity drainage from the sand and gravel layers was still significant. Data from 1,000 to 12,000 minutes in the test give a reasonably good match on the Theis nonequilibrium type curve. The data later than 12,000 minutes, which deviate from the trace of the curve, indicate accelerated drawdown, probably due to interference effects of pumping from nearby wells. These late-time data, therefore, are not reliable for analysis of aquifer constants. The transmissivity and storage coefficients were computed to be 6,000 $ft^2$/day (560 $m^2$/day) and 0.14 respectively as shown in table 2 and on figure 6.

Results from aquifer-test analyses for thin unconfined aquifers with large drawdowns are questionable because the nonequilibrium formula does not take into account the thinning of the saturated zone as drawdown increases (Stallman, 1965). The aquifer test at well 18-28W-18acc (owned by Jay Walker) illustrates the problem of a thinning saturated zone and large drawdown.

The test was run from August 9 to 23, 1972; it lasted 20,300 minutes, or 14.1 days. The well discharge averaged 625 gpm (39.4 l/s), which was measured by both an inline, propeller-driven, accumulating water meter and, periodically, by a pitot-tube water meter. At the test site the aquifer consists of sand and gravel of the Ogallala Formation, which fills a bedrock channel. Observation well 18-28W-18acc2 was drilled 100 feet (30 m) south of the pumped well (see log in Stullken and others, 1974), and observation well 18-28W-18acc3 was drilled 200 feet (61 m) south of the pumped well. The static water level at the start of the test was 60 feet (18 m) and the initial saturated thickness was 44 feet (13 m).

The water levels were recorded and the data adjusted for dewatering using the method by Jacob (1944). Figure 7 shows drawdown plotted versus distance from the pumped well at the end of the test (20,300 minutes). The distance-drawdown curve represents a section through the cone of depression at the time of 20,300 minutes. The data were analyzed by the Thiem method (Thiem, 1906) for calculating transmissivity and by the Jacob intercept method (Ferris and others, 1962) for calculating the storage coefficient. Results of the aquifer-test analysis indi-

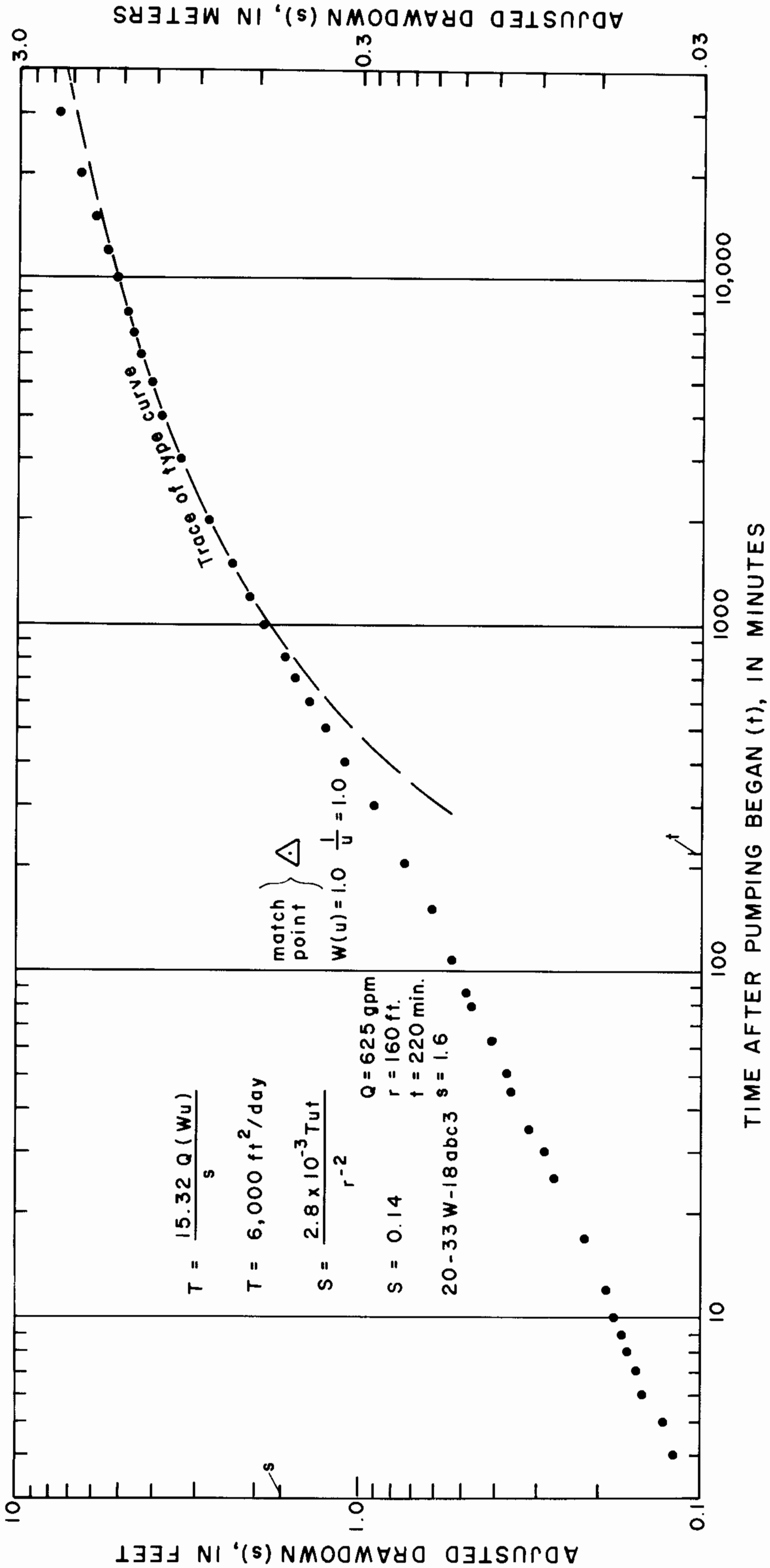


FIG. 6.—Drawdown of water level in observation well 20-33W-18abc3, plotted against time in minutes after pumping began.

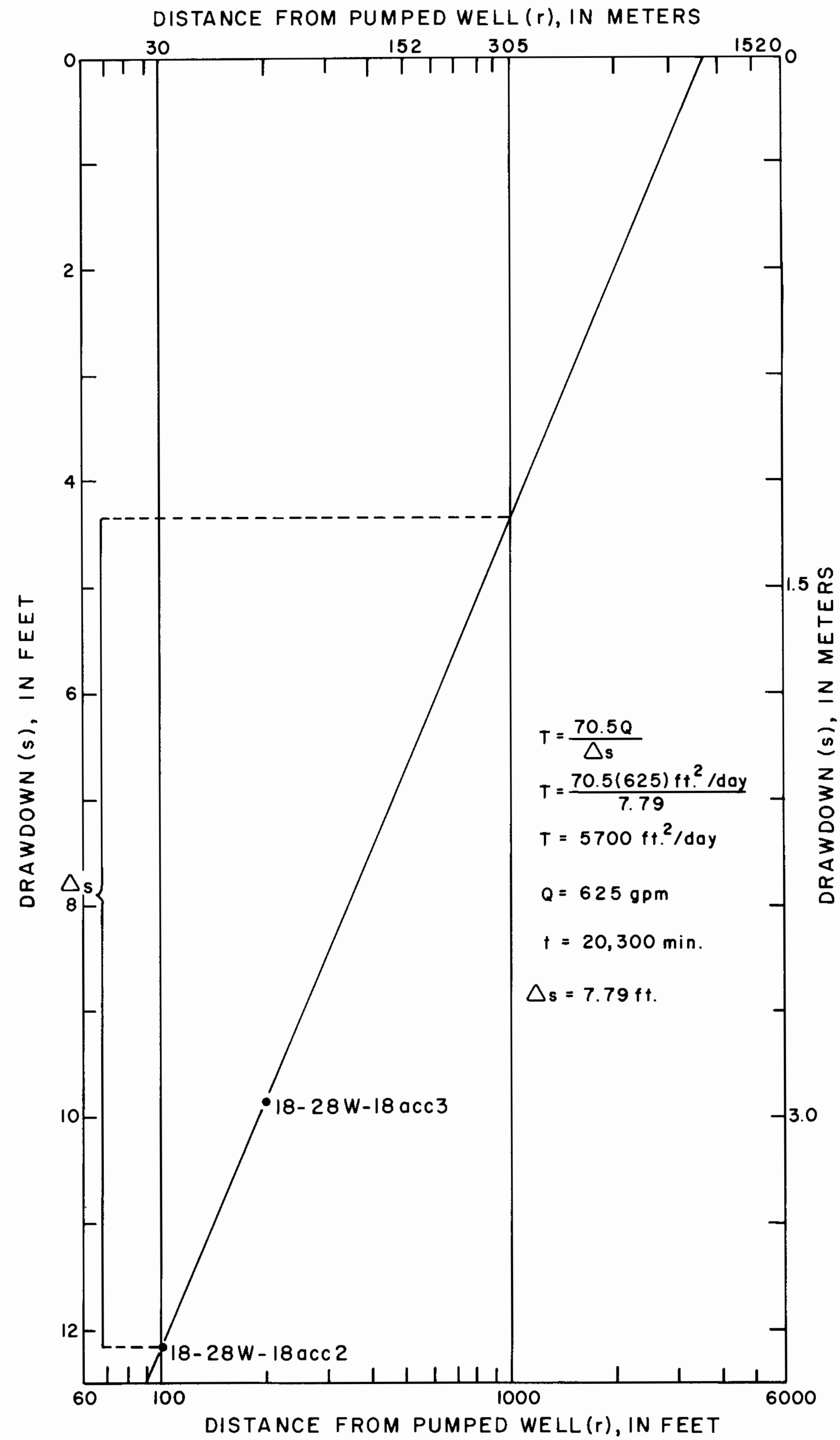


Fig. 7.—Drawdown of water levels in observation wells 20,300 minutes after pumping began in well 18-28W-18acc.

cate a transmissivity of 5,700 $ft^2$/day (530 $m^2$/day) and an apparent storage coefficient of 0.013. A storage coefficient in this range would indicate that the water in the aquifer is semiconfined. However, the lithology at the observation wells show that semiconfinement should not exist at this location. Jacob (1944) points out that equations describing aquifer constants are valid for confined, homogenous, isotropic aquifers, or for similar unconfined aquifers where the drawdowns are small with respect to the initial saturated thickness. After 20,300 minutes of pumping, the saturated thickness was reduced by about 56 percent at the pumped well, 28 percent at the observation well 100 feet (30 m) away, and 23 percent at the observation well 200 feet (61 m) away. The authors believe that the exceptionally high ratio of drawdown to initial saturated thickness greatly affected the analysis, with minor influence from slow drainage as the well was pumped, resulting in the calculation of a much lower storage coefficient than field observation suggested. The transmissivity value, however, is not as greatly affected by deviation from the theoretical assumptions.

Additional transmissivity values were derived from the calculated specific-capacity values of 30 well-production tests, as summarized in table 3. The specific-capacity values were used to calculate the ability of the well to obtain water from the aquifer when the well is pumped at a rate sufficient to produce a drawdown equivalent to 70 percent of the effective saturated thickness. The transmissivity in feet squared per day can be estimated by multiplying the specific capacity by 203, which is the median of values ranging from 150 to 320 derived from the relation of specific capacity to transmissivity in the seven aquifer tests (table 2).

TABLE 3.—Summary of data from well-production tests.

| | Range (30 tests) | Median |
|---|---|---|
| Specific capacity (gpm per ft drawdown) | 5 to 50 | 18 |
| Transmissivity ($ft^2$ per day) | 885 to 10,500 | 4,200 |
| Hydraulic conductivity (ft per day) | 22 to 309 | 81 |
| Saturated thickness (feet) | 17 to 145 | 60 |
| Effective thickness | | |
| (feet) | 5 to 93 | 40 |
| (percent) | 25 to 100 | 80 |
| Potential yield (gpm) | 145 to 2,400 | 825 |

In areas where data from aquifer tests and well-production tests were lacking, the transmissivity values were estimated from drillers' and sample logs of wells and test holes using a method described by Fader and others (1964). The method involves assigning a hydraulic conductivity to each layer of material penetrated between the water table and the bedrock. The transmissivity of each layer is equal to the thickness of that layer multiplied by its hydraulic conductivity. The estimated transmissivity of the water-yielding section is the summation of the transmissivities computed for each layer. Values of hydraulic conductivity (table 3) ranged from 309 ft/day (94 m/day) for very coarse grained material to 22 ft/day (7 m/day) for fine silty sand with a median value of 81 ft/day (25 m/day). In areas where the water-yielding materials are mostly fine grained, the average hydraulic conductivities were about 40 ft/day (12 m/day). This method is subjective because lower or higher values of hydraulic conductivity may be assigned to a particular layer of material according to the collection methods employed and the experience and judgment of the observer.

All three methods of obtaining transmissivity data were used to prepare the transmissivity map shown on plate 3. The transmissivity values for coarse-grained deposits greatly exceed those for fine-grained deposits of equal thickness. The transmissivity values are greatest in areas where the bedrock channels are filled with loose coarse-grained alluvial materials. Material deposited away from the main channels is fine grained and the transmissivity values are correspondingly small.

The distribution of values used to prepare the transmissivity map of the unconsolidated aquifer was determined using the following input data (listed by degree of accuracy):

1. From aquifer tests (table 2)
2. From well-production data (2- to 6-hour step-drawdown tests) reported by water-well contractors
3. By estimation of transmissivity values from logs of test holes.

The transmissivity map can be used as a general guide for estimating the potential yield of wells, but decisions to drill wells should not be made solely on estimated transmissivity values. Local changes in lithologic character of the unconsolidated aquifer result in areal transmissivity changes too variable to map in detail. Test drilling would be necessary to determine whether or not the lithology of the aquifer at a selected site indicated a potential yield to wells adequate for the intended use.

### Water-Table Configuration

The configuration of the water table in Lane and Scott Counties is shown on plate 2. Data for this map were obtained during the winter (January 1973) when the effects of seasonal pumping for irrigation were at a minimum. The major features of the water-level map are the shape and slope of the water surface. Contours were not shown where water levels are at or near the bedrock surface or isolated from the main body of the unconsolidated aquifer.

Confining conditions occur locally in Lane and Scott Counties where the alluvial deposits are extremely heterogeneous. In parts of the major south-trending trough, differences in head occur between water-yielding layers during periods of heavy pumpage because movement of water between layers is retarded by beds of clay. During the intervening periods of little pumpage, the beds of clay also retard the upward movement of water in response to artesian pressure to reach a static level (potentiometric surface) not significantly different from the water table. Therefore, the two surfaces are not differentiated in plate 2.

The water surface generally slopes eastward across the study area at about 10 feet per mile (1.9 m/km) and the water movement is in that direction. In the vicinity of the buried south-trending trough south of Scott City, the slope of the water surface changes direction to southward and flattens to about 3 feet per mile (0.6 m/km). The change in direction is caused partly by the effect of the prominent bedrock high north of Dry Lake (pl. 1). Flattening of the gradient, as evidenced by the widely spaced contours, probably is due to high conductivity of the material through which the water is moving, increased thickness of water-bearing materials, or both. The area defined by the widely spaced contours is underlain by very highly conductive sand and gravel deposits that fill the south-trending trough and its tributaries. In the area west of Shallow Water, the configuration of the water surface partly reflects the flow of water towards a center of intensive pumping, which has distorted the general flow pattern.

Closely spaced contours in the two counties indicate a steep slope of the water surface that probably is due to low hydraulic conductivity, reduced thickness of water-bearing materials, or both. The areas defined by closely spaced contours, however, may not have less water available to wells than areas defined by more widely spaced contours. A thin, highly conductive aquifer can yield as much water as a thick aquifer having a low conductivity. Wells in thin, very conductive deposits in the tributary valleys in Tps. 17-20 S., R.34 W. have greater yields than wells in the adjacent areas having less conductive materials, although both areas have closely spaced contours.

The unnamed tributary of Ladder Creek that flows through Timber Canyon is an example of a gaining stream because it has intercepted the water table. Thus, the upstream flexure of contours shows flow toward the stream. The lack of upstream flexures in other areas where contour lines cross stream valleys indicates that the water table lies below the streambed, and that the streams receive no contribution from ground water.

In Lane County the area within the main body of the unconsolidated aquifer includes 34 percent of the county or 244 square miles (632 km$^2$). The area within the main body in Scott County includes 81 percent of the county or 589 square miles (1,526 km$^2$). In the area outside of the main body, the unconsolidated aquifer is extremely thin or absent. Ground water may occur in isolated channels cut into the bedrock, as in the area east of Dry Lake in T.20 S., R.31 W., Scott County. Wells in this area are developed in the alluvium of a small stream. Data were not available to accurately delineate the water table in areas where the aquifer is thin or in areas of rough topography where tributaries of the Smoky Hill River dissect the upland surface.

Two small areas within the main body of the unconsolidated aquifer are shown to be dry. In these areas, in T.20 S., Rs. 33-34 W., Scott County, and T.18 S., R.29 W., Lane County, the water table probably exists in the chalk aquifer because the bedrock surface lies above the surrounding water table. To obtain a domestic or stock supply, wells must be drilled to either the chalk or the sandstone aquifers.

### Saturated Thickness

The saturated thickness of the unconsolidated deposits is shown on plate 2. Within the main body of the unconsolidated aquifer, the saturated thickness ranges from less than 40 feet (12 m) to about 160 feet (49 m). Generally the deposits that fill the south-trending trough in Scott County contain the greatest saturated thickness. Outside of this trough, the saturated thickness generally does not exceed 80 feet (24 m) in Lane or Scott Counties.

The general relation of the land surface, the water table, and bedrock surface is shown on geohydrologic sections A-A′ (fig. 8) and B-B′ (fig. 9). The sections illustrate that the saturated thickness is greatly influenced by the configuration of the bedrock surface. The effect of the bedrock high on saturated thickness east of the deep south-trending trough is illustrated by section B-B′.

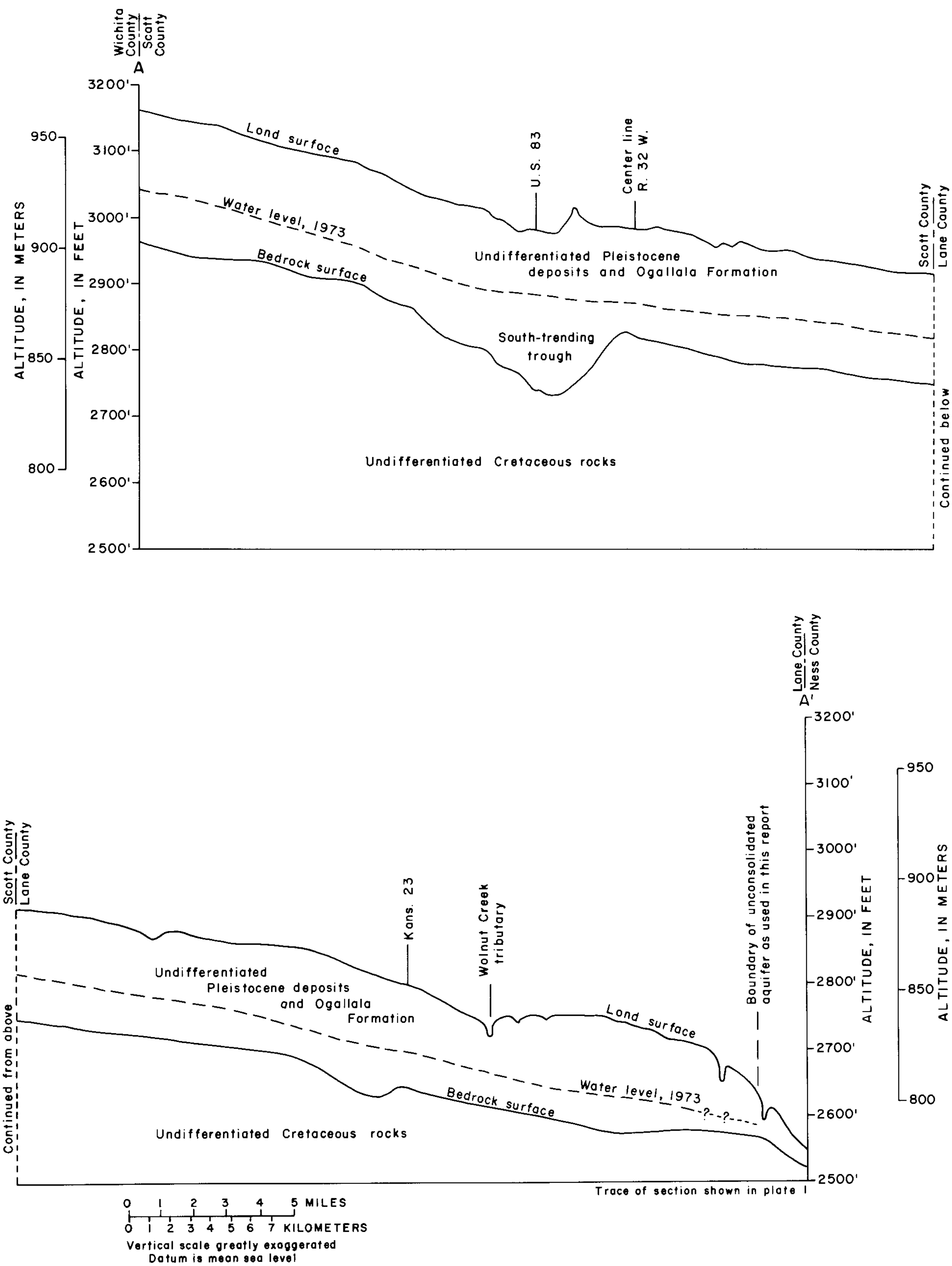


FIG. 8.—Geohydrologic section A-A'.

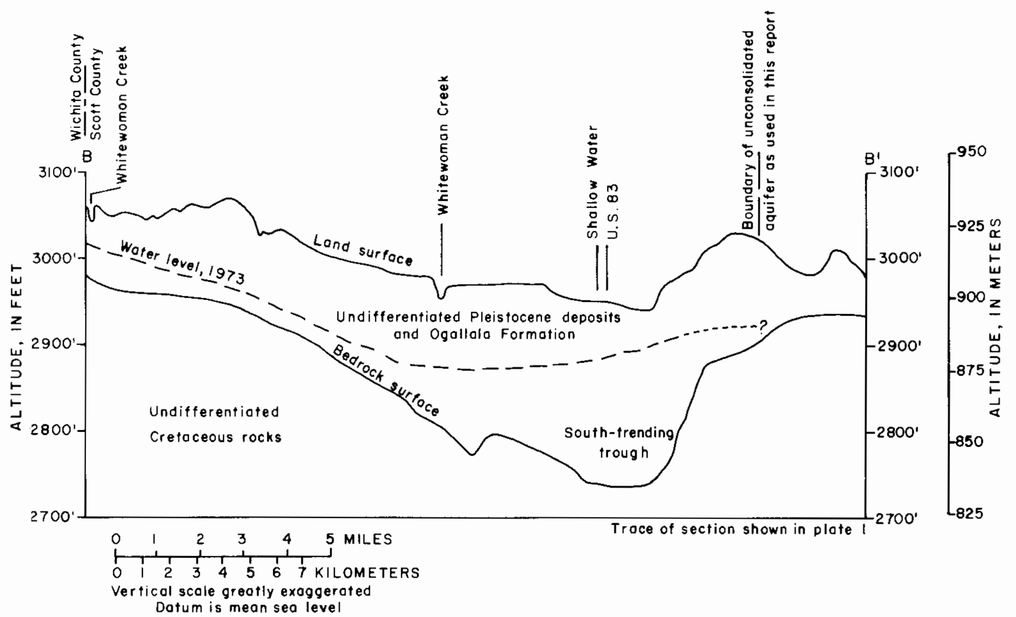


FIG. 9.—Geohydrologic section B-B′.

A large saturated thickness does not guarantee a successful irrigation well. Test hole 19-32W-8dcc (see Stullken and others, 1974, for log of well) is in an area where saturated thickness is about 150 feet (46 m), but the widely spaced layers of water-yielding poorly sorted sand and gravel consist of only 20 feet (6 m) or 13 percent of the total thickness. It would be difficult at this location to develop a well producing 100 gpm (6.3 l/s). On the other hand, irrigation wells in eastern Lane and western Scott Counties have been developed in as little as 20 feet (6 m) of saturated, well-sorted sand and gravel. The log of test hole 18-34W-33ccd3 (see Stullken and others, 1974, for log of well) indicates that all the 21 feet (6 m) of saturated deposits are water-yielding, and that a well at this site should produce about 150 to 200 gpm (9.4 to 12.6 l/s).

In some areas outside the main body of the unconsolidated aquifer, an irrigation well might be developed where very thin saturated deposits overlie and are in hydraulic connection with fractures and solution openings in the chalk aquifer. In other areas, isolated channels may have a sufficient saturated thickness and may contain enough water-yielding materials to supply irrigation wells.

The distribution, thickness, degree of sorting, and hydraulic conductivity of water-yielding materials within the saturated section are important considerations in developing an irrigation supply. Saturated thickness, however, can be used as an approximation in locating a possible well site. The water-well contractor generally can estimate well yields by calculating the percent of water-yielding materials within the total saturated section. (See section on potential yield.)

The amount of ground water stored in the unconsolidated aquifer in Lane and Scott Counties can be computed by planimetering the saturated-thickness intervals shown on plate 2, multiplying by the average saturated thickness of each interval, summing the products, and multiplying this summation (volume) by the specific yield. The unconsolidated aquifer, in general, has a specific yield (storage coefficient) between 0.15 and 0.20 (Meyer and others, 1970; Pearl and others, 1972). A storage coefficient of 0.15 would also be representative of aquifer tests in the unconfined main body of the unconsolidated aquifer (table 2). In the south-trending trough, numerous beds of low hydraulic conductivity separate the various water-yielding layers and result in confined or semiconfined conditions. The specific yield in this area probably ranges from 0.01 to 0.15. Aquifer tests in the trough area have been made using wells completed in the lower more confined water-bearing layers. Storage coefficients determined from these tests are as low as 0.001 (table 2). The area considered as confined, generally coinciding with the south-trending trough, contains about 10 percent of the study area and about 20 percent of the total saturated thickness of the unconsolidated aquifer in Lane and Scott Counties.

Allowing for the range in specific yield, the total volume of water in storage in Lane and Scott Counties is estimated to be between 4 and 6 million acre-feet (4,900 and 7,400 $hm^3$) as of January 1973. Assuming that only 70 percent of the total volume of water is

TABLE 4.—Chemical analyses of water from selected wells and springs in Lane and Scott Counties.
[Dissolved constituents and hardness given in milligrams per liter. Analyses by Kansas Department of Health and Environment.]

| Well number | Well depth (feet) | Geologic source[1] | Date of collection | Temperature (°C) | Dissolved solids (residue at 180°C) | Dissolved silica ($SiO_2$) | Iron (Fe) | Dissolved manganese (Mn) | Dissolved calcium (Ca) | Dissolved magnesium (Mg) | Sodium and potassium (Na + K) | Bicarbonate ($HCO_3$) | Dissolved sulfate ($SO_4$) | Dissolved chloride (Cl) | Dissolved fluoride (F) | Dissolved nitrate ($NO_3$) | Hardness ($CaCO_3$) Total | Hardness Carbonate | Hardness Noncarbonate | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lane | | | | | | | | | | | | | | | | | | | | | |
| 16-28W-32cac | 110 | To | 8- 5-71 | 15.5 | 294 | 21 | .06 | .0 | 48 | 19 | 30 | 244 | 25 | 13 | 3.2 | 2.9 | 200 | 200 | 0 | 450 | 7.7 |
| 16-29W-11ccc | 749 | Kd | 9-15-48 | 18.0 | 932 | 9.2 | .98 | ... | 5.2 | 3.0 | 380 | 734 | 39 | 110 | 8.0 | .7 | 26 | 26 | 0 | .... | ... |
| 17-27W-28acc | 127 | To | 8- 5-71 | 15.0 | 318 | 13 | .05 | .0 | 59 | 20 | 25 | 232 | 40 | 21 | 2.4 | 8.0 | 230 | 191 | 39 | 500 | 7.8 |
| 17-30W-20bbc | 165 | To | 8- 5-71 | 15.5 | 316 | 22 | .06 | .0 | 54 | 17 | 32 | 224 | 48 | 18 | 2.2 | 8.4 | 200 | 180 | 20 | 490 | 7.8 |
| 18-28W-16ccd | 55 | To | 6-18-71 | 15.0 | 380 | 65 | 1.1 | .0 | 45 | 24 | 45 | 288 | 24 | 18 | 4.4 | 13 | 210 | 210 | 0 | 570 | 8.1 |
| 19-29W-7bab | | To | 7-27-71 | 15.0 | 340 | 18 | .62 | .0 | 64 | 23 | 22 | 281 | 7.5 | 10 | .8 | 45 | 250 | 226 | 24 | 540 | 7.7 |
| 20-27W-12a | Spring | Kn | 6-21-71 | 13.0 | 704 | 21 | .15 | .0 | 130 | 18 | 85 | 300 | 200 | 63 | .5 | 38 | 400 | 250 | 150 | 1,070 | 7.4 |
| 20-29W-3ccb | 80 | To | 7-23-71 | 17.0 | 384 | 14 | .06 | .0 | 58 | 22 | 46 | 254 | 43 | 29 | 1.0 | 35 | 240 | 213 | 27 | 620 | 7.8 |
| Scott | | | | | | | | | | | | | | | | | | | | | |
| 16-33W-13ba | Spring | To | 8- 5-71 | 16.0 | 272 | 14 | .11 | .0 | 45 | 14 | 31 | 207 | 33 | 12 | 2.0 | 9.7 | 170 | 170 | 0 | 440 | 7.7 |
| 16-33W-30bab | 187 | To | 8-12-71 | 15.5 | 300 | 25 | .19 | .0 | 43 | 18 | 32 | 207 | 38 | 14 | 2.0 | 9.7 | 180 | 168 | 12 | 430 | 8.1 |
| 17-31W-27aba | 187 | To | 6-16-64 | | 380 | 46 | .00 | .0 | 56 | 20 | 42 | 237 | 60 | 26 | 2.2 | 11 | 220 | 192 | 28 | 540 | 7.6 |
| 17-34W-16acb | 208 | To | 7-10-64 | | 351 | 41 | .00 | .0 | 46 | 22 | 39 | 222 | 64 | 18 | 2.2 | 8.9 | 210 | 186 | 24 | 530 | 7.4 |
| 18-33W-13dad | 225 | Qu | 4-10-68 | ... | 326 | 52 | .00 | .0 | 50 | 18 | 30 | 229 | 38 | 14 | 1.6 | 10 | 200 | 189 | 11 | 480 | 7.9 |
| 18-33W-22bcc | 120 | To | 12-21-71 | 14.0 | 738 | 41 | .27 | .0 | 140 | 46 | 41 | 303 | 200 | 95 | 1.0 | 17 | 530 | 250 | 280 | 1,100 | 7.9 |
| 19-31W-16cba | 76 | Kn | 8-12-71 | 15.0 | 362 | 26 | .29 | .0 | 75 | 12 | 29 | 254 | 40 | 29 | .4 | 9.7 | 240 | 212 | 28 | 510 | 7.8 |
| 19-32W-30bab2 | 200 | Qu To | 8- 3-64 | .... | 579 | 31 | .01 | .0 | 69 | 42 | 79 | 366 | 40 | 25 | 2.2 | 6.2 | 340 | 296 | 44 | 880 | 7.4 |
| 19-33W-12ddc2 | 140 | To | 8- 5-71 | 14.0 | 2,250 | 17 | .10 | .0 | 240 | 160 | 260 | 364 | 1,100 | 200 | 2.4 | 12 | 1,200 | 260 | 940 | 2,900 | 7.5 |
| 20-32W- 7cba | 112 | To | 8- 5-71 | 13.5 | 1,020 | 21 | .08 | .0 | 150 | 63 | 101 | 351 | 390 | 90 | 2.0 | 13 | 630 | 290 | 340 | 1,470 | 7.6 |
| 20-33W-16cbb2 | 137 | To | 7-10-64 | ... | 321 | 30 | .00 | .0 | 56 | 21 | 26 | 210 | 49 | 28 | .8 | 7.1 | 230 | 176 | 54 | 500 | 7.4 |

[1] Geologic units abbreviated as follows: Kd, Dakota Formation; Kn, Niobrara Chalk; To, Ogallala Formation; Qu, undifferentiated Pleistocene deposits.

recoverable by wells, between 2.8 and 4.2 million acre-feet (3,500 and 5,200 $hm^3$) are available for pumping.

## Chemical Quality

Chemical character of ground water in the study area is indicated by the selected analyses shown in table 4. More analyses are published in the basic-data report. (See table 4 in Stullken and others, 1974.) The analyses show only the dissolved mineral content of the water, not its sanitary condition. For a discussion of the significance of chemical constituents in ground water, the reader is referred to the reports of Waite, 1947; Prescott, 1951; and Meyer and others, 1970.

Results of chemical analyses show that concentrations of some constituents in ground water from Lane and Scott Counties exceed the limits recommended by the Kansas Department of Health and Environment for drinking water. These limits are listed below in milligrams per liter (mg/l):

| | |
|---|---|
| Chloride (Cl) | 250 |
| Fluoride (F) | 1.2 |
| Iron (Fe) | .3 |
| Manganese (Mn) | .05 |
| Nitrate ($NO_3$) | 45 |
| Sulfate ($SO_4$) | 250 |
| Dissolved solids | 500 |

Dissolved fluoride and dissolved nitrate may be health hazards when present in concentrations much higher than the recommended limits (U.S. Public Health Service, 1962, pp. 41, 47-50). Fluoride concentrations greater than 1.5 mg/l may cause mottled tooth enamel if the water is consumed by children during the period of formation of permanent teeth (Dean, 1936). Bone changes may occur when water containing more than 8 mg/l fluoride is consumed for a long period of time (Shaw, 1954), but such changes have not been noted in the United States (U.S. Public Health Service, 1962, p. 41). Concentrations of fluoride from 1.0 to 1.2 mg/l in drinking water can aid in preventing tooth decay (Kansas State Board of Health, 1973). Water from several of the wells listed in table 4 contained higher-than-recommended concentrations of fluoride.

Water containing nitrate in concentrations greater than 45 mg/l may cause methemoglobinemia, or cyanosis, in infants and the public should be informed of the danger in areas where high concentrations occur (U.S. Public Health Service, 1962, p. 50). Water containing 45 mg/l nitrate was found in one well listed in table 4 and higher-than-normal concentrations were found in two other water samples. In Lane and Scott Counties, such high concentrations of nitrate generally indicate local pollution of ground water by animal wastes that enter the water through improperly sealed wells or by percolation through permeable sediments above the water table.

### WATER TYPES

The results of chemical analyses of water samples from the unconsolidated aquifer (Ogallala Formation and Pleistocene deposits) and one sample from a well in the chalk aquifer (Niobrara Chalk) indicate that the water, classed by predominant ions, generally is a calcium bicarbonate type and ranges in hardness from 200 to 530 mg/l, although there are some exceptions. Well 19-32W-30bab2 yields a magnesium bicarbonate water, well 19-33W-12ddc2 yields a magnesium sulfate water, and well 20-32W-7cba yields a calcium sulfate water. These wells are located in an area of a shallow water table and undrained surface depressions. Under these conditions, residual salts resulting from evaporation accumulate in fine- to medium-textured soils. Subsequent flushing of the more soluble salts from the soil causes relative enrichment of magnesium, sodium, sulfate, and chloride ions in the ground water (Meyer and others, 1970).

Water from most wells in the unconsolidated and chalk aquifers is suitable for most domestic, stock, and irrigation uses. Water from wells in the sandstone aquifer (Dakota Formation) is of the sodium bicarbonate type and the analysis shown in table 4 and figure 10 indicates the water is unsuitable for most uses. Water from the sandstone aquifer should be analyzed as to suitability for the intended use.

### SUITABILITY FOR IRRIGATION

The development and maintenance of successful irrigation requires the control of salinity and alkalinity of soils, as well as supplying irrigation water to the land. The chemical characteristics of water that are most important in determining its suitability for irrigation in Lane and Scott Counties are: (1) total concentration of soluble salts, and (2) relative proportion of sodium to other principal cations (calcium, magnesium, and potassium). The total concentration of soluble salts in irrigation water can be expressed in terms of electrical conductivity. Electrical conductivity is the ability of the solution to conduct an electrical current, and is expressed in micromhos per centimeter at 25° Celsius. Water with a conductivity value (fig. 10) below 750 micromhos/cm at 25°C is satisfactory for irrigation insofar as salt content is concerned, although crops sensitive to salt may be adversely affected by irrigation water with conductivity values in the range 250 to 750 micromhos/cm at 25°C. Water in the range 750 to 2,250 micromhos/cm at 25°C is widely used, and satisfactory crop growth may be obtained under favorable soil-drainage conditions and good management. However, saline soil conditions will develop when leaching is incomplete and excess soluble salts are deposited in the root zone. Very few instances are known where water with conductivity values greater than 2,250 micromhos/cm at 25°C has been used successfully. The use of large quantities of such water on soils and subsoils with excellent drainage may allow the more salt-tolerant crops to be grown.

Figure 10 indicates that water in the chalk aquifer and in the unconsolidated aquifer is in the $C_2$-$S_1$ class. This represents medium-salinity water ($C_2$) that can be used if moderate leaching occurs. Moderately salt-tolerant plants generally can be grown without special salinity control practices. Low-sodium water ($S_1$) can be used on most soils with scant danger of the development of harmful levels of exchangeable sodium.

The sample of water from a spring issuing from the Niobrara Chalk in eastern Lane County (20-27W-12a) is in the $C_3$-$S_1$ class which indicates that it is a high-salinity water ($C_3$) and would need special management even on adequately drained soils growing salt-tolerant plants. Water in the chalk aquifer generally is classified with water from the unconsolidated aquifer, except for the spring issuing from Niobrara Chalk. The similarity of chemical quality is further evidence that water in the chalk aquifer is supplied by drainage from the overlying unconsolidated aquifer.

The sample of water from the Dakota Formation (16-29W-11ccc) lies in the $C_3$-$S_4$ class. This is a high-salinity water ($C_3$) combined with a very high-sodium water ($S_4$); it is unfit for all types of irrigation, including lawns. The possibility does exist that better-quality water than the water in this sample might be found elsewhere in the sandstone aquifer.

## GROUND-WATER DEVELOPMENT

Irrigation has been practiced in Scott County on a small scale since about 1650 when the Taos Indians diverted water from Ladder Creek to irrigate crops in an area near the present Lake Scott. Pumping ground water for crops was practiced as early as 1888. By 1895, 24 individuals were reported to be irrigating a total of 40 acres (16 hm²) (McCall, 1944).

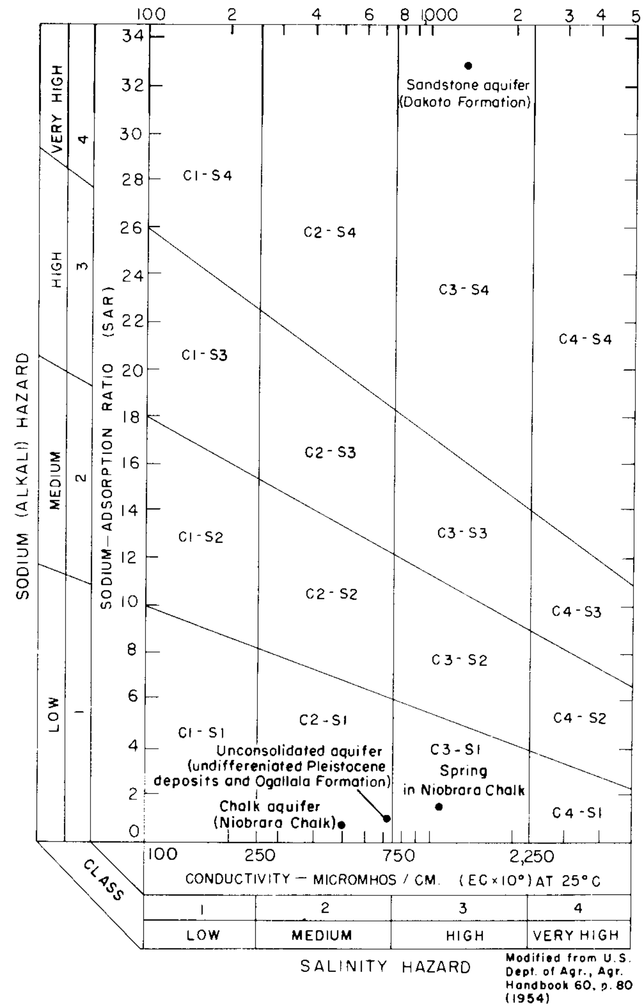


Fig. 10.—Suitability of water for irrigation.

All the power was supplied by windmills and each well probably irrigated little more than a garden plot. According to McCall (1944), the next phase of irrigation development began in 1908 when E. E. Coffin operated an irrigation plant that pumped about 120 gpm (7.6 l/s) using a centrifugal pump driven by a gasoline engine. Two new windmill plants were constructed in 1911 and 1912. Each windmill plant had several wells and a reservoir for storing water. In 1917, J. W. Lough, who was called the "father of pump irrigation in Scott County," completed a $75,000 plant for generating electricity to power his wells. This local electric plant used fuel oil for energy. Although definite information is not available, irrigated acreage in Scott County apparently reached a peak of about 5,000 acres (2,020 hm²) in 1922 and then declined steadily to a low of 1,020 acres (410 hm²) in 1932 (McCall, 1944). According to Pfister (1955), the extension of electric lines into the Shallow Water area in 1932 helped increase irrigated acreage to 4,000 acres (1,620 $hm^2$) in 1934. Acreage remained nearly constant until 1937, when it increased during 1937-38 to 10,355 acres (4,190 $hm^2$). The increase that started in 1937 was partly due to the extension of natural gas lines into the pumping district. The irrigated acreage for Scott County continued to grow, reaching 12,389 acres (5,010 $hm^2$) in 1939. In 1945 a total of 129 wells supplied 18,400 acre-feet (23 $hm^3$) of water to irrigate 21,000 acres (8,500 $hm^2$) (Waite, 1947).

Irrigation development in Lane County was slower than in Scott County, as there were less than 500 acres (200 $hm^2$) irrigated from three wells in 1949 (Prescott, 1951).

From these meager beginnings, irrigation increased until 1972 when about 100,000 acres (40,470 $hm^2$) were irrigated in Scott County and about 20,000 acres (8,090 $hm^2$) were irrigated in Lane County. An average of 136 acres (55 $hm^2$) per well are being irrigated in the two counties.

## Location of Wells

As of January 1973, there were 164 large-capacity wells in Lane County and 717 large-capacity wells in Scott County. This total includes all irrigation, industrial, and municipal wells that yield 100 gpm (6.3 l/s) or more. Most of the wells have been drilled within the main body of the unconsolidated aquifer shown on plate 2. Wells in T.18 S., R.31 W. are in the chalk aquifer and wells in T.20 S., R.31 W. are in an isolated alluvial channel separated from the main body of the unconsolidated aquifer.

## Irrigated Acreage

In 1972 about 20,000 acres or 31.2 square miles (80.9 $km^2$) were irrigated in Lane County and about 100,000 acres or 156.2 square miles (404.6 $km^2$) in Scott County (fig. 11). These data are from records of the Division of Water Resources, Kansas State Board of Agriculture. The data have been adjusted to account for duplication of the same acreage under more than one application. The graph shows that the amount of land under application to appropriate ground water has continued to increase rapidly since the middle 1960's.

As part of a study to improve accuracy and timeliness of information on land use, such as irrigated acreage, the Kansas Geological Survey is utilizing imagery acquired from the Earth Resources Technol-

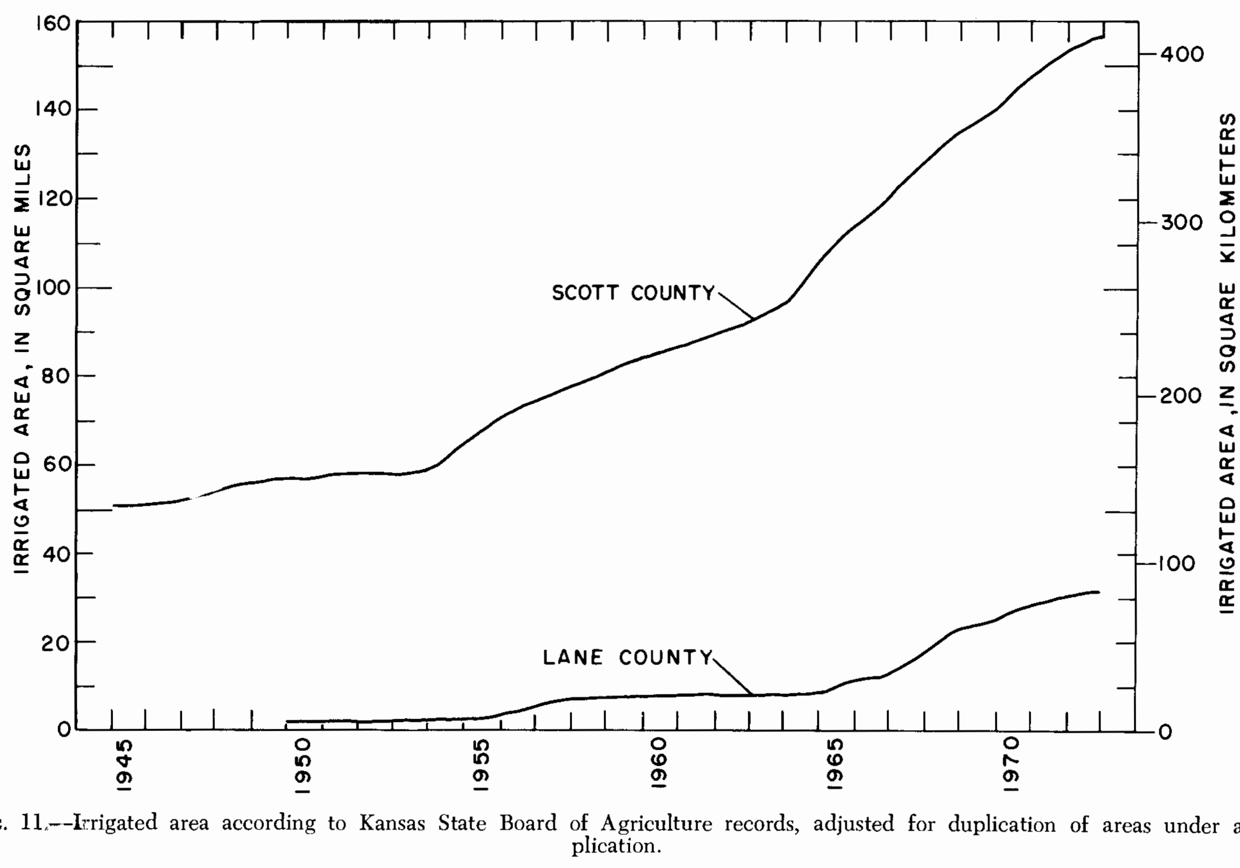


FIG. 11.—Irrigated area according to Kansas State Board of Agriculture records, adjusted for duplication of areas under application.

ogy Satellite (ERTS)[1]. Figure 12 is a portrayal of Lane and Scott Counties produced from imagery at an altitude of 570 nautical miles (1,054 km).

The drainage pattern of Ladder Creek in northwestern Scott County and the major forks of Walnut Creek and Hackberry Creek in eastern Lane County are seen as a sinuous pattern of dark gray-black tone where springs and seeps provide adequate moisture for phreatophyte growth. Outcrop areas of the Niobrara Chalk along the northern and eastern borders exhibit irregular patterns of light-gray tone.

The east-west orientation of fields is a means of reducing erosion by the predominant southerly and northerly winds. In general, medium- to light-gray tones are pasture land and fallow or stubble fields. Dark-gray tones represent untilled grass land illustrated by the sandhills in southwest Lane County and southeast Scott County. Dark gray-black tones are indicative of irrigated fields; the circular patterns of about 140 acres (57 $hm^2$) are irrigated by center-pivot sprinklers. Two distinctive northeast trending dark-gray bands on the figure represent areas wetted by heavy thunder showers that occurred one week before the imagery was taken.

## Annual Withdrawals

The quantity of water pumped can be estimated for those large-capacity wells for which power-consumption and pump-discharge data are available. Water pumped from the gas-powered wells can be estimated by dividing the total cubic feet of gas used by an appropriate power factor. Water pumped from the electric-powered wells can be estimated by dividing the total kilowatt-hours used by an electric-power factor.

The power factor ($K_g$) for natural gas was determined by measuring the discharge of the well, the rate of natural-gas consumption at that discharge, the line pressure at the meter, and applying the equation:

$$K_g = \frac{1.955 \times 10^7 \, V \, P_g}{Q \, t_g}$$

where:

$K_g$ = power factor measured in cubic feet of natural gas to pump 1 acre-foot of water ($ft^3$/acre-ft)
Converting to metric units: Cubic meters of gas to pump 1 cubic hectometer of water ($m^3/hm^3$) = 23 $K_g$,

$V$ = cubic feet of natural gas consumed in $t_g$ seconds,

$P_g$ = pressure factor,

$Q$ = pump discharge, in gallons per minute,

$t_g$ = time, in seconds, to consume V cubic feet of natural gas.

The pressure factor ($P_g$), furnished by the gas company, is a function of atmospheric pressure, altitude above sea level, and gas-line pressure. It is used to standardize the amount of gas consumed.

The electrical power factor ($K_e$), representing the amount of electricity required to pump an acre-foot of water in the study area, was determined by applying the equation:

$$K_e = \frac{1.955 \times 10^4 \, R \, K_h}{Q \, (t_e)}$$

where:

$K_e$ = power factor measured in kilowatt-hours to pump 1 acre-foot of water (Kwh/acre-ft)
Converting to metric units: Kilowatt-hours of electricity to pump 1 cubic hectometer of water (Kwh/$hm^3$) = 810 $K_e$,

$R$ = revolutions of meter disc in $t_e$ seconds,

$K_h$ = constant for each meter (generally stamped on the nameplate of the instrument) giving the number of watt-hours represented by one revolution of the meter disc,

$Q$ = pump discharge, in gallons per minute,

$t_e$ = time, in seconds, for meter disc to make R revolutions.

To estimate the annual withdrawals from the area, fuel and power records were obtained from Kansas-Nebraska Natural Gas Company, Inc., Lane-Scott Electric Cooperative, and Wheatland Electric Co-op, Inc. Power consumption mainly varies with differences in pump efficiency, pump discharge, discharge pressure, and depth to water. Values of $K_g$ for 22 wells ranged from 3,800 to 13,000 $ft^3$/acre-ft (87,000 to 299,000 $m^3/hm^3$) with a median value of 5,600 $ft^3$/acre-ft (129,000 $m^3/hm^3$). The median $K_e$ value for 8 wells is 417 Kwh/acre-ft (338,000 Kwh/$hm^3$) with a range of 219 to 555 Kwh/acre-ft (177,000 to 450,000 Kwh/$hm^3$).

Approximations of ground water pumped by natural gas and electricity were computed by applying the median values of $K_g$ and $K_e$ to the total power consumed in the counties for the years 1971 and 1972 as tabulated in table 5. The total annual pumpage of all wells in the two-county area may be extrapolated by assuming that the average amount of water pumped per well by natural gas or electricity equals the average amount of water pumped per well by all fuels. Data in table 5 show a total pumpage of about 180,000 acre-feet (220 $hm^3$) in 1971 and 120,000

[1] Now referred to as LANDSAT.

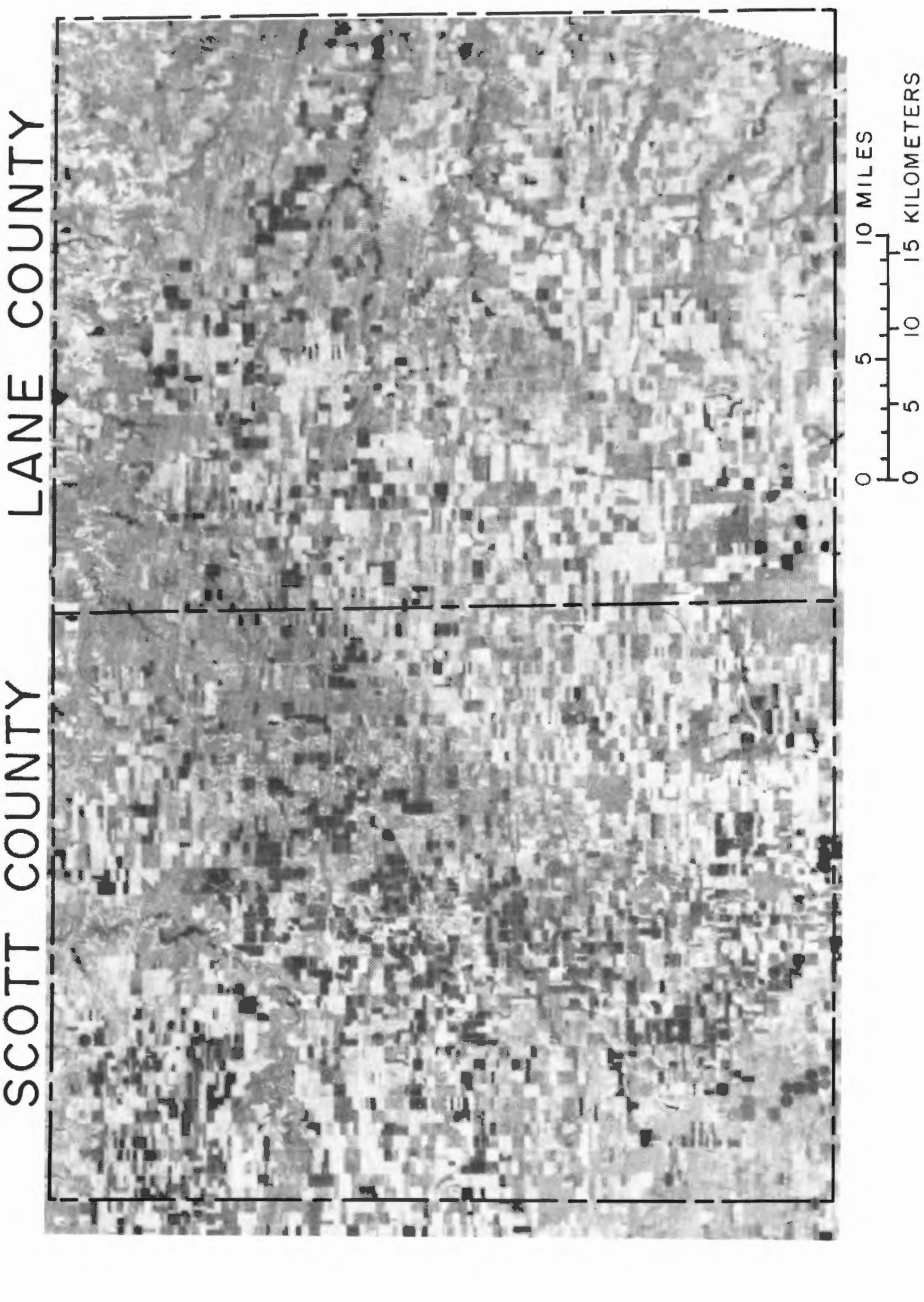


FIG. 12.—MSS Band 5 (red band) imagery of Lane and Scott Counties from altitude of 570 nautical miles (1,054 kilometers). Imagery by NASA, Earth Resources Technology Satellite, Sept. 22, 1972.

TABLE 5.—Power consumption and calculated pumpage for Lane and Scott Counties for 1971 and 1972.

| Year | County | Type of power | Percent of wells | Power consumption | Calculated water pumped (acre-ft) | Estimated irrigated acres | Water applied annually (ft/acre) |
|---|---|---|---|---|---|---|---|
| 1971 | Lane | Natural Gas | Assumed same as 1972 | 143,208,300 ft³ | 25,600 | 19,000 | 1.6 |
| | | Electricity | | 1,115,866 Kwh | 2,700 | | |
| | | Other (e) | | | 2,100 | | |
| | | Total | | | 30,400 | | |
| | Scott | Natural Gas | Assumed same as 1972 | 740,473,000 ft³ | 132,000 | 98,000 | 1.5 |
| | | Electricity | | 3,652,304 Kwh | 8,800 | | |
| | | Other (e) | | | 9,000 | | |
| | | Total | | | 149,800 | | |
| | Summary for Lane and Scott Counties | | | | 180,200 | 117,000 | 1.5 |
| 1972 | Lane | Natural Gas | 61 | 117,387,000 ft³ | 21,000 | 20,000 | 1.2 |
| | | Electricity | 32 | 923,349 Kwh | 2,200 | | |
| | | Other (e) | 7 | | 1,700 | | |
| | | Total | | | 24,900 | | |
| | Scott | Natural Gas | 90 | 457,036,800 ft³ | 81,600 | 100,000 | 0.9 |
| | | Electricity | 4 | 3,047,060 Kwh | 7,300 | | |
| | | Other (e) | 6 | | 5,700 | | |
| | | Total | | | 94,600 | | |
| | Summary for Lane and Scott Counties | | | | 119,500 | 120,000 | 1.0 |

(e) denotes extrapolated data.

acre-feet (150 hm³) in 1972. The greater amount pumped in 1971 and the lesser amount pumped in 1972 are attributed to below-normal and above-normal precipitation during the growing season respectively, although annual precipitation for both years was above normal (See table 6).

The amount of water pumped in Scott County by natural gas in 1972 was about 38 percent less than in 1971 as opposed to only 18 percent reduction in pumpage by other methods in the two counties. This difference in Scott County is attributed to the fact that the natural-gas-powered wells generally have high yields and are closely regulated to dry and wet periods. The effect of precipitation on total pumpage from low-yielding wells, however, is not as pronounced because of the longer pumping periods required to cover the acreage being irrigated.

The amount of natural gas used to generate electricity is currently about 17 cubic feet (0.48 m³) per kilowatt-hour. The amount of natural gas required to generate the power for electric motors, when added to the amount of natural gas used directly by natural-gas-fueled motors, gives an approximation of the total natural gas consumed for irrigation. In 1971 a reported total (State Corporation Commission, 1973) of 778 billion cubic feet (22.0 billion m³) of natural gas was produced from 5,396 wells in all fields in southwestern Kansas. Natural-gas production averages about 400,000 cubic feet (11,000 m³) per well per day. During 1971, 960 million cubic feet (27 million m³) of gas was used—880 million cubic feet (25 million m³) directly and 80 million cubic feet (2.3 million m³) for generation of electric power—to provide power for irrigation wells in Lane and Scott Counties. Thus, the 1971 gas-energy input for irrigation pumpage was 0.12 percent of the total natural gas produced in southwestern Kansas, which is equivalent to the production of about 6 typical gas wells. In 1972, the gas-energy input for irrigation pumpage was 0.08 percent of the total natural gas production in southwestern Kansas, or the production of about 4.5 typical gas wells.

## EFFECTS OF GROUND-WATER DEVELOPMENT

The development of large quantities of ground water for irrigation in Lane and Scott Counties has caused a decline in water levels, a reduction in base flow of Ladder Creek, and a decrease in the amount of ground water in storage.

### Water-Level Changes

The amount of water-level change associated with the development of ground water for irrigation can be determined by comparing data collected by Waite (1947) and Prescott (1951) to similar data collected in 1973. Water-level (head) declines in the period from

TABLE 6.—Precipitation (in inches).[1]

| | HEALY | | | | SCOTT CITY | | | |
|---|---|---|---|---|---|---|---|---|
| | ANNUAL | | APRIL-SEPTEMBER | | ANNUAL | | APRIL-SEPTEMBER | |
| Year | Total | Departure from norm | Total | Departure from norm | Total | Departure from norm | Total | Departure from norm |
| 1971 | 20.87 | +2.22 | 11.23 | −2.93 | 20.05 | + .88 | 13.49 | −1.00 |
| 1972 | 27.31 | +8.66 | 22.40 | +8.24 | 27.91 | +8.74 | 22.47 | +7.98 |

[1] From Climatological Data, U.S. Dept. of Comm., Environmental Data Service.

1940-48 to 1973 ranged from less than 10 feet (3 m) to about 50 feet (15 m), as shown on plate 3. The greatest declines, located in T.18 S., R.33 W.; T.20 S., R.32 W.; and T.20 S., R.33 W. on the flanks of the south-trending trough, are interpreted to be in areas where the aquifer has a low specific yield under confined conditions. The drawdown and lateral extension of the cone of depression must be greater under confined than under unconfined conditions to yield equal amounts of water. If the storage coefficient is assumed to be 0.15 for unconfined conditions and .001 for confined conditions, the unconfined aquifer would yield 150 times more water than the confined aquifer for the same water-level decline.

As pumping continues, water levels in the confined part of the aquifer may decline below the top of the principal water-yielding material. At that time water in the aquifer would become unconfined, and the rate of water-level decline decreases. As shown on figure 13, water levels declined less than 10 feet in about one-half of the area from 1940-48 to 1973. Declines greater than 30 feet occur in about 10 percent of the area underlain by the unconsolidated aquifer.

Measurements in 46 wells in Scott County indicate that water-level declines averaged 1.15 feet per year (0.35 m/yr) during 1966-74 (Pabst and Jenkins, 1974). Water-level declines in wells throughout the two-county area underlain by the unconsolidated aquifer probably would average slightly less.

A long-term hydrograph (fig. 14) of water levels in observation well 18-33W-12add, located 1 mile (1.6 km) north of Scott City, is based on measurements provided by the Division of Water Resources, Kansas State Board of Agriculture. Because the observation well is in the vicinity of many irrigation wells, the hydrograph shows the response of water levels to seasonal pumping for irrigation. More importantly, however, the hydrograph shows long-term trends of water levels in the area. The period 1939-47 was one of slight decline, indicative of an area under early irrigation development. The period 1950 through the summer of 1952 was one of rising water levels culminating in the highest recorded water level on May 26, 1952. The rise is attributed to reduced pumping during a period of above-normal precipitation that recharged the aquifer and permitted artesian head to reach a high static level. Water levels declined as irrigation development accelerated during the drouth that lasted from mid-1952 to 1957. Recharge from precipitation caused a slight rise from 1957 to 1959, but declines in water levels during summer months show that pumping continued. The steadily declining water levels since 1960 are evidence of ground-water mining resulting from intensive irrigation development.

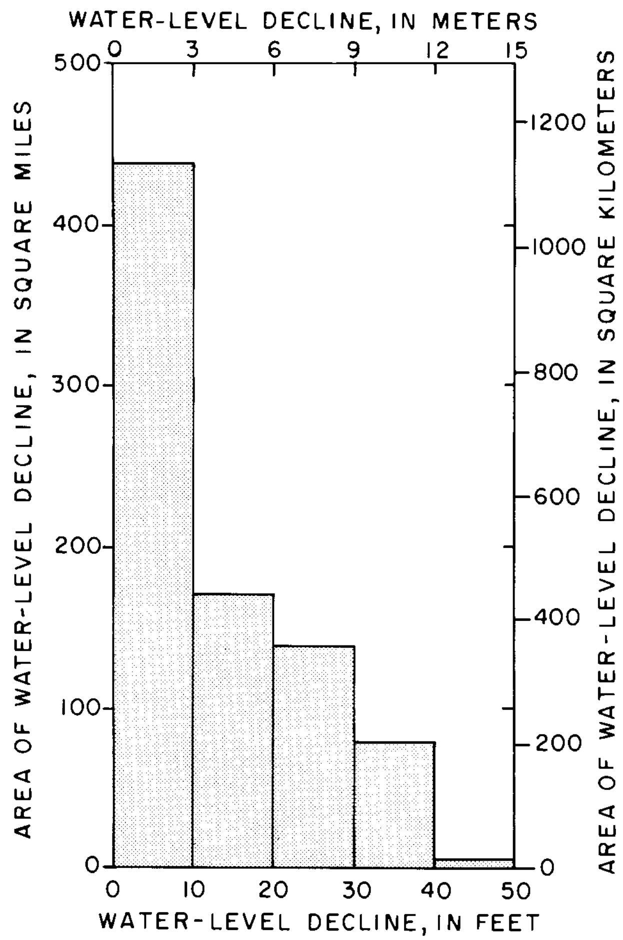


FIG. 13.—Areal extent of water-level declines from 1940-48 to 1973, in feet, in the unconsolidated aquifer.

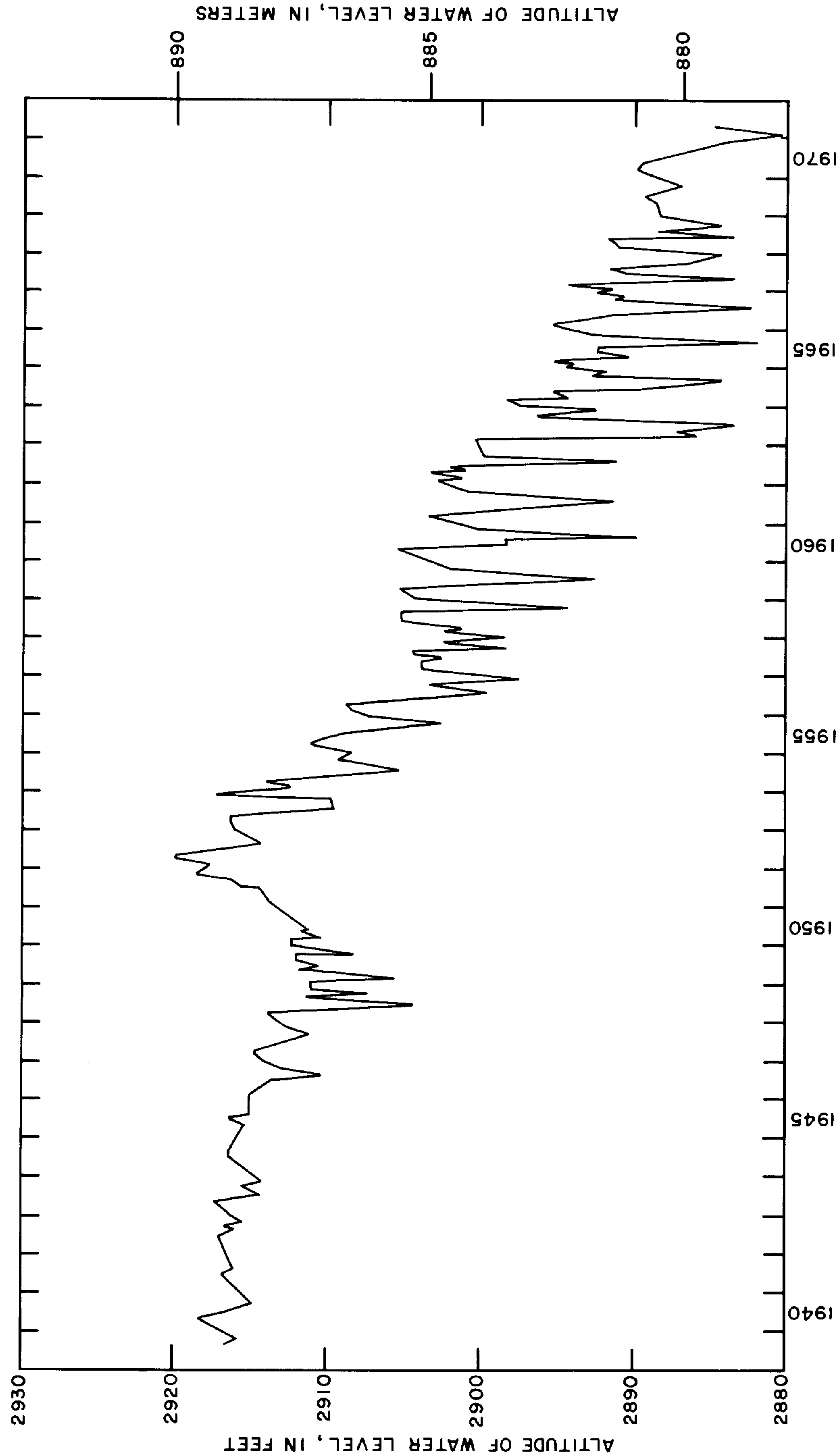


FIG. 14.—Hydrograph of observation well 18-33W-12add.

Observation well 18-33W-12add and the closest irrigation well are about 85 to 90 feet (26 to 27 m) deep. The seasonal fluctuations in the hydrograph may represent the effect of pumping from the closest irrigation well where water in the upper part of the aquifer is unconfined. The fluctuations may also represent, in part, pumping from other nearby irrigation wells that are about 180 to 220 feet (55 to 67 m) deep. It is possible, however, that the deep wells pump from the lower part of the aquifer where the water is semiconfined or confined beneath intercalated clay lenses. The net result of the ground-water mining has been the dewatering of the upper part of the aquifer as a direct response to withdrawals for irrigation.

### Depletion of Ground Water in Storage

Depletion of ground water in storage is indicated by water-level declines resulting from irrigation development. To relate the long-term effects of irrigation withdrawals to changes in ground-water storage, the water-level declines during 1940-48 to 1973 are illustrated in plate 3 as a percent of change from the 1940-48 saturated thickness. The percent decline in saturated thickness with respect to area is graphically summarized in figure 15. Throughout most of the main body of the unconsolidated aquifer, the saturated thickness has been reduced by an amount ranging from 10 to 60 percent. Saturated thickness in two areas has been reduced 100 percent, and the aquifer is dewatered.

The significance of the water-level decline can be determined by comparison of the areal distribution of water-level changes and the percent change in saturated thickness. For example, the saturated thickness at Scott City was about 185 feet (56 m) during 1940-48. By 1973, a decline in water levels of 30 feet (9 m) reduced the saturated thickness to about 155 feet (47 m)—a reduction of about 16 percent. The saturated thickness in T.18 S., R.34 W. (an area of extensive development) was about 60 feet (18 m) during 1940-48. By 1973, a decline in water levels of 30 feet (9 m) reduced the saturated thickness to about 30 feet (9 m)—a reduction of about 50 percent. The effect of water-level declines has been a reduction in well yields and an increase in the cost of pumping.

Assuming that the specific yield is about 15 percent where the water is unconfined and about 1 percent where the water is semiconfined or confined, the annual reduction of ground-water storage in Scott County is estimated to be about 57,000 acre-feet (70 $hm^3$) for the period 1966-74. This value for reduction in storage, based on water-level declines, is comparable to the 101,000 to 47,000 acre-feet (125-128 $hm^3$) estimated from the ground-water inventory for 1971 and 1972, respectively.

An extreme example of ground-water depletion is illustrated by the diagrammatic sketch (fig. 16) showing a generalized section across the southwestern part of Scott County, where a thin saturated area that overlies a bedrock nose on the west side of the deep south-trending trough and is adjacent to an area of intensive pumping has been completely dewatered. The exact amount of water-level decline and the time when the decline occurred are not known, but in at least part of the area the saturated thickness has decreased by 100 percent (pl. 3). There is no

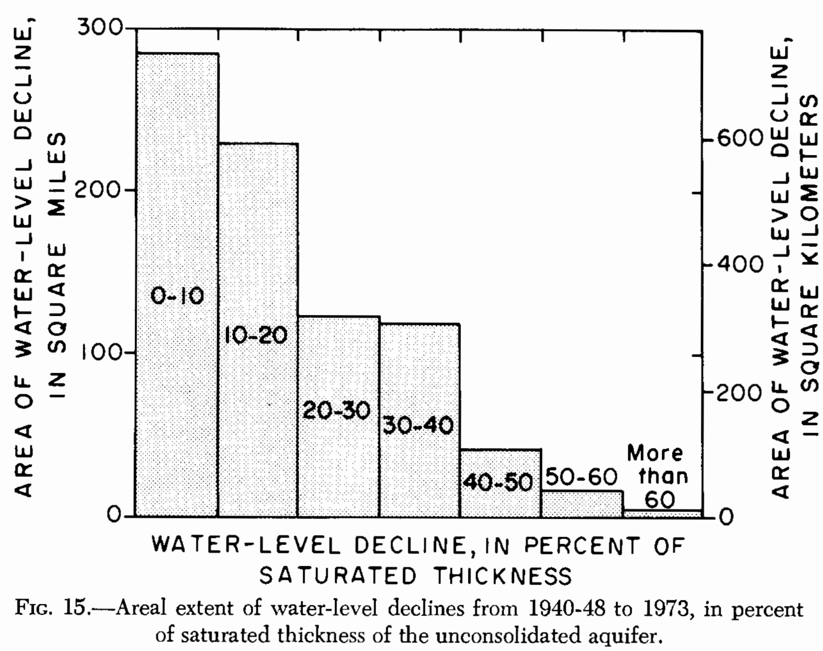


FIG. 15.—Areal extent of water-level declines from 1940-48 to 1973, in percent of saturated thickness of the unconsolidated aquifer.

evidence that deposits overlying the bedrock high east of the deep south-trending trough ever were saturated.

## FUTURE OUTLOOK FOR IRRIGATION

### Potential Yields

Potential yield is defined as the yield that can be expected when the water-level drawdown in the pumped well is equivalent to 70 percent of the effective thickness of the aquifer. The effective thickness, which is comprised of those parts of the aquifer material yielding most of the water to wells, probably is the most important factor in estimating well yield. Effective-thickness computations for the sites where large-capacity wells were tested, amount to 80 percent or more of the total saturated thickness. Effective thicknesses at most irrigation wells are greater than 20 feet (6 m). Where the saturated thickness and effective thickness are known, an estimated potential-yield value can be based on the median specific-capacity value of 18 (derived from well-production tests shown on table 3) multiplied by the proposed drawdown. For example, a site that is underlain by 40 feet (12 m) of saturated thickness and contains 32 feet (10 m) of water-yielding material has 80 percent effective thickness, which is typical of irrigation wells in the area. The estimated potential yield at this site, computed by multiplying the drawdown of 22 feet (7 m) or 70 percent of the effective thickness by the median specific-capacity value of 18, would be about 400 gpm (25 l/s).

Potential yield to irrigation wells in the unconsolidated aquifer in Lane and Scott Counties ranges from less than 250 gpm to greater than 1,000 gpm (16 to 63 l/s). Plate 3 shows the potential well yields that can be expected in the unconsolidated aquifer in the two-county area. Data from existing wells, well-production tests summarized in table 3, saturated thickness, and transmissivity were used in preparing the map; thus, the most favorable sites are represented and the potential-yield values generally indicate the maximum that could be expected.

The potential-yield value would apply to a fully efficient well in an areally extensive aquifer and does not take into account great changes in lithology, interference effects of nearby pumping wells, or effects of water-level declines during the pumping season. Because the potential yields shown on plate 3 are based on scattered data points, the values serve as a general guide to be substantiated by test-hole data. As with the other similar maps, the potential yield is not shown in the area where irrigation wells have been developed in an alluvial deposit east of Dry Lake.

### Economic Factors

The 1973 upsurge in prices from long-term averages for grain and the removal of acreage controls undoubtedly will result in an increase in irrigation in Lane and Scott Counties. Since the middle 1950's, the major part of the area's economy has been dependent on irrigation and irrigation-related business. Landowners and farm operators consider irrigation as an insurance against drought, which is a constant threat in western Kansas. The effect that projected shortages of energy may have on irrigation practices is unknown, but it may be significant.

### Ground-Water Management

Increased irrigation will increase the demand on the ground-water reservoir. However, the amount of water in storage in the ground-water reservoir beneath Lane and Scott Counties is not unlimited. In Scott County, the calculated average annual inflow to the ground-water reservoir ranged from 23,000 to 33,000 acre-feet (28 to 41 $hm^3$). When net pumpage (annual withdrawals minus the seepage lost to deep percolation) exceeds the inflow rate, the result is mining of ground water. A direct consequence of the mining is persistent lowering of the water level in the heavily pumped area, a decrease in saturated thickness and in well yields, and increased pumping costs. Installation of new wells to irrigate additional land and to supplement the yield of existing wells will accentuate both the rate of depletion and mutual interference between wells. A continuing decrease in ground-water resources may force individuals in some areas to revert from irrigation farming to dryland farming. Thus, there are two opposing motives at work: (1) Increased production because of greater profit, and (2) conservation of ground water in storage for use in the future.

Kansas Ground-Water Management District Number 1, which has recently been formed in the area, will have the responsibility to efficiently manage the ground-water reservoir. The policy that the district follows will be determined by the landowners. The rate at which the remaining resources are consumed is a decision that must be made by the local water users. Several alternatives that should be considered to conserve the ground-water supply are:

1. Conservation of water by the use of tail-water recovery pits. Collection and use of runoff combined with good management practices could improve utili-

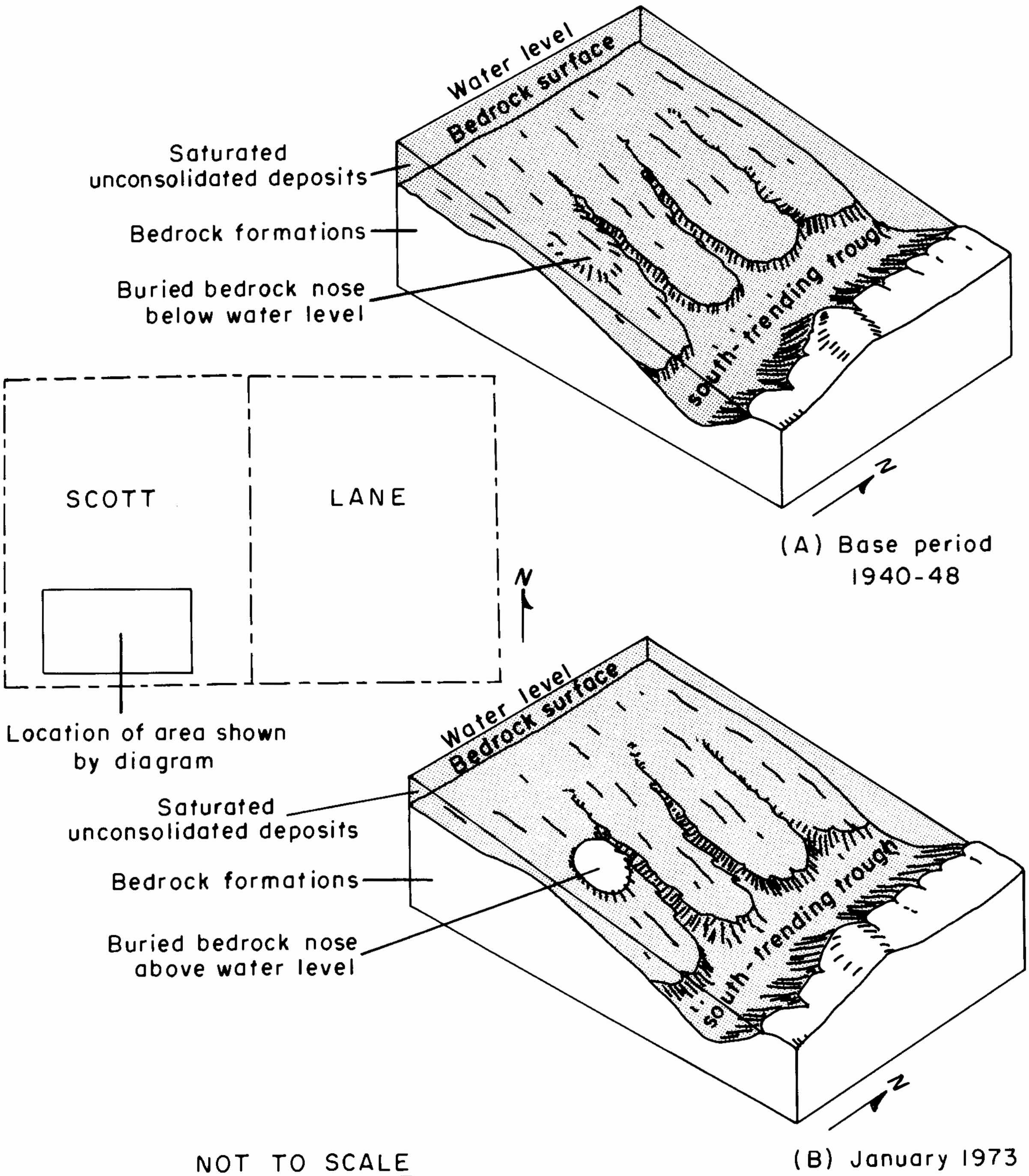


FIG. 16.—Effects of water-level decline in the vicinity of a bedrock nose, southwestern Scott County.

zation of the supply and decrease the amount of ground-water withdrawal.

2. Monitoring of soil-moisture requirements and metering water applications to meet the soil-moisture deficit could limit pumping to the minimum amount necessary to satisfy crop and leaching requirements. The quantity of water pumped and the energy required could be reduced by better irrigation efficiency.

3. Crop research on planting, growing practices, and transpiration suppression to determine the optimum yield for each crop from the least amount of water applied.

4. Limiting further development of ground water in areas where the saturated deposits are thin and where large water-level declines already have occurred (pl. 3). Increasing the number of wells in these areas will accelerate the water-level decline and hasten the time when irrigation locally becomes uneconomic.

5. Weather modification and importation of water to decrease the amount of ground water used for irrigation.

6. Plan well spacing to minimize the effects of mutual well interference in areas where the ground-water resources are presently being developed.

## FUTURE STUDIES

Water-resource studies that still need to be made in Lane and Scott Counties include more accurate determination of (1) the areal variations in values of the storage coefficient, (2) the amount of recharge to the ground-water reservoir from precipitation and return from applied irrigation water, (3) the amount of ground water withdrawn annually for irrigation, (4) the amount of water stored in the chalk and sandstone aquifers, and (5) the chemical quality of water in the chalk and sandstone aquifers. Studies that need to be continued in the area include monitoring (1) the continuing development of ground water for irrigation by maintaining an accurate, up-to-date inventory of wells, and (2) the effects of the development by continuing annual measurement of water levels in wells.

## ACKNOWLEDGMENTS

The writers of this report express appreciation to the residents of Lane and Scott Counties who gave information regarding their wells and permitted the use of their land and irrigation wells for aquifer tests. Appreciation is extended to the county officials who allowed the use of the county road right-of-ways for test drilling. Records and information were obtained through the courtesy and cooperation of the following drilling contractors: Northwest Drilling Co. and Weishaar Drilling Co. of Scott City, Kansas; and Henkle Drilling and Supply Co., High Plains Drilling Co., Layne-Western Drilling Co., and Minter-Wilson Drilling Co., all of Garden City, Kansas.

Acknowledgment is given to Lynn Apperson of the Kansas Water Resources Board for leading a field party to obtain altitudes of irrigation wells in Lane and eastern Scott Counties. Acknowledgment is given to Howard Corrigan, Water Commissioner, Division of Water Resources, Kansas State Board of Agriculture, and his staff for their cooperation in supplying well information and water levels.

Appreciation also is extended to Winfred Wells, District Conservationist, Lane County, and Keith Lebbin, Former District Conservationist of Scott County.

Records of electrical consumption are from the Lane-Scott Electric Cooperative and the Wheatland Electric Co-op, Inc. Records of natural gas consumption are from the Kansas-Nebraska Gas Co., Inc.

## INDEX MAPS

This investigation is a part of a systematic study of the ground-water resources of Kansas that began in 1937. This cooperative program is being conducted by the Kansas Geological Survey and the U.S. Geological Survey with the support of the Division of Water Resources, Kansas State Board of Agriculture, and the Division of Environment, Kansas Department of Health and Environment. The present status of the ground-water investigations in Kansas is shown in figure 17. The numbers on the map refer to Bulletins by the Kansas Geological Survey and to Hydrologic Investigations Atlases and Water Supply Papers by the U.S. Geological Survey.

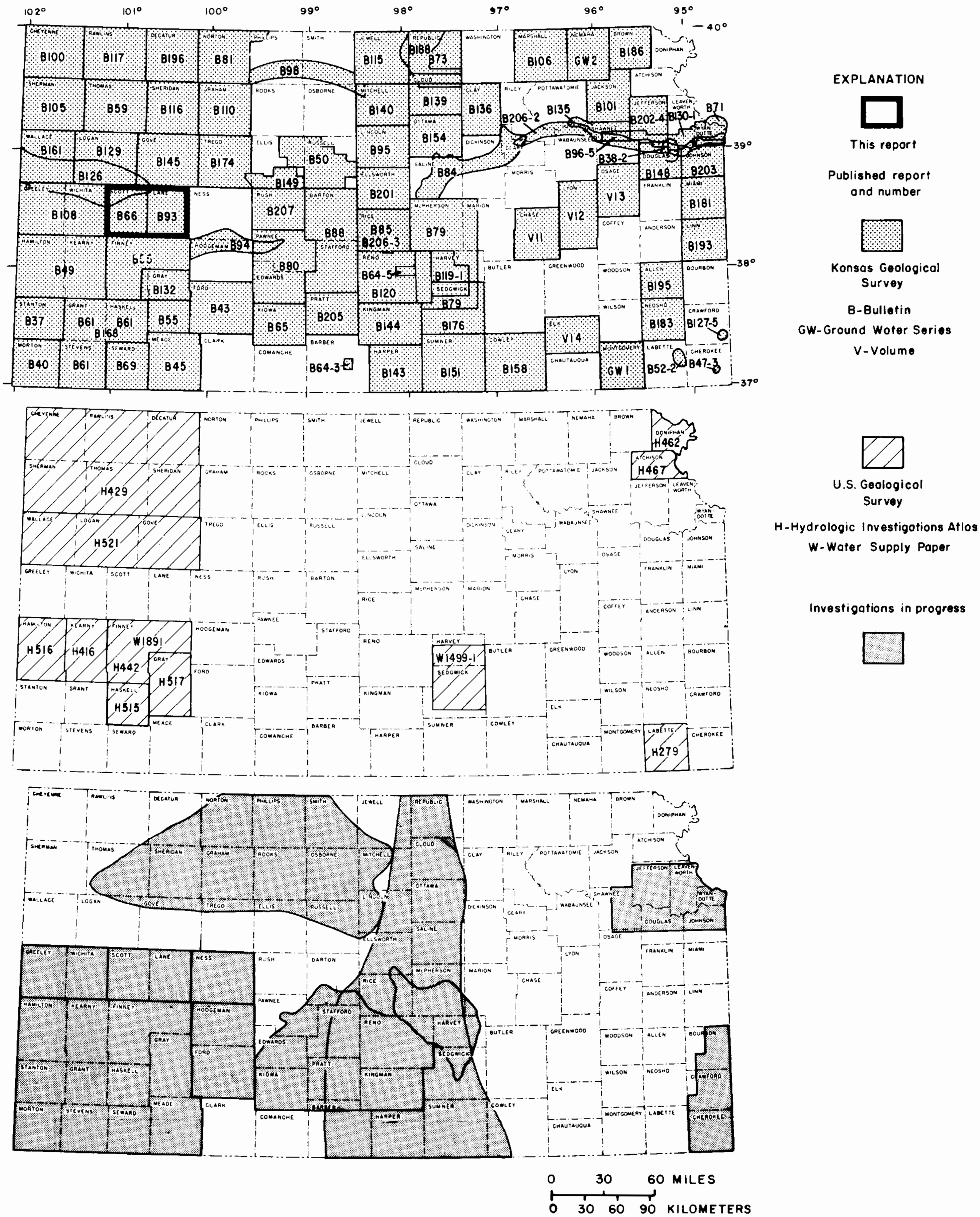


FIG. 17.—Index maps showing area discussed in this report, and other areas for which ground-water reports have been published or are in preparation.

## METRIC UNITS

For those readers who are familiar with or are interested in the metric system, the English units of measurement given in this report also are given in equivalent metric units (in parentheses) using the following abbreviations and conversion factors:

| *English unit* | *Multiply by* | *Metric unit* |
|---|---|---|
| Length | | |
| inch (in) | 2.54 | centimeter (cm) |
| foot (ft) | .3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| nautical mile (nm) | 1.85 | kilometer (km) |
| Area | | |
| square feet ($ft^2$) | 0.0929 | square meter ($m^2$) |
| acre | .4047 | square hectometer ($hm^2$) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| Volume | | |
| gallon (gal) | 3.785 | liter (l) |
| cubic foot ($ft^3$) | .02832 | cubic meter ($m^3$) |
| acre-foot (acre-ft) | $1.233 \times 10^{-3}$ | cubic hectometer ($hm^3$) |
| Flow | | |
| gallons per minute (gpm) | .06309 | liters per second (l/s) |
| cubic feet per second ($ft^3/s$) | .02832 | cubic meters per second ($m^3/s$) |
| Hydraulic conductivity | | |
| feet per day (ft/day) | .3048 | meters per day (m/day) |
| Transmissivity | | |
| square feet per day ($ft^2$/day) | .0929 | square meters per day ($m^2$/day) |
| Specific capacity | | |
| gallons per minute per foot (gpm/ft) | .207 | liters per second per meter (l/s)/m |
| Gradient | | |
| feet per mile (ft/mi) | .1894 | meters per kilometer (m/km) |

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