Water in the Dakota Formation, HODGEMAN and NORTHERN FORD COUNTIES, Southwestern Kansas

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IRRIGATION SERIES 5

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By

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EXECUTIVE SUMMARY

The agricultural economy of western Kansas is becoming increasingly dependent on irrigation from ground water. In Hodgeman and northern Ford Counties, most irrigation supplies are obtained from wells in the Dakota Formation. Therefore, a study of the availability and chemical quality of water in the formation is of great importance to continued irrigation development in the area.

Water in the Dakota generally occurs in sandstone beds that are quite variable in thickness, areal extent, and degree of cementation. Consequently, irrigation development may be restricted to those areas where adequate quantities of water are obtainable. Yields from existing wells range widely from about 100 to as much as 2,200 gallons per minute.

Results from several aquifer tests and data from well drillers indicate that much of the water in the sandstones is confined under artesian head. For this reason, water-level declines during pumping will be great, and mutual interference between wells could be significant.

The quality of water from the sandstones also is variable at different depths and from one area to another. Dissolved solids range from about 300 to 1,420 milligrams per liter. When used for irrigation, the water has a medium to very high salinity hazard and a low to very high sodium hazard. Thus, amendments commonly are needed for continued crop productivity.

Continued development of irrigation wells in the Dakota Formation is likely, and water levels are expected to decline significantly in the confined aquifers. Additional study will be needed in the future to assess the effects of increased irrigation development on the quantity and quality of ground water in storage.

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GLOSSARY OF GEOLOGIC AND HYDROLOGIC TERMS

Acre-foot—The amount of water needed to cover 1 acre to a depth of 1 foot, equals 325,851 gallons.

Alluvium—Unconsolidated deposits of clay, silt, sand, and gravel laid down by streams during comparatively recent geologic time.

Anhydrite—A widely distributed mineral consisting of anhydrous calcium sulfate; $CaSO_4$.

Aquifer—Formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow—Discharge entering stream channels from ground water or other delayed sources.

Confining bed—a bed that retards but does not necessarily prevent the flow of water from or to an adjacent aquifer.

Cubic foot per second—A volume flow of 1 cubic foot per second, which equals approximately 449 gallons per minute.

Dip—The angle that a formation or planar surface is inclined from the horizontal.

Formation—Basic rock unit in local classification of rocks, consists of an identifiable body of rock generally characterized by some distinctive lithologic features.

Geophysical log—A continuous graphic record of the response to physical or chemical properties of the rock material as a geophysical instrument is lowered into the borehole or well.

Gypsum—A widely distributed mineral consisting of hydrous calcium sulfate; $CaSO_4 \cdot 2H_2O$.

Hydraulic conductivity—The volume of water at the existing kinematic viscosity that will move in a unit of time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In this report, the hydraulic conductivity is the volume of water that would move each day through a 1-square-foot area of porous sandstone under a gradient of 1 foot per foot.

Hydrograph—A graph showing some property of water with respect to time, such as the water level or hydraulic head measured in a well.

Lenticular—Describes deposits shaped like lenses when viewed in cross section.

Lignite—A brownish-black coal that is intermediate between peat and subbituminous coal.

Lithology—The description of rock or of the general physical character of a rock.

Loess—A homogeneous, unstratified, commonly calcareous deposit consisting predominantly of wind-laid silt.

Mortar bed—A deposit consisting of a mixture of clay, silt, sand, and gravel cemented by porous calcium carbonate and resembling hardened mortar or cement. Used interchangeably with caliche.

Percolation—Laminar flow of water, usually downward, by the force of gravity, through small openings within a porous material.

Permeability—The property or capacity of a porous rock, sediment, or soil for transmitting a fluid.

Potentiometric surface—A surface that represents the hydrostatic head. In a confined (artesian) aquifer, the surface is defined by the levels to which water in wells rises above the producing zone; in an unconfined aquifer, the surface coincides with the water table.

Sandstone—A sedimentary rock composed of abundant rounded or angular fragments, generally of sand-size quartz, more or less firmly cemented by some material such as iron oxide or calcium carbonate.

Sedimentary rocks—Layers of rock resulting from the consolidation of loose sediment, consisting of mechanically transported fragments, chemically precipitated minerals, or organically secreted material.

Shale—A fine-grained rock of consolidated clay, silt, or mud characterized by finely stratified structure.

Siltstone—A massive sedimentary rock composed of mostly silt-sized material.

Specific capacity—The rate of discharge from a well divided by drawdown of water level within the well. If the specific capacity is constant except for the time variation, it is roughly proportional to the transmissivity of the aquifer. It can vary with well construction and development, type of screen or casing, discharge of well, and length of pumping period.

Storage coefficient—The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths. In this report, it is given in units of feet squared per day.

Water table—That surface in an unconfined water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just enough to hold standing water. The water table is a particular potentiometric surface.

METRIC UNITS

For readers familiar with or interested in the metric system, U.S. customary units of measurement given in this report are listed in equivalent metric units using the following abbreviations and conversion factors:

U.S. customary unit	*Multiply by*	*Metric unit*
Length		
inch (in)	2.54	centimeter (cm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
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)	1.233×10^{-3}	cubic hectometer (hm^3)
Flow		
gallon per minute (gal/min)	.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
Hydraulic conductivity		
foot per day (ft/day)	.3048	meter per day (m/day)
Transmissivity		
foot squared per day (ft^2/day)	.0929	meter squared per day (m^2/day)
Specific capacity		
gallon per minute per foot [(gal/min)/ft]	.207	liter per second per meter [(L/s)/m]
Gradient		
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)

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SUMMARY AND CONCLUSIONS

Wells developed in sandstone of the Dakota Formation in Hodgeman and northern Ford Counties produce between 7,700 and 15,000 acre-feet of water per year, which is used primarily to irrigate approximately 7,700 acres of cropland. The major irrigated localities are near Jetmore, Spearville, and Ford. Both confined and unconfined conditions occur in the aquifer. Most irrigation wells are pumping from the confined part of the aquifer. Yields range from about 100 to 2,200 gallons per minute.

Development of the formation is restricted because the thickness, extent, and cementation of the sandstone are so variable that productive units are difficult to locate.

Results of two aquifer tests provide transmissivity values of 2,000 and 7,100 feet squared per day and storage coefficients of 0.0005 and 0.07, respectively. The lower coefficient indicates a confined aquifer, and the higher coefficient indicates an unconfined aquifer.

Recharge from overlying unconsolidated formations occurs chiefly in the southeast corner of the area. Additional water enters the area by subsurface flow within the aquifer from the south and west.

Water from the Dakota Formation in northern Ford County generally has a medium salinity hazard and a low sodium hazard when used for irrigation. In Hodgeman County, the water generally has a high to very high salinity hazard, and the sodium hazard ranges from low to very high. Dissolved solids range from 296 to 1,420 milligrams per liter; specific conductance ranges from 450 to 2,450 micromhos per centimeter at 25° C; and the sodium-adsorption ratio ranges from 0.5 to 40.

Continued development of irrigation, using water from wells in the Dakota Formation, is likely even though the sandstone units are of limited extent. Water-level declines are expected to continue slowly in the unconfined areas, especially where recharge offsets some of the withdrawal, and more rapidly in confined areas where recharge generally is limited to lateral subsurface inflow.

INTRODUCTION

Location

The report area is located in southwestern Kansas. It includes all of Hodgeman County and that

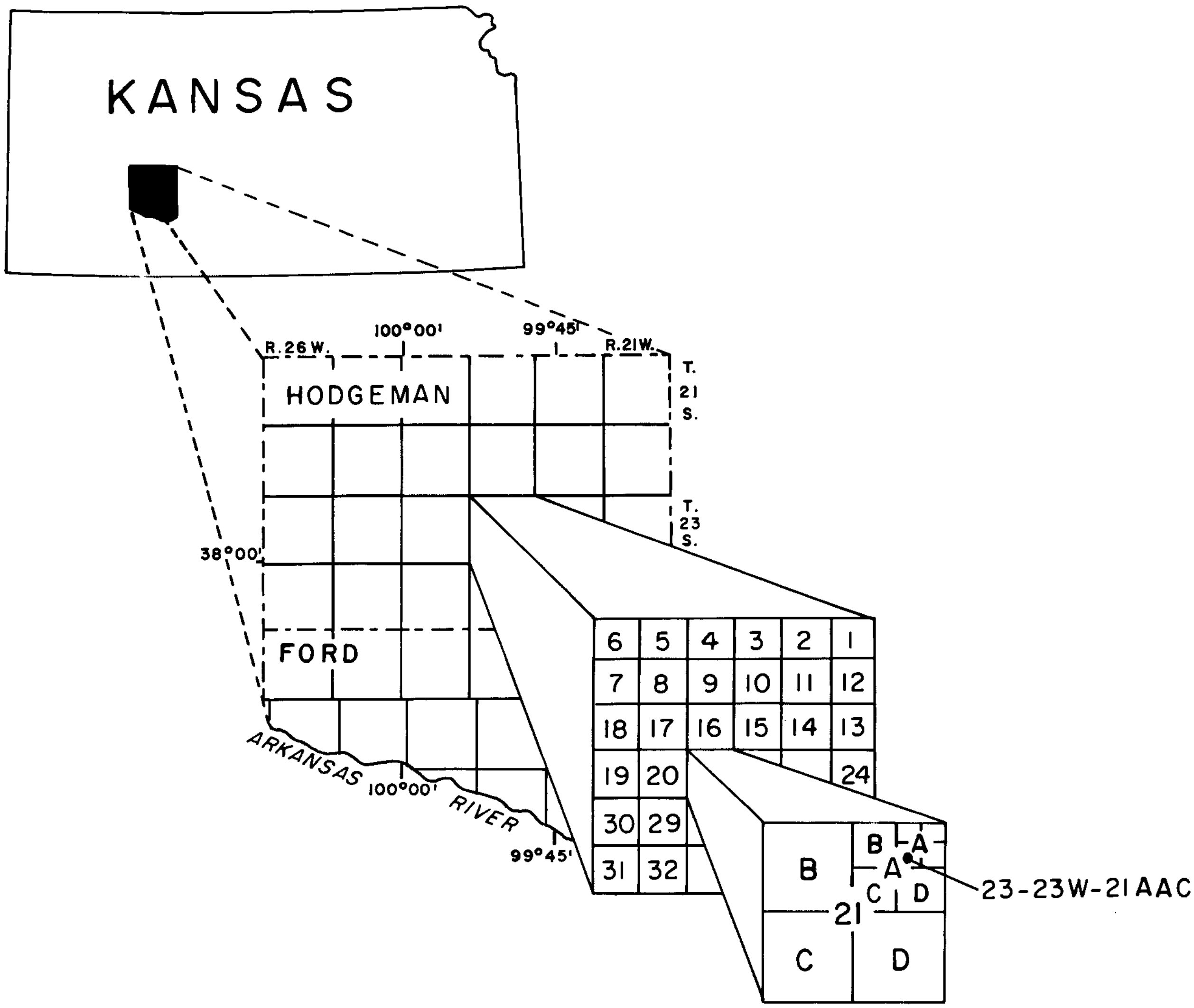


FIGURE 1.—Location of report area and diagram showing well-numbering system.

part of Ford County north of the Arkansas River, as shown in figure 1.

Purpose

The purposes of the study are (1) to determine the extent and hydraulic characteristics of the water-yielding sandstones of the Dakota Formation[1], (2) to determine the degree and effects of irrigation-well development, and (3) to assess the potential for future development.

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

Ground-water use for irrigation has steadily increased in parts of Hodgeman and northern Ford Counties. In the valley of the Arkansas River and in the southwestern part of the area, shallow unconsolidated sand and gravel deposits generally yield adequate supplies of water for domestic, stock, and irrigation use. Elsewhere, sandstone lenses in the Dakota Formation are the principal source of water. Figure 2 is a generalized geologic map of Hodgeman and northern Ford Counties that shows where the different formations crop out at the surface. Geologic formations that are significant to the water resources of the area are summarized in table 1.

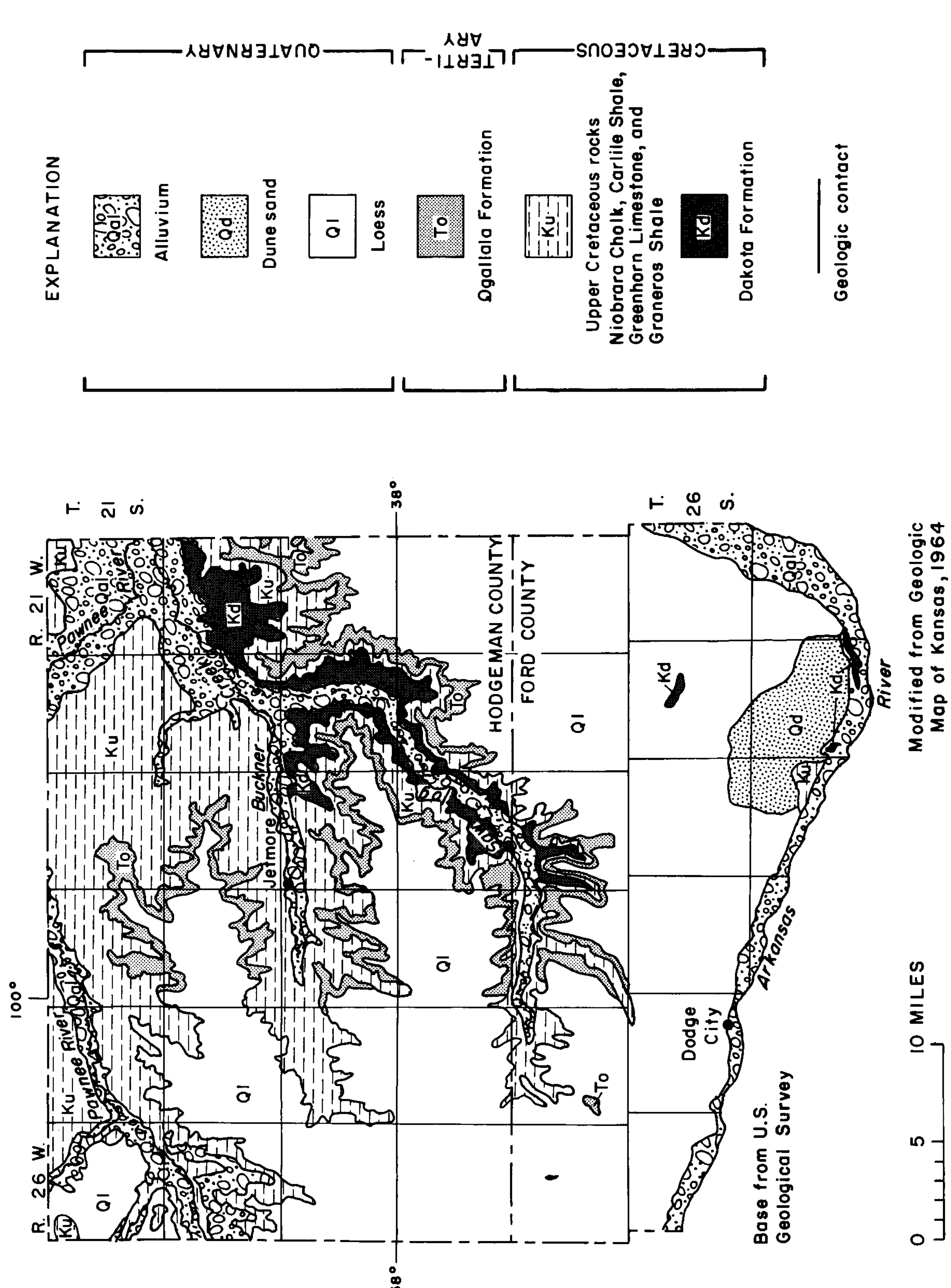


FIGURE 2.—Generalized geologic map.

TABLE 1.—Generalized section of geologic formations and their hydrologic characteristics.

System	Series	Geologic unit	Thickness (feet)	Physical characteristics	Hydrologic characteristics
Quarternary	Pleistocene	Alluvium and undifferentiated Pleistocene deposits	0-150	Clay, silt, sand, and gravel. Deposited by streams along the principal stream valleys and in older stream valleys.	Sand and gravel may yield as much as 2,000 gal/min to wells.
		Dune sand	0- 10	Sand, fine to medium, mostly windblown. Covers small area north of the Arkansas River valley.	Generally above the water table. Not known to yield water to wells.
		Loess	0- 10	Silt, windblown, locally reworked and deposited by streams. Covers upland.	Most of deposits above the water table. Not known to yield significant quantities of water to wells; yields are less than 10 gal/min.
Tertiary	Pliocene	Ogallala Formation	0-150	Silt, clay, caliche, sand, and gravel. Mostly unconsolidated, but cemented locally into mortar beds by calcium carbonate (lime).	Principal aquifer in the southwestern part of the area. Yields to irrigation wells range from 100 to 1,500 gal/min.
Cretaceous	Upper Cretaceous	Niobrara Chalk	0- 30	Limestone, massive, chalky, tan-white to light-gray.	Not known to yield significant quantities of water to wells.
		Carlile Shale	0-260	Clay, weathered, yellow-orange to gray, overlying a gray-brown to blacky chalky shale with orange and light-gray to white lenses of bentonite and thin layers of chalky limestone.	
		Greenhorn Limestone	0-125	Shale, thin-bedded, chalky, light- to dark-gray and chalky limestone beds; contains thin lenses of bentonite.	May yield small quantities of water from solution cavities or joints.
		Graneros Shale	0- 50	Shale, black to dark-gray; contains gypsum, bentonite, thin limestone beds, and fine-grained silty sandstone layers.	Not known to yield significant quantities of water to wells.

	Lower Cretaceous	Dakota Formation	100-450	Shale, gray to yellow-brown or black, with interbedded sandstone lenses commonly cemented with iron oxide or calcium carbonate. The sandstone is commonly light yellow-brown to white, varying in hardness with the amount of cement. Also contains thin discontinuous layers of clay, siltstone, ironstone, and lignite. The lignite layers are most common near the top and the bottom of the formation.	Yields as much as 2,200 gal/min to wells in loose (poorly cemented) sandstone beds. Constitutes an important aquifer in the two counties, but locally may not yield any water to wells.
		Kiowa Formation	160-250	Shale, gray to black, clayey, with thin discontinuous lenses of sandstone and limestone. Locally contains gypsum. Also contains thin fossil shell beds, some of which may be continuous throughout the area.	Not known to yield significant quantities of water to wells.
		Cheyenne Sandstone	20-300	Sandstone, light-gray to yellow, fine- to coarse-grained. Commonly cemented with iron sulfide or calcium carbonate. Interbedded shales vary from white to green or dark gray.	Water highly mineralized and unsuitable for irrigation.
Permian	Undifferentiated Permian	Undifferentiated red beds	1,000	Shale, sandstone, and siltstone, red; contains beds of gypsum, anhydrite, and dolomite. Underlain by about 2,000 feet of older Permian limestone and shale.	May yield saline water to wells that flow at the surface in the Pawnee River and Buckner Creek valleys in northeastern Hodgeman County.

Well-Numbering System

The well and test-hole numbers in this report give locations according to the Bureau of Land Management's system of land subdivision. The first number indicates the township; the second number indicates the range west of the sixth principal meridian; and the third number indicates the section, followed by letters that indicate the subdivision of the section in which the well or test hole is located. The first letter denotes the quarter section or 160-acre tract; the second letter, the quarter-quarter section or 40-acre tract; and the third letter, when used, the quarter-quarter-quarter section or 10-acre tract. The 160-acre, 40-acre, and 10-acre tracts are designated A, B, C, and D in a counterclockwise direction beginning in the northeastern quadrant. As an example, well 23-23W-21AAC is in the SW¼NE¼NE¼ sec.21, T.23 S., R.23 W. (fig. 1). When two or more wells are located in a 10-acre tract, consecutive numbers beginning with 2 are added to the letters in the order in which the wells or test holes are inventoried.

Cooperative Statement and Acknowledgments

This report was prepared by the U.S. Geological Survey and the Kansas Geological Survey, with data and support from 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 authors are grateful to the irrigators who assisted in making discharge measurements and to the many landowners for their interest and cooperation.

Appreciation is expressed to the drilling contractors (Henkle Drilling and Supply Company, Inc., High Plains Drilling and Supply, Johnson Drilling Company, Layne-Western Company, and Minter-Wilson Drilling Company, Inc.), who furnished data on wells and test holes in the area, and to personnel of the Soil Conservation Service, U.S. Department of Agriculture, who furnished valuable information.

HYDROGEOLOGY OF THE DAKOTA FORMATION

Geologic Characteristics

The Dakota Formation in Hodgeman and northern Ford Counties consists of mostly continental deposits. The clay, siltstone, shale, and sandstone were deposited near or slightly above sea level. The black marine shales and gray sandstones of the underlying Kiowa Formation grade upward into lower beds of the Dakota containing traces of lignite, which indicate a swampy environment. These beds are overlain by middle beds of the Dakota containing predominantly gray to red clay with tan to white sandstone lenses. The middle beds of the Dakota grade upward into upper beds of the Dakota of dark-gray clay and sandstone containing lignite layers, indicating a return to a swampy condition. The upper part of the formation grades upward into the black marine shale of the Graneros Shale.

Studies in central Kansas (Bayne and others, 1971; Franks, 1976) indicate that the Dakota Formation was deposited by westward flowing streams of low gradient. The sandstone lenses probably were deposited in thin layers by meandering streams. Location of drillers' and geophysical logs that show an aggregate thickness of more than 50 feet of sandstone are shown in figure 3. However, other areas have not been thoroughly tested by drilling. Conversely, two closely spaced logs showing more than 50 feet of sandstone do not necessarily indicate that a test hole drilled between them will penetrate more than 50 feet of sandstone.

THICKNESS

The approximate thickness of the Dakota Formation is shown in figure 3. Thickness ranges from about 100 feet in T.27 S., R.22 W. to 450 feet in T.26 S., R.23 W. (both areas are in northern Ford County), but most commonly ranges from 200 to 250 feet. Those areas showing a thickness of more than 300 feet also may include some hard gray sandstone of the Kiowa Formation. Because the Dakota Formation has been extensively eroded in the northeastern and southeastern parts of the area, the lesser thicknesses may not represent less deposition.

DEPTH TO THE TOP OF THE DAKOTA FORMATION

The depth to the top of the Dakota Formation, as shown in figure 4, indicates the thickness of sediments above the Dakota. These data combined with the formation thickness (fig. 3) indicate the approximate total well depth for projected Dakota tests and depths needed to drill a well.

In much of the eastern one-third of the study area, the Dakota Formation is exposed or is overlain by less than 50 feet of deposits. In the remainder of the area, the thickness of overlying deposits ranges from about 50 to 350 feet, but most commonly ranges from about 100 to 200 feet.

CONFIGURATION OF THE TOP OF THE DAKOTA FORMATION

The general configuration of the top of the Dakota Formation, as shown in figure 5, represents the contact between the Dakota and the overlying deposits, except in the outcrop areas. Along Coon Creek, Saw Log Creek, and Buckner Creek, the detailed contours represent areas of outcrop or very thin overburden where extensive erosion of the Dakota Formation has taken place. Erosion also has occurred in other small areas along the Pawnee River and its tributaries in northeastern Hodgeman County.

The regional dip of the Dakota averages 8 feet per mile to the northeast. Gentle upwarping of the Dakota Formation probably has occurred along an east-west line in the southern part of T.25 S.

Water-Bearing Characteristics

The ability of sandstone in the Dakota Formation to contain or transmit water is related to the uniformity of size and shape of the sand grains, the percentage of clay or cementing material contained, and the interconnection and thickness of sandstone lenses. The sand ranges from poorly sorted to well sorted and generally ranges in size from very fine to fine. The amount of silt, clay, and cementing material contained in the sandstone may differ greatly within short distances. Also, the interconnection of sandstone lenses is highly erratic owing to the mode of deposition.

POTENTIOMETRIC SURFACE

The configuration of the potentiometric surface of the Dakota Formation is shown in figure 6. The surface slopes generally northeast at about 9 feet per mile, indicating that the movement of water in the Dakota is in that direction.

The potentiometric surface is irregularly shaped as a result of the widely differing geohydrologic conditions within the Dakota. The widely spaced contours in the Spearville area generally reflect a good interconnection between sand layers and a relatively high hydraulic conductivity in those layers. Closely spaced contours, as in the northeast part of T.25 S., R.23 W., probably reflect a combination of (1) poor interconnection between sand layers, (2) a relatively low hydraulic conductivity in part or all of those layers, and (3) changes in head as a result of heavy pumping from an artesian system. Pumping also has altered the regional gradient. The potentiometric surface shown is based on measurements taken during the spring of

1973 before the start of the irrigation season. During the summer months, aquifer conditions are changed so that the potentiometric surface is more complex than the one shown in figure 6.

CONFINED AND UNCONFINED CONDITIONS

Generally, the Dakota Formation contains water under confined conditions throughout most of western Kansas. However, unconfined conditions prevail in parts of the report area where the overlying confining shales have been removed by erosion or where the water level is below the top of a water-bearing sandstone lens. Water levels in wells penetrating more than one sandstone may show a composite potentiometric head.

Water in the Dakota Formation in wells south of Jetmore is about 100 feet below the top of the shallowest water-bearing sandstone and is unconfined. However, water levels in wells screened in more than one layer also may be affected by the hydraulic head in a lower confined sandstone layer that is not hydraulically connected with the upper unconfined layer.

Water in wells west of Spearville is slightly below the top of the shallowest water-bearing sandstone and is unconfined. In the Spearville area, well logs indicate that the Dakota may consist almost entirely of sandstone with a few thin shale layers.

The height of the water level ranges from about 100 feet below the top of the Dakota Formation in wells south of Jetmore to more than 300 feet above the top in wells northwest of Jetmore.

YIELDS TO WELLS

Discharge measurements were made on nearly all the large-yielding wells. The well-yield data, along with the depth to water, are shown on the well-location map (fig. 7). Well yields throughout the formation ranged from a few gallons per day to 2,200 gal/min.

HYDRAULIC PROPERTIES

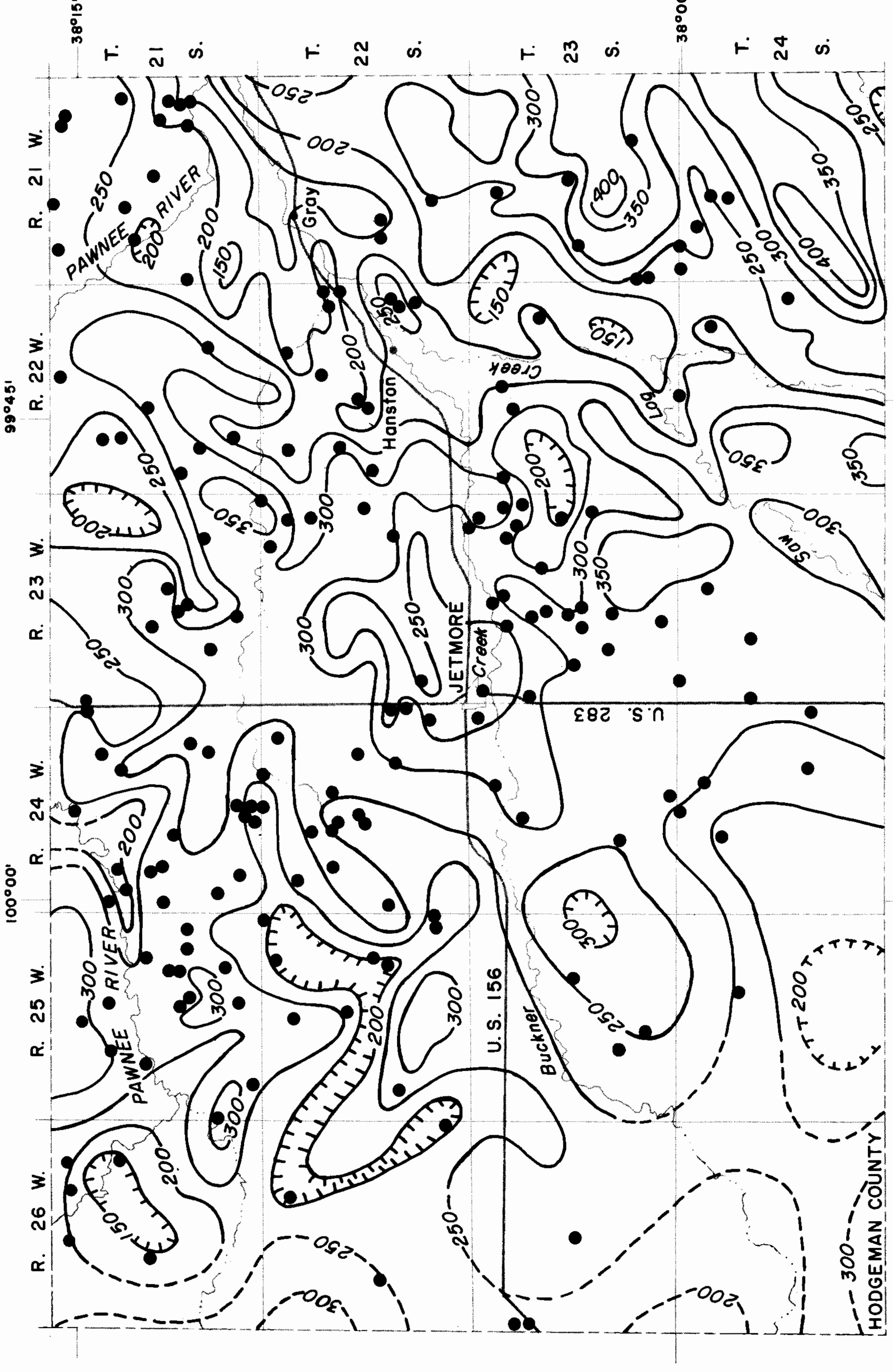
Aquifer tests were run in two areas to determine representative hydraulic characteristics in the area and to test the performance of wells at the two sites. The hydraulic properties of the aquifer are expressed in terms of transmissivity, storage coefficient, and hydraulic conductivity (Lohman, 1972). The specific capacity measured during the test relates to the hydraulic properties and to the well efficiency. Results of the tests are summarized in table 2.

TABLE 2.—Summary of aquifer tests in Ford and Hodgeman Counties, Kansas.

Well number	Transmissivity, T (ft^2/day)	Storage coefficient, S (dimensionless)	Hydraulic conductivity (ft/day)	Depth of well (feet)	Depth to water (feet)	Effective thickness[1] (feet)	Effective thickness[1] (percent)	Average discharge (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Duration of test (minutes)	Date
25-23W-35DDB[2]	7,100	0.07	41	320	142	175	99	950	44	22	12,960	February 1969
22-24W-16ADB	2,000	0.0005	16	565	261	125	41	558	91	6	7,200	June 1973

[1] Thickness of water-yielding sandstone as related to total thickness of Dakota Formation penetrated, expressed in feet and percent.

[2] Test made and interpreted by H. L. Mackey, Division of Water Resources, Kansas State Board of Agriculture.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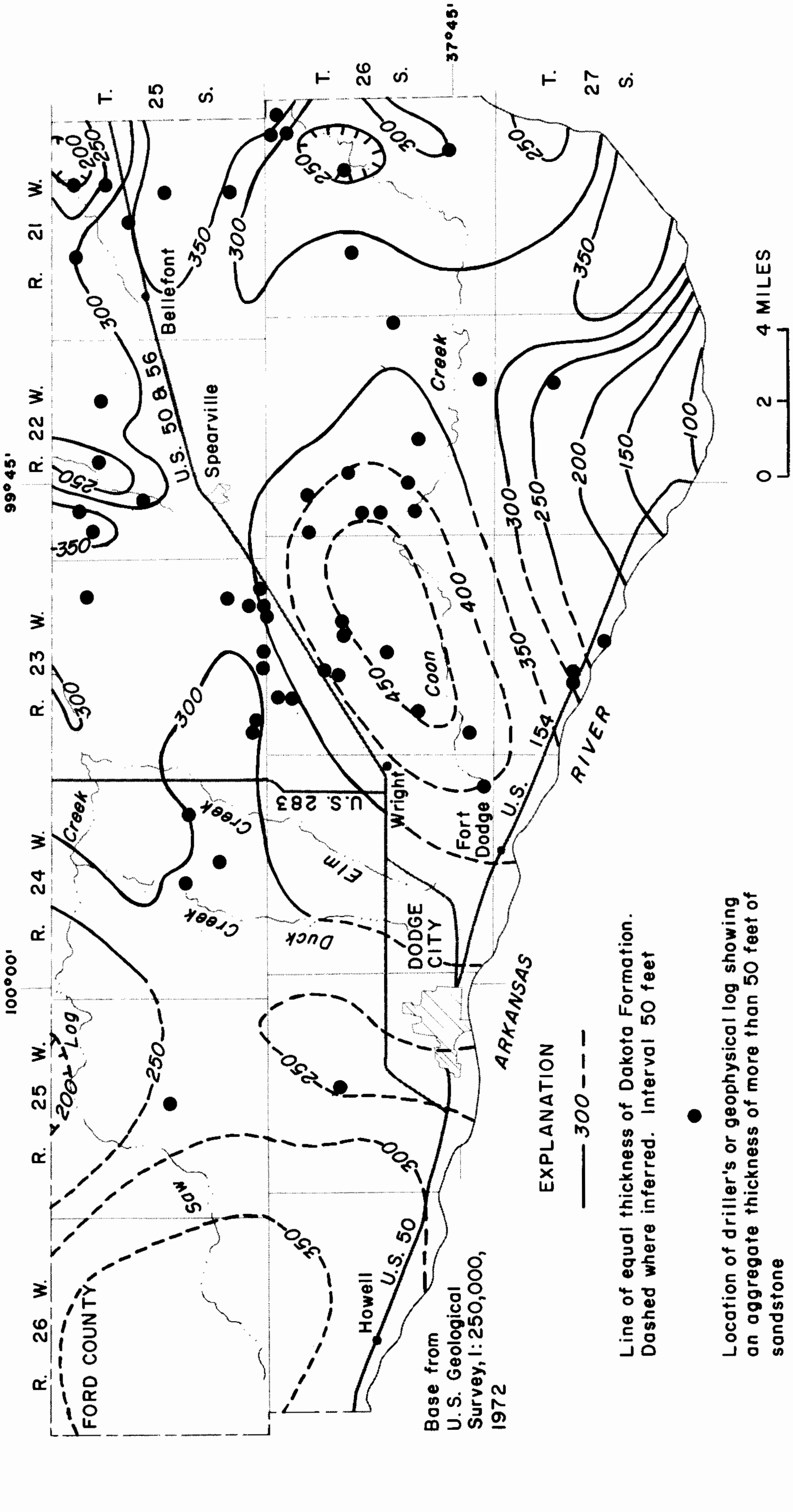
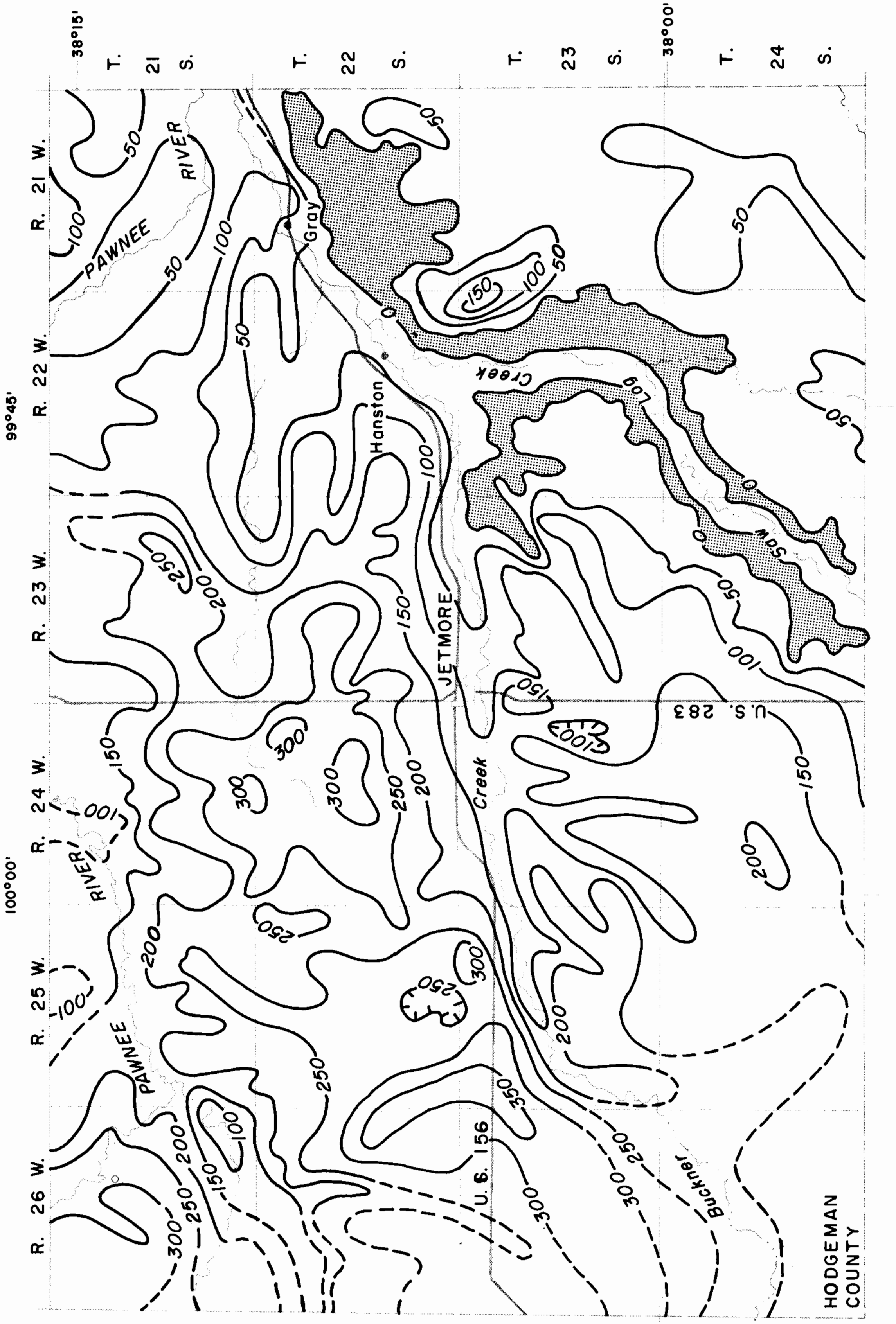


FIGURE 3.—Approximate thickness of Dakota Formation and location of logs showing more than 50 feet of included sandstone.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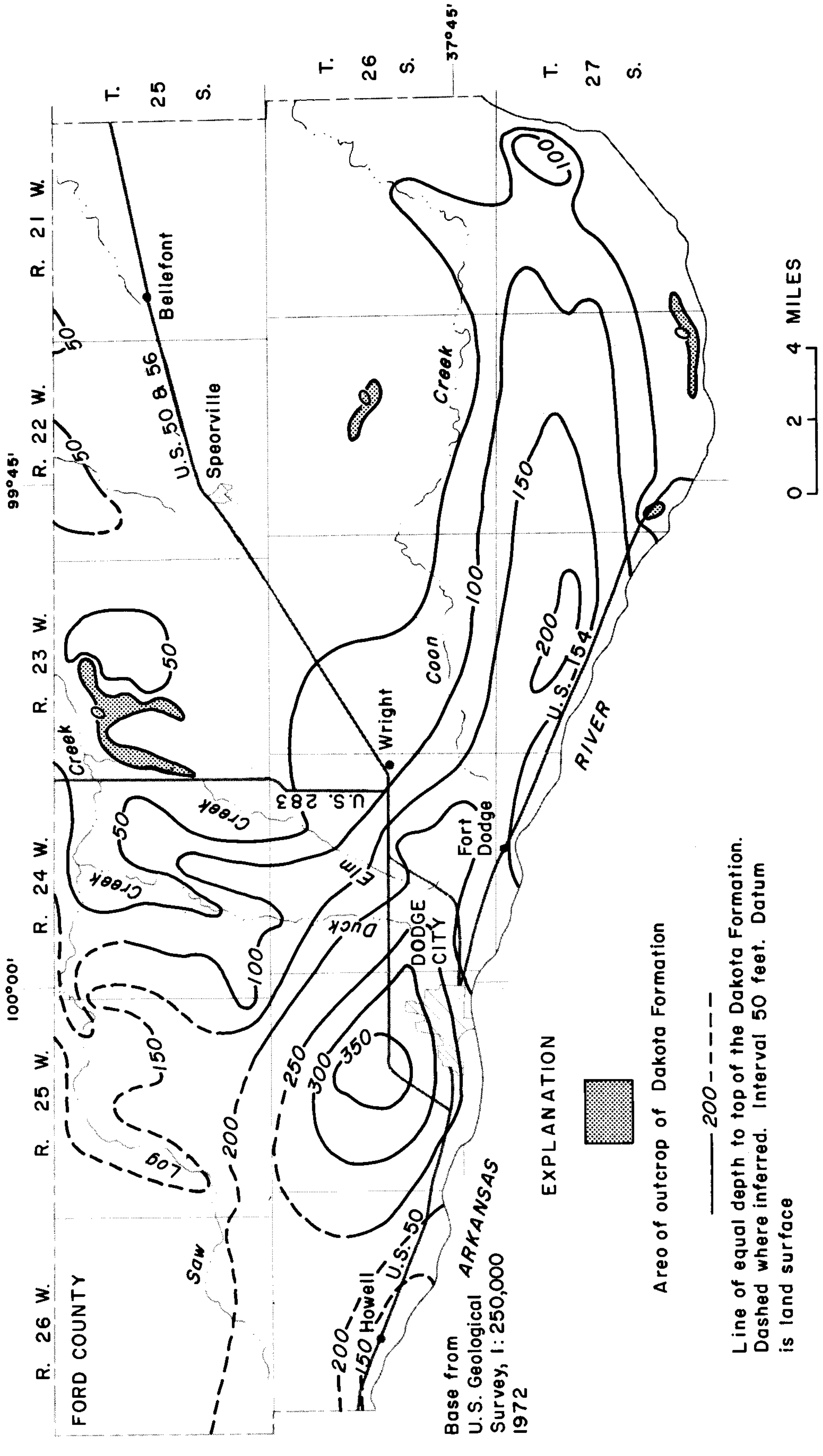
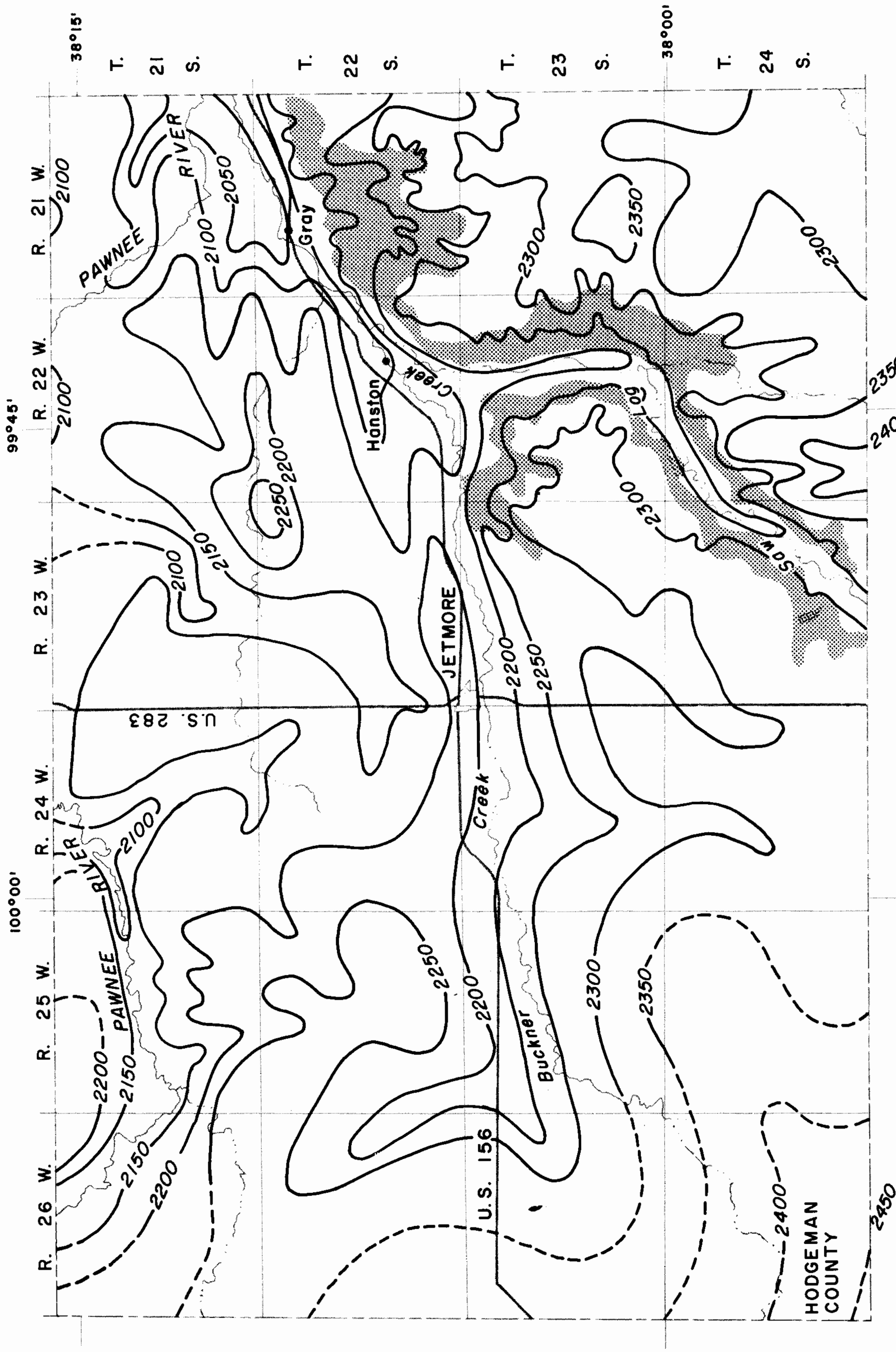


FIGURE 4.—Approximate depth to top of the Dakota Formation.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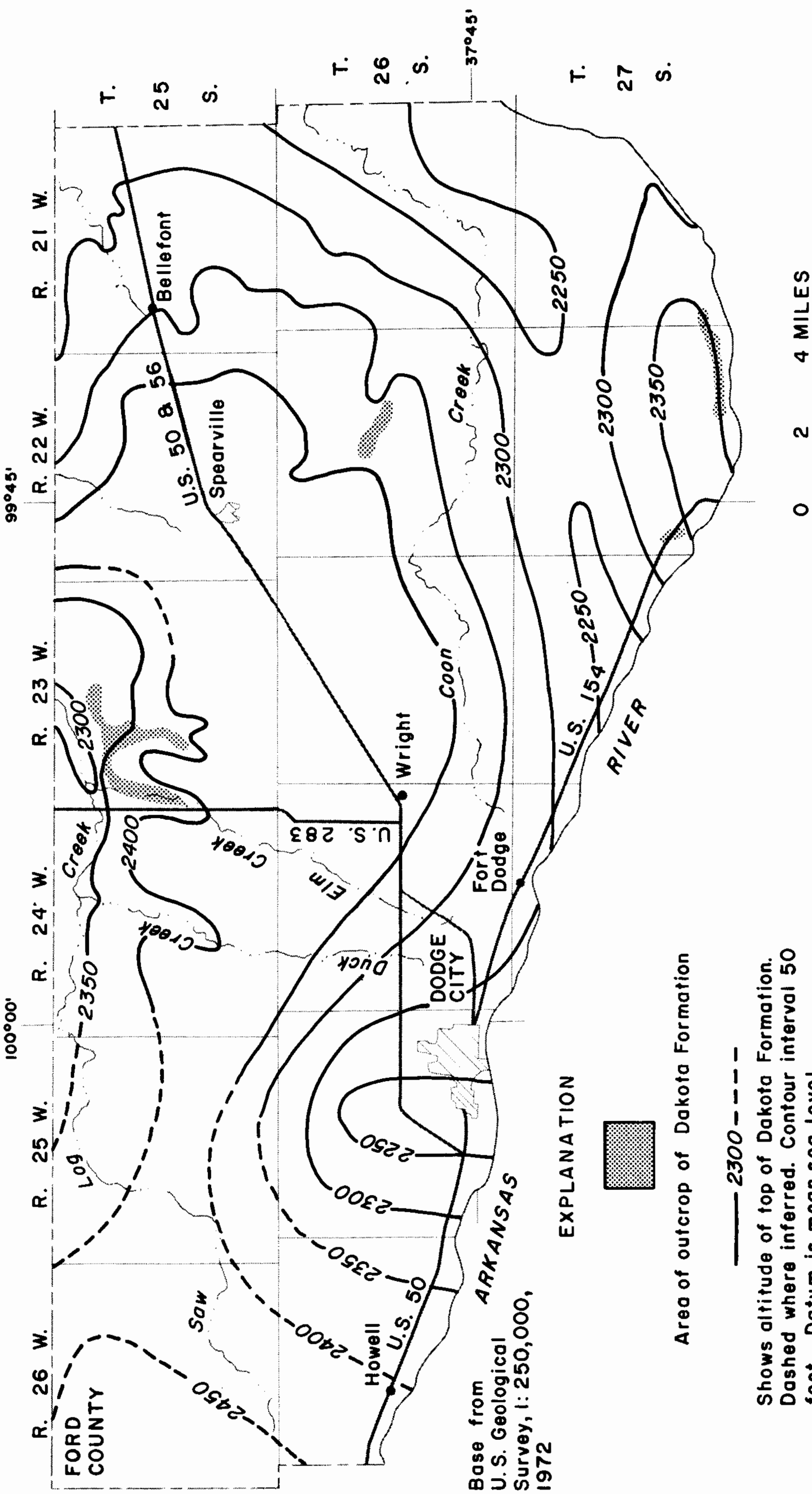
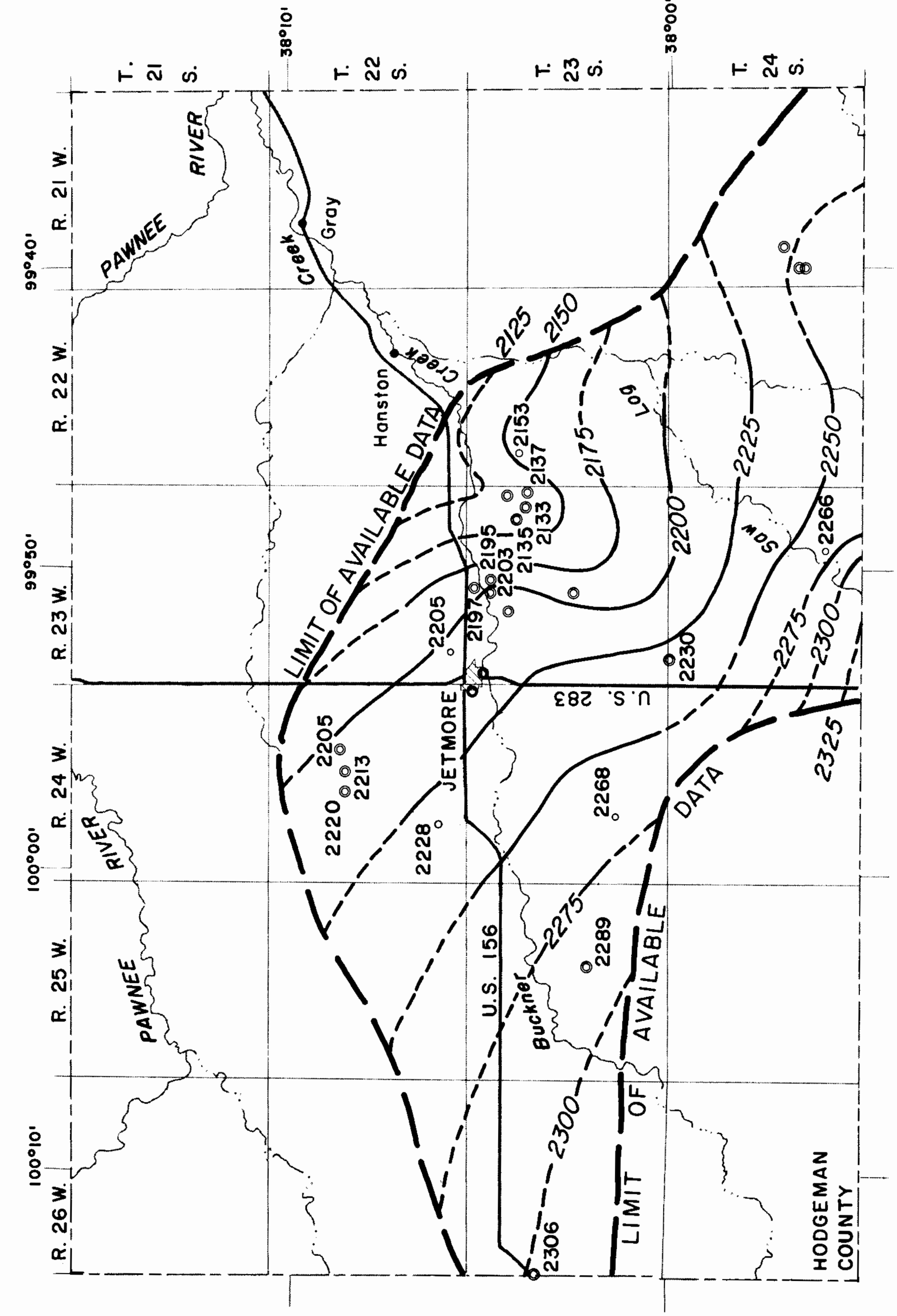


FIGURE 5.—General configuration of the top of the Dakota Formation.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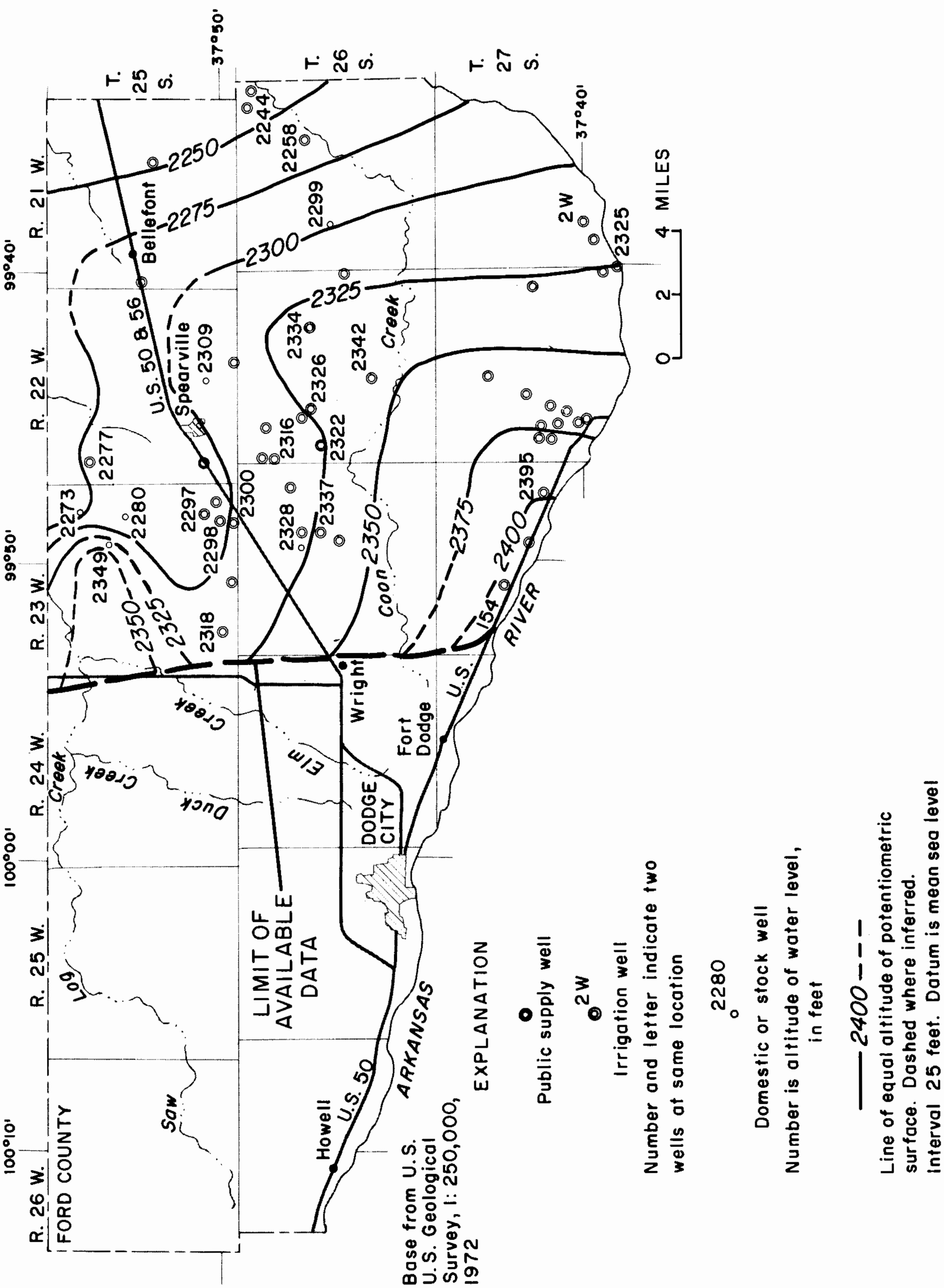
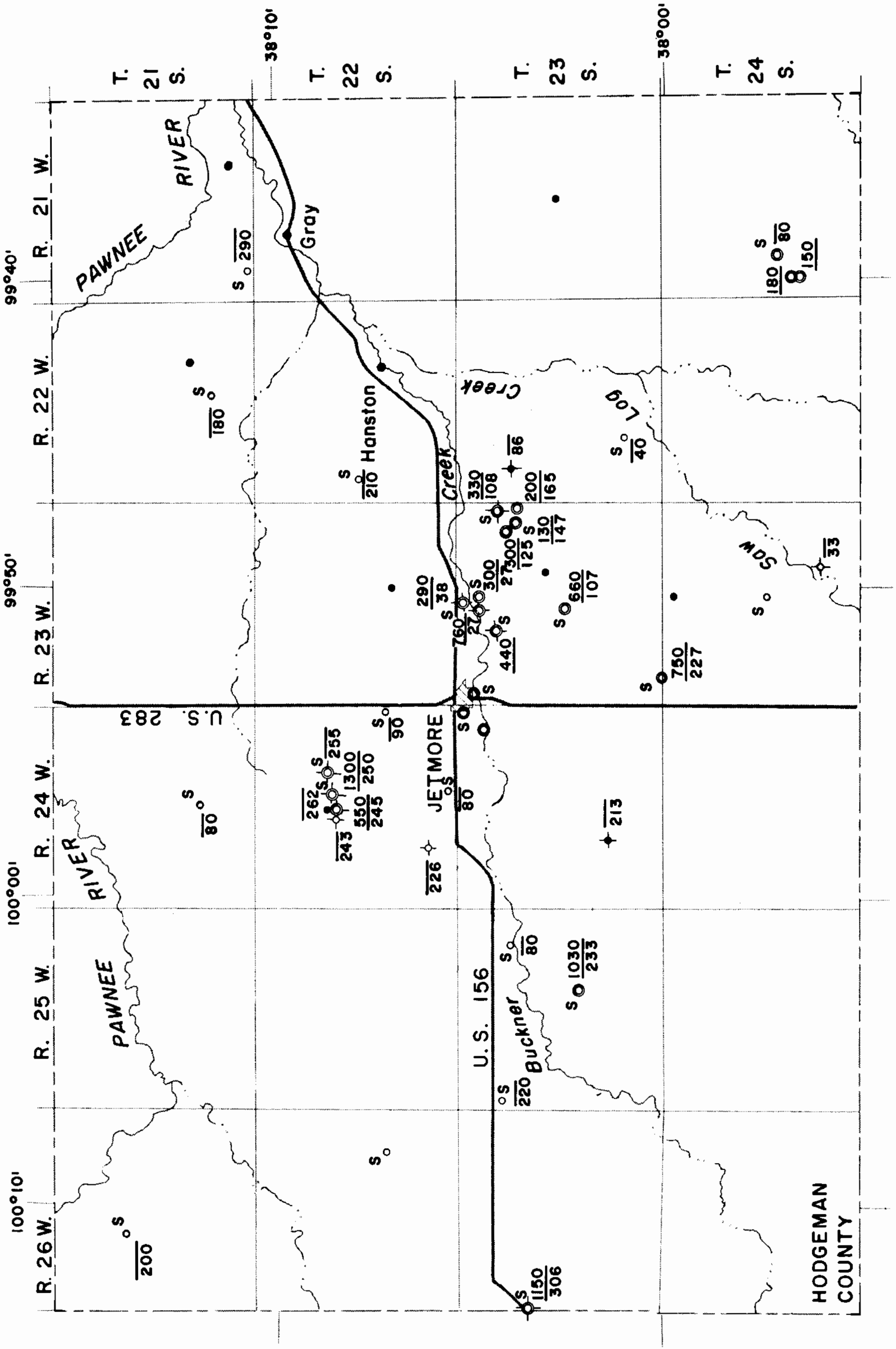


FIGURE 6.—Configuration of the potentiometric surface of the Dakota Formation, spring 1973.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Buckner
HODGEMAN COUNTY

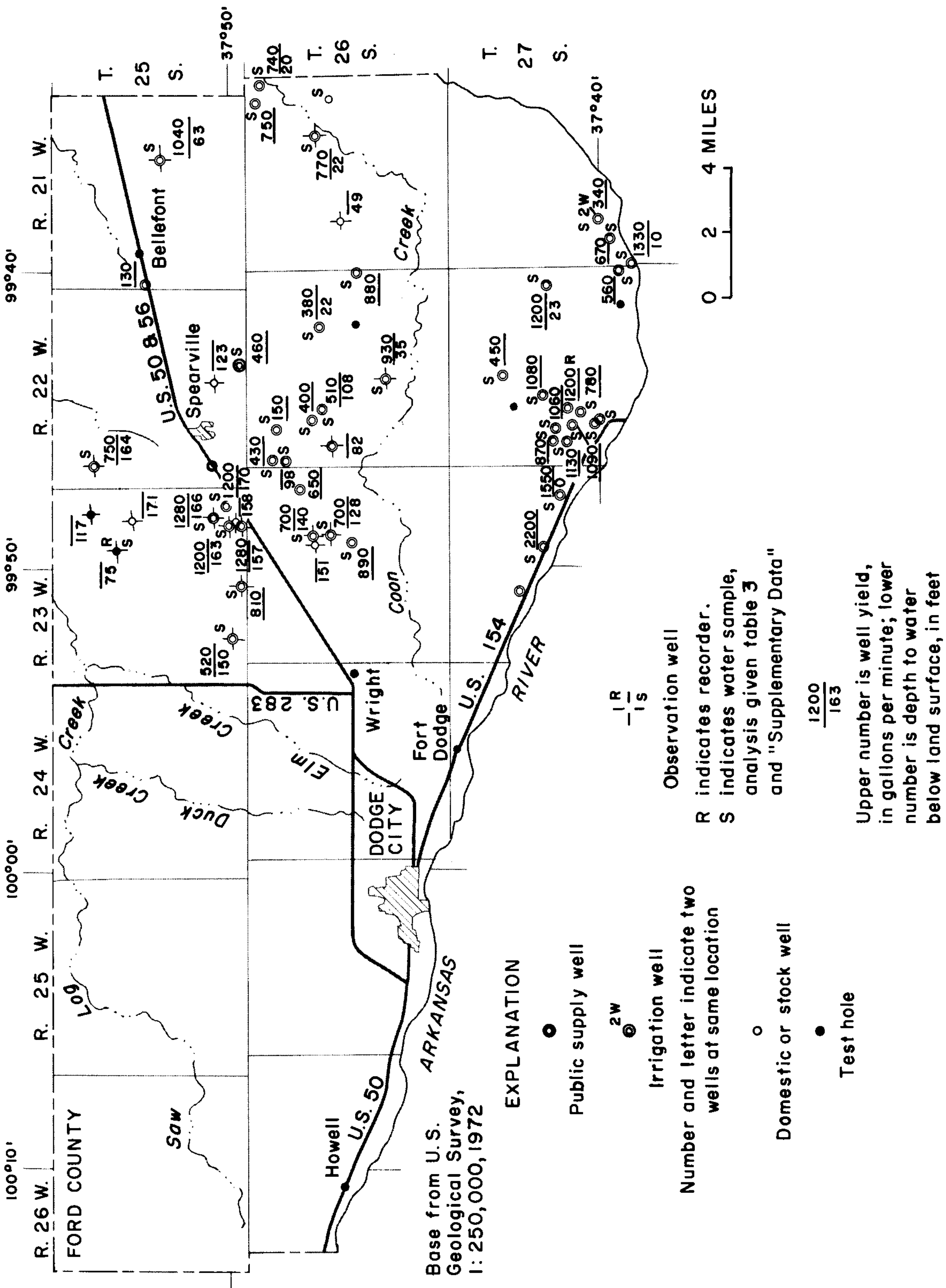

FIGURE 7.—Location of selected wells and yields, test holes, and sampling sites for water quality in Dakota Formation, 1973.

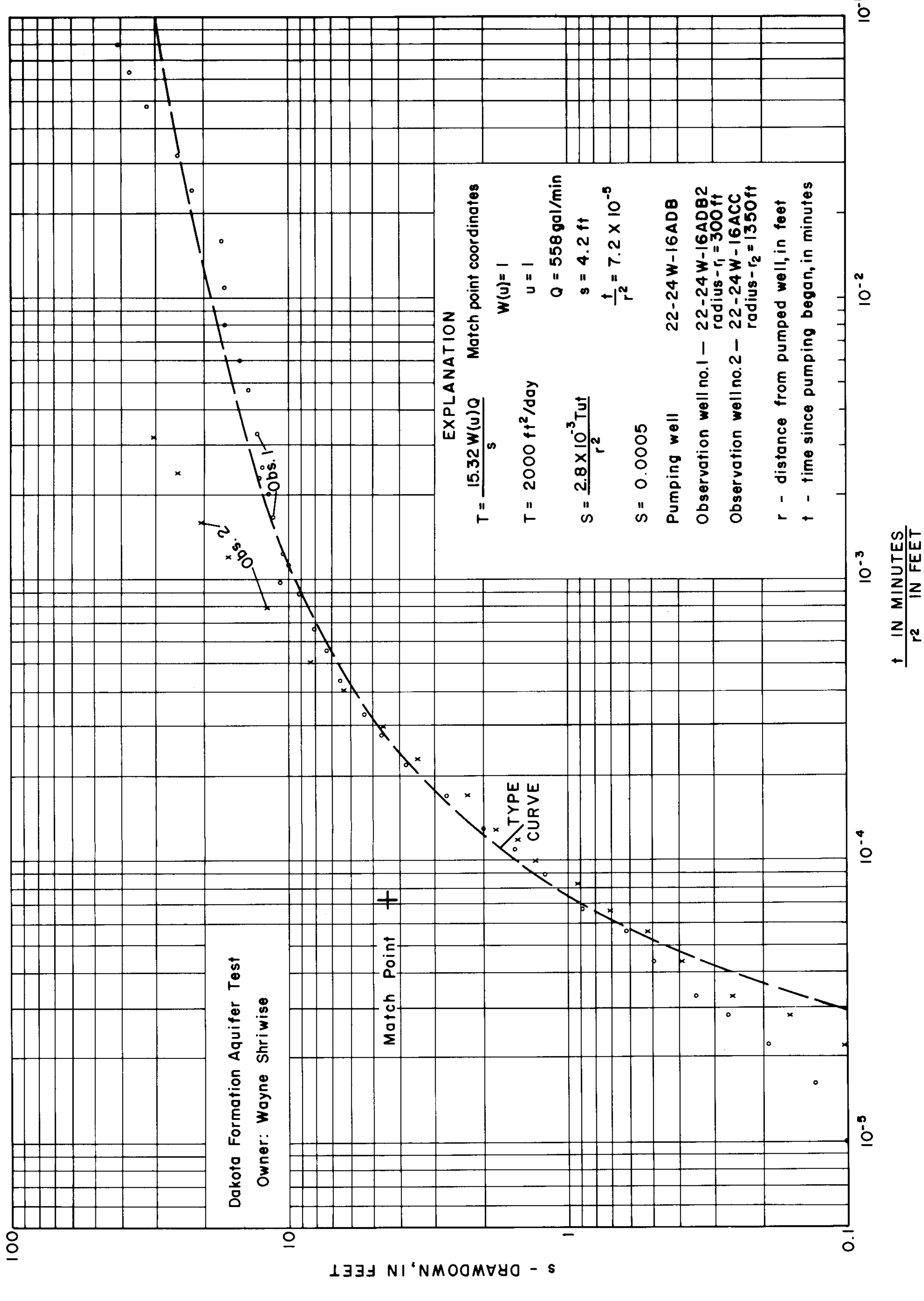

FIGURE 8.—Aquifer-test data superimposed on type curve.

The test on well 25-23W-35DDB in Ford County, belonging to Melvin Stein, is representative of the results in the unconfined area; whereas the test on well 22-24W-16ADB in Hodgeman County, belonging to Wayne Shriwise, is representative of the results in the confined area. Departure from ideal conditions, as indicated by the results late in the second test (fig. 8), indicates that the hydraulic properties determined are valid only a short distance from the well. The same is true of the first test because of the heterogeneity of the Dakota Formation.

The development of wells in the Dakota Formation involves a higher risk than development in the unconsolidated deposits. Pumping large quantities of water from a formation in which the water is under confined conditions may cause large drawdown over several square miles. Also, the limited extent and lack of connection between many of the sandstone lenses may result in a large initial well yield that rapidly dewaters the surrounding area and greatly reduces the sustained yield.

Large-Capacity Well Development

A total of 62 large-capacity wells (yielding more than 100 gal/min) were completed in the Dakota Formation between 1967 and 1973. Fifty-nine of these are for irrigation, primarily for feed crops, and three are for feedlot water systems. The towns of Jetmore in Hodgeman County and Spearville in northern Ford County also obtain water from the Dakota Formation.

LOCATION OF WELLS

The locations of irrigation and public-supply wells completed in the Dakota Formation are shown in figure 7. The wells are in an area extending from west-central to southeast Hodgeman County and northeast Ford County. The areas of greatest development are near Jetmore, Spearville, and Ford.

Power Consumption and Annual Withdrawal

Energy consumed in pumping an acre-foot of water was calculated for those wells where discharge was measured in order to estimate total pumpage for irrigation in the area. Four types of energy are used to power the irrigation systems: diesel fuel, electricity, natural gas, and LPG (liquified petroleum gas). Energy used for 33 of the systems is diesel fuel; 20 use electricity; 4 use natural gas; and 2 use LPG. An average of 27 gallons of diesel fuel, 350 kwh (kilowatt-hours) of electricity, or 12,000 cubic feet of natural gas is required to pump 1 acre-foot of water in the area. The ranges for energy consumption per acre-foot are: 14 to 34 gallons diesel fuel, 107 to 480 kwh of electricity, and 8,900 to 13,800 cubic feet of natural gas. No data were collected on LPG consumption; however, the amount of fuel, in gallons, required to power an LPG engine is about double that required for a diesel engine.

An average of 270 kwh is required to pump 1 acre-foot of water for flood irrigation and 410 kwh for sprinkler irrigation. The sprinkler system operates under a greater discharge head, which accounts for the increased amount of energy consumed. Power requirements vary with efficiency of the pumping plant, pumping lift, and the pressure head at the pump.

Computations based on electrical power records of 15 wells (25 percent of the total of 59 irrigation wells) show that annual withdrawal for 1973 was about 1,210 acre-feet to irrigate 1,210 acres. The average annual pumpage of water per acre for sprinkler systems was about 0.8 acre-foot, and for flood systems, 1.1 acre-feet. Although the land irrigated by the 15 sampled wells is more sandy than other lands under irrigation, the results were used to estimate withdrawal from the Dakota aquifer.

Assuming 1 acre-foot per acre pumped in 1973 for the 15 wells sampled, then pumpage by all 59 wells to irrigate 7,700 acres would be about 7,700 acre-feet. Irrigation normally requires a seasonal application of about 1.5 to 2 feet. The requirement of 1 foot for 1973 was less because of above-normal precipitation. According to records of the National Weather Service (National Oceanic and Atmospheric Administration, U.S. Department of Commerce), annual precipitation for 1973 at Dodge City and Jetmore was 32 inches as compared to the normal 20 inches for 1968-73, as shown in figure 9. Precipitation at Dodge City and Jetmore during 1972 and 1973 growing seasons, April through September, averaged 22 inches, which was 7 inches above normal.

About 7,700 acres were irrigated in 1973 by water pumped from the Dakota Formation. Assuming that irrigation requirements range from 1 to 2 acre-feet per year, withdrawals would range from about 7,700 to 15,000 acre-feet per year at a rate inversely proportional to annual precipitation.

Water-Level Changes

Water-level changes in wells in the Dakota Formation of Hodgeman and northern Ford Counties mainly indicate the effects of ground-water withdrawals for irrigation. Highest water levels generally occur in

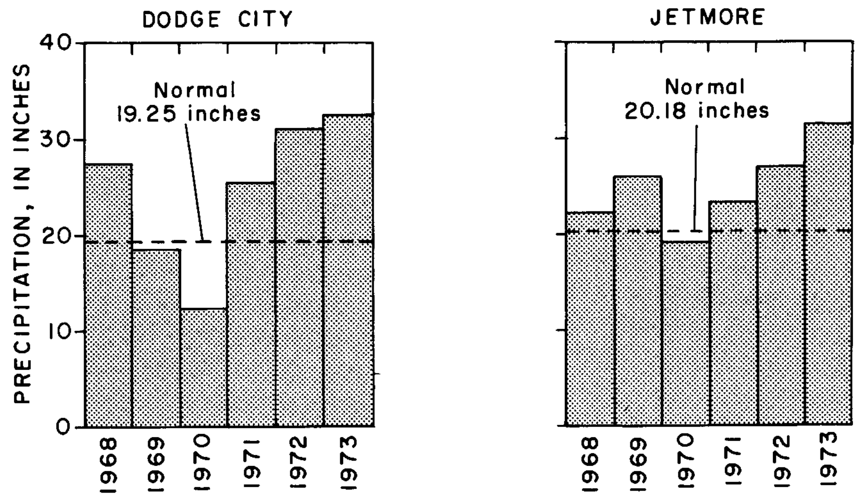

FIGURE 9.—Annual precipitation at Dodge City and Jetmore (1968-73). [From records of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce]

the winter or early spring when the effects of pumping for irrigation are at a minimum. The year-to-year differences in these highest water levels indicate the amount of long-term decline in the aquifer.

Nearly all wells in the Dakota Formation have shown long-term declines in water levels. Measurements in wells from December 1967 to the spring of 1973 showed declines ranged from 0 to 40 feet, and most commonly were about 20 feet. As shown by the hydrographs in figure 13 (see Supplemental Data), the greatest long-term decline was 40 feet in irrigation well 23-23W-12ABD in Hodgeman County. Nearby irrigation well 23-23W-4AAD showed virtually no long-term decline but showed seasonal fluctuations as great as 125 feet. Water levels in this well probably are influenced by recharge of water from the alluvium of Buckner Creek. Water levels in most domestic and stock wells in the Dakota Formation declined in a manner similar to those in the irrigation wells, although the seasonal changes were generally less.

RECHARGE AND DISCHARGE

Fluctuations caused by pumping for irrigation mask any seasonal variations caused by natural recharge and discharge. Only a small part of the Dakota aquifer in the study area is in contact with the overlying sand and gravel and is recharged by percolation of precipitation or by water from overlying unconsolidated deposits. Most of the water enters the Dakota aquifer in areas of Kansas southwest of Hodgeman and northern Ford Counties.

Natural discharge from the Dakota Formation in the study area occurs as springs and seeps along Buckner, Saw Log, and Coon Creeks and as ground water discharged into the alluvium along streams. It is estimated that the contribution of ground water to the three streams total about 1.5 cubic feet per second or about 1,100 acre-feet per year. Additional discharge by other means (domestic and stock wells, evapotranspiration, etc.) is estimated to be 1,200 acre-feet per year. Discharge to streams of 1,100 acre-feet combined with the estimated 7,700 acre-feet of pumpage for irrigation and 1,200 acre-feet by other means, gives a total of about 10,000 acre-feet discharged from the Dakota Formation in 1973.

CHEMICAL QUALITY OF THE WATER

Quality of water in the Dakota Formation in Hodgeman and northern Ford Counties varies widely, as shown by the 67 analyses of water samples included in table 6 (see Supplemental Data). The various water types discussed in this section are classified according to the predominant ions. Well 27-22W-20BBD in northern Ford County, near the area where the Dakota is being recharged from the Ogallala Formation, yields water of a calcium-bicarbonate type. As a calcium-bicarbonate water moves through the Dakota Formation, it changes by the process of ion exchange to a sodium-bicarbonate type water such as that from well 23-25W-22DBB. Well 27-21W-30DDD yields water of a mixed calcium-sodium-bicarbonate-sulfate type similar to that of water in the nearby

Arkansas River alluvium, which probably is the source of recharge.

The sodium-chloride-nitrate water from well 23-23W-4AAD probably indicates pollution from animal wastes from an unidentified source. Another analysis, showing a sodium-chloride water from well 21-21W-31DDA, probably indicates the upward movement of a highly mineralized water from Permian beds.

The great variation in water quality in the Dakota Formation in Hodgeman and northern Ford Counties probably is caused by the movement of water from underlying and overlying formations. Some of the variation may be caused by differences in quality with depth, as the wells generally do not tap the entire thickness of the formation.

Suitability for Irrigation

Many complex factors influence the suitability of water for irrigation. Two of these are the salinity hazard, as indicated by the conductivity, and the sodium (alkali) hazard, which is based on a relationship between the sodium content and the other cations in the water. These relationships are used to indicate, in a general manner, the suitability of water for irrigation, as shown in figure 10. The method of classification is that of the U.S. Salinity Laboratory (U.S. Department of Agriculture Handbook 60, 1954).

In general, water having a high to very high salinity and high sodium hazard should not be used for irrigation. However, some well-drained soils may tolerate less suitable water, and proper irrigation practices may reduce the hazards. Deterioration of the soil caused by application of unsuitable water is slow, so that several years may pass before the results become evident.

Suitability for Domestic Use and Other Uses

Water from the Dakota Formation commonly contains concentrations of some mineral constituents that exceed the limits for domestic and public supplies recommended by the Kansas Department of Health and Environment, as shown in table 3. Special note should be taken of the high fluoride content, which commonly causes mottling of teeth in children who drink the water during the time that their permanent teeth are being formed. Another common problem is the high iron concentration in water from the Dakota Formation. Although some softening may occur naturally, a method of iron removal commonly is necessary before the water is suitable for household use. Generally the water presents no natural health hazard,

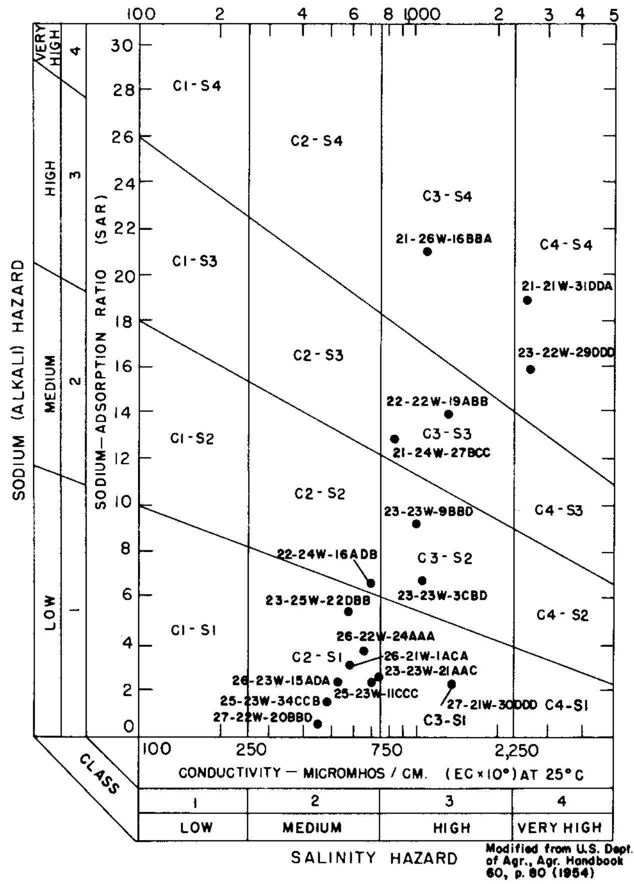

FIGURE 10.—Suitability of water from the Dakota Formation for irrigation. (Chemical analyses of water for well number indicated given in table 6.)

except for persons who must reduce their sodium intake. A high nitrate concentration, such as the 42 mg/L (milligrams per liter) from well 27-21W-31CCB and the 230 mg/L from well 23-23W-4AAD, commonly indicates local pollution. The latter sample also contains enough nitrate to cause fatalities in very young children or young animals.

Water-quality requirements for industry are extremely varied. For some uses where quality is not critical, much of the water in the Dakota Formation could be used with only moderate treatment to remove

TABLE 3.—Recommended concentrations of constituents in water for domestic and public supplies.

Constituent	Recommended limits, in milligrams per liter
Dissolved solids	500
Iron (Fe)	.3
Manganese (Mn)	.05
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.5
Nitrate (NO_3)	45

excessive iron or reduce excessive hardness. Other uses may require treatment too extensive to be practical.

Depth to Highly Mineralized Water

No quantitative analysis was made during this study of the chemical quality of water in the strata below the Dakota Formation. Resistivity logs of oil and gas tests compared to analyses of water in adjacent areas indicate that the Cheyenne Sandstone and the Permian red beds in this area contain water unsuitable for irrigation. Figure 11 shows the depth to sandstone units containing highly mineralized water (more than 2,000 mg/L). This depth generally coincides with the top of the Cheyenne Sandstone. Geophysical logs commonly indicate more than 100 feet of shale in the Kiowa Formation between the Dakota Formation and the water-bearing sandstone in the Cheyenne. This confining shale zone probably should not be penetrated when test drilling for irrigation supplies.

The maximum depth to sandstone containing mineralized water is slightly more than 800 feet in the extreme northwest corner of the area. The minimum depth is in the Pawnee River valley in northeastern Hodgeman County where the depth is nearly 400 feet. Most commonly the depths range from about 500 to 700 feet.

FUTURE OUTLOOK FOR IRRIGATION FROM THE DAKOTA FORMATION

The increasing demand for farm products may encourage the irrigation of more land, but increasing energy costs and decreasing crop prices could reduce the rate of development. At many locations, the thickness and permeability of water-yielding sandstone is insufficient to supply ground water for irrigation wells, and the chemical quality of water in most of Hodgeman County also may inhibit future development.

Development of new wells is expected to continue in the sandhill area north of Ford and, to a lesser extent, in the area southeast of Spearville. Elsewhere, development probably will be extremely limited. In some areas, water from the Dakota Formation could be developed in combination with water from the Ogallala Formation to provide additional irrigation yields in a manner similar to that used in some other areas of southwestern Kansas.

FUTURE INVESTIGATIONS

Additional investigation of the hydrologic system in the area is needed because water levels and water quality are closely related to ground-water conditions in the overlying unconsolidated aquifer and to streamflow.

A regional study of the geohydrology of the Lower Cretaceous formations was made by Keene and Bayne (1977) to determine the amount and quality of water available for a future supply, including water that might be used if appropriate desalinization is utilized, and to determine what formations might need protection from pollution. Additional detailed studies are needed in localized areas as the demand for usable water increases.

The lignite in the upper and lower parts of the Dakota Formation may have sufficient thickness for mining in some parts of the area, and water-quality and environmental problems associated with the mining of these beds would need to be studied before any appreciable development occurs.

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SUPPLEMENTAL DATA

Index Maps

This investigation is a part of a continuing study of the ground-water resources of Kansas that began in 1937. The 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 12. The numbers and letters on the map refer to reports published by the Kansas Geological Survey and to reports published by the U.S. Geological Survey.

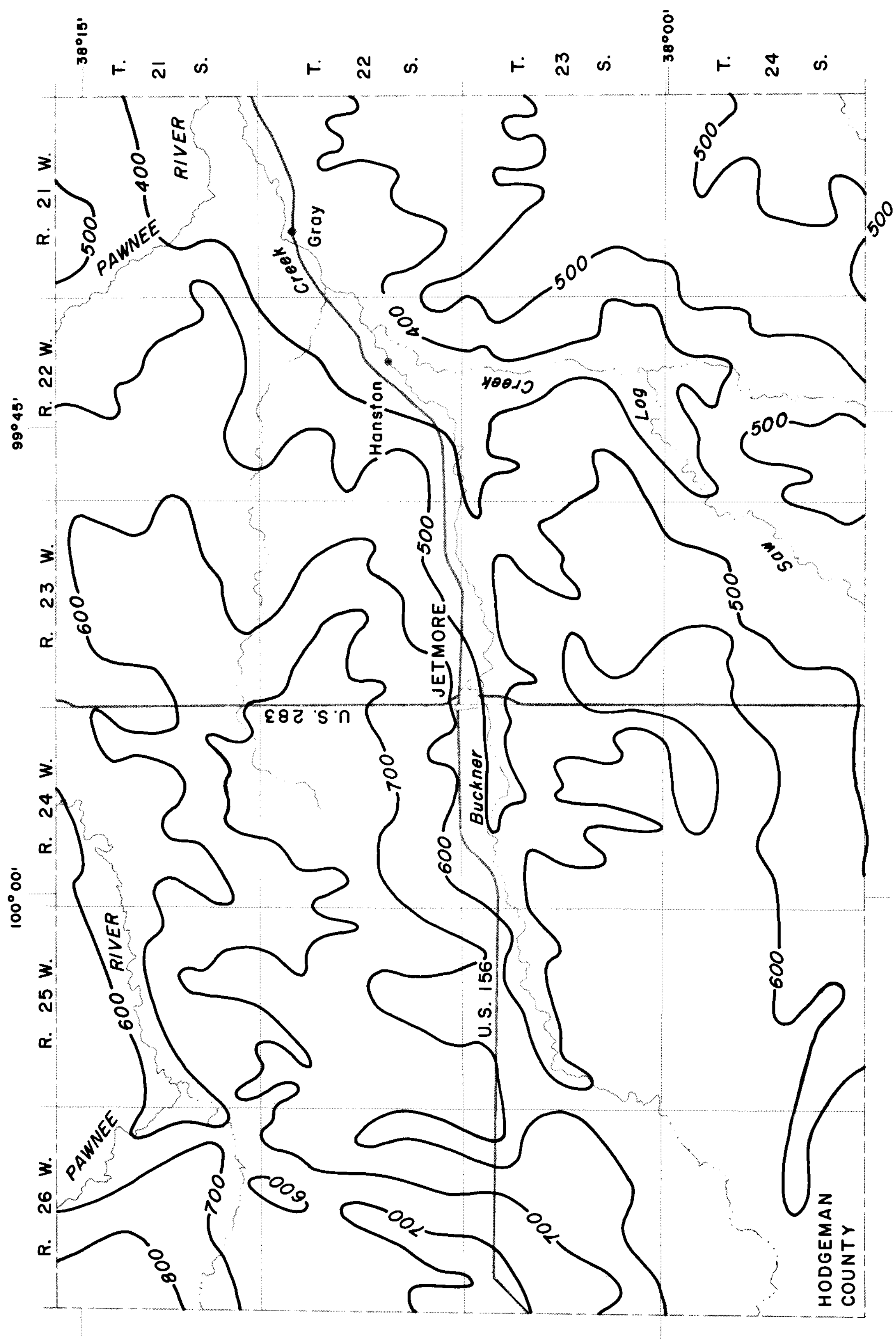
Selected Geohydrologic and Chemical-Quality Data

The hydrographs of 24 observation wells in the Dakota Formation (fig. 13) show the water-level changes in selected wells in Hodgeman and northern Ford Counties (locations shown in figure 7). These hydrographs illustrate the different seasonal fluctuations resulting from ground-water withdrawals in areas of confined and unconfined aquifer conditions and the gradual long-term water-level declines owing to the reduction in ground-water storage.

Table 4 lists the records of 94 selected wells that obtain most or all of their water supply from the Dakota Formation. Listed are records of 62 irrigation wells, 5 public-supply wells, 20 domestic wells, and 7 unused wells where water levels are measured.

Table 5 lists the logs of 14 test holes drilled by the Kansas Geological Survey (locations shown in figure 7). Altitudes are referenced to mean sea level datum and are reported to the nearest foot. Depth of all holes and depth to water in two cased wells are reported in feet below land surface.

Table 6 lists the chemical analysis of water samples from 67 wells that obtain their supply from the Dakota Formation (locations shown in figure 7). Analyses were made by the Kansas Department of Health and Environment.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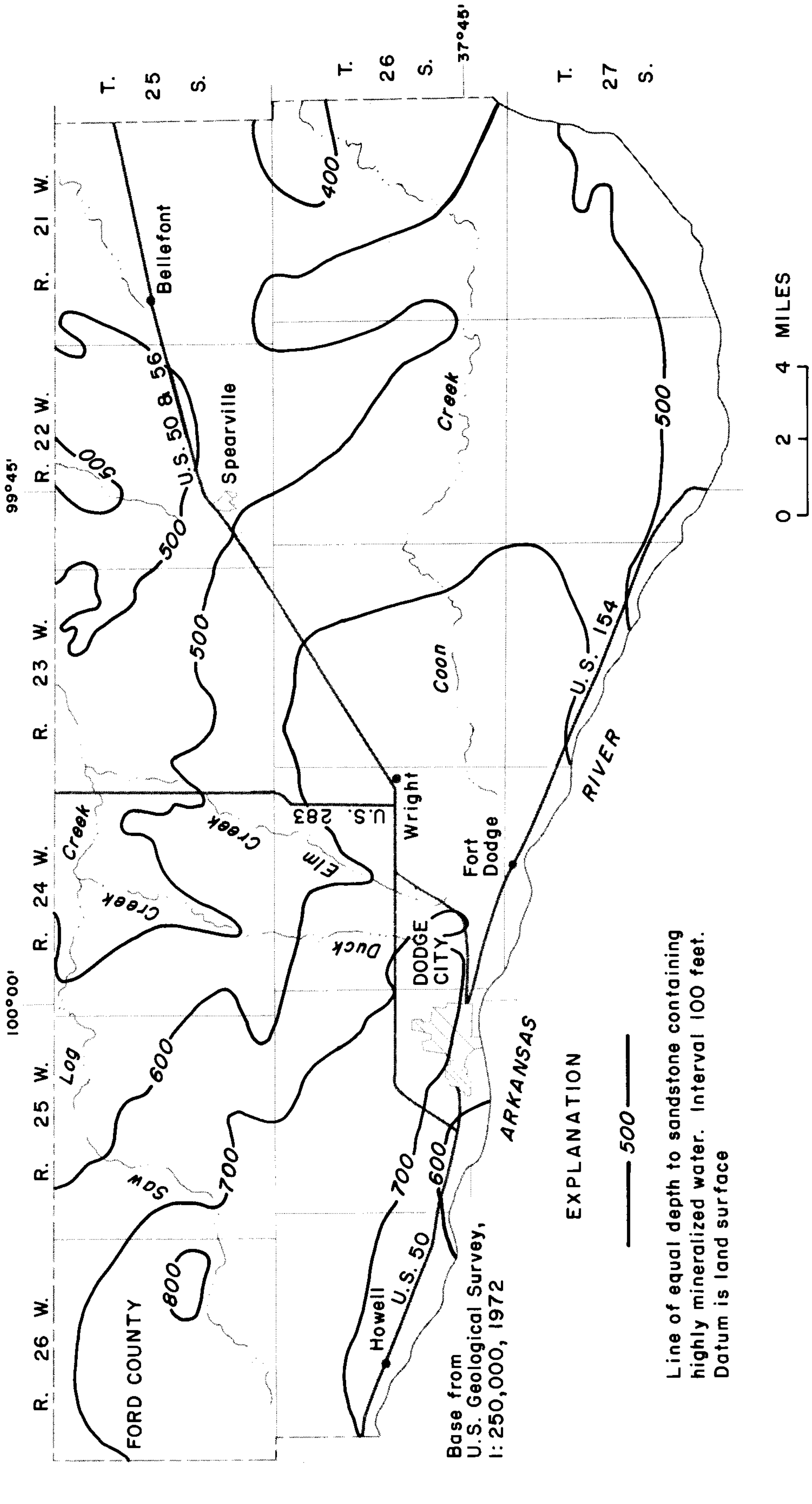

FIGURE 11.—Depth to sandstone containing highly mineralized water.

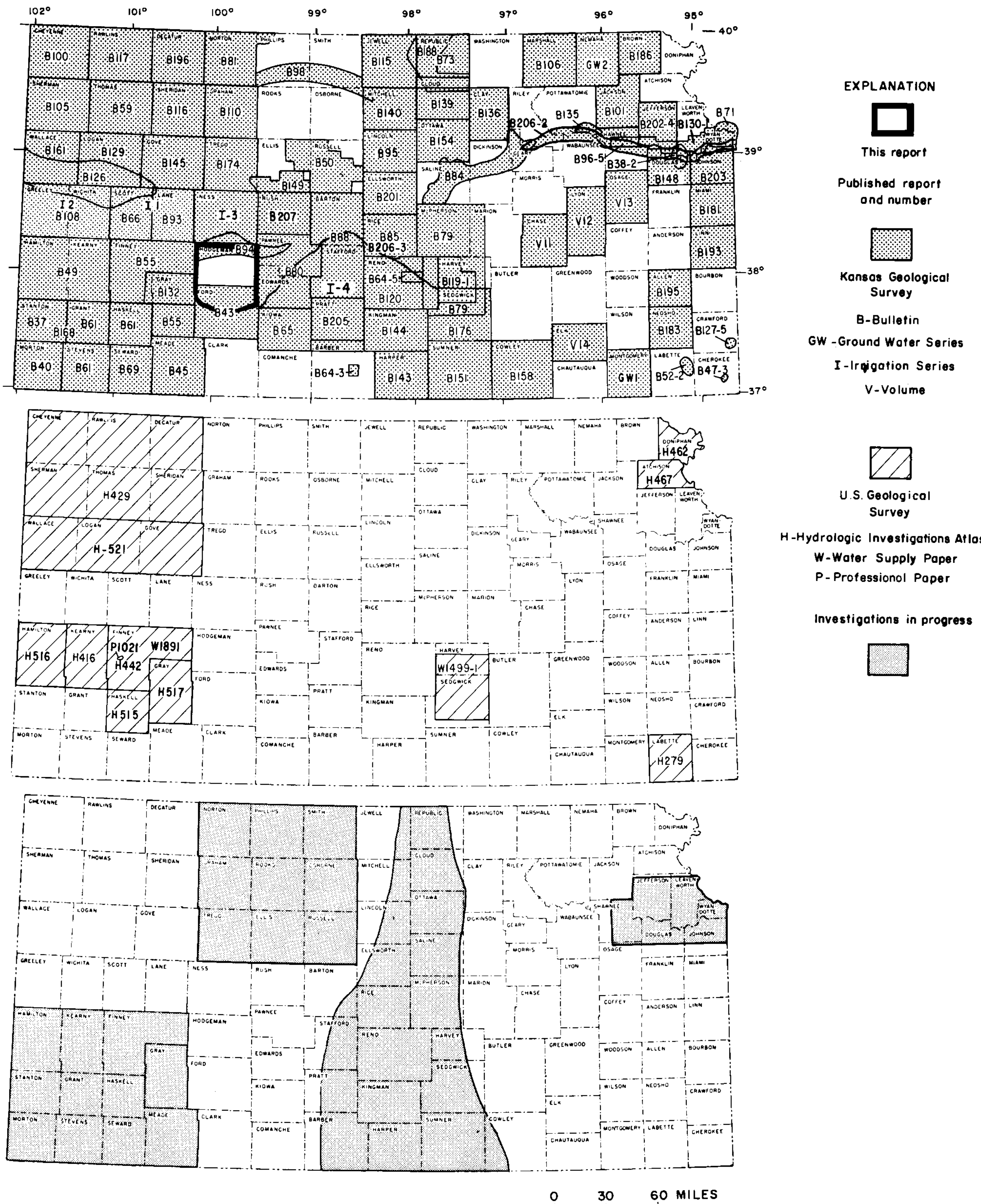

FIGURE 12.—Area described in this report and other areas for which reports are available or are in preparation.

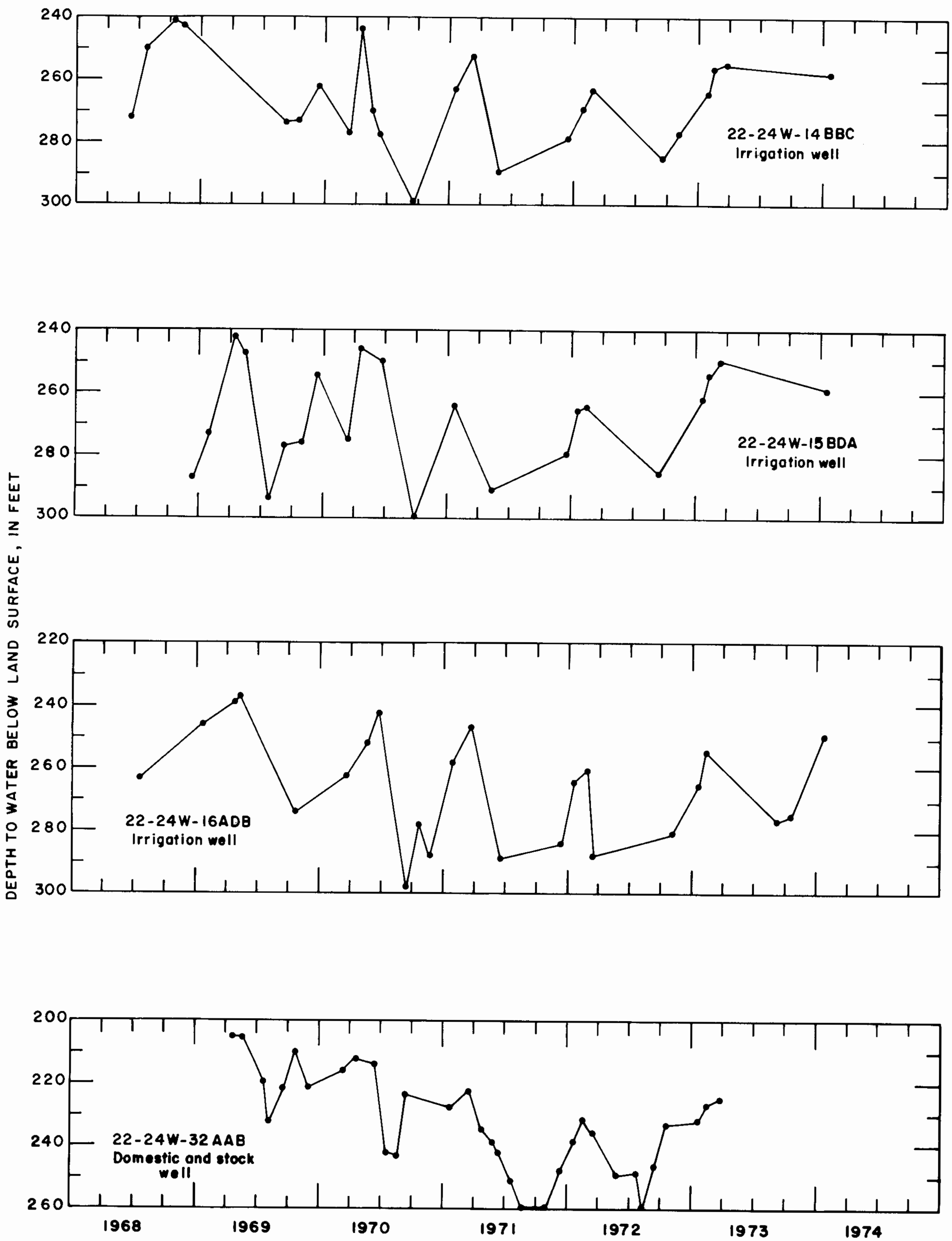

FIGURE 13.—Hydrographs for selected wells in Dakota Formation.

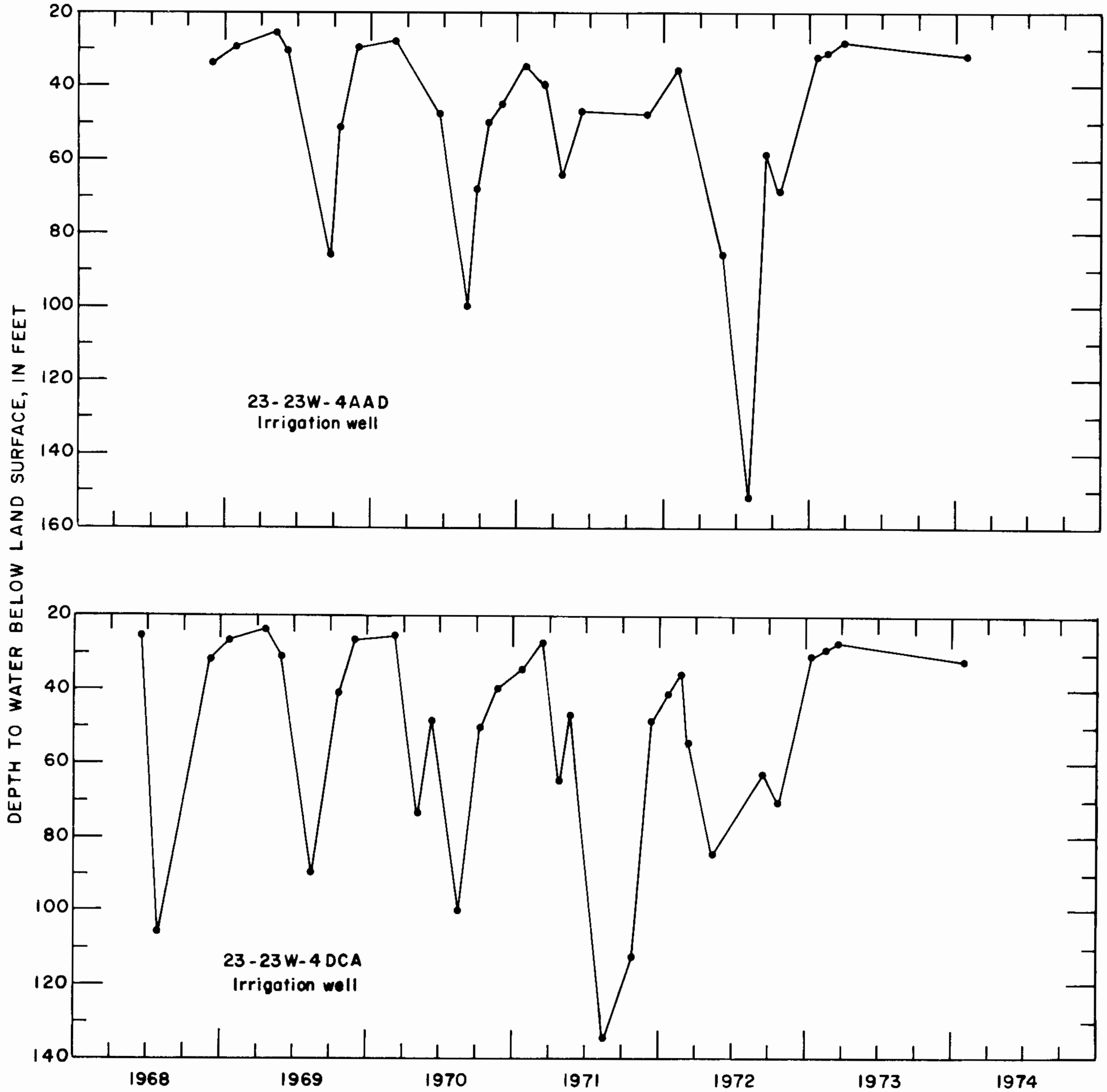

FIGURE 13.—Hydrographs for selected wells in Dakota Formation (continued).

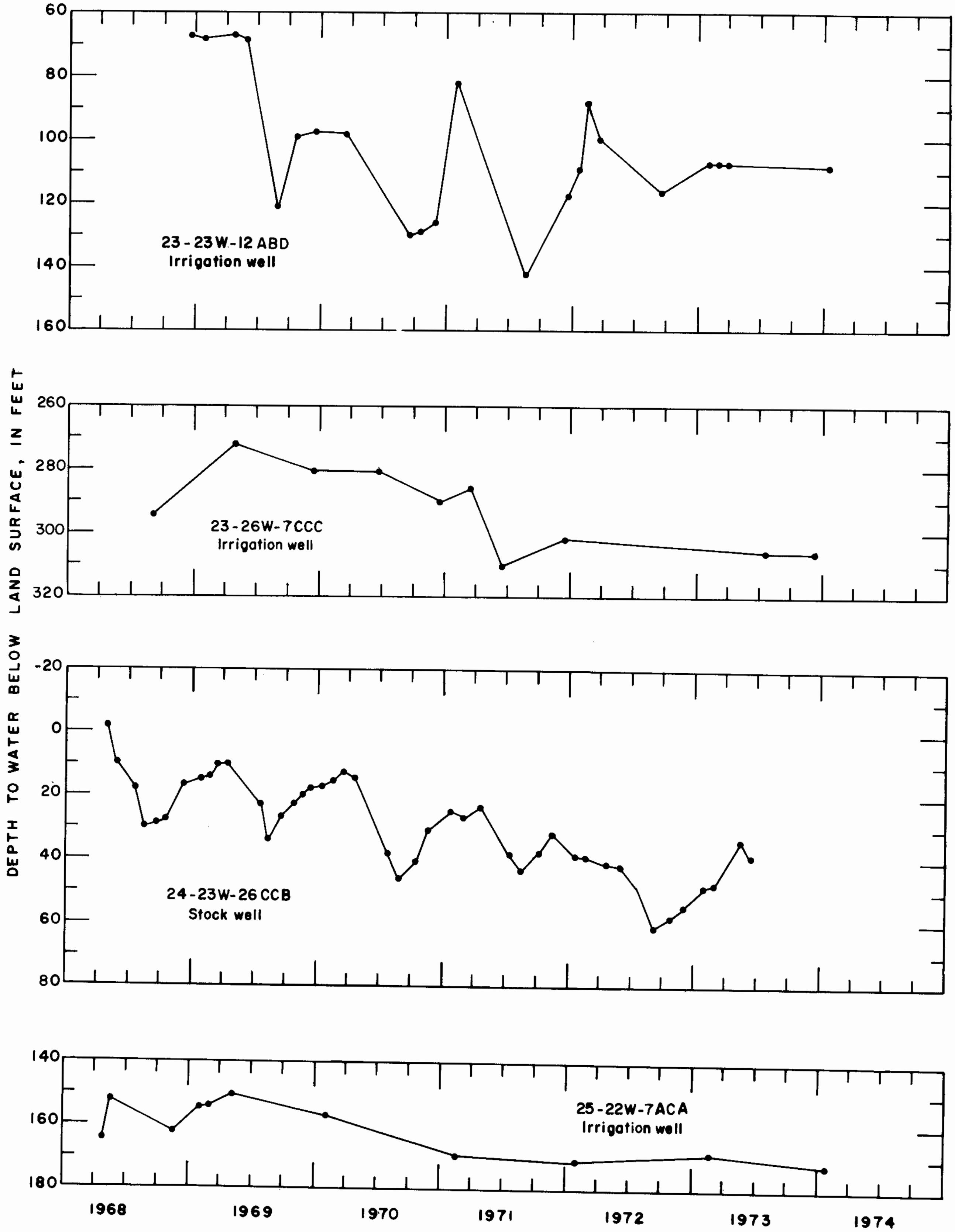

FIGURE 13.—Hydrographs for selected wells in Dakota Formation (continued).

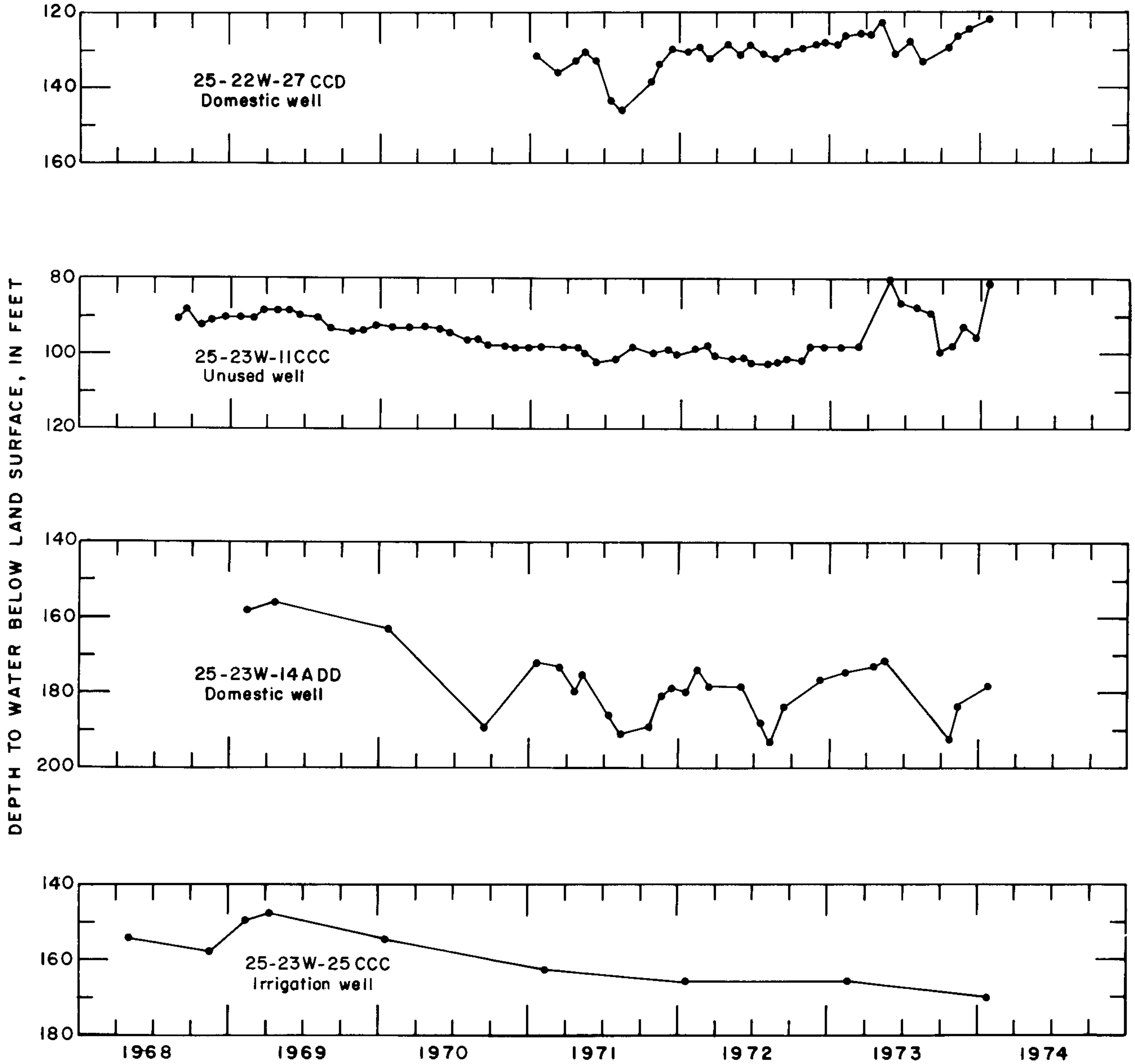

FIGURE 13.—Hydrographs for selected wells in Dakota Formation (continued).

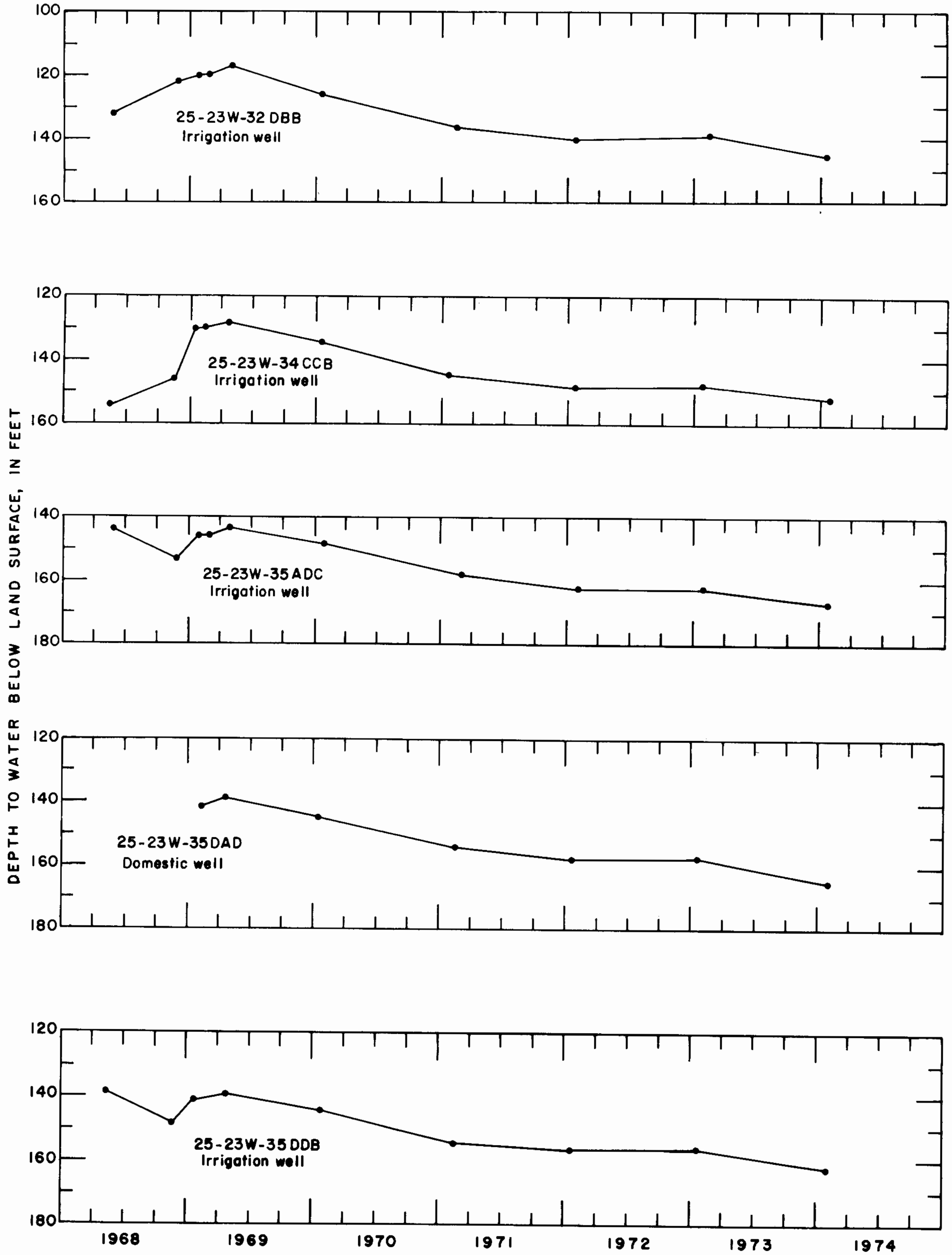

FIGURE 13.—Hydrographs for selected wells in Dakota Formation (continued).

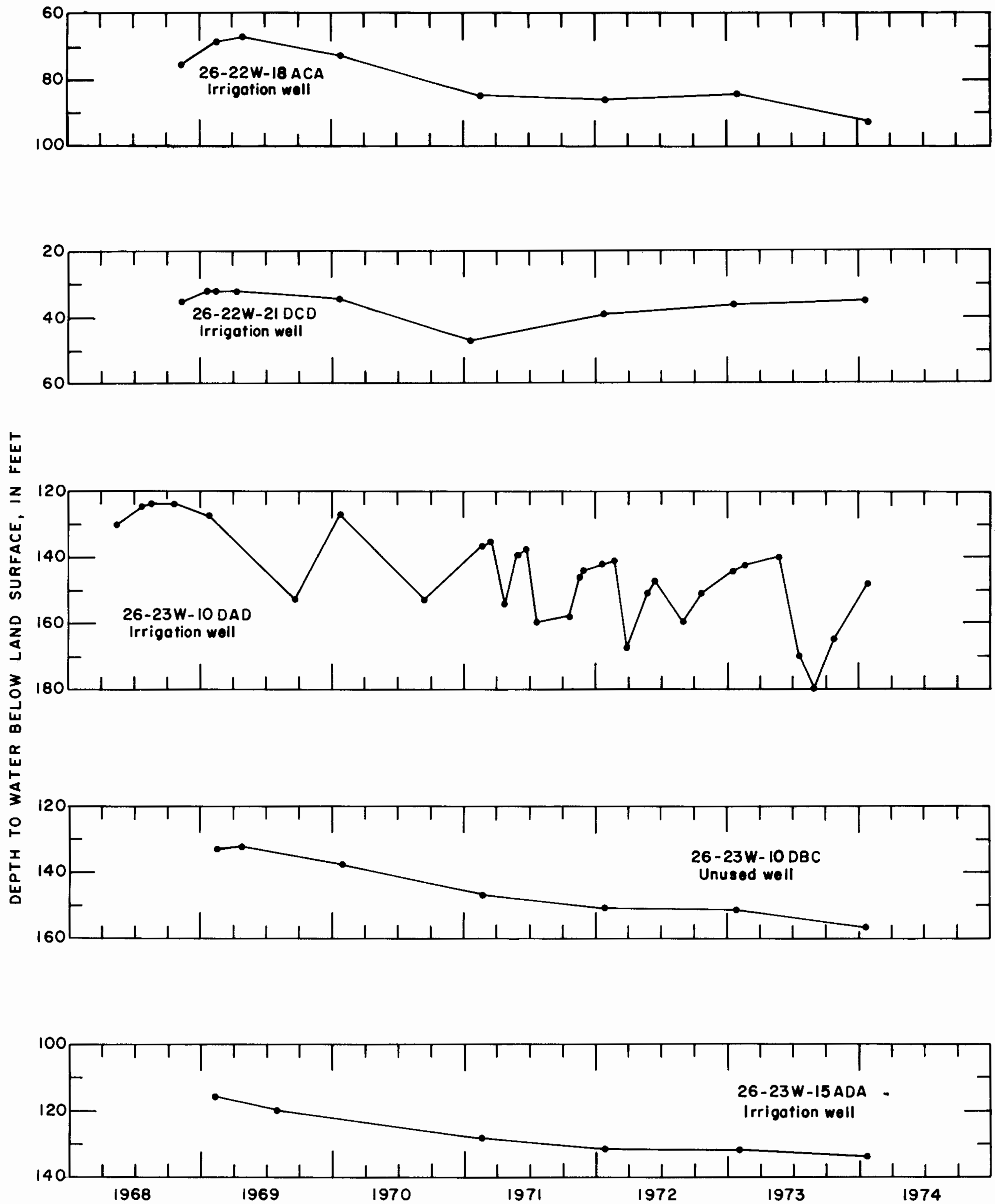

FIGURE 13.—Hydrographs for selected wells in Dakota Formation (concluded).

Table 4.—Records of selected wells.

Well number (1)	Owner or user	Year completed (19...)	Depth of well (ft) (2)	Diameter of casing (in)	Method of lift and type of power (3)	Use (4)	Yield (gal/min) (5)	Specific capacity: Gal/min/ft dd (6)	Specific capacity: Hrs	Altitude of land surface above mean sea level (ft) (7)	Depth to water below lsd (ft) (8)	Date of measurement (9)	Acres irrigated	Power consumption per acre-ft: Kwh (10)	Power consumption per acre-ft: Ft³ ng/100	Power consumption per acre-ft: Gal diesel fuel
					HODGEMAN COUNTY											
21-21W-31DDA	Jim Wright	47	360 R		CY,W	S					290.	6/72				
21-22W-27CB	Claude Selfridge	45	287 R			D,S					180.	5/72				
21-23W- 3CDB	R. G. Frusher	61	400 R			D					200.	6/72				
21-24W-27BCC	Roy Croft	56	330 R			D,S					80.	5/72				
21-26W-16BBA	Merle Evans		368 R	6		S					200.	5/69				
22-22W-19ABB	Ethel Oppy		228 R			S					208.	5/72				
22-24W-14BBC	Clare Shriwise		560 R	16	T,NG	I,O	850	5	960	2,460	255.	3/73	500		89	
22-24W-15BDA	William McKibben		585 R	12	T,NG	I,O	1,300	7	312	2,463	250.	3/73	400		117	
22-24W-16ACC	Wayne Shriwise		365 R	6	CY,W	D				2,470	262.	6/73				
22-24W-16ADB	Wayne Shriwise		565 R	16	T,NG	I,O	560	6	960	2,465	245.	5/73	110		138	
22-24W-16ADB2	Wayne Shriwise	72	565	1	N	O				2,465	243.	5/73				
22-24W-24DDC	Bernard Springer	60	430 R			D,S					90.	5/72				
22-24W-32AAB	Mrs. Wilbur Walter		340 R	6		D,S,O				2,454	226.	3/73				
22-24W-34CDD	Cecil Shelton	66	390 R			D,S					80.	5/69				
22-26W-23DCC	L. L. Glunt		505 R			S										
23-22W- 7DAA	Fred Korf	72	482 R	1		O				2,239	86.	5/73				
23-22W-29DDD	Frank Sebes		350 R			S					40.	5/72				
23-23W- 3CBD	Quinton Hubin	69	257 R	16	T,E	I	300			2,222	27.	2/73	50	481		
23-23W- 4AAD	3 J Ranch	68	282 R	16	T,D	I,O	290	2	960	2,235	38.	4/73	59			
23-23W- 4DCA	L. G. Hoagland		260 R	16	T,LPG	I,O	760	4	312	2,230	27.	3/73	130			
23-23W- 6CAB	City of Jetmore		385 R	16	T,E	PS				2,263						
23-23W- 9BBD	3 J Ranch		290 R	16	T,D	I,O	440			2,254			125			
23-23W-12ABD	3 J Ranch	68	245 R	14	T,D	I,O	330				107.	3/73	110			
23-23W-12BCC	3 J Ranch	70	265 R	16	T,LPG	I	300			2,260	125.	2/73	30			
23-23W-12CAC	3 J Ranch	68	256 R	12	SUB,E	I	130	6	552	2,280	147.	2/73				
23-23W-12DDB	3 J Ranch	70	275 R	16	T,D	I	200			2,302	165.	2/73	135			
23-23W-15DAB	State of Kansas				SUB,E	PS										
23-23W-21AAC	3 J Ranch	72	395 R	15	T,D	I	660	4	960				130			
23-24W- 1AAC	City of Jetmore		395 R	16	T,E	PS				2,315						
23-24W- 1C	City of Jetmore			16	T,E	PS										
23-24W-28BCC	Heating/Cooling Inc.	72	570 R	1		O				2,481	213 R	3/73				
23-25W- 7B	Ray Wilson	64	505 R			D,S					220.	6/72				
23-25W-11ADA	Roy Carder		200 R	6		D,S					80.	5/69				
23-25W-22DBB	Roy Carder		575 R	16	T,D	I	1,030	8	984	2,522	233.	5/73	196			34
23-26W- 7CCC	Harry Cohoon		490 R	16	T,D	I,O	1,150	12	600	2,612	306.	7/73	210			31
24-21W-30ABB	Vernon Katz		250 R	16	T,E	I	180			2,341						
24-21W-30ABC	Vernon Katz		250 R	16	T,E	I	150			2,341						
24-23W- 6AAB	Frank Wolf		517 R	16	T,D	I	750	5	960	2,457	227.	5/73	150			
24-23W-22B	Raymond Fagan		200 R			D										
24-23W-26CCB	Russell Beil		117 R	2	CY,W	S,O				2,299	33.	5/73				
					FORD COUNTY											
25-21W-18CCD	Kermit Froetschner				T,E	I	130			2,384			23			
25-21W-23BCB	Gail Hubbell	69	127 R	16	T,E	I,O	1,040			2,311	63.	3/73	140			
25-22W- 7ACA	Kermit Froetschner	68	350 R	16	T,D	I,O	750	7	960	2,441	164.	5/73	160			30
25-22W-27CCD	James Nietling		240 R		CY,W	D,O				2,432.	123.	5/73				
25-22W-30DCC	City of Spearville			16	T,E	PS										

Table 4.—Records of selected wells (concluded).

Well number (1)	Owner or user	Year completed (19__)	Depth of well (ft) (2)	Diameter of casing (in)	Method of lift and type of power (3)	Use (4)	Yield (gal/min) (5)	Specific capacity: Gal/min/ft dd (6)	Specific capacity: Hrs	Altitude of land surface above mean sea level (ft) (7)	Depth to water below lsd (ft) (8)	Date of measurement (9)	Acres irrigated	Power consumption per acre-ft: Kwh (10)	Power consumption per acre-ft: Ft³ ng/100	Power consumption per acre-ft: Gal diesel fuel
25-22W-34DDB	Norbert Tasset	73	410 R	14	T,D	I	460 R			2,423			120			
25-23W-11CCC	KGS + USGS	68	385	1	N	O				2,424	75.	5/73				
25-23W-12BBB	KGS + USGS	72	362	1	N	O				2,390	117.	5/73				
25-23W-14ADD	T. Gleason		263 R	5		D,S,O				2,452	171.	5/73				
25-23W-25CCC	Donald Stein		372 R	16	T,D	I,O	1,280	9	912	2,463	166.	2/73	160			
25-23W-32DBB	Tom Feist	68	380 R	16	T,D	I,O	520	2	912	2,463	150.	5/73	230			
25-23W-34CCB	Bernard Knoeber	67	350 R	16	T,D	I,O	810			2,461			160			
25-23W-35ADC	Wendeline Stegman	67	360 R	16	T,D	I,O	1,200	17	960	2,461	163.	2/73	160			
25-23W-35DAD	Melvin J. Stein		310 R			D,O				2,456.	158.	2/73				
25-23W-35DDB	Melvin J. Stein		300 R	16	T,D	I,O	1,280			2,457	157.	2/73	160			
25-23W-36BDA	Josephine Stein		380 R	16	T,D	I	1,200	22	696	2,466	170 R	3/73	180			32
26-21W- 1ACA	Jack Kersting	68	165 R	16	T,E	I	740			2,264	20.	5/73	34			
26-21W- 1BCA	Jack Kersting		135 R	16	T,E	I	750			2,263			50			
26-21W-11CBD	H. W. Wetzel	67	174 R	16	T,D	I,O	770			2,280	22.0	5/73	100			
26-21W-13BD	H. C. Wetzel		25 R			D,S										
26-21W-17DBC	Larry Strong	73		12		O				2,348	49.1	5/73				
26-22W- 5CBA	D. D. Imel	73	435 R	16	T,D	I	150			2,435			110			
26-22W- 6BCD	James Knoeber		350 R	16	T,D	I	430			2,431.			180			26
26-22W- 6CCA	Melvin Habiger	68		18	T,D	I				2,414	98.0	5/73	80			
26-22W- 8CAD	American Products	73	243 R	16	T,D	I	400 R			2,427			135			
26-22W- 8DDC	D. D. Imel			16	T,D	I	510			2,434	108.	2/73	83			
26-22W-11CDC	B. L. Hornung		154 R	12	T,E	I	380			2,356	22.	5/73	50			
26-22W-18ACA	Ford Co. Bank		273 R	16	T	I,O				2,404	82.	5/73				
26-22W-21DCD	Norbert Tasset	68	360 R	14	T,D	I,O	930	4	504	2,377	35.	5/73	180			26
26-22W-24AAA	Cletus Heeke	68	250 R	12	T,NG	I	880			2,335					137	
26-23W-10DAD	J. A. McGwin		278 R	16	T,E	I,O	700 R	7	960	2,463	140.	5/73	163	291		
26-23W-10DBC	J. A. McGwin		280 R		N	O				2,475.	151.	2/73				
26-23W-12BDB	Merle Barnes				T,D	I	650			2,439			163			
26-23W-15ADA	William Claussen		288 R	16	T,D	I,O	700	6	984	2,465	128.	5/73	101			28
26-23W-15DCD	William Claussen		330 R	16	T,D	I	890			2,468			131			25
27-21W-29DBB	Albert Miller		126 R	12	T,E	I				2,318			65			
27-21W-29DBB2	Albert Miller		126 R	12	T,E	I	340			2,318			65			
27-21W-30DDD	Albert Miller		126 R	12	T,E	I	670			2,328			65	258		
27-21W-31CBB	Leo Konda		115 R	12	T,D	I	1,330	20	312	2,335	10.0	8/73	80			
27-22W- 9DAB	Henry Schomaker		390 R	16	T,D	I	450			2,418			60			
27-22W-13CDD	Henry Schomaker	73	246 R	12	T	I	1,200			2,412	23.	11/73	135			
27-22W-16CCA	Duane Riegel		240 R	12	T,E	I	1,080			2,415			130	244		
27-22W-19AAC	Ford Land + Cattle				T,E	I	870			2,418			135	461		
27-22W-19DAB	Ford Land + Cattle				T,E	I	1,130			2,417			135	390		
27-22W-20BBD	Ford Land + Cattle			16	T,E	I	1,060			2,418			135	458		
27-22W-20CAC	Ford Land + Cattle			16	T,E	I	1,090			2,420			135	461		
27-22W-20DAB	Ford Land + Cattle				T,E	I	1,200 R			2,415			135	388		
27-22W-20DCD	Ford Land + Cattle				T,E	I	780			2,412			135			
27-22W-29BDD	Ford Land + Cattle		90 R	16	T,E	I				2,403						
27-22W-29CAA	Ford Land + Cattle		110 R	16	T,E	I				2,405						

27-22W-36AAD	Leo Konda		115 R	12	T,E	I	560		2,341			80	
27-23W-15DCB	Francis Ricke	70	442 R	12	T,D	I	2,200		2,399			147	24
27-23W-16BAB	Stanley Kliesen	69	470 R	16	T,D	I			2,416				
27-23W-24BCB	Elmer Riegel	72	220 R	16	T,D	I	1,550		2,395		4/73	106	14

(1) Numbering system described in text.
(2) Depths of wells given in feet below land surface—no letter after number, measured; R, reported.
(3) Method of lift—CY, cylinder; N, none; SUB, submersible; T, turbine. Type of power—D, diesel; E, electric; LPG, liquid petroleum gas; NG, natural gas; W, wind.
(4) Use—D, domestic; I, irrigation; O, observation; PS, public supply; S, stock.
(5) Yield gal/min, yield given in gallons per minute—no letter, measured during present study; R, reported.
(6) Specific capacity—gal/min/ft dd, gallons per minute per foot of drawdown for the time shown in hours.
(7) Altitude of land surface in feet above mean sea level—measured when followed by decimal point (.); others determined by topographic map or altimeter.
(8) Depth to water below land surface datum (lsd) in feet—measured depths less than 100 feet are given to nearest 0.1 foot, and those greater than 100 feet are given to nearest foot followed by decimal point (.); R, reported.
(9) Date of water-level measurement—month and year.
(10) Power consumption—kwh, kilowatt hours of electricity per acre-foot of water pumped; ft^3 ng/100, hundreds of cubic feet of natural gas per acre-foot of water pumped; gal diesel fuel, gallons of diesel fuel per acre-foot of water pumped.

TABLE 5.—Logs of test holes.

21-21W-34ADA.—Drilled October 17, 1972. Altitude 2,121 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Alluvium		
Clay, dark-brown	3	3
Clay, medium-brown	1	4
Clay, light-brown	4	8
Clay, dark-brown	2	10
Clay, medium-brown	4	14
Clay, light-brown	6	20
Sand and clay streaks	10	30
Sand, fine to coarse, brown, and fine to medium gravel; contains gray clay streaks	32	62
Sand, fine to medium, loose, gray, with a few very thin clay streaks	10	72
Sand, fine, silty, brown	3	75
Sand, fine to medium, loose, brown	7	82
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained, slightly cemented, tan	13	95
Sandstone, fine-grained, yellow-orange	5	100
Clay, gray	18	118
Clay, red	2	120
Clay, sandy, gray and red	10	130
Clay, gray and red, with a few thin hard layers	65	195
Clay, dark-gray, light-gray, and red	10	205
Clay, slightly sandy, light-gray	2	207
Clay, light-gray, dark-gray, and red, with thin hard streaks	3	210
Clay, dark-gray and red, with gray thin hard sandstone layers	25	235
Kiowa Formation		
Clay, dark-gray, with thin hard layers	20	255
Clay, sticky, gray, with a few thin hard layers	45	300
Clay, sticky, gray, with a few thin hard layers; contains shell material	15	315
Clay, sticky, gray, and hard gray clay; contains a few very thin hard streaks	15	330
Clay, dark-gray, with a few gray and black thin shale layers and gray hard sandstone layers	67	397
Cheyenne Sandstone		
Clay, very slightly sandy, green	5	402
Clay, green turning to red with depth	17	419
PERMIAN SYSTEM		
Undifferentiated red beds		
Clay, red	15	434

21-22W-26BBB.—Drilled October 19, 1972. Altitude 2,260 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY AND TERTIARY SYSTEMS		
Pleistocene and Pliocene Series, undifferentiated		
Topsoil, dark-brown	2	2
Silt, sandy, tan, with limestone chips as large as 6 inches in diameter	5	7
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Limestone, and yellow and white clay	3	10
Shale, light-tan and white, with light-yellow and white limestone layers	5	15
Shale, yellow, and white limestone layers; contains a few dark-gray thin shale layers	20	35
Shale, black, and light- to dark-gray limestone	20	55
Shale, black, and light-gray limestone	4	59
Bentonite, light-gray	1	60
Shale, black, and light-gray limestone	15	75

Graneros Shale		
Shale, black	10	85
Bentonite, light-gray	1	86
Shale, black; contains a few hard layers	24	110
Lower Cretaceous Series		
Dakota Formation		
Clay, sticky, gray, with gray thin hard silty sandstone layers	35	145
Clay, very light gray, and yellow and red clay	10	155
Clay, very light gray, and light-tan clay	25	180
Clay, very light gray, and red clay	15	195
Clay, red, very light gray, and yellow	15	210
Clay, very light gray and red	15	225
Clay, very light gray, red, and yellow	47	272
Clay, pale dusky-red, with lignite streaks	16	288
Clay, light-gray, and light-gray very fine grained sandstone	12	300
Clay, very light gray, red, and yellow	15	315
Clay, light-gray and red	30	345
Clay, gray and red, with some ironstone layers and a small amount of sand	20	365
Clay, red	5	370
Clay, dark-gray, light-gray, and red	20	390
Clay, dark-gray, black, light-gray, green, and red; contains thin lignite beds and a small amount of pyrite	17	407
Sandstone, fine-grained, gray	3	410
Kiowa Formation		
Clay, dark-gray, with hard layers	6	416
Sandstone, fine-grained, gray	5	421
Clay, dark-gray, with thin hard layers	35	456
Clay, dark-gray, with thin hard layers; contains small shell fragments	6	462
Clay, dark-gray	24	486
Clay, dark-gray, with very hard layers	12	498
Shale, black, with light-gray shale; contains very hard layers and numerous large shell fragments	14	512
Shale, hard, black	49	561

22-23W-27BAA.—Drilled September 9, 1972. Altitude 2,335 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Clay, brown	5	5
Clay, limy, tan	3	8
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Clay, gray to yellow (weathered shale)	3	11
Clay, gray to yellow, and gray to yellow limestone	6	17
Bentonite, light-gray	1	18
Clay, gray to yellow, and gray to yellow limestone	9	27
Clay, red	1	28
Clay, gray to yellow, and gray to yellow limestone	16	44
Shale, hard, gray, and orange bentonite	1	45
Shale, gray, and gray limestone	10	55
Shale, black, with thin limestone layers	3	58
Bentonite, orange to white, and black shale	1	59
Shale, hard, black, and gray limestone	59	118
Graneros Shale		
Bentonite, pale-gray, dark-green shale and gray and black shale	2	120
Shale, gray to black, with thin hard limestone and sandstone layers	51	171
Lower Cretaceous Series		
Dakota Formation		
Clay, gray	9	180
Clay, carbonaceous, dark- to very dark gray, with a few lignite streaks	12	192
Sandstone, very fine grained, silty, light-gray and dark-gray clay	16	208
Lignite	1	209
Clay, sandy, gray, with lignite streaks	16	225
Clay, gray	10	235
Clay, gray and red	12	247
Sandstone, fine- to medium-grained, hard, brown	3	250
Clay, sandy, brown, and lignite	5	255
Clay, gray, brown sandstone, brown clay, and a few streaks of lignite	43	298
Clay, red and gray, with brown sandstone layers	104	402
Clay, dark-gray	5	407
Clay, dark-gray, red, and green	4	411
Clay, dark-gray and red, with sandstone and ironstone layers	39	450
Kiowa Formation		
Clay, dark-gray, with hard layers	77	527

22-24W-16ADB2.—Drilled September 18, 1972. Altitude 2,465 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY AND TERTIARY SYSTEMS		
Pleistocene and Pliocene Series, undifferentiated		
Clay, dark-brown	4	4
Clay, yellow-green	6	10
Clay, brown, with thin fine sand layers	9	19
Caliche, granular, white	3	22
Clay, hard, brown, with caliche and fine to medium sand	16	38
Sand, fine, lime-cemented, tan and pink to brown, with thin hard clay layers	7	45
Clay, pink to tan, with a few thin sand and caliche layers	20	65
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Fairport Chalk Member		
Clay, yellow to yellow-orange, gray, and white	16	81
Clay, dark-gray to dark-brown, with white bentonite streaks	4	85
Shale, black, with light-gray bentonite layers	5	90
Shale, black, with thin moderately hard layers; contains bentonite and a few shells	47	137
Greenhorn Limestone		
Shale, gray to black, with dark-gray limestone layers	23	160
Shale, gray to black, with gray fossiliferous limestone layers and light-gray bentonite layers	20	180
Shale, gray to black, with gray limestone layers	75	255
Graneros Shale		
Shale, black, with very dark gray thin limestone layers	15	270
Shale, black, with very dark gray thin sandstone layers	15	285
Lower Cretaceous Series		
Dakota Formation		
Clay, dark-gray	15	300
Shale, light-gray to black, with thin lignite layers	45	345
Sandstone, fine- to very fine grained	50	395
Shale, black, and fine-grained sandstone	40	435
Sandstone, very fine to medium-grained	30	465
Sandstone, with thin hard layers	15	480
Sandstone, fine- to medium-grained, with a few very soft and a few very hard layers	80	560
Shale, black, red, and gray	5	565

23-21W-16DDD.—Drilled October 13, 1973. Altitude 2,345 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Topsoil, dark-brown	1	1
Silt, light-tan	5	6
TERTIARY SYSTEM		
Pliocene Series		

Ogallala Formation		
Caliche, white, and tan sandy silt	5	11
Caliche, hard, white	2	13
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Clay, white to yellow, with thin limestone layers	15	28
Shale, black, with thin limestone layers	12	40
Shale, black, with a thin bentonite layer	1	41
Shale, black, with thin limestone layers	16	57
Graneros Shale		
Bentonite, gray shale, and green shale	3	60
Shale, black, with a few thin hard layers	29	89
Limestone, brown	1	90
Shale, black	11	101
Lower Cretaceous Series		
Dakota Formation		
Clay, dark-gray	3	104
Sandstone, very well cemented, brown	1	105
Clay, dark-gray	16	121
Clay, dark-gray and lignite	14	135
Clay, sandy, dark-brown, with lignite streaks	20	155
Clay, sandy, gray, and white siltstone	11	166
Sandstone, brown to gray, and white clay	24	190
Sandstone, brown, and white to red clay	25	215
Sandstone, hard	2	217
Sandstone and clay	10	227
Clay, gray, white, black, and red, with a few sandstone streaks	37	264
Clay, red	2	266
Clay, gray, red, and black	34	300
Clay, sandy, gray and red	30	330
Sandstone, fine-grained, pink	30	360
Sandstone, fine- to medium-grained, brown	20	380
Sandstone, fine- to medium-grained, brown, with hard layers	15	395
Kiowa Formation		
Clay, sandy, gray, with hard layers	12	407
Clay, dark-gray, with thin hard layers	28	435
Clay, dark-gray, with a few thin hard layers	39	474
Clay, dark-gray, hard; contains shells and fish scales	2	476
Clay, dark-gray, with thin hard layers	4	480

23-22W-7DAA.—Drilled October 4, 1972. Altitude 2,239 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Topsoil, brown	1	1
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Clay, sandy, limy, tan, with tan clay layers	14	15
Clay, sandy to gravel, limy, tan, with tan clay layers	13	28
Clay, brown to gray-brown	2	30
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, gray to red	11	41
Clay, red	3	44
Clay, gray, red, and yellow	10	54
Sandstone, fine- to medium-grained, yellow	6	60
Ironstone and gray clay	1	61
Sandstone, yellow to brown	5	66
Clay, gray to red and yellow, with fine-grained sandstone streaks	12	78
Clay, gray to red and brown	12	90
Clay, light-gray	5	95
Clay, dark-gray	5	100
Clay, light-gray	2	102
Clay, gray and red	13	115
Clay, gray	12	127
Clay, very dark gray	5	132
Clay, gray, with some red clay	3	135
Clay, gray, with lignite layers	5	140
Clay, gray, with some red clay	14	154
Sandstone, gray	2	156
Clay, carbonaceous, gray, with lignite	3	159
Sandstone, fine-grained, yellow to brown	8	167
Clay, gray and yellow	13	180
Clay, gray, with a few hard streaks	12	192
Clay, gray and red	34	226
Clay, light-gray and red	11	237
Kiowa Formation		
Clay and shale, dark-gray, light-gray, and red, with hard sandstone layers	90	327
Shale, black	23	350
Shale, black; contains shells	10	360
Shale, black, with thin hard layers	60	420
Cheyenne Sandstone		
Shale, sandy, gray to black, with thin hard layers	20	440
Siltstone, white to light gray-green	5	445
PERMIAN SYSTEM		
Undifferentiated red beds		
Shale, red, with a few thin hard layers	37	482

23-24W-28BCC.—Drilled September 25, 1972. Altitude 2,481 feet. Depth to water 199.02 feet (October 24, 1972).

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Silt, slightly sandy, dark-brown	2	2
Silt, sandy, limy, tan	4	6
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Caliche, sandy, silty in layers	15	21
Silt, well-cemented, tan	4	25
Silt, cemented, sandy, tan	10	35
Sand, cemented, tan	2	37
Silt, cemented, tan	2	39
Sand, cemented, tan, and tan cemented silt with a small amount of clay; contains small gypsum (?) nodules and limestone pebbles	4	43
Sand, fine to coarse, tan	5	48
Sand, fine to coarse, brown, and fine to medium gravel	7	55
Clay, yellow	1	56
Silt, sandy, brown	12	68
Silt, sandy, tan	5	73
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Clay, white to yellow	3	76
Clay, very dark brown	4	80
Limestone (?), hard, black	1	81
Shale, black, with gray thin limestone layers and a few thin bentonite layers	69	150
Graneros Shale		
Shale, black, with a few thin limestone layers	42	192
Lower Cretaceous Series		
Dakota Formation		
Clay, gray, with a few hard layers	18	210
Clay, gray, with white silt layers and a few very thin sandstone layers	21	231
Lignite	1	232
Sandstone, very fine to fine-grained, gray to brown, with gray thin clay layers	8	240
Sandstone, very fine grained, gray, with white silt and gray shale	22	262
Sandstone	2	264
Sandstone, hard	1	265
Sandstone, takes water	5	270
Sandstone, silty, light-gray, and light-gray clay with a small amount of red clay	35	305
Sandstone	8	313
Sandstone, very silty, light-gray, and light-gray clay	6	319

	Thickness, in feet	Depth, in feet
Sandstone, hard	1	320
Clay	6	326
Sandstone	29	355
Clay, dark-red, and sandstone; contains gray to white clay	14	369
Clay, hard, light- to dark-gray, and gray very fine grained sandstone	25	394
Clay, hard, light- to dark-gray, and very fine grained sandstone with lignite	2	396
Sandstone, hard	1	397
Clay, sandy, gray to light-gray; contains some clay	18	415
Sandstone	1	416
Clay, gray and light-gray, and sandy clay	28	444
Clay, red to gray-green, maroon, and gray, with a hard layer at 462 feet	36	480
Clay, red to gray-green and gray, with hard ironstone layers	16	496
Kiowa Formation		
Clay, gray	8	504
Clay, gray, with gray thin hard sandstone layers	36	540
Shale, black, and gray clay with thin very hard shale layers	30	570

24-23W-3BCD.—Drilled October 1972. Altitude 2,410 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Topsoil, brown	2	2
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Caliche and orange clay	3	5
Caliche; contains hard and soft layers	8	13
Silt, sandy, tan, and caliche	7	20
Caliche, hard; contains a few hard silt and silty sand streaks	12	32
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Limestone, white, and weathered tan to gray shale; lost circulation at 40 feet	8	40
Shale, black	12	52
Shale, black, with gray limestone and light-gray bentonite layers	38	90
Graneros Shale		
Shale, dark-gray, with black oily shale streaks	30	120
Lower Cretaceous Series		
Dakota Formation		
Clay, sticky, dark-gray	30	150
Clay, gray, with thin well-cemented sandstone layers	35	185
Clay, dark-gray	10	195
Clay, light-gray, with a small amount of pink clay	15	210
Clay, gray to red, with a few thin hard sandstone layers	50	260
Lignite and dark-gray clay	10	270
Clay, light-gray, with hard streaks	15	285
Clay, brown, and lignite; contains tan and light-gray clay	15	300

25-23W-11CCC.—Drilled August 5, 1968. Altitude 2,423 feet. Depth to water 98 feet.

	Thickness, in feet	Depth, in feet
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Silt, pink, with fine sand and clay	10	10
Sand, pink, very fine to fine, with silt, clay, and caliche	20	30
Sand, very fine to medium, with some silt and clay	9	39
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Shale, platy, black, with ledges of brown to black chalky limestone (streak of gray bentonite at 80 feet)	46	85
Graneros Shale		
Shale, firm, light-gray	11	96
Limestone, platy, black, with thin gray shale ledges	4	100
Shale, light-gray, with thin black limestone ledges	9	109
Ironstone, hard, black	1	110
Shale, hard, light-gray, with thin brown to black chalky limestone ledges	17	127
Shale, very hard, blocky, black	5	132
Lower Cretaceous Series		
Dakota Formation		
Ironstone, hard, dark-gray	1	133
Shale, sandy, tight, light-gray	9	142
Shale, firm, very light gray, with brown and red streaks	14	156
Shale, light-gray, with thin gray sandstone ledges	1	157
Shale, tight, very light gray, with brown and red streaks	5	162
Shale, tight, dark-gray, with brown and red streaks	22	184
Ironstone, hard, gray, with thin gray shale streaks	4	188
Shale, tight, gray, with brown, yellow, red, and black clay streaks	13	201
Ironstone, silty, hard, dark-gray, with gray shale ledges	2	203
Shale, tight, dark-gray, with red and yellow clay streaks	9	212
Ironstone, silty, tightly cemented, gray	11	223
Shale, very tight, gray	10	233
Shale, silty and sandy, tight, gray	19	252
Ironstone, hard, gray to tan, with sandy shale ledges	8	260
Shale, very tight, dark-gray, with brown and red clay streaks	15	275
Shale, sandy, tight, gray, with loose sandstone ledges	5	280
Shale, yellow to gray, firm, with tan sandstone ledges	52	332
Sandstone, silty, firm, gray, with gray to black shale ledges	33	365
Sandstone, tan to light-gray, firm to loosely cemented ledges; contains a few black shale streaks	19	384
Shale, hard, black	1	385

25-23W-12BBB.—Drilled October 25, 1972. Altitude 2,390 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Soil, dark-brown	5	5
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Clay, sandy, orange, with caliche	8	13
Sand, fine to coarse, and fine to medium gravel	27	40
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Graneros Shale		
Limestone, white	1	41
Clay, yellow to light-gray	2	43
Shale, black, with dark-gray hard limestone layers	12	55
Lower Cretaceous Series		
Dakota Formation		
Clay, sticky, very dark gray	20	75
Clay, light-gray to dark-gray; contains some lignite	15	90
Clay, light-gray	15	105
Clay, light-gray and red	60	165
Sandstone, fine- to medium-grained, brown; contains some ironstone	30	195
Sandstone, fine-grained, with ironstone and some red to gray clay	7	202

	Thickness, in feet	Depth, in feet
Sandstone, fine-grained, very loose	3	205
Sandstone, fine- to medium-grained, brown, with ironstone and red to gray clay	30	235
Clay, very sandy, red	5	240
Clay, red and gray, with hard streaks	25	265
Clay, very sandy, yellow	10	275
Clay, gray and red, with hard streaks	8	283
Clay, red	3	286
Sandstone, fine- to medium-grained, hard, red to brown, with layers of red and gray clay	44	330
Clay, red to gray	15	345
Clay, dark-gray, with lignite streaks	17	362

26-22W-23BAA.—Drilled August 22, 1972. Altitude 2,375 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Silt, brown	5	5
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, soft, light-gray, with some brown iron-oxide-stained clay	10	15
Clay, soft, light-gray, with thin ironstone streaks	25	40
Clay, dark-gray, with several lignite layers 1-foot thick	15	55
Clay, carbonaceous, dark-gray, with thin layers of lignite	20	75
Clay, hard, gray to brown, and lignite layers (rough drilling)	15	90
Clay, hard, brittle, brown, yellow, and gray	15	105
Clay, hard, brittle, brown and yellow, with red mottled gray clay and gray slightly sandy clay	15	120
Clay, sandy, gray, with ironstone and light-brown sandstone	15	135
Sandstone, slightly cemented, with dark-brown ironstone streaks	13	148
Clay, slightly sandy, light-gray and red	17	165
Clay, hard to soft, light-gray, dark-gray, and red	30	195
Clay, light- to dark-gray and red, with dark-brown sandstone streaks	30	225
Sandstone, fine- to medium-grained, light-brown, with few clay streaks	18	243
Clay, gray, yellow, dark-gray, and red, with a few sandstone streaks	27	270
Clay, red, green, yellow, and gray, with very fine grained sandstone streaks	30	300
Clay, gray, green, red, and dark-gray	40	340
Clay, gray, with a small amount of red clay	20	360
Kiowa Formation		
Clay, gray	48	408
Shale, very hard, black	17	425

27-22W-8DDD.—Drilled August 25, 1972. Altitude 2,416 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY SYSTEM		
Pleistocene Series		
Dune sand		
Sand, fine, silty, tan	10	10
TERTIARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Caliche, sandy, with gray clay; caved during drilling	5	15
Caliche, sandy, and tan sandy clay	18	33
Sand, fine to coarse, and fine to medium gravel	19	52
Clay, tan	3	55
Caliche	2	57
Sand, silty, tan	5	62
Clay, tan	4	66
Sand, fine to coarse, and fine to medium gravel with clay layers	57	123
Sand, fine to coarse, silty, brown, with a few hard layers	19	142
Sand, fine to coarse, silty, brown, with many thin hard layers	8	150
Sand, fine to very fine, well-cemented	8	158
Sand, fine to coarse, silty, iron-stained	4	162
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellow, brown, and gray, with ironstone layers	23	185
Clay, gray	12	197
Clay, gray and red, with sandstone and lignite streaks	19	216
Clay, gray and red	23	239
Clay, gray and red, with sandstone streaks	39	278
Clay, gray and red	52	330
Clay, gray, with a small amount of red clay	25	355
Clay, light- to dark-gray, and red clay streaks with hard layers	35	390
Clay, dark-gray	12	402
Kiowa Formation		
Clay, dark-gray, with hard streaks	43	445
Clay, dark-gray, with streaks of very fine grained silty slightly cemented sandstone	22	467
Clay, dark-gray, with a few hard streaks	53	520
Clay, dark-gray, with a few hard streaks; contains fish scales and a small amount of shell material	15	535
Clay, dark-gray, and black very hard shale	45	580
Shale, hard, black; contains a few gypsum crystals	15	595

27-22W-35AAD.—Drilled July 18, 1972. Altitude 2,392 feet.

	Thickness, in feet	Depth, in feet
QUATERNARY AND TERTIARY SYSTEMS		
Pleistocene and Pliocene Series, undifferentiated		
Topsoil, dark-brown	1	1
Silt, sandy, light-tan	7	8
Silt, limy, slightly cemented, and fine to medium sand	19	27
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellow and gray	5	32
Clay, gray, red, yellow, maroon, and brown, with a few thin ironstone layers	30	62
Clay, moderately soft, dark-gray, with buff-tan and red clay	22	84
Clay, soft, sticky, gray	8	92
Clay, dark-gray, with a few hard streaks	17	109
Clay, dark-gray	6	115
Sandstone, very fine grained, light-gray, and light-gray clay with hard streaks	20	135
Clay, dark-gray, with a small amount of lignite and gray thin sandstone streaks	5	140
Kiowa Formation		
Clay, dark-gray, with thin streaks of very fine grained sandstone	115	255
Clay, dark-gray; contains hard streaks of very fine grained sandstone and some shells and fish scales	15	270
Clay, dark-gray, with thin hard sandstone layers	47	317
Clay, dark-gray	13	330
Shale, black	19	349
Cheyenne (?) Sandstone		
Shale, black, with very fine grained sandstone and sandy shale layers	41	390
Clay, light-gray	15	405
Clay, light-brown to dark-buff	25	430
PERMIAN SYSTEM		
Undifferentiated red beds		
Clay, red-brown	20	450

TABLE 6.—Chemical analyses of water from selected wells in the Dakota Formation.

Well number	Well depth (feet)	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180° C)	Hardness (Ca, Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos/cm at 25° C)	pH
HODGEMAN COUNTY																						
21-21W-31DDA	360	6/16/72	15.5	8.4	3.1	0.14	27	14	480	19	0	271	190	540	3.0	5.3	1,420	125	0	19	2,440	8.0
21-22W-27CBC	287	5/21/72	18.5	13	2.5	.19	59	22	180	13	0	337	235	81	2.2	.4	768	238	0	5.1	1,210	7.9
21-23W- 3CDB	400	6/16/72	18.0	8.4	.31	.00	8.0	2.9	186	6.6	0	246	111	89	2.4	.7	548	32	0	14	880	8.1
21-24W-27BCC	330	5/21/72	18.0	7.6	.13	.00	6.4	4.9	175	6.8	0	237	112	75	2.6	.2	502	36	0	13	850	8.1
21-26W-16BBA	368	5/15/69	15.5	6.8	.62	.00	6.4	2.0	232	7.0	0	278	152	96	4.0	1.7	648	24	0	21	1,060	7.9
22-22W-19ABB	228	5/21/72	16.5	6.2	.87	.17	16	8.8	272	11	0	307	178	166	3.0	.9	810	76	0	14	1,370	7.8
22-24W-14BCC	560	7/24/73	......	11	.28	.00	19	12	128	5.5	0	242	79	65	2.0	.1	460	97	0	5.7	740	7.6
22-24W-15BDA	585	7/18/73	......	11	.14	.00	16	7.8	128	5.0	0	244	64	62	1.6	.1	410	72	0	6.6	690	7.5
22-24W-16ADB	565	7/18/73	19.5	10	.06	.00	16	8.8	134	5.5	0	242	85	49	2.4	.6	434	76	0	6.7	700	7.6
22-24W-24DDC	430	5/21/72	18.5	7.9	.59	.00	12	6.3	168	7.6	0	259	77	94	2.4	1.5	500	56	0	9.8	850	7.8
22-24W-34CDD	390	5/09/69	......	8.7	.05	.03	19	11	140	8.6	0	266	82	64	2.4	.9	464	92	0	6.3	770	7.6
22-26W-23DCC	505	5/21/72	16.5	7.9	.28	.00	4.8	2.9	447	11	0	393	244	291	5.6	.7	1,220	24	0	40	2,020	8.2
23-22W-29DDD	350	5/22/72	16.5	7.0	.74	.00	35	19	460	18	0	332	107	560	3.0	1.1	1,400	166	0	16	2,450	7.8
23-23W- 3CBD	257	7/17/73	16.5	11	.03	.00	40	10	189	8.2	0	293	108	143	2.4	1.1	652	141	0	6.9	1,120	7.3
23-23W- 4AAD	282	7/17/73	18.0	13	.05	.00	42	11	192	8.2	0	49	125	147	2.0	230	816	150	110	6.8	1,490	6.8
23-23W- 6CAB	385	6/19/72	18.5	11	1.2	.20	17	13	326	14	0	268	115	340	2.6	.0	974	96	0	14	1,730	7.9
23-23W- 9BBD	290	7/17/73	......	9.6	1.4	.00	19	9.8	195	7.2	0	278	88	131	2.4	.3	606	88	0	9.1	1,030	7.3
23-23W-12ABD	245	7/17/73	......	15	.05	.00	40	12	213	7.8	0	312	87	190	2.4	1.1	740	150	0	7.6	1,240	7.6
23-23W-12CAC	256	7/17/73	......	15	.10	.00	32	19	142	8.0	0	283	76	110	2.4	1.4	546	158	0	4.9	920	7.2
23-23W-21AAC	395	7/17/73	17.0	22	.05	.00	59	12	90	5.0	0	283	69	60	2.0	.7	460	196	0	2.8	730	7.5
23-24W- 1AAC	395	6/19/72	18.0	13	......	.24	30	11	191	10	0	283	109	144	2.4	1.5	652	120	0	7.6	1,100	7.7
23-25W- 7B	505	6/21/72	18.0	10	.66	.08	4.8	2.9	200	8.2	0	256	156	59	3.6	.7	578	24	0	18	930	8.1
23-25W-11ADA	200	5/15/69	16.5	5.8	.42	.00	18	9.5	132	8.2	0	254	114	33	2.8	.7	447	84	0	6.3	720	7.8
23-25W-22DBB	575	7/ /73	......	11	.48	.05	16	6.8	104	4.8	0	227	63	29	2.0	.2	362	68	0	5.5	590	7.6
23-26W- 7CCC	490	5/27/68	......	25	.15	.00	38	19	35	5.5	10	149	57	39	.8	4.2	322	173	35	1.2	500	8.4
24-23W- 6AAB	517	7/18/73	......	11	.63	.08	27	12	220	8.0	0	300	87	181	2.4	.1	712	117	0	8.9	1,220	7.8
24-23W-22B	200	5/09/69	17.0	6.6	.23	.00	14	20	252	18	0	307	186	160	4.0	.2	804	117	0	10	1,330	7.5
FORD COUNTY																						
25-21W-23BCB	127	7/06/73	......	30	0.03	0.00	64	11	34	3.0	0	283	17	16	0.8	2.2	310	204	0	1.0	520	7.5
25-22W- 7ACA	350	7/18/73	......	44	2.9	.02	42	18	59	5.8	0	283	46	20	2.2	1.2	374	179	0	1.9	560	7.9
25-22W-34DDB	410	7/20/73	......	49	.11	.00	78	15	24	4.0	0	264	21	35	.6	18	390	256	40	.7	570	7.4
25-23W-11CCC	385	8/19/68	18.0	......	1.3	.00	32	19	95	10	0	278	36	67	3.6	8.0	440	158	0	3.3	740	8.1
25-23W-25CCC	372	7/31/73	......	43	.03	.00	35	19	59	5.2	0	266	43	17	2.0	2.0	356	166	0	2.0	540	7.3
25-23W-32DBB	380	7/24/72	......	28	.11	.00	37	15	62	5.5	0	271	50	12	2.4	.9	352	154	0	2.2	540	7.3
25-23W-34CCB	350	7/24/73	......	46	.05	.00	35	20	45	4.8	0	256	39	10	2.2	2.7	334	170	0	1.5	490	7.4
25-23W-35ADC	360	7/18/73	......	50	.46	.00	42	18	38	4.5	0	261	31	12	2.0	2.4	314	179	0	1.3	480	7.4
25-23W-36BDA	380	7/09/73	......	42	.04	.00	43	16	50	4.5	0	261	32	18	2.0	7.3	340	174	0	1.7	530	7.3
26-21W- 1ACA	165	7/11/73	......	25	.44	.00	46	13	88	3.5	0	307	54	34	1.6	1.3	410	168	0	3.0	660	7.5
26-21W- 1BCA	135	7/11/73	......	26	.07	.00	42	9.5	88	3.2	0	281	55	30	1.6	.4	384	144	0	3.2	620	8.2
26-21W-11CBD	174	7/18/73	......	30	.40	.00	123	25	35	3.2	0	327	54	95	.5	32	580	410	142	.8	940	7.3
26-21W-13BD	25	5/20/64	......	21	.00	.00	101	44	108	4.7	0	339	180	137	1.4	16	780	433	155	2.3	1,250	7.5
26-22W- 5CBA	435	7/20/73	......	35	.33	.00	27	13	81	5.0	0	261	51	17	2.2	2.9	360	121	0	3.2	560	7.4
26-22W- 6BCD	350	7/11/73	......	34	.03	.00	29	13	74	5.0	0	256	50	15	2.4	2.2	364	126	0	2.9	550	7.3

26-22W- 6CCA	----	8/23/72	16.5	37	.05	.00	30	15	72	5.2	0	261	53	17	2.0	2.7	360	136	0	2.7	550	7.8
26-22W- 8CAD	243	7/24/73	----	19	.03	.00	30	15	90	4.5	0	259	80	22	2.0	.2	382	136	0	3.4	600	7.4
26-22W- 8DDC	----	7/18/73	----	21	.25	.00	26	11	82	4.2	0	234	77	16	2.4	.3	352	110	0	3.4	540	7.6
26-22W-11CDC	154	7/18/73	----	31	.42	.00	64	11	20	3.8	0	273	17	13	.4	.1	296	204	0	.6	470	7.3
26-22W-21DCD	360	7/24/73	----	14	.07	.00	43	11	148	5.2	0	283	137	74	3.1	2.1	578	152	0	5.2	920	7.8
26-22W-24AAA	250	8/14/73	----	26	.06	.00	32	11	100	3.8	0	259	70	42	1.1	.5	410	125	0	3.9	660	7.3
26-23W-10DAD	278	8/23/73	----	41	.08	.00	27	15	69	5.0	10	234	49	12	2.4	1.5	348	129	0	2.6	540	8.4
26-23W-15ADA	288	7/31/73	----	37	.02	.00	30	17	67	4.5	0	256	55	15	2.0	1.6	350	145	0	2.4	540	7.4
26-23W-15DCD	330	7/18/73	----	41	.05	.00	30	13	70	5.0	0	256	53	11	2.2	2.0	342	128	0	2.7	530	7.4
27-21W-29DBB2	126	7/12/73	----	47	.58	.00	75	20	106	3.5	0	227	228	40	1.2	22	654	269	83	2.8	960	7.7
27-21W-30DDD	126	7/12/73	----	31	.04	.00	144	30	132	4.0	0	334	348	68	.8	41	974	483	209	2.6	1,380	7.4
27-21W-31CBB	115	8/23/73	----	21	1.5	.17	171	32	86	5.5	0	329	366	49	1.6	42	948	558	288	1.6	1,360	7.6
27-22W- 9DAB	390	7/20/73	----	42	.19	.00	70	13	24	3.5	0	288	16	12	.4	15	338	228	0	.7	520	7.3
27-22W-13CDD	246	7/20/73	----	47	1.3	.00	70	7.2	22	3.2	0	256	12	11	.5	18	316	204	0	.7	480	7.4
27-22W-16CCA	240	7/ /73	----	58	1.6	.00	59	10	20	2.2	0	242	17	10	.4	11	302	188	0	.6	450	7.8
27-22W-19AAC	----	7/18/73	----	46	.46	.00	69	9.0	16	2.8	0	251	6.6	12	.4	14	310	209	3	.5	460	7.4
27-22W-19DAB	----	7/31/73	----	37	.03	.00	72	6.9	16	3.0	0	244	9.9	13	.3	24	324	208	8	.5	460	7.4
27-22W-20BBD	----	7/18/73	----	40	.03	.00	70	10	14	3.2	0	256	12	11	.4	8.5	310	216	6	.4	460	7.5
27-22W-20CAC	----	7/18/73	----	45	.93	.14	75	8.0	16	3.0	0	249	11	16	.4	24	320	220	16	.5	480	7.5
27-22W-20DCD	----	7/18/73	----	49	.03	.00	74	6.7	15	3.0	0	232	4.9	13	.5	33	320	212	22	.5	470	7.5
27-22W-29BDD	----	7/18/73	----	47	.07	.00	70	7.2	23	3.0	0	229	14	15	.4	34	336	204	16	.7	480	7.4
27-22W-29CAA	110	7/18/73	----	48	.03	.00	70	6.2	23	2.5	0	229	14	17	.4	34	340	200	12	.7	480	7.4
27-22W-36AAD	115	8/23/73	----	46	.12	.00	91	10	60	4.2	0	300	86	41	.3	10	506	268	22	1.6	770	7.5
27-23W-15DCB	442	7/09/73	----	23	.35	.00	51	13	88	4.8	0	259	66	61	1.6	6.2	450	180	0	2.9	720	7.5
27-23W-24BCB	220	7/18/73	----	27	9.3	.19	50	15	40	4.2	0	239	43	25	.4	6.8	324	186	0	1.3	520	7.3