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Hydrogeology of Butler County, Nebraska

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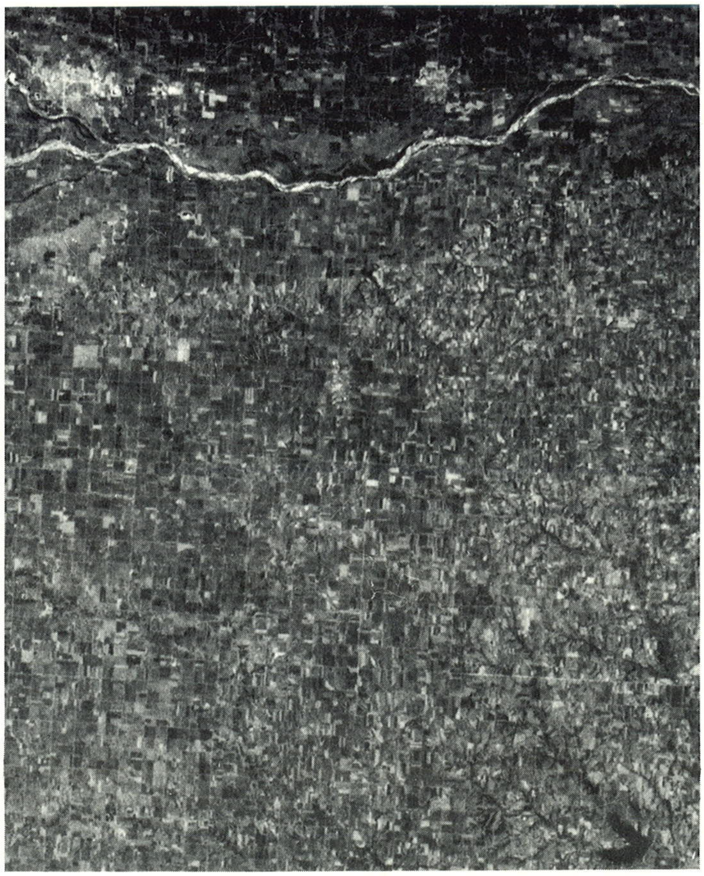

Prepared in cooperation with the U.S. Geological Survey

NEBRASKA WATER SURVEY PAPER 55

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Conservation and Survey Division
Institute of Agriculture and Natural Resources
The University of Nebraska–Lincoln

The Conservation and Survey Division of the University of Nebraska is the agency designated by statute to investigate and interpret the geologically related natural resources of the state, to make available to the public the results of these investigations, and to assist in the development and conservation of these resources.

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UNITED STATES GEOLOGICAL SURVEY
Dallas L. Peck, Director

Water Resources Division
William Kastner, District Chief

September 1983

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GLOSSARY

aquifer: a water-bearing stratum of rock or sediment capable of yielding supplies of water

artesian: of or relating to groundwater confined under hydrostatic pressure

confining bed: a layer of relatively impermeable geologic material overlying or underlying an aquifer

drift: rock material directly deposited by or from a glacier or by water issuing out of a glacier

electric log: a graphic record of the electrical properties of geologic strata within a well or borehole, plotted as a continuous function of depth

geomorphic: of or relating to the form of the features of the earth's surface

head: the height of a column of water, supported by static pressure, above a standard datum (in this report, mean sea level)

hydraulic conductivity: the capacity of a porous material to transmit water under a unit hydraulic gradient and at the existing kinematic viscosity, measured as the volume of water that will move through a unit area at a right angle to the direction of flow *leaky* (of artesian conditions): permitting slow movement of water to or from an aquifer

lithologic: of or pertaining to rock characteristics such as color, mineral content, or structure

loam: soil material composed of 7 to 27 percent clay, 28 to 50 percent silt, and sand in quantities not exceeding 52 percent

paleodivide: ancient dividing ridge (used in this publication to describe a feature of the bedrock surface)

paleovalley: ancient drainage way (used in this publication to describe a feature of the bedrock surface)

perched aquifer: a water-bearing bed or stratum of rock or sediment capable of yielding supplies of water and containing unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone

potentiometric surface: the upper hydrologic boundary to which a water level rises in a tightly cased well

specific discharge: the rate of groundwater movement through a unit area measured at a right angle to the direction of flow

subcrop: the uppermost buried bedrock unit at a location; the bedrock unit that would be visible if all overlying unconsolidated sediment were removed

till: generally unstratified, unsorted, and unconsolidated drift consisting of intermingled clay, sand, gravel, and boulders

FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC UNITS

Multiply English Units	By	To Obtain Metric Units
	Length	
inches (in.)	25.4	millimeters
feet (ft)	0.3048	meters
miles (mi)	1.609	kilometers
	Area	
acres	4047	square meters
square miles (mi^2)	2.590	square kilometers
	Flow	
gallons per minute (gal/min)	0.00006309	cubic meters per second
cubic feet per second (ft^3/s)	35.31	cubic meters per second
	Gradient	
feet per mile (ft/mi)	0.1894	meters per kilometer
	Temperature	
°Fahrenheit (°F)	(°F-32)/1.8	°Celsius

SELECTED ABBREVIATIONS

°F -- degree Farenheit

ft -- foot (feet)

ft^2 -- square foot (feet)

ft^3 -- cubic foot (feet)

gal/d -- gallons per day

gal/min -- gallons per minute

in. -- inch(es)

mg/l -- milligram(s) per liter

mi -- mile(s)

mi^2 -- square mile(s)

R. -- range

sec. -- section

T. -- township

μmho -- micromhos per centimeter at 25° Celsius

ABSTRACT

This report describes the occurrence, availability, and quality of groundwater in Butler County, a 584-square-mile area in east-central Nebraska, and the geologic framework in which that groundwater exists. Almost all groundwater used in the county is from the Pleistocene aquifer system, absent only in the northeastern part of the county and south of Dwight. Some, however, is from sandstones in the Dakota Group, undivided--the county's only bedrock source of groundwater.

The base of the Pleistocene aquifer system generally reflects the bedrock surface. Carlile Shale is the youngest bedrock formation in western and northern Butler County where it is present as subcrops on paleodivides. Its distribution is more restricted in the central and eastern parts of the county. The Greenhorn Limestone--Granerous Shale is present as subcrops on paleovalley bottoms and side slopes in the western part of the county, on paleovalley side slopes and paleodivides in the central part, and on paleovalley side slopes in the eastern part. The Dakota forms the paleovalley floor in the central part of the county and paleovalley side slopes and floors in the eastern part of the county.

The county is divided into three hydrogeologic regions. Region I coincides with the Platte River Valley Plain. Region II comprises the western two-thirds of the county south of that

Valley Plain, and Region III constitutes the remainder of the county. Wells producing from 600 to 1,200 gallons per minute generally can be developed in Regions I and II, and in Region III where major buried paleovalleys occur. Elsewhere in Region III, such large capacity wells are difficult to obtain, and in some places even adequate supplies for domestic wells may be difficult to obtain.

A map of the average potentiometric surface indicates that groundwater movement generally is from southwest and west to northeast and southeast. According to such a map, total head loss across the county is greater than 200 feet.

Thickness of saturated Pleistocene sand and gravel ranges from zero to more than 200 feet. Areas of greatest thickness generally correspond with paleovalleys; areas of high transmissivity--more than 200,000 gallons per day per foot--generally correspond with paleovalleys; and areas of low transmissivity generally correspond with paleodivides. Lowest transmissivities occur south of Dwight and in northeastern Butler County, areas in which the Pleistocene aquifer system is thin or absent.

Groundwater in Pleistocene sediments generally is of the calcium bicarbonate or magnesium bicarbonate type. Concentrations of dissolved solids range from about 300 to 700 milligrams per liter. The quality of water from the three hydrogeologic regions is indistinguishably similar.

INTRODUCTION

Purpose and Scope

Development for irrigation has greatly increased the use of groundwater in Butler County. Much water is stored in aquifers underlying the county; but as the demand for water increases, the groundwater resource is being increasingly stressed. The purpose of this report is to describe the geology[1] and groundwater hydrology of the county to provide all interested persons with a better understanding of the resource.

Description of the County

Location, Population, and Type of Agriculture

Butler County, in east-central Nebraska (fig. 1), is 584 mi^2 (373,760 acres) in area. It is 24 mi from east to west, averaging 24.33 mi from north to south. The county is bordered on the north by the Platte River, on the east by Saunders County, on the south by Seward County, and on the west by Polk County.

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[1] The classification and nomenclature of stratigraphic units used in this report are those of the Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, which differ somewhat from those of the U.S. Geological Survey.

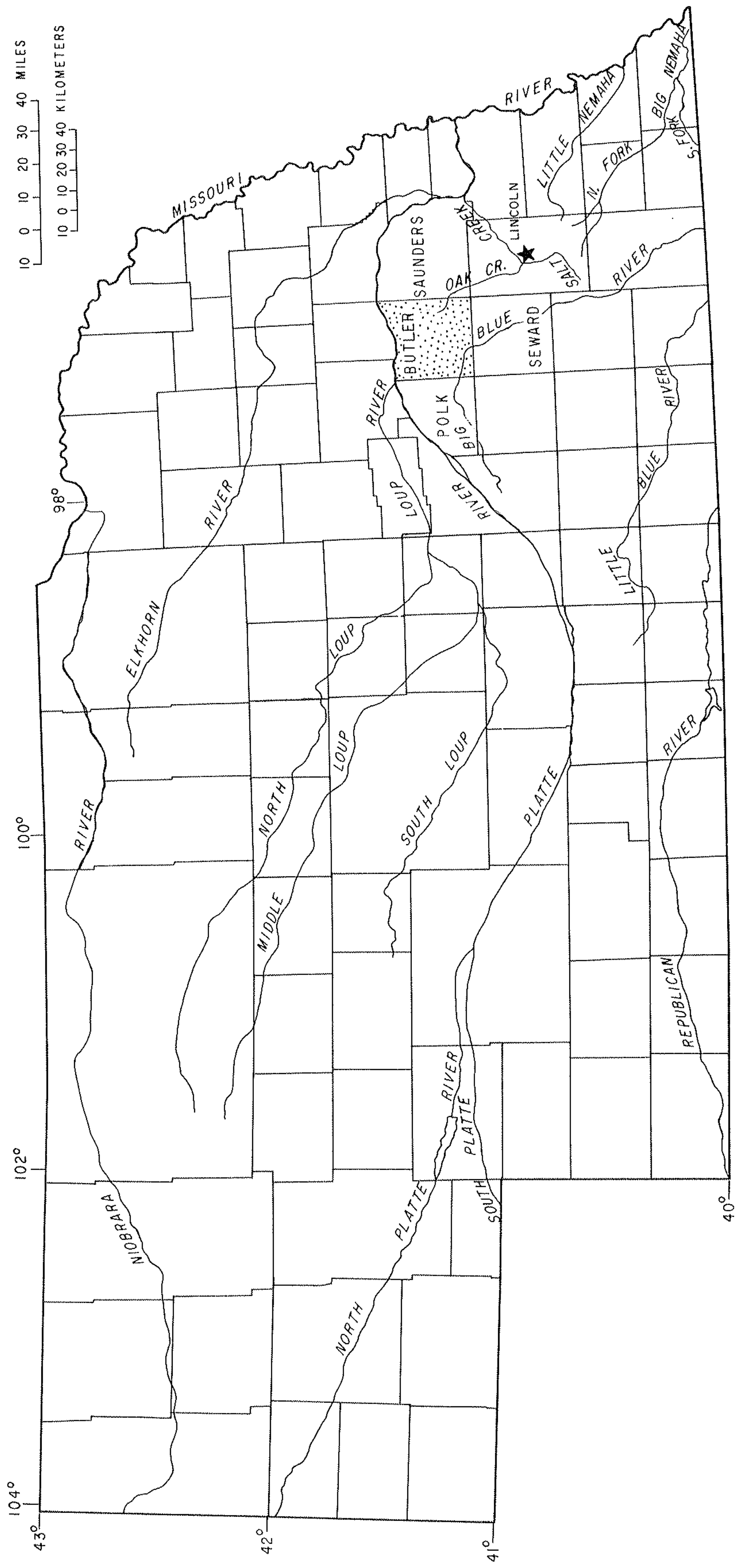


Fig. 1. Location of study area

In 1980 the population of Butler County was 9,330 (U.S. Department of Commerce, Bureau of the Census, 1981, p. 29-8), averaging about one person to 40 acres. The larger communities include David City, Bellwood, Rising City, Brainard, and Ulysses (fig. 6).

Agriculture is the major industry in Butler County. In 1977 there were 1,050 farms, each with annual sales of more than $1,000 for animals and crops. Animals being raised on these farms as of January 1, 1978, included 45,000 cattle, 38,700 hogs, and 4,000 sheep (Nebraska Department of Agriculture, 1979, pp. 119, 127, 129, 179). The major crops are corn, sorghum, and soybeans, From 1955 through 1977, the area of land irrigated with groundwater increased from 4,100 to 77,900 acres, and the area irrigated with surface water increased from 200 to 600 acres (personal communication, Staff, Agricultural Stabilization and Conservation Service, David City, Nebraska, 1979). During a dry year, irrigated land significantly outproduces unirrigated land. For example, in 1975 the average yield per acre of corn on irrigated land was 119 bushels, whereas the average yield on unirrigated land was only 49 bushels (Nebraska Department of Agriculture, 1977, p. 21).

Climate

The climate of Butler County is continental with cold winters, hot summers, and moderate precipitation. Precipitation distribution and quantities are variable, large and rapid temperature changes being frequent in all seasons of the year. Temperature and precipitation data for David City near the center of the county, for 1951 through 1980, are summarized as follows:

Average annual temperature	50.3° F
Warmest month, July, average temperature	77.0° F
Coldest month, January, average temperature	20.1° F
Average annual precipitation	29.18 in.
Driest month, January, average precipitation	0.74 in.
Wettest month, June, average precipitation	5.02 in.

Large variations from normals occur. In more than 80 years of record at David City, climatic extremes were:

Highest temperature	114° F in July 1936
Lowest temperature	-30° F in January 1892 and 1912 and in February 1899
Wettest month	June 1967, 16.54 in.
Driest months	January 1935, March 1936, October 1938, November 1939, October 1958, November 1976, and January 1981, 0.0 in.
Wettest year	1973, 45.00 in.
Driest year	1936, 11.49 in.

Rarely does annual precipitation approximate average precipitation (fig. 2). As indicated in figure 2, it was less than average annual precipitation for 16 of the 30 years from 1951 through 1980, and more than 5 in. less in half of those years (U.S. Department of Commerce, 1962-82).

Most precipitation occurs during the growing season as

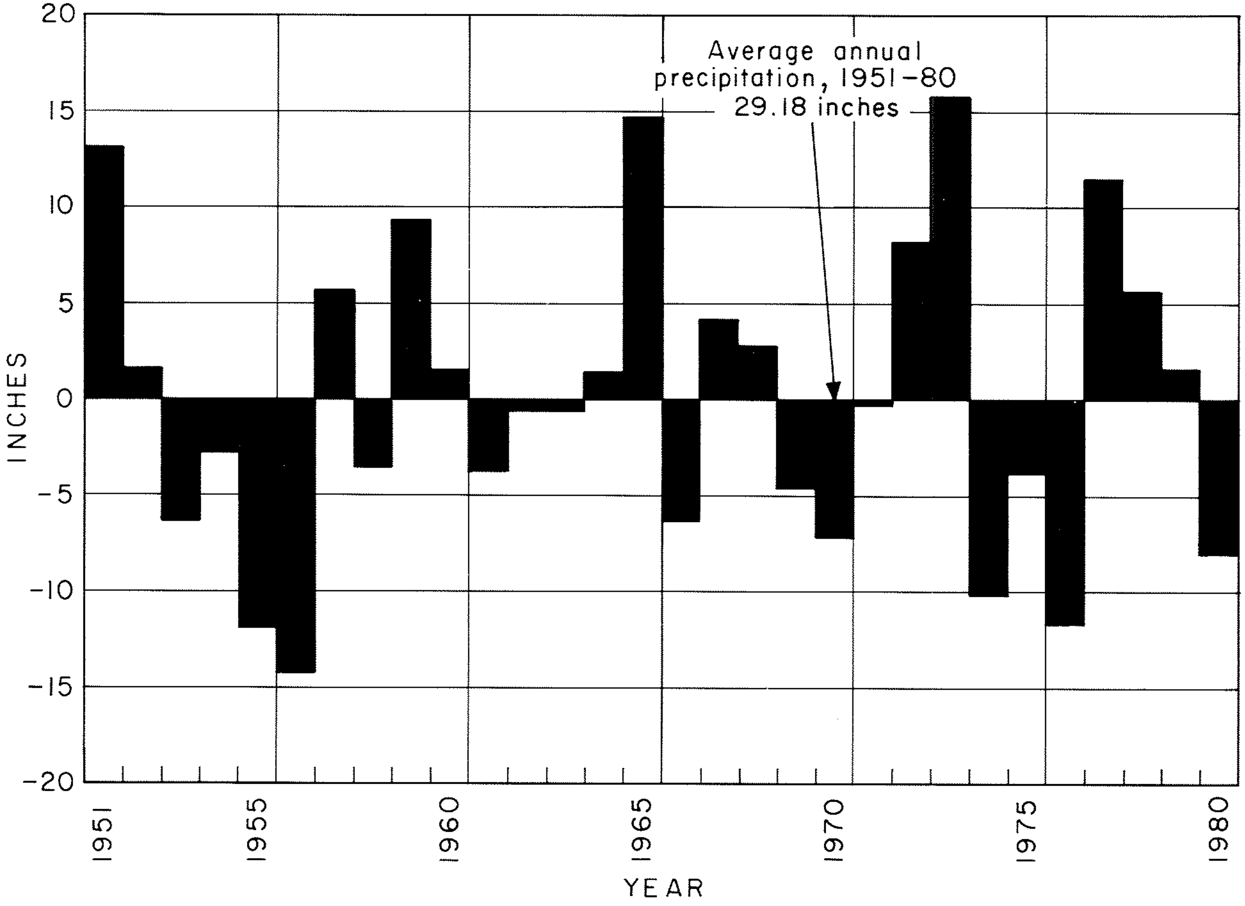


Fig. 2. Departure from average annual precipitation at David City, 1951-80

spring and summer rains. Whether rainfall for a particular year is conducive to good crop production often depends as much on the timing of the rainfall as on the quantity. Because of the variability in precipitation, both from one year to another and within the growing season, irrigation with groundwater is a viable option for farmers who have access to adequate water supplies.

Irrigation-Well Development

The cumulative total of irrigation wells in Butler County has increased from an estimated six wells in 1935 to at least the 924 registered wells at the end of 1979. The rate at which that total increased from 1935 to 1979 is indicated in figure 3. The change in geographic distribution of wells at nearly decade intervals from 1950 is shown in figures 4a, 4b, 4c, and 4d.

Three physical factors are important in the potential for the development of groundwater supplies for irrigated agriculture; namely, topography, soil characteristics, and water availability. Topography is important because extremely rough terrain hinders the use of irrigation systems and causes rapid runoff of water and attendant erosion. Soil characteristics are important because a large percentage of clay in the soil retards percolation of water into the root zone and may create waterlogged conditions. Availability of groundwater, which is dependent on geology, is of course crucial.

Until the early 1950s, the principal systems for applying

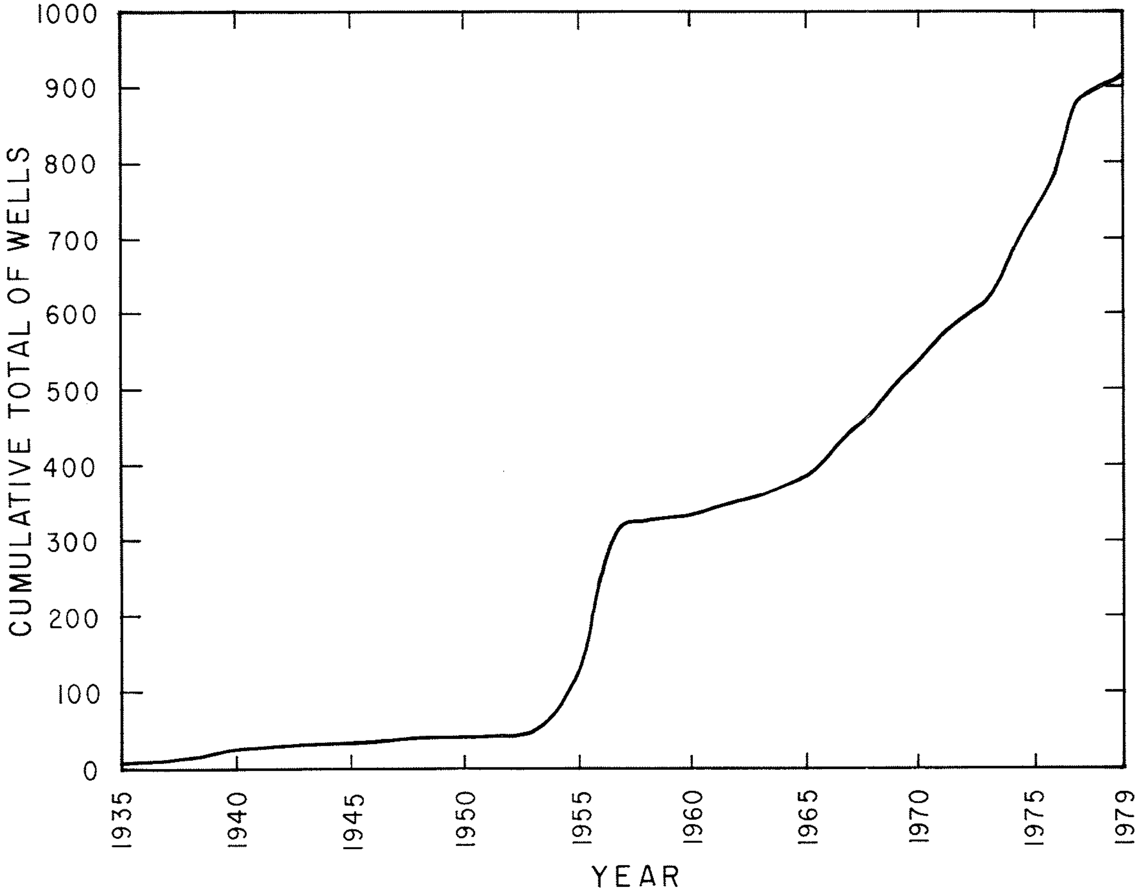


Fig. 3. Increase in registered irrigation wells in Butler County, 1935-79

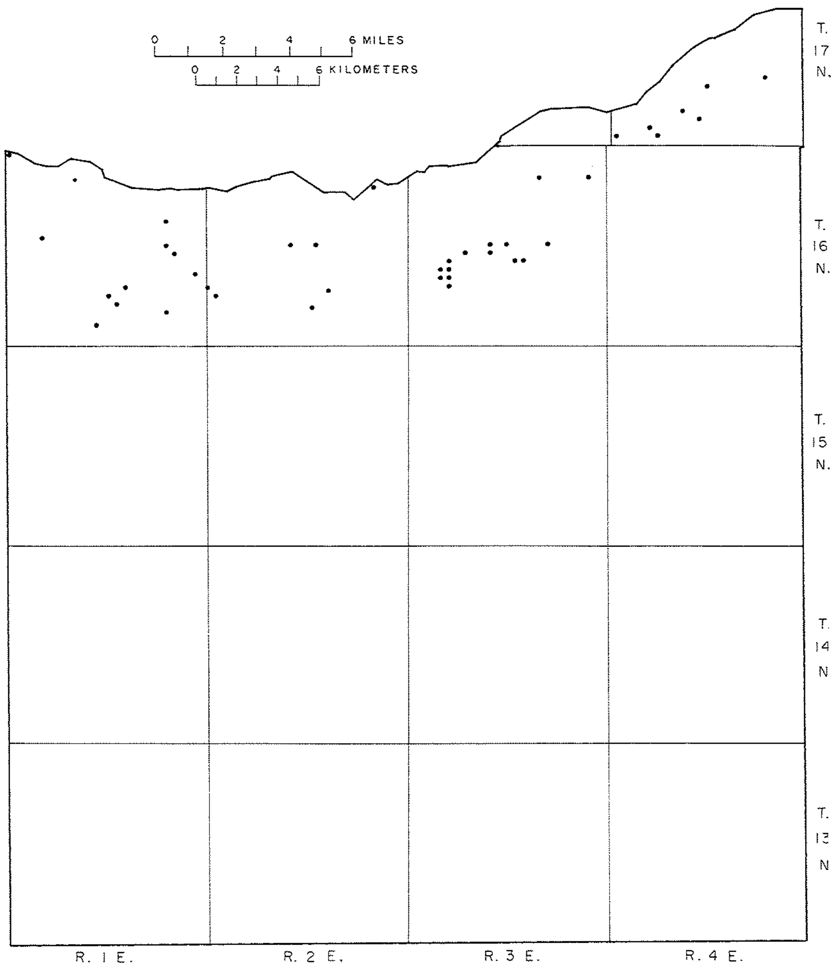


Fig. 4a. Location and distribution of irrigation wells in Butler County, 1950

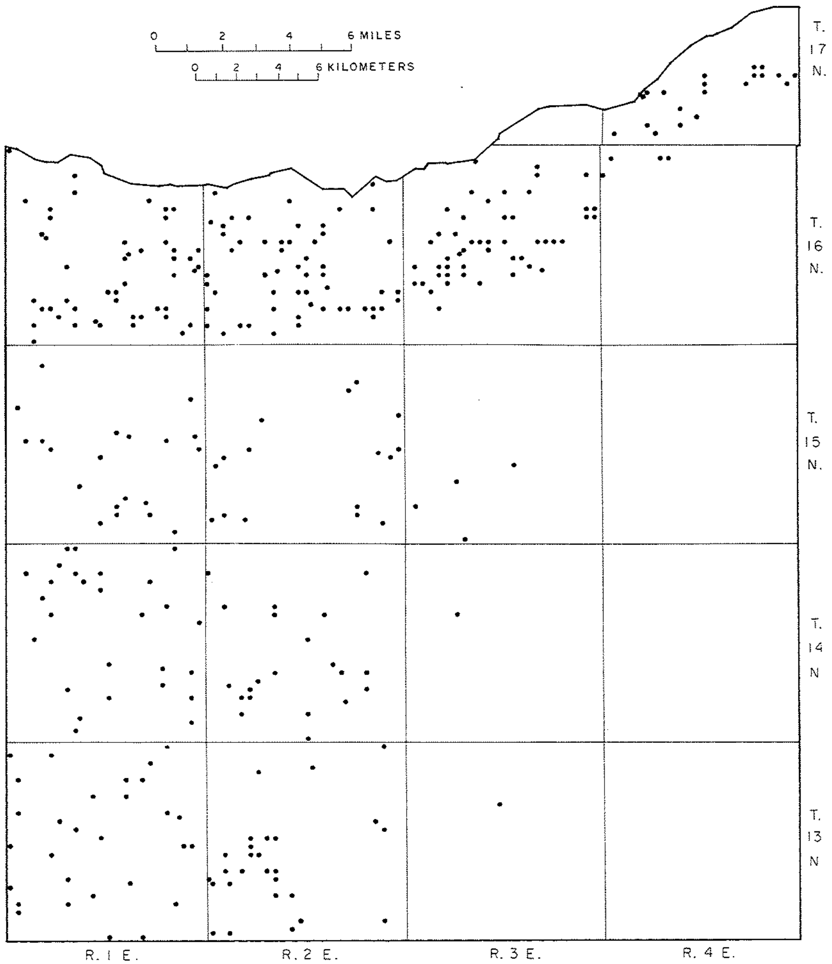


Fig. 4b. Location and distribution of irrigation wells in Butler County, 1960

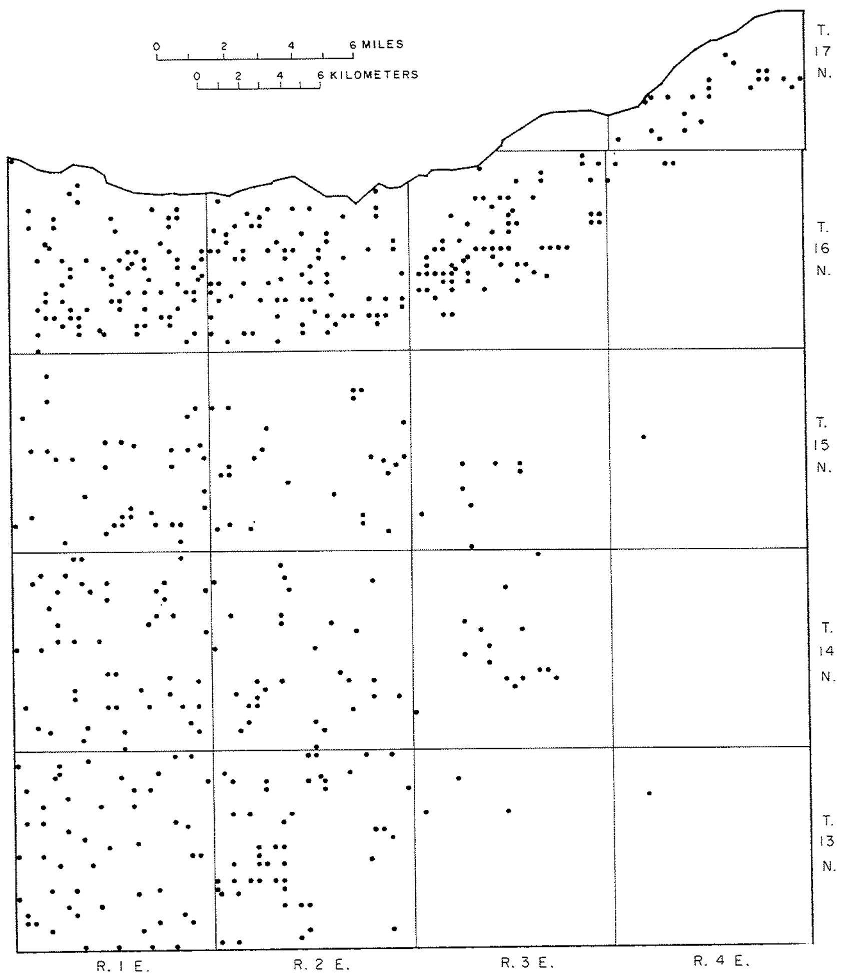


Fig. 4c. Location and distribution of irrigation wells in Butler County, 1970

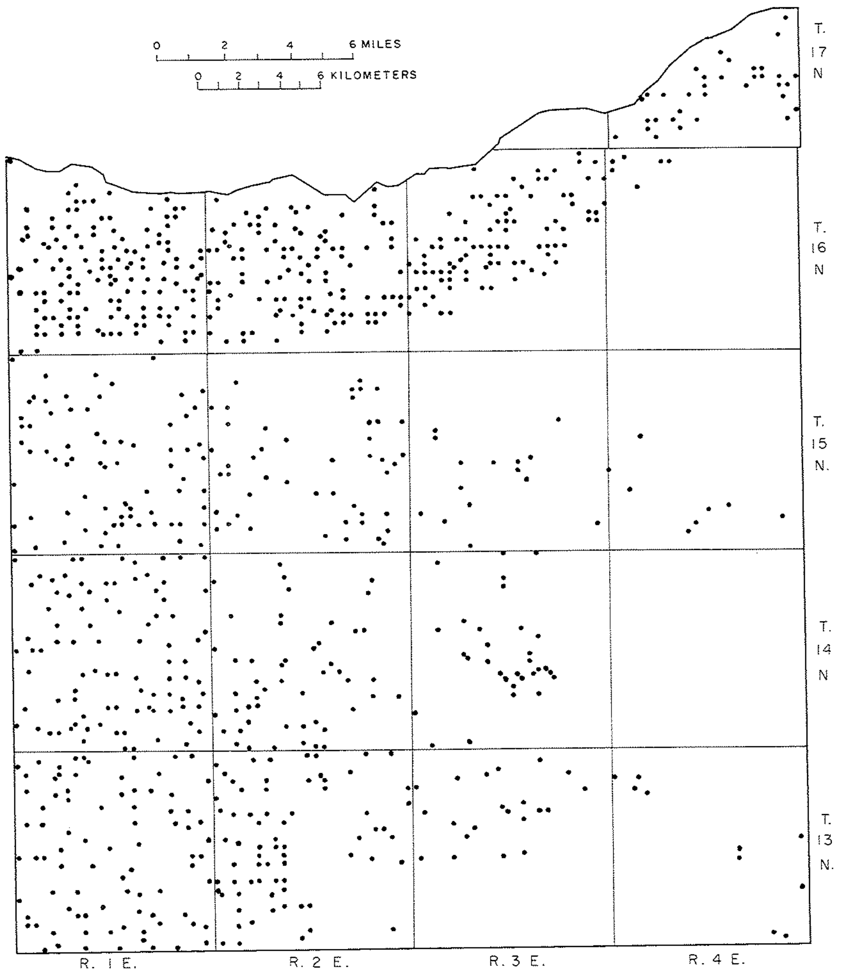


Fig. 4d. Location and distribution of irrigation wells in Butler County, 1979

irrigation water in Nebraska were gated pipe, skid tow, side-roll sprinkler, big gun, solid set, hand-moved irrigation, and siphon tubes (personal communication, Paul Fischbach, University of Nebraska-Lincoln, 1979). In the early 1950s, the development of the center-pivot irrigation system revolutionized irrigation practices, although the greatest increase in the use of center pivots did not come until the late 1960s.

The use of center pivots requires far less labor than the use of other irrigation systems. Also, the use of center pivots enables farmers to irrigate lands that previously were considered unirrigable because of their relatively steep slopes. The limit on slope for land to be irrigated with gated pipe is 2 percent; the recommended limit for land to be irrigated with center pivots, however, is 6 percent. By the end of 1981 there were 215 center-pivot systems in the county (University of Nebraska-Lincoln, 1983).

Soils

Soils in Butler County are developed on till, alluvium, and loess. A soil is formed from its parent material through the process of weathering. The kind of soil developed depends on the parent material, climate under which it formed, the length of time of formation, the living organisms present on and in the developing soil, and the topography on which it developed. The nature of the parent material is an important factor in determining the hydrologic characteristics of the soil.

The ability of the soil to absorb or transmit water to the groundwater reservoir depends principally on the soil's texture and slope. Texture determines a soil's permeability and water-holding capacity. Clay in soils retains water at or near the ground surface and retards its downward percolation to the groundwater reservoir. Coarse-grained soils more readily permit downward movement of water than do fine-grained soils. Steep slopes cause rapid runoff of water, which allows little time for percolation. Flat surfaces and gentle slopes slow down runoff, which aids downward percolation.

Other factors affecting the water-transmitting properties of soil are soil structure (arrangement of soil particles), type of clay present, quantity of organic material present, the aerating activity of animals, temperature, and the sequence of the horizons in a soil profile.

Most soils in the Platte Valley are on nearly level slopes; some are on gentle slopes. Vertical drainage is significant and rapid where the soil is underlain by sand and gravel, but limited and slow where the percentage of clay in the soil is large in the low-lying bottomlands. Soils in the uplands are on nearly level to very steep slopes. Here vertical drainage is limited and moderate where the percentage of clay is medium, limited and slow where the percentage of clay is large. There are many broad, shallow depressions with almost no surface drainage. One of the largest of these lies between David City and Garrison.

The texture of the soils in the Platte Valley ranges from fine sand to silty clay in both surface and subsoil. In the uplands the textures are silty to clayey with silt loam or silty clay loam in the surface and silty clay loam, clay loam, and silty clay in the subsoil.

The texture of the surface and subsoil affects infiltration rates, movement of water into and through the subsoil, water-holding capacity and water release to plants. For more specific information on characteristics of soils in Butler County, the reader is referred to The Soil Survey of Butler County, Nebraska (Kerl et al., 1982).

Topography, Drainage, and Geomorphic Areas

Physiographically, Butler County is in the Interior Plains Division of the United States. The county includes part of both the Dissected Till Plain section of the Central Lowland Province and the High Plains section of the Great Plains Province (Fenneman and Johnson, 1930). The altitude of the county ranges from about 1,695 ft, 2 mi north-northwest of Brainard, to about 1,300 ft on Duck Creek in the Platte River floodplain at the Butler-Saunders county boundary.

Butler County can be divided into three areas according to geomorphology (fig. 5). The Platte River Valley Plain, hereafter referred to in the text as the Valley Plain, is a relatively flat-lying area in northern Butler County bounded by the Platte River on the north and the bluff line on the south. It is a part of the Platte Valley topographic region and includes floodplain lands and low to intermediate river terraces. The Valley

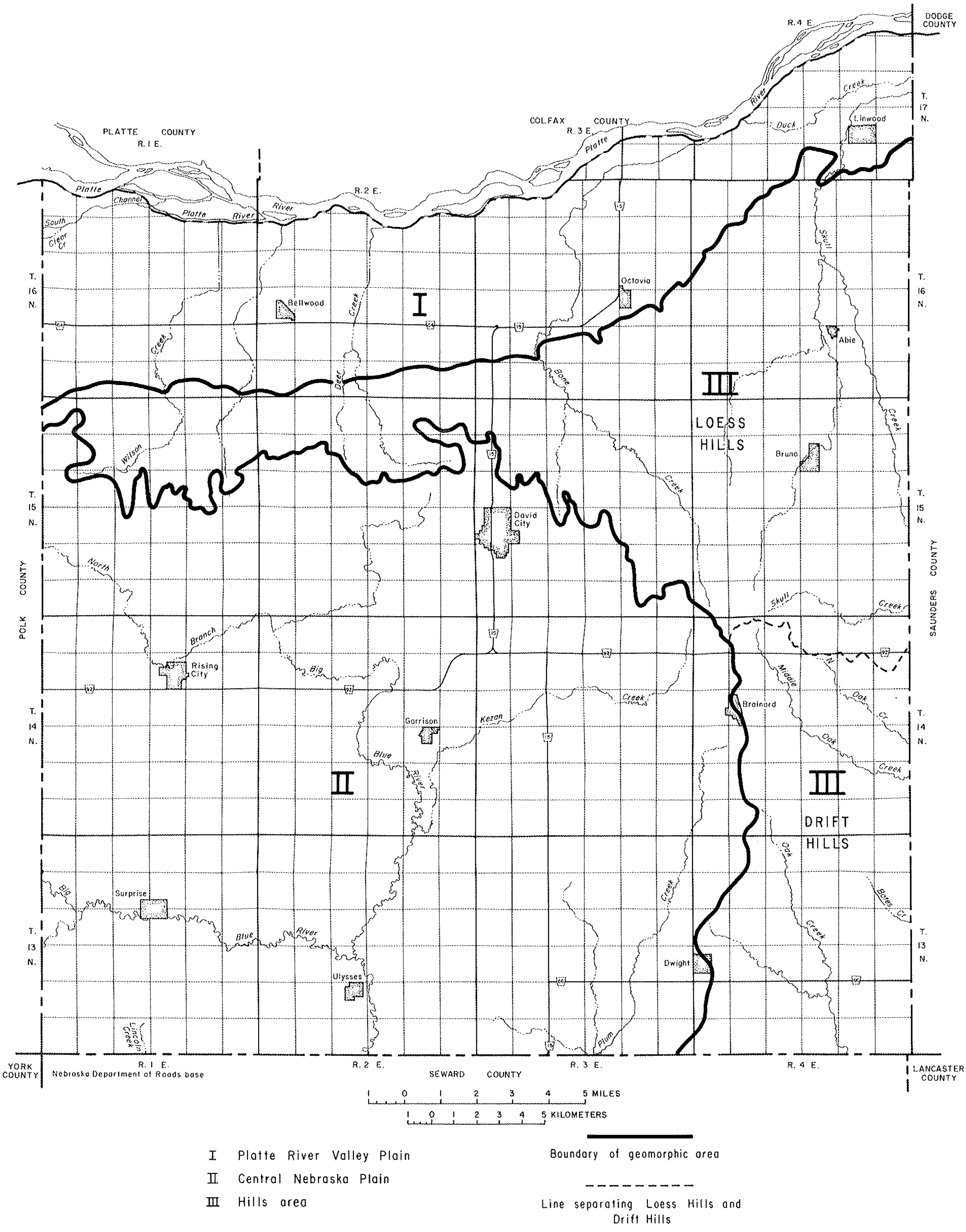


Fig. 5. Geomorphic areas in Butler County

Plain ranges in width from about 2 mi in the eastern part of the county to about 6 mi at the western border. Near the Platte River, the land slopes toward the east with a gradient of about 5.5 ft/mi. At its southern boundary, the Valley Plain is separated by steep bluffs from the upland, about 150 ft above.

The western two-thirds of the area south of the Valley Plain is part of the Central Nebraska Plain and is hereafter referred to as the Upland Plain. The Upland Plain slopes gently toward the east and is mantled by Peoria Loess, which ranges in thickness from about 15 to 40 ft. Thin on steep slopes, the loess has been removed by erosion in some drainageways. The relatively smooth, flat-lying Upland Plain is marked with shallow depressions. Part of the drainage is internal and toward the depressions. The Upland Plain is drained to the south by the Big Blue River and its tributaries. Maximum relief occurs where the Big Blue River valley is entrenched as much as 100 to 150 ft into the plain. Steep valley walls separate the river from the adjacent plain.

The Big Blue River enters the county 3 mi west of Surprise at an altitude of 1,545 ft and exits 2 mi south of Ulysses at an altitude of 1,480 ft. The average gradient of its floodplain is about 5.25 ft/mi.

The remaining one-third of the area south of the Valley Plain is the Hills Area which is composed of the bluffs along the south side of the Valley Plain and the rolling hills, ridges, and steep valley-wall slopes of the eastern part of the county. The Hills Area may be divided into Loess Hills (the area generally north of U.S. Highway 92) and Drift Hills (the area generally south of the highway). Maximum relief in the region is 350 ft and slopes between drainageways and hilltops in many places are 100 to 200 ft/mi.

Peoria Loess of late Wisconsinan age, once mantling all the Hills area, has been eroded from most of the Drift Hills (Condra and Reed, 1959). The Drift Hills area is drained to the south and east by Oak Creek and its tributaries.

Loess covers glacial drift in the Loess Hills, although the drift is exposed on the side slopes of deeper valleys. The Loess Hills area is drained by several small tributaries to the Platte River, some of which flow only in response to overland runoff (small intermittent streams are not shown on the figures of this report).

Sources of Information on Hydrogeology

Since 1941, 33 test holes have been drilled as part of the test-drilling program conducted by the Conservation and Survey Division in cooperation with the U.S. Geological Survey (fig. 6). One other test hole was drilled under a National Science Foundation grant. Depths of the test holes range from 80 to 450 ft, and all but one were drilled through the unconsolidated deposits and into bedrock. Descriptions of the geologic materials from 12 of these test holes were published in *Logs of test holes--Butler and Colfax counties, Nebraska* (University of Nebraska, 1953), and descriptions of seven others were published in *Supplement to Logs of Test Holes--Butler County, Nebraska* (University of

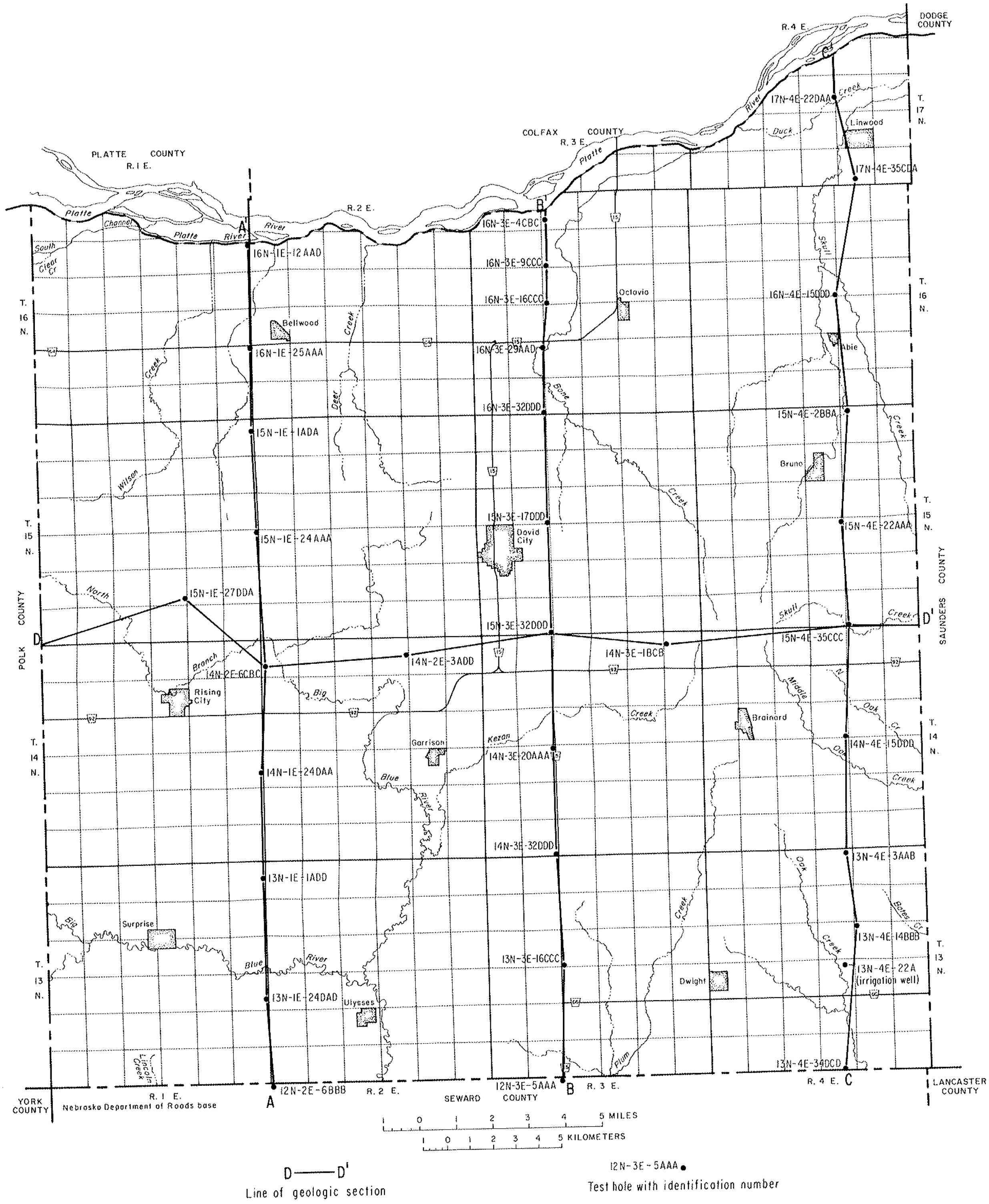


Fig. 6. Location of test holes and geologic sections in Butler County

Nebraska, 1955b). Electric logs were obtained for 19 of the 34 test holes. Sample descriptions and electric logs of Conservation and Survey Division test holes drilled in 1976 and 1977 are available at the Conservation and Survey Division, University of Nebraska, in Lincoln, Nebraska. In addition, geologic logs are available from several wells and test holes drilled privately for oil and gas exploration. Other sources of hydrogeologic information include: well-registration files of the Nebraska Department of Water Resources; test-hole records of the Nebraska Department of Roads, the U.S. Army Corps of Engineers, and the U.S. Soil Conservation Service; municipal records; and private records of drillers and landowners.

Water-level information was obtained from wells measured by the U.S. Geological Survey, the Conservation and Survey Division, the Upper Big Blue Natural Resources District, the Lower Platte South Natural Resources District, and the Lower Platte North Natural Resources District. Three wells were equipped with continuous water-level recorders.

Earlier geologic and hydrologic studies of Butler County and surrounding areas were valuable sources of information used in preparing this report. An unpublished groundwater study of Butler County was prepared by the Conservation and Survey Division in 1955. Keech (1972) authored <u>Ground-water in Polk County, Nebraska</u> and (1978) <u>Water Resources of Seward County, Nebraska</u>. Waite and others (1949) prepared <u>Progress Report on the Geology and Ground-water Hydrology of the Lower Platte River Valley, Nebraska</u> and Cady and Ginsberg (1979) authored <u>Interpretive</u>

Study and Numerical Model of the Hydrogeology, Upper Big Blue Natural Resources District, Nebraska.

Surface-water quality and discharge data were obtained from the U.S. Geological Survey publications Water Resources Data for Nebraska, Part 2, Water Quality Records for the water years 1966-70, 1972-74, and Water Resources Data for Nebraska for the water years 1975-78.

System for Numbering Wells and Test Holes

Each well and each test hole referred to in this report is identified by a location number based on the system of land subdivision used in the U.S. Bureau of Land Management's survey of Nebraska. The number preceding N (North) indicates the township, the number preceding E (East) indicates the range, and the number preceding the terminal letters indicates the section in which the well is located. The terminal letters denote location within the section and are assigned in a counter-clockwise direction beginning with A in the northeastern quarter of each tract. As shown in figure 7, the first of these letters indicates the quarter section (160-acre tract); the second, the quarter-quarter section (40-acre tract); and the third, the quarter-quarter-quarter section (10-acre tract). As shown by the example in figure 7, a well or test hole in the SE¼SE¼SE¼ sec. 15, T. 14 N., R. 4 E., is identified by the number 14N-4E-15DDD.

When additional wells are located in the same tract, they are

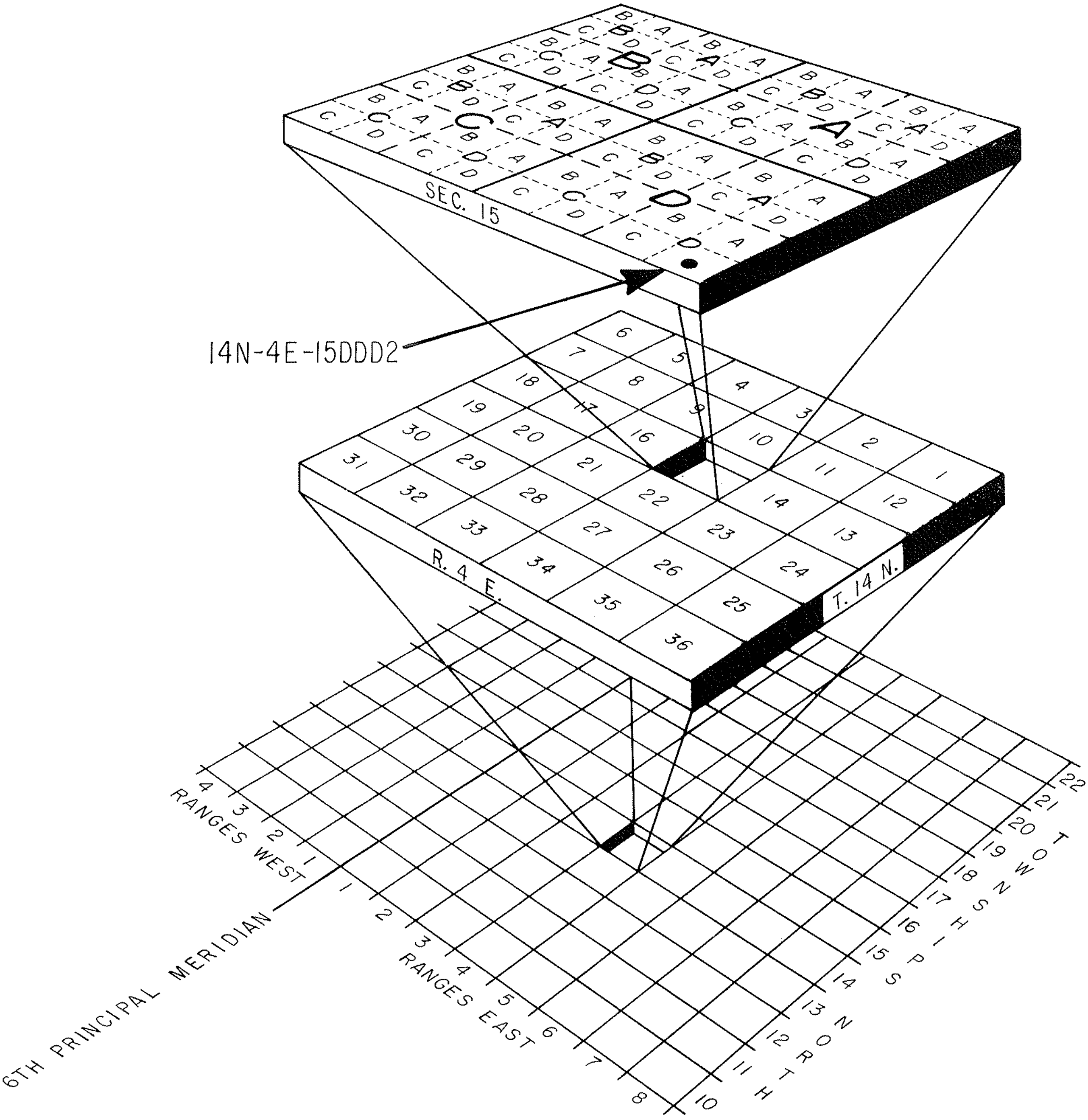


Fig. 7. System for identifying test holes and wells according to their location

distinguished by the sequential digit at the end of the number. For example, a second well in the SE¼SE¼ sec. 27, T. 15 N., R. 1 E., would be assigned the number 15N-1E-27DD2.

Acknowledgments

The author is grateful to John A. Elder and Richard L. Myers of the Conservation and Survey Division and to Richard A. Engberg of the U.S. Geological Survey for their contributions to the sections on Soils, Climate, and Water Quality, respectively, and to Vincent H. Dreeszen of the Conservation and Survey Division for his help in determining the potentiometric surface for the eastern part of the county.

GEOLOGY

Detailed information on the geology and geologic history of Butler County has been obtained principally through analysis and interpretation of test-hole data and data from irrigation well logs. Developed nearly three decades ago were a map showing the configuration of the surface of the Cretaceous bedrock in the county, a map showing thickness of water-saturated sand and gravel deposits, and two geologic sections across the county (University of Nebraska, Conservation and Survey Division, 1955a). Hydrologic and geologic information obtained subsequently facilitated the revision of these maps and permitted the construction of two additional geologic sections. Location of the test holes in the county is shown on figure 6. Geologic sections prepared from the test-hole data and other data are shown on figures 8a, 8b, 8c, and 8d.

The geologic sequence in Butler County can be subdivided into two groups--older rocks, composed of consolidated sediments and classed as bedrock, and younger rocks consisting of unconsolidated material overlying bedrock. Both groups are present in all the county, except for two small areas in the northeastern corner of the county where the bedrock is exposed at the land surface.

The oldest bedrock unit of known hydrologic importance in Butler County is the Dakota Group, undivided, of Early Cretaceous

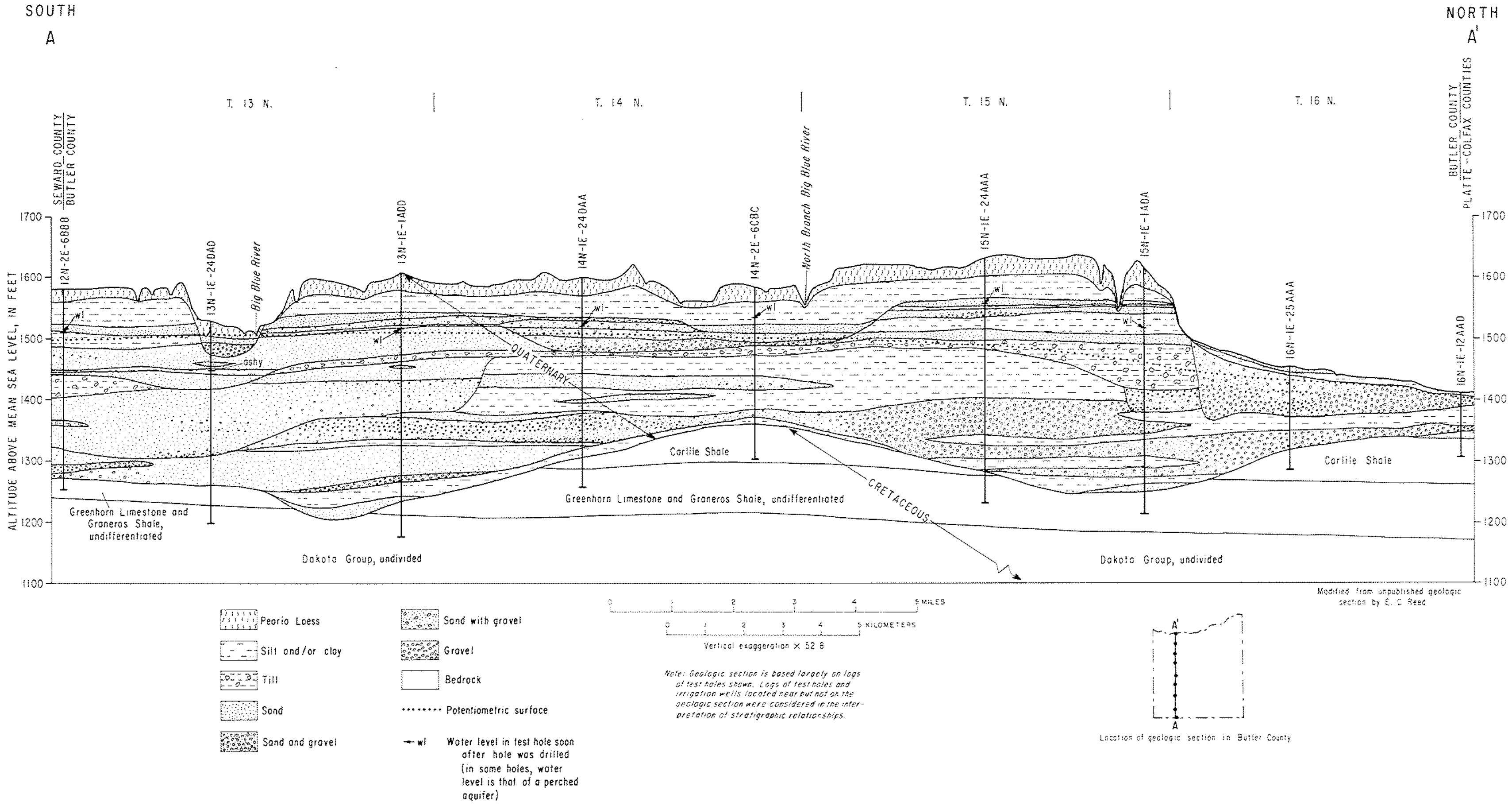
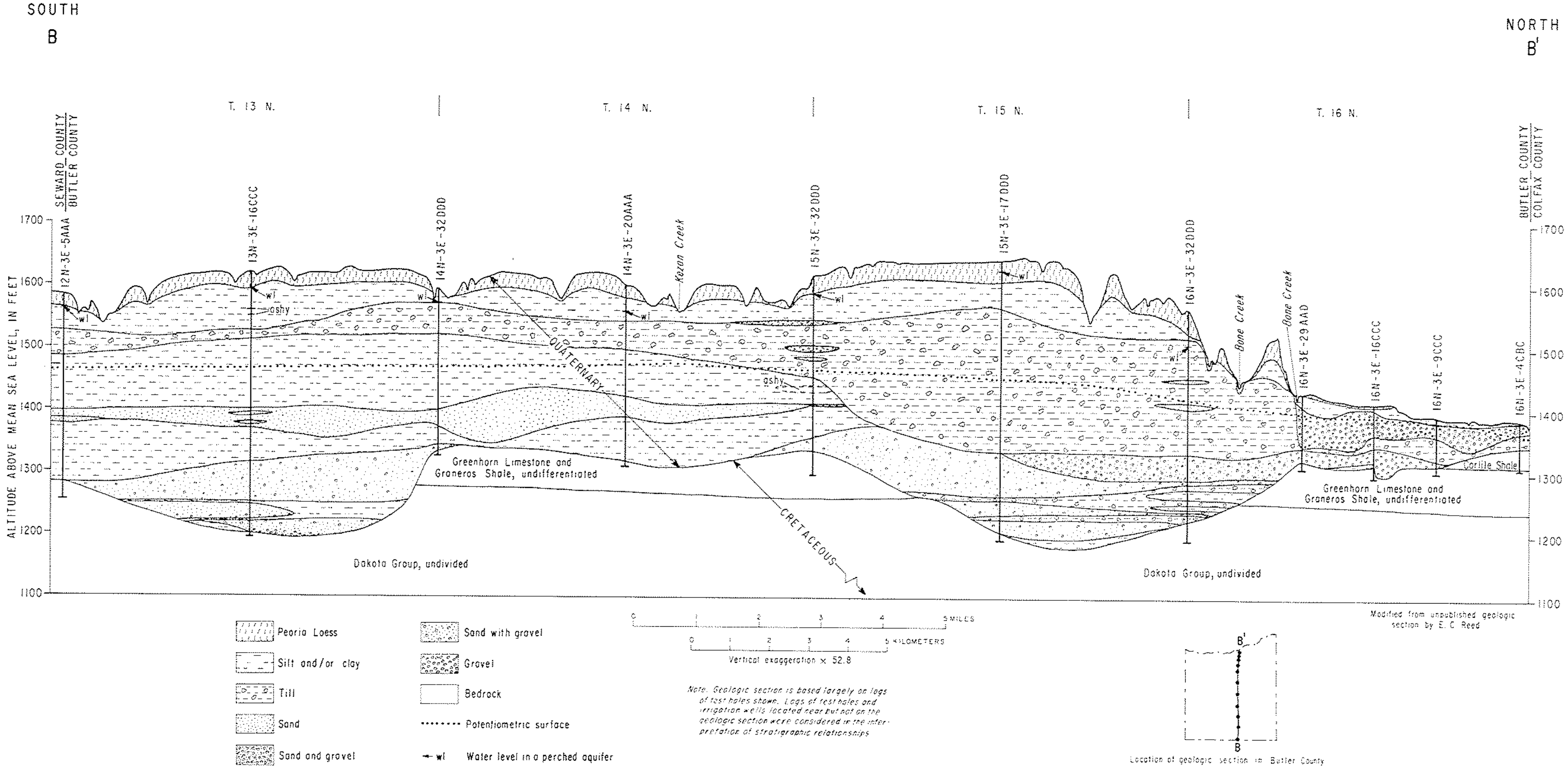


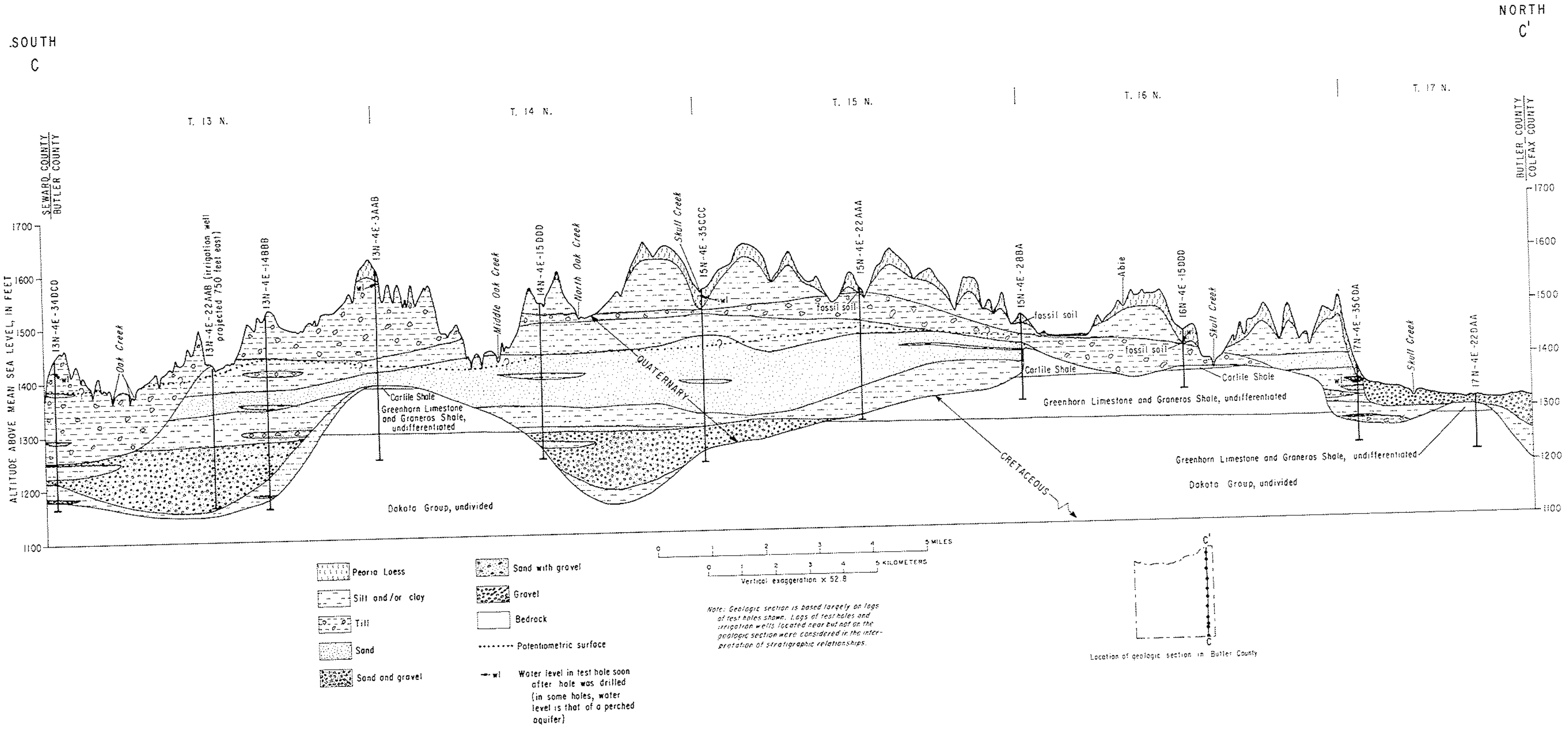
Fig. 8a. North-south geologic section through the western part of Butler County



Note. Geologic section is based largely on logs of test holes shown. Logs of test holes and irrigation wells located near but not on the geologic section were considered in the interpretation of stratigraphic relationships

Modified from unpublished geologic section by E. C. Reed

Fig. 8b. North-south geologic section through the central part of Butler County.



Note: Geologic section is based largely on logs of test holes shown. Logs of test holes and irrigation wells located near but not on the geologic section were considered in the interpretation of stratigraphic relationships.

Fig. 8c. North-south geologic section through the eastern part of Butler County

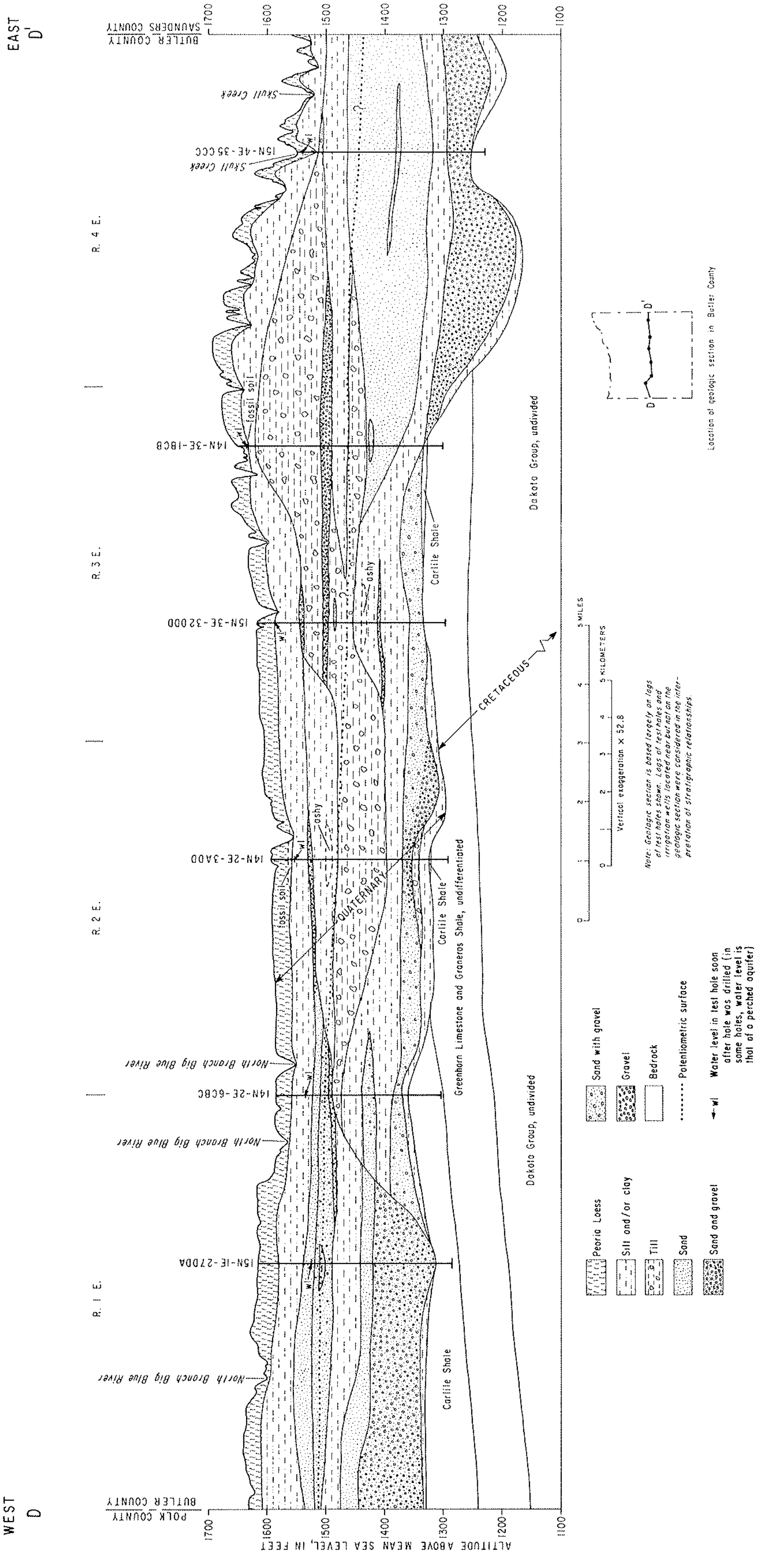


Fig. 8d. East-west geologic section through the central part of Butler County

age (table 1). Geographic distribution of the bedrock units is shown on figure 9. In this county, the Dakota is composed predominantly of sandstones and shales. The total thickness of the Dakota underlying Butler County is estimated to range from about 500 to 600 ft, probably increasing toward the south. The Dakota was deposited in a fluvial to near-shore marine environment. It is present as subcrops on the base of the paleovalleys in the central part of the county and on the base and lower side slopes of paleovalleys in the eastern part of the county.

After deposition of the Dakota Group, the sea again encroached on the land and subsequent Cretaceous rock units were deposited in a marine environment (Rocky Mountain Association of Geologists, 1972, p. 194). Where it has not been removed by erosion, the Granerous Shale of Late Cretaceous age immediately overlies the Dakota. The Graneros primarily is a dark gray shale. It can be divided into a lower noncalcareous zone and an upper calcareous zone. The maximum thickness of the Graneros beneath Butler County is about 65 ft.

Overlying the Graneros is the Greenhorn Limestone of Late Cretaceous age. The Greenhorn is composed of thin limestones interbedded with shales. It has a maximum thickness of about 25 ft, but in some places it has been completely removed by erosion. Two Greenhorn outcrops can be found in sec. 10, T. 16 N., R. 4 E. One is along Skull Creek in the south half of the section; the other is in the extreme north-central part of the section, about 1,000 ft to the east of the creek along a

Table 1

Geologic units and their water-bearing properties, Butler County

System	Series	Stratigraphic unit	Thickness (feet)	Character and distribution	Water supply
Quaternary	Holocene (?)	Surficial flood-plain and terrace deposits and soil	0-10(?)	Unconsolidated stream-deposited sand, gravel, silt, and clay	May contribute water to wells
	Pleistocene	Unconsolidated deposits	25±-400±	Wind-deposited silt; stream-deposited sand, gravel, silt, and clay; ice-deposited till	Stream-deposited sand and gravel constitute the major reservoir in the county and yield water to large-capacity wells
Tertiary(?)	Pliocene(?)	Mostly unconsolidated silt	0-50±	May blanket Cretaceous bedrock at base and on side slopes of paleo-valleys	Generally too fine textured to yield water to wells
Cretaceous	Upper Cretaceous	Carlile Shale (Blue Hill and Fairport Members)	0-90±	Blue Hill Member is gray argillaceous shale Fairport Member is bluish-gray shale containing thin fossiliferous limy layers (Condra and Reed, 1959, p. 17)	Not known to supply water to wells
		Greenhorn Limestone	25±	Thin, medium soft, gray limestones interbedded with gray shales (Condra and Reed, 1959, p. 18)	Not known to supply water to wells
		Graneros Shale	65±	Dark-gray shale interbedded with thin calcareous layers; contains some sand and sandy shale, also carbonaceous material in basal part	Does not supply water to wells
	Lower Cretaceous	Dakota Group, undivided	500±-600±	Principally composed of sandstones and shales	Sandstones may be aquifers but water may be moderately or highly mineralized

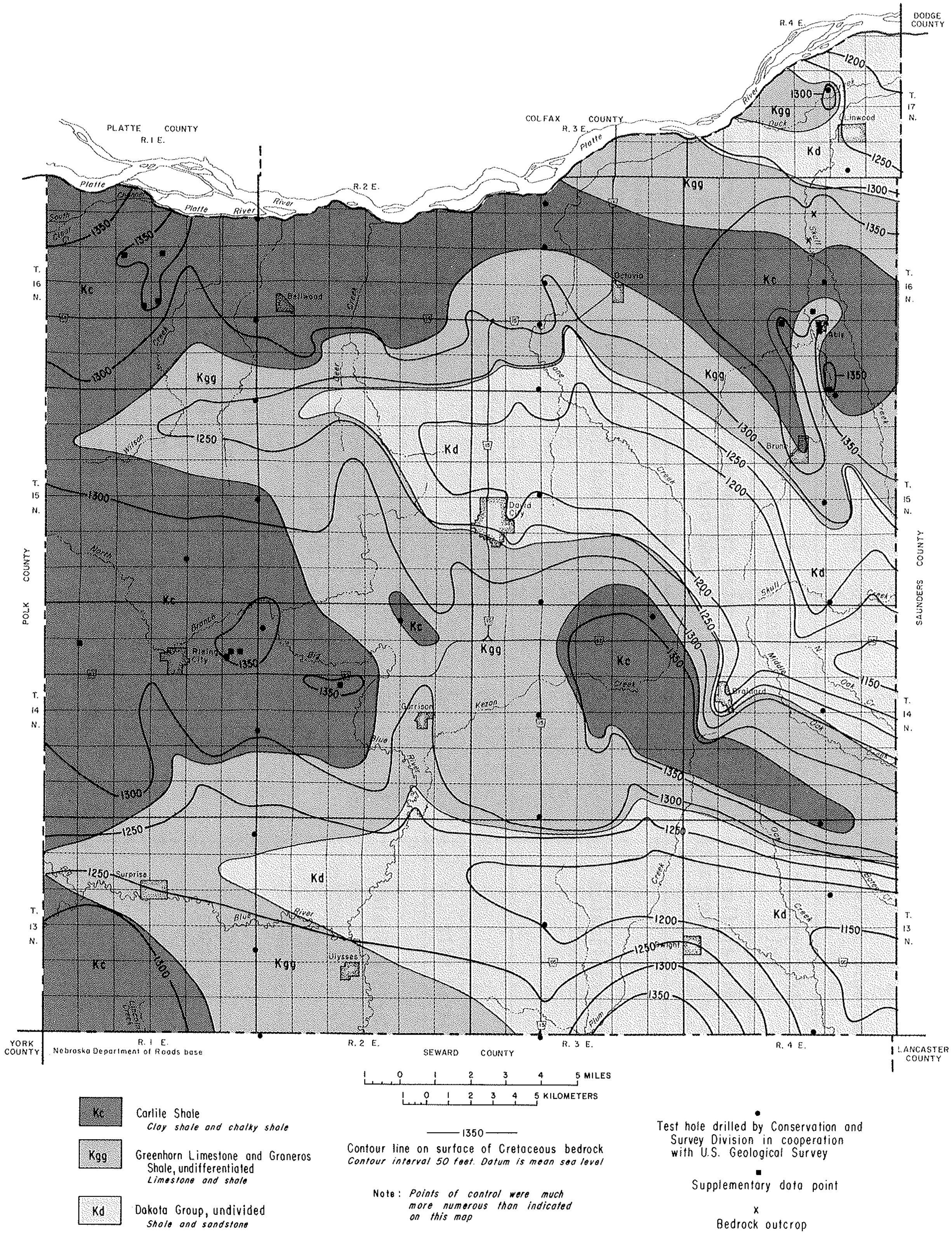


Fig. 9. Areal distribution of Cretaceous rock units and configuration of surface of Cretaceous rocks in Butler County

small tributary. In this report, the Graneros Shale and Greenhorn Limestone are not differentiated on maps or geologic sections.

The Greenhorn Limestone and Graneros Shale are present in subcrops on paleovalley bottoms and lower side slopes in the western part of the county, on paleovalley side slopes and paleodivides in the central part, and on upper paleovalley side slopes in the eastern part.

The youngest bedrock formation underlying Butler County is the Carlile Shale of Late Cretaceous age, present most extensively in the western third of the county. The Carlile thickens toward the west, with the maximum thickness beneath the county being estimated at about 90 ft. In the county, the Carlile is composed of two members: the Fairport Member and the overlying Blue Hill Member. The Fairport represents most of the Carlile Shale in the county. Since the Fairport is calcareous, with lithology similar to that of the underlying Greenhorn, it is difficult to distinguish from the Greenhorn by means of drill cuttings only. The two, however, are readily distinguishable by inspection of electric-log data. The Blue Hill Member probably is present in parts of R. 1 E. Younger material of Cretaceous age may have been deposited above the Blue Hill, but subsequent erosion would have removed all traces of it. The sea withdrew after Cretaceous time, and the Cretaceous rock units were later tilted slightly to the northwest (Seyfert and Serkin, 1973, p. 389).

During early Tertiary time, erosion removed much material of Cretaceous age to form an east-southeastward sloping surface. In addition, two major channels (paleovalleys) were eroded by streams flowing across the county from the northwest, probably in early Tertiary time. This erosion combined with pre-Tertiary tilting caused the complex subcrop pattern in the bedrock that underlies the county (fig. 9).

As streams of Tertiary (?) age eroded Cretaceous material from higher land to the west, they deposited a sequence of fine sediments in the paleovalleys. Originally, these fine deposits may have been much thicker, the upper part having been removed by subsequent erosion.

During Pleistocene time, continental glaciers advanced into eastern Nebraska from Canada and spread west through Butler County. Streams flowing eastward from the Rocky Mountains were dammed or diverted to the south because of the advancing glaciers. These debris-laden streams deposited their sediment load of sand, gravel, silt, and clay upon entering the low-energy environment west of the glacial front(s). The sediment transported into the area by these east-flowing streams merged with material transported by ice-marginal streams from the north and with material transported by streams of meltwater issuing from the glacier. The sediments upon which the Platte River alluvium rests and into which it has incised its channel were deposited primarily by such eastward- and southward-flowing streams.

The geologic materials above the bedrock contain most of the groundwater utilized in Butler County. These materials, composed of sand, sand and gravel, silt, and clay, were deposited by water, wind, and glaciers over a period from approximately 10,000 years to perhaps as long as 5 million years ago (that is, during the Pleistocene and perhaps late Tertiary age). These materials, absent in small areas where the bedrock outcrops, are as much as 455 ft thick in the upland over the paleovalley in the southern part of the county. They are of Pleistocene and perhaps late Tertiary (that is, Pliocene) age, but are referred to as Pleistocene in this report.

Till and till-related deposits are present in the eastern and central parts of the county but are absent in the extreme western part. The sequence of till and till-related deposits is thicker in the eastern half than in the western half of the county (figs. 8a, 8b, 8c, and 8d), being thickest in the general area between Octavia and David City, in an area immediately northwest of Brainard, and in the extreme southeastern corner of the county.

During late stages of Pleistocene time, wind-deposited layers of silt--called loess--blanketed the older material. The name Peoria Loess is applied to the youngest loess (figs. 8a, 8b, 8c, and 8d). Erosion later removed some of the loess, particularly from the Drift Hills, producing the rolling-hills topography of the Hills area.

Formerly, names were assigned to units of Pleistocene sediments with similar lithology. However, as the increasing complexity of stratigraphic relationships within the Pleistocene becomes evident, many of the formational names are being reconsidered. A few, such as the stratigraphically well-defined Peoria Loess, have been maintained.

Unconsolidated Pleistocene (and Holocene?) deposits underlie stream beds and floodplains. Where valley fills are composed of fine-grained sediments washed from uplands, they do not generally serve as aquifers.

GROUNDWATER PRINCIPLES

Hydrologic Properties of Rock Materials

Groundwater is obtained from water stored in the saturated part of an aquifer. Water so stored occurs in pore spaces between rock particles comprising the aquifer. The volume of water stored may be as much as 50 percent of the volume of the aquifer. The interconnection of pores is necessary for stored water to flow through rock materials. Thus clays, which may have porosities as high as 50 percent, transmit little water partly because the interconnection of pore spaces is limited. Sands and gravels, however, with porosities of perhaps only 20 to 40 percent, commonly transmit large quantities of water because the interconnection of pores is significant.

Water flows through saturated deposits according to Darcy's law:

$$q = \frac{Q}{A} = -K\frac{dh}{dl} \qquad (1)$$

where

q = specific discharge,

$\frac{Q}{A}$ = total discharge of water flowing through area A,

K = hydraulic conductivity,

$\frac{dh}{dl}$ = hydraulic gradient, or change in static head per unit of distance in a given direction.

Hydraulic conductivity (K) multiplied by the saturated thickness (b) of an aquifer gives a value called transmissivity (T). Transmissivity is a measure of the volume of water that can be transmitted horizontally through a unit width of the aquifer in a unit of time.

For groundwater, the hydraulic conductivity of a sand or gravel is greater than that of an equal thickness of clay. For the same rock type, transmissivity of a thin saturated zone is less than that for a thick saturated zone.

The flow velocity of the water through an aquifer is determined by the hydraulic conductivity and porosity of the rock and by the hydraulic gradient. The flow velocity may be calculated by:

$$\bar{v} = \frac{q}{p} = \frac{Q}{Ap} = \frac{-K\frac{dh}{dl}}{p} \qquad (2)$$

where $\bar{v}$ is average velocity, p is porosity as a decimal fraction (percent voids), and the other terms are as defined in equation 1.

Groundwater moves slowly compared to surface water. Keech (1978, p. 24), in discussing neighboring Seward County, states that the groundwater there "moves very slowly, generally less than a foot per day, except near wells that are being pumped." This statement probably is also true for Butler County. A sample calculation of the average velocity of groundwater flow beneath Surprise near the southwest corner of Butler County gave an answer of 0.16 ft/d.

Because the calculation of average velocity beneath Surprise illustrates use of the equation given, it is presented below. Numbers substituted into the equation, except 0.3 for p, are from maps to be presented later in this report. Numbers for computing hydraulic gradient are taken from figure 12. Those for transmissivity and saturated thickness of the aquifer are taken from figures 14 and 15 respectively. To facilitate calculations, transmissivity as (gal/d)/ft is converted to the more consistent unit of $(ft^3/d)/ft$. Because one (gal/d)/ft equals 0.13369 $(ft^3/d)/ft$, the 140,000 (gal/d)/ft taken from figure 14 becomes 18,717 $(ft^3/d)/ft$.

$$\frac{dh}{dl} = \frac{10\ ft}{(4.25\ mi)(5,280\ ft/mi)} = 0.00044563$$

p is assumed to be 0.3, a value commonly used for deposits similar to those beneath Surprise

$$K = \frac{\text{transmissivity}}{\text{saturated thickness of aquifer}} = \frac{18,717(ft^3/d)/ft}{175\ ft} = 107\ ft/d$$

$$\bar{v} = \left(\frac{107\ ft/d}{0.3}\right) 0.00044563 = 0.16\ ft/d$$

Confined and Unconfined Conditions

Groundwater exists under saturated conditions in either a confined or an unconfined state. Where the upper boundary of an aquifer is the water table--that is, free-water surface at atmospheric pressure--the aquifer is said to be unconfined, nonartesian, or under water-table conditions. The water level in only those wells open to the uppermost part of an unconfined aquifer coincides with the water table. The static water level in wells that penetrate the aquifer to greater depths and are open to the aquifer below the upper part of the aquifer may be higher or lower than the water table. Unless there is a significant vertical-flow component, however, the static water level in wells penetrating to greater depths ordinarily should be close to the water-table elevations. Under water-table conditions, water-level declines result from the draining of pore spaces in the aquifer.

Where the upper boundary of an aquifer is a confining layer, the aquifer is described as confined or artesian. The water level in wells completed in confined aquifers is higher than the top of the aquifer. A well will flow if drilled into a confined aquifer having a static head higher than the land surface.

The water level in tightly cased wells defines the potentiometric or pressure surface of an aquifer, whether the aquifer is confined or unconfined. Under confined conditions, net water-level decline is a result of the reduction of water pressure. The pressure reduction is a result of the removal of water from storage, even though the aquifer continues to be saturated. Pumping of a water-table aquifer decreases saturated thickness. Pumping of a confined aquifer reduces head but does not begin to dewater the aquifer until water-table conditions have been reached.

The response to the pumping of aquifers under confined and unconfined conditions can be seen by comparing a hydrograph from an observation well that produces from an unconfined aquifer with that of a well that produces from a confined aquifer. The Schuyler recorder well (fig. 10a), located immediately north

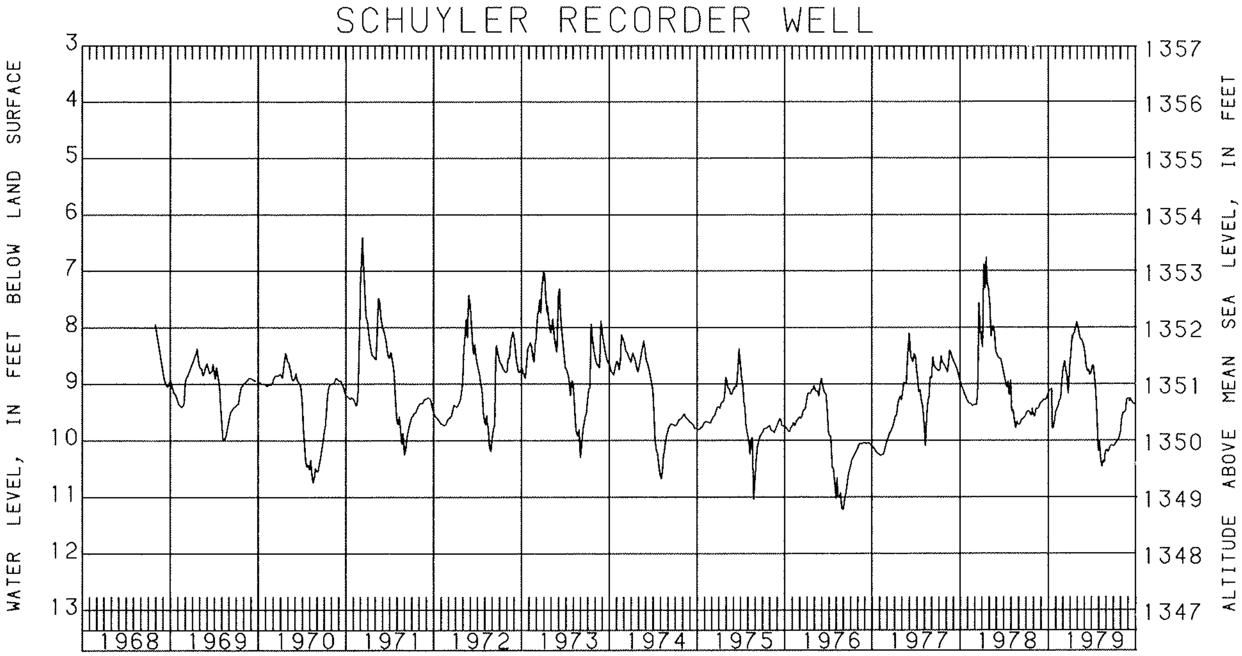


Fig. 10a. Hydrograph of a well, immediately north of Butler County, in an unconfined aquifer

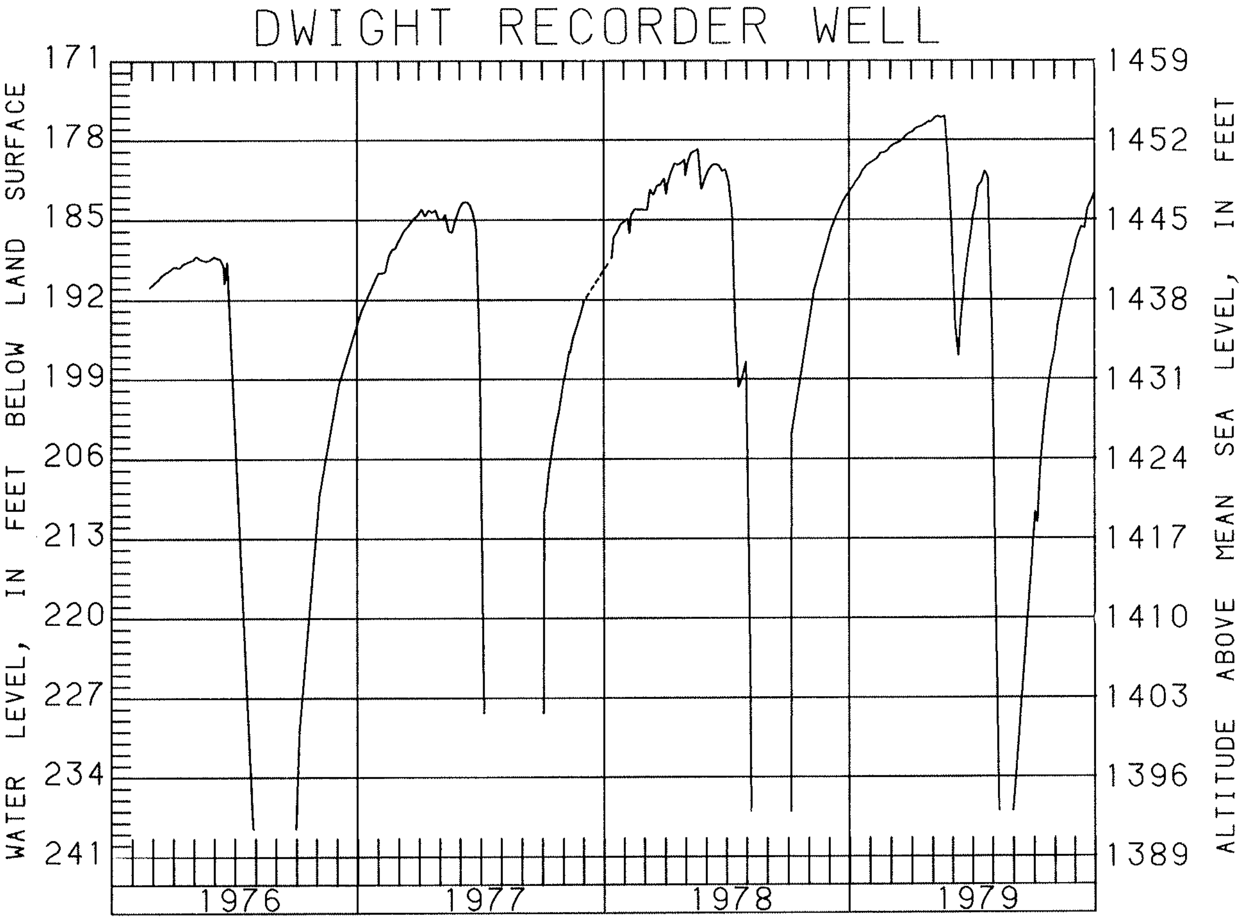


Fig. 10b. Hydrograph of a well in a confined aquifer

of Butler County, is completed in unconfined sand and gravel in the Valley Plain. Since the water table is shallow and the aquifer unconfined, the water level in this well rises fairly rapidly because of precipitation or recharge from Lost Creek during high stages. Conversely, the water level declines fairly rapidly during the growing season because of evapotranspiration by deep-rooted vegetation and water withdrawal by irrigation pumps (Ellis and Pederson, 1978, p. 66).

Because the Dwight recorder well (fig. 10b) is completed in a confined sand and gravel aquifer, the hydrograph for this well shows a significant water-level decline in response to pumping during the irrigation season. Whereas magnitude of decline and length of time to reach maximum decline varies with rock type and hydrologic conditions, a hydrograph of a well producing from a confined aquifer generally shows a relatively abrupt and large water-level decline compared with that of a well producing from an unconfined aquifer.

GROUNDWATER HYDROLOGY

Water Balance

Under completely natural conditions, without interference by mankind, recharge to the groundwater reservoir in Butler County is from subsurface groundwater inflow from the west (F_i) and from precipitation (P) via seepage from streams and infiltration through the soil. Only a small fraction of precipitation that falls ultimately reaches the groundwater reservoir. Discharge from the groundwater reservoir is via subsurface outflow to the east (F_o), evapotranspiration (E_t), seepage to streams (S), and discharge through springs (D).

Before any development of groundwater resources by mankind, the shape and volume of the groundwater reservoir underlying the county remained virtually unchanged with time. Except for seasonal changes in water levels that resulted from variations in climatic events, the reservoir was in natural equilibrium. Under equilibrium conditions, inflow equals outflow:

$$F_i + P = F_o + E_t + S + D \qquad (1)$$

where the left side of the equation is input to the groundwater system and the right side is output from the system.

Effects of development have changed conditions from equilibrium. Superimposed on predevelopment equilibrium are discharges from groundwater pumpage (Q) and recharge from irrigation water (R). Thus equation 1 becomes:

$$F_i + P + R \leq Q + F_o + E_t + S + D \qquad (2)$$

For present conditions in Butler County, the right side of equation 2 generally is equal to or greater than the left side, the difference equaling change in storage. Where the right side of the equation is greater, a net loss of water from the groundwater reservoir is indicated. Large-volume pumpage of groundwater depletes the reservoir faster than recharge can replenish it. Such depletion results in reduction of the total volume of groundwater in storage and may cause a decrease in flow from springs, a lowering of water levels, and a reduction of streamflow.

Several locations in Butler County show the effects of large-volume groundwater pumpage. Declines of 5 ft or more have been documented in two locations, one in the extreme southwest corner of the county and the other immediately east of Garrison (Johnson and Pederson, 1981, pp. 13, 15). The decrease in flow of springs and wells in the Dwight-Valparaiso area, at least partially in response to large-volume pumpage, is discussed in this report in the section "Water-Level Fluctuations in the Dwight-Valparaiso Area."

Hydrogeologic Regions

For the purpose of this report, Butler County has been divided into three hydrogeologic regions (fig. 11). The regions

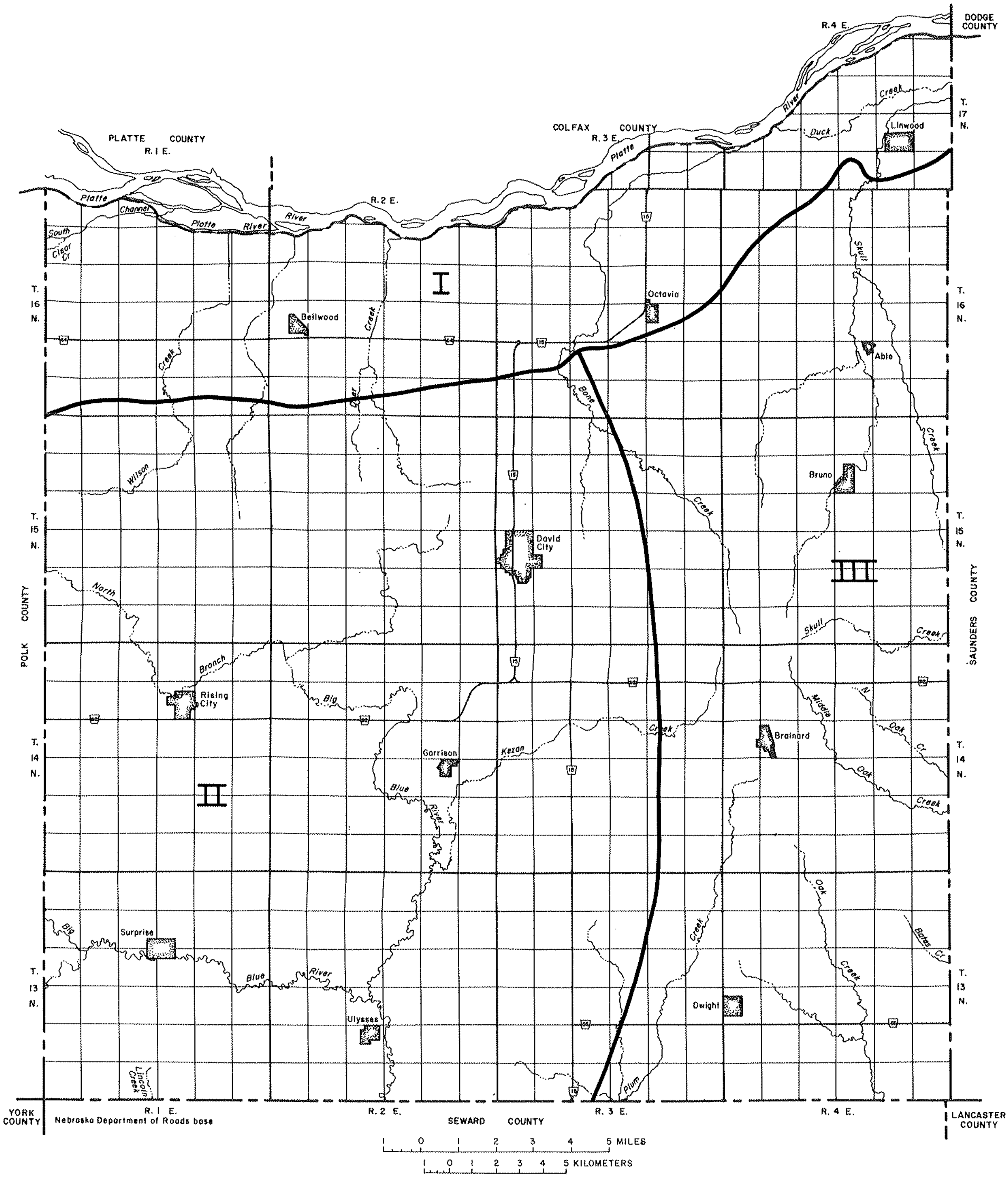


Fig. 11. Hydrogeologic regions in Butler County

are differentiated according to the water-bearing properties of underlying materials. Variations in groundwater availability result from the different geologic settings of the hydrogeologic regions.

Region I coincides with the Valley Plain. The principal aquifer in this region is composed of alluvial sand and gravel. The present-day Platte River has incised its channel into those deposits. The aquifer is generally less than 80 ft thick, although it is half again as thick where some wells penetrate. Large-capacity wells (600 to 1,200 gal/min) generally can be developed in this region.

Water in the principal aquifer of Region I exists under unconfined conditions, the depth to water being shallow, generally between 5 and 35 ft. The aquifer has significant hydraulic connection with the Platte River. Near the river the potentiometric surface (fig. 12) reflects the water level of the river and is only indirectly related to conditions in Regions II and III.

Sand and gravel deposits that are major aquifers south of hydrogeologic Region I either do not extend as far north as the Platte River valley aquifer or extend beneath it. For the most part, they are separated from it by silts and clays. There is little hydraulic connection between the sands and gravels of the Platte River valley aquifer and those of aquifers beneath it and to the south of it.

Region II is the area south of the Valley Plain from the western edge of the county to a concave line that reaches its

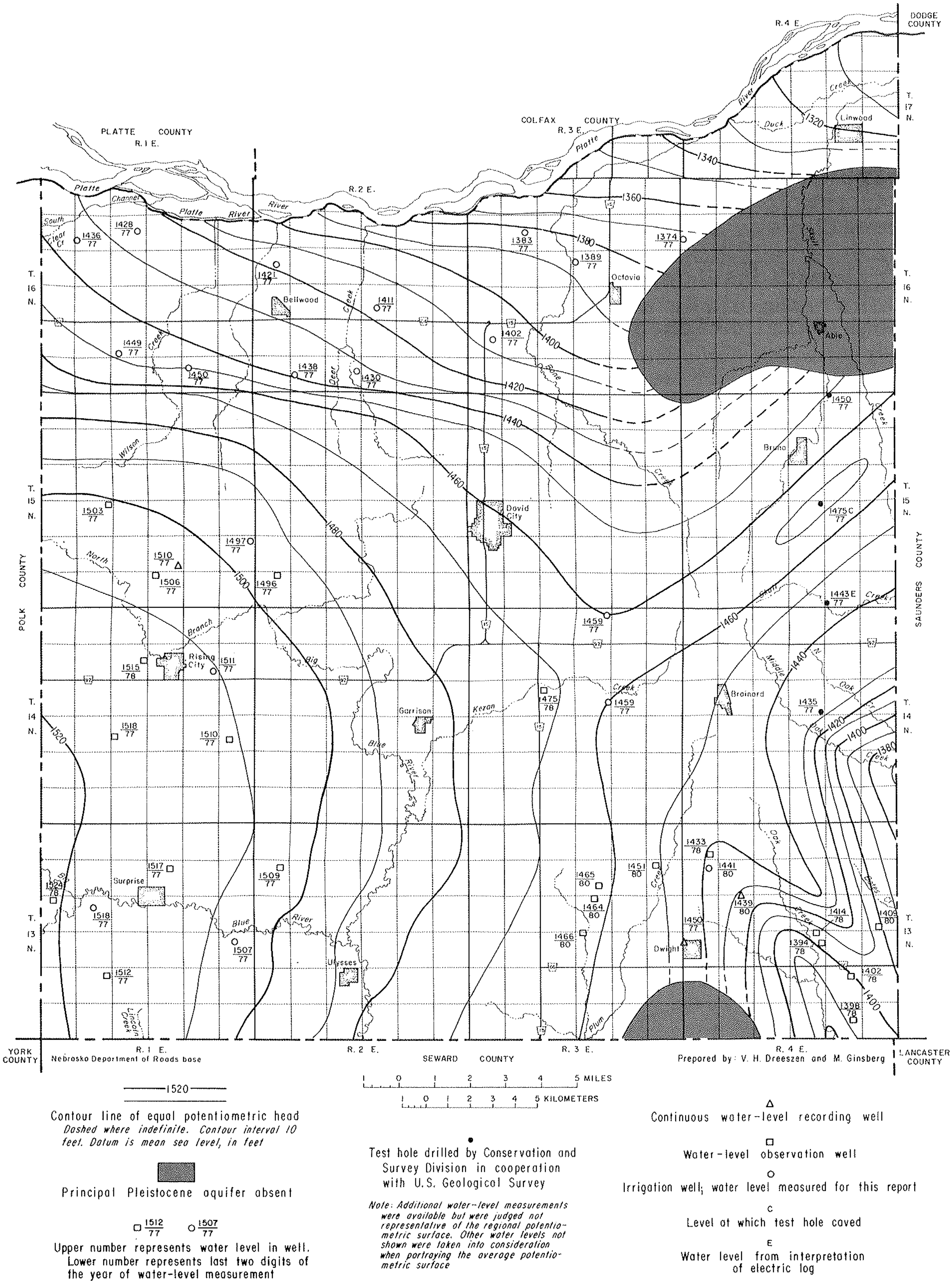


Fig. 12. Generalized configuration of the average potentiometric surface in the Pleistocene aquifer system in Butler County, spring late-1970s

easternmost point about 2.5 mi west of Brainard. Aquifer sequences are associated with major paleovalleys and thick sands, in part gravelly, which overlie paleodivides and sediment-filled paleovalleys. The paleovalleys have no topographic expression. Their locations, orientations, and dimensions are known only through examination of logs of test holes and wells. They trend generally east to west or southeast to northwest and may be as much as 6 mi wide (fig. 9). One paleovalley passes under and immediately north of David City, another underlies Surprise and Dwight. The deepest wells in the region are associated with the paleovalleys. Large-capacity wells generally can be developed throughout this region.

The average potentiometric surface in Region II may reflect either confined or unconfined conditions. Where two or more saturated sand and/or gravel bodies are present, they generally are in partial hydraulic connection; that is, the lower aquifer exists under either unconfined or leaky artesian conditions. The average potentiometric surface for aquifers in Region II is shown in figure 12.

A perched aquifer occurs throughout much of hydrogeologic Region II. Two types of evidence indicate this. First, in several test holes drilled by the Conservation and Survey Division in which the bottom of the test holes collapsed at depths shallower than the major aquifers, the water levels stood at much higher altitudes than the top of the major aquifers. Second, depth to water in two observation wells drilled side by side in NE¼ of sec. 27, T. 15 N., R. 1 E., differed by 16.5 ft. In the shallower of the two wells, screened only between 121 and 131 ft, depth to water was 89.3 ft on December 2, 1979. In the deeper well drilled into a major aquifer and screened from only 197 to 207 ft, the depth to water on the same day was 105.8 ft (Elliott, 1981). The difference in head between the two wells indicates that one penetrates a perched aquifer and the other, a major aquifer.

In places, perched water levels may be as much as 200 ft above the regional potentiometric surface. The thickness of the perched zone of saturation is unknown; however, it is sufficient to supply water to shallow domestic and stock wells. The water-bearing material comprising the perched aquifer material ranges from silt and clay to sand and sand and gravel.

In the early years of irrigation development, some irrigation wells were completed with perforations in both the perched aquifer zone and the underlying major aquifers. However, in these wells and in other wells with casings that were not tight, water from the perched zone cascaded down the well. By being exposed to the atmosphere, minerals dissolved in the cascading water precipitated and contributed to incrustation of well screens in the major aquifers. Well capacities were reduced as much as 50 to 75 percent in some wells in only three or four years. Use of solid casings to seal out water from the perched zone has eliminated this problem of incrustation.

Region III is the area south of the Valley Plain and east of the concave line that passes 2.5 mi west of Brainard. There are few large-capacity wells in this region. Those that exist are in areas coinciding with the eastward extension of major paleovalleys. In well-registration files of the Nebraska Department of Water Resources, some wells reportedly yield as much as 1,750 gal/min. The deepest large-capacity well is 454 ft and penetrates all, or almost all, of the Pleistocene sequence.

Till and till-related deposits are part of the stratigraphic sequence. Thin sand and gravel layers in the till serve as small groundwater sources for domestic and stock wells. The sand and gravel deposits are not areally extensive and can be delineated only by test drilling. In some places, these deposits may be sufficiently thick to provide enough water for irrigation. However, the limited areal extent and isolated nature of these deposits generally limit the volume of water storage in them, the recharge to them, and thus the volume of water available from them.

In the southern three-quarters of Region III, a thick sand layer overlies paleodivides and sediment-filled paleovalleys. This sand serves as an aquifer for many domestic wells in the region; and in places, it is used as a secondary aquifer for some irrigation wells. Water in this sand exists under conditions ranging from unconfined to partially confined. Water-level data are sparse for wells screened exclusively in the upper sand aquifer or exclusively in the lower paleovalley sands and gravels. However, water levels in wells in the upper and lower aquifers probably coincide approximately.

The southern paleovalley extends into the general area between Dwight and the western edge of North Oak Creek Valley near Brainard. The groundwater in sand and gravel in this paleovalley exists under confined conditions.

No major Pleistocene aquifer is present in the northern quarter of Region III (fig. 8c); therefore, mapping of an average potentiometric surface was not attempted there. Aquifers in the area cannot provide enough water for irrigation wells; in some locations, it may be difficult to obtain enough water for domestic wells. Nearly all existing wells produce from thin isolated sands and gravels in the till.

Aquifer Systems

The principal source of groundwater in Butler County is from undifferentiated deposits of Pleistocene age. The Pleistocene deposits of sand and gravel interbedded with silt and clay store, receive, and release groundwater, constituting in effect a groundwater reservoir. Some water-saturated sediments of silt, clay, sand, and gravel in the river valleys may be of Holocene (?) age but are included in this report as a part of the Pleistocene aquifer system.

Perched aquifers, also of Pleistocene age, are discussed separately because they are not directly connected physically or hydrologically with the main groundwater reservoir. The perched aquifers also store considerable quantities of groundwater but are generally not a major source of water to wells.

Information about the aquifer characteristics of sandstones of the Dakota Group, undivided, is limited. A few test holes and wells have been drilled into the Dakota, which is not at this time considered to be a major source of water in the county.

The Dakota Group, undivided, rests directly on Pennsylvanian age shales and limestones (Burchett, 1982, pp. 3, 5, 11), which are not thought to be a source of water. The Pennsylvanian units overlie rocks of Mississippian through Cambrian age (Burchett, 1979, p. P2; and Carlson, 1970, figs. 8-15). Silurian age units are absent in the northern half of the county and Mississippian age units are absent in the southeastern corner of the county. The Mississippian through Cambrian sequence of sandstones, shales, limestones, and dolomites may have the potential to yield water to wells. However, the quality of water from these rocks is probably poor.

Two oil test holes were drilled to pre-Cambrian rock in sec. 29, T. 16 N., R. 2 E. The test holes penetrated approximately 1,150 ft of the Mississippian through Cambrian sequence and intersected the top of the pre-Cambrian at a depth of about 2,500 ft (1,030 ft below sea level).

Pleistocene Aquifer System

The Pleistocene aquifer system in Butler County is defined in this report as being composed of the Pleistocene sands and gravels that constitute the major aquifers underlying Butler County (figs. 8a, 8b, 8c, and 8d). Interbedded silts and clays are considered to be part of the system because they yield a small amount of water, via gravity drainage, to wells screened in a lower sand or gravel. Not included in the system are thin sand

and gravel lenses that are part of the till sequences.

The base of the system is considered to be at the bottom of the lowermost major sand or gravel. Thin basal Pleistocene sand and gravel layers, separated from the major aquifer system by thick deposits of silt or clay, are tapped by very few wells and are not considered to be part of the system in this report. The configuration of the base of the system is shown in fig. 13. The base corresponds with the top of the bedrock only where a major sand or gravel rests directly on bedrock. Where silt or clay deposits intervene, the base of the system and top of the bedrock do not coincide, altitudes differing by the thickness of the intervening layers.

Thick sequences of saturated sand and gravel occur many places within major paleovalley channel fills. Thick sequences of saturated sand also are present above paleovalleys, particularly in the southern half of the county. These upper sands overlie paleodivides and sediment-filled paleovalleys without regard to bedrock-surface configuration.

Aquifers within paleovalleys are extensions of the major regional aquifers underlying the Big Blue River basin to the west and southwest of Butler County. By about halfway through Saunders County, aquifers in paleovalleys have thinned markedly. Sand aquifers not lithologically identical to those in Butler County overlie paleovalleys to the west and southwest of the county. To the east, the upper sand thins markedly beneath Saunders County (Souders, 1967).

Transmissivity of the Pleistocene aquifer system in the

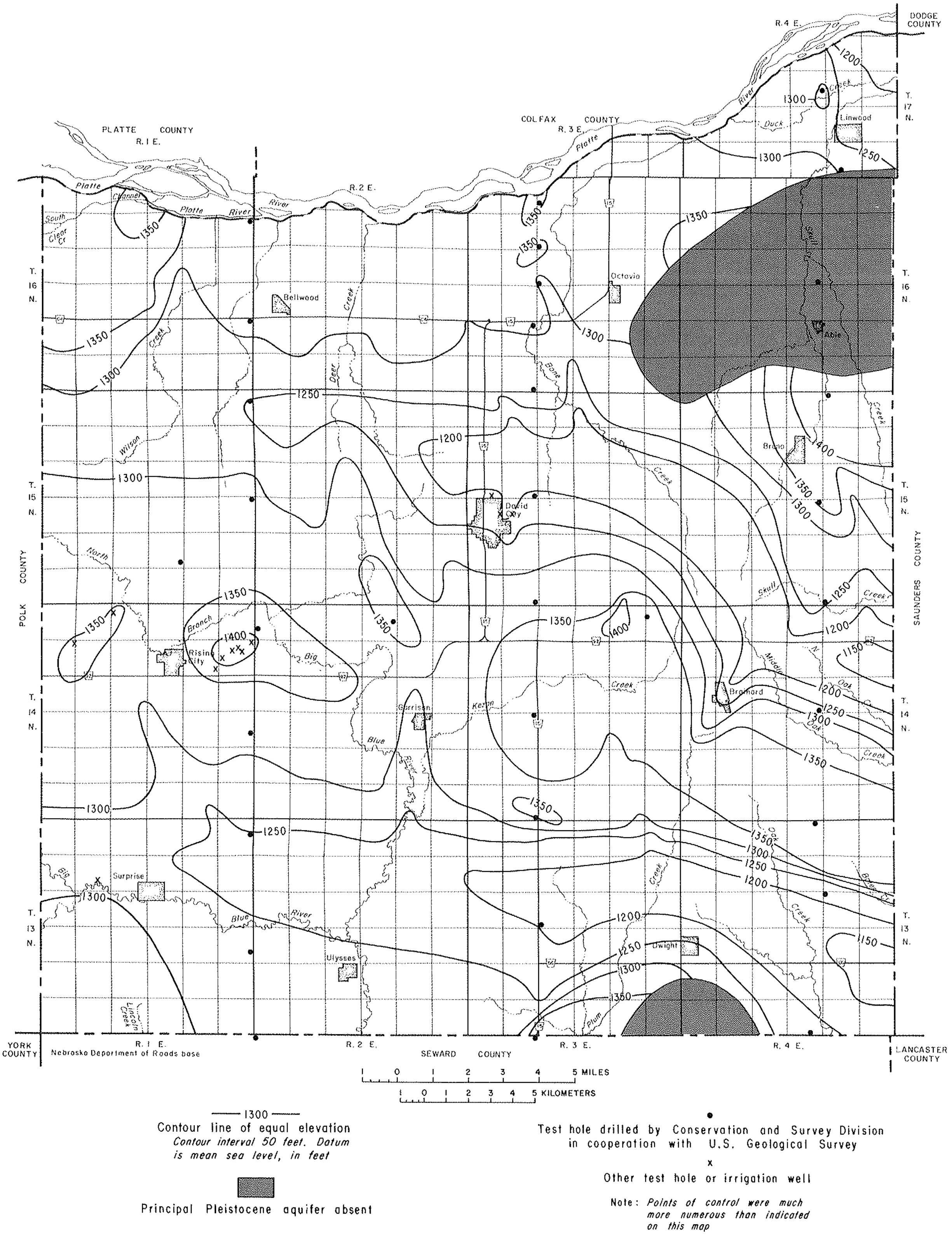
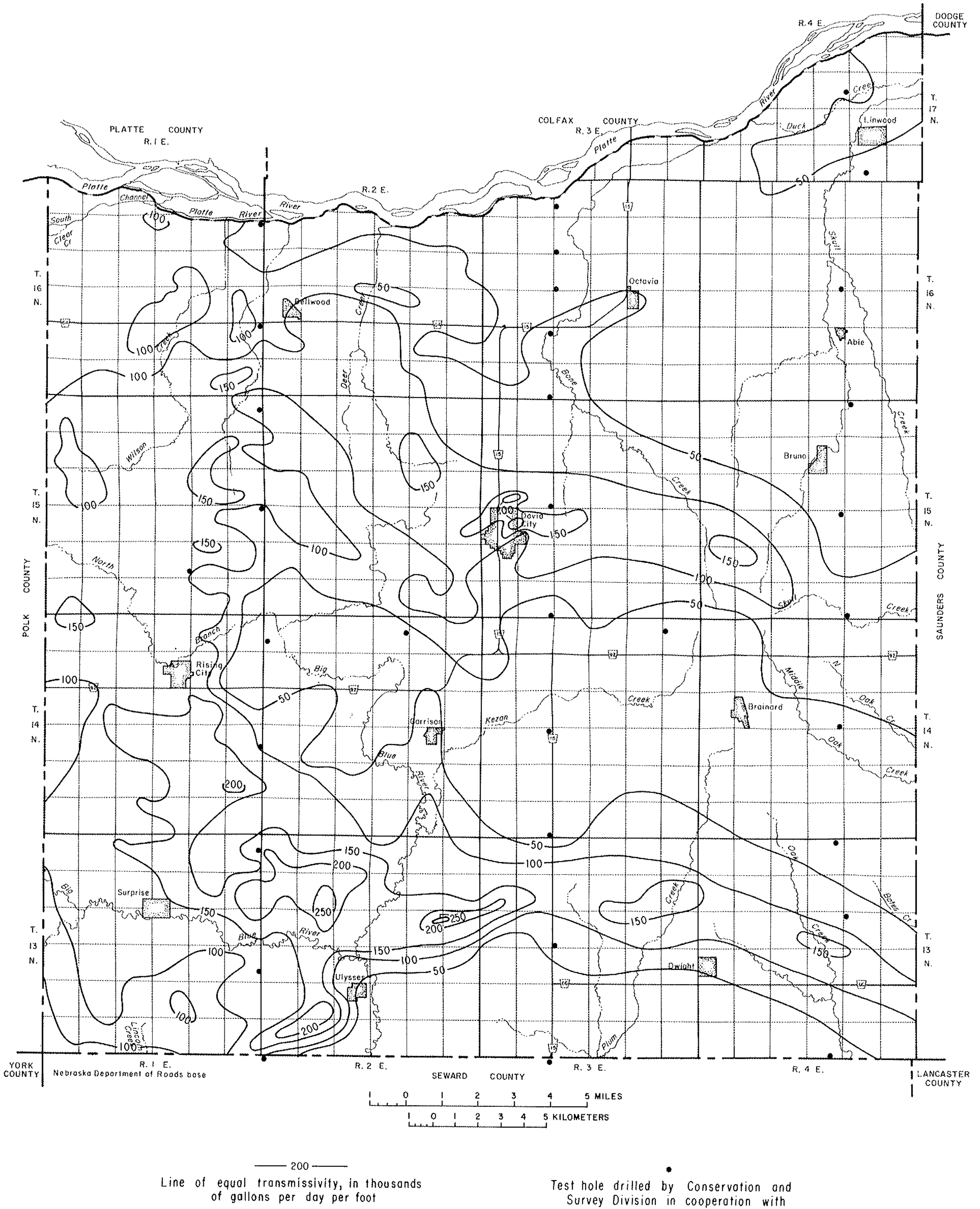


Fig. 13. Configuration of the base of the Pleistocene aquifer system in Butler County

county is shown in figure 14. The transmissivity at numerous specific locations was estimated by using information from well logs and from test-hole samples provided by the Conservation and Survey Division and from information based on logs of wells and test holes from other sources. For a given location, a value for hydraulic conductivity was assigned to each unit of water-bearing material at the location by using a method adapted from Keech and Dreeszen (1959, p. 38) that depends on particle-size range, degree of sorting, and silt content of the water-bearing material. The values assigned to the individual water-bearing units then were multiplied by the thicknesses of the respective units and the products were summed to give a transmissivity for the entire aquifer thickness at that location. The transmissivity for the numerous specific locations then provided the basis for drawing the lines of equal transmissivity shown on the figure.

The thickness of saturated Pleistocene sand and gravel is shown in figure 15. Because thick deposits of sand and gravel are found in paleovalleys, areas of greater transmissivity tend to correspond with the general locations of these valleys. Conversely, areas of lesser transmissivity correspond approximately with paleodivides. Layers of sand and gravel that overlie paleodivides and paleovalleys in the western part of the county account for part of the transmissivity of the aquifer system and, to some extent, mask the locations of paleovalleys and paleodivides. Thus, only a general correspondence exists between transmissivity and the paleovalleys and paleodivides. Such correspondence may in fact be only general because



——200—— Line of equal transmissivity, in thousands of gallons per day per foot

● Test hole drilled by Conservation and Survey Division in cooperation with U.S. Geological Survey

Note: *Points of control were much more numerous than indicated on this map*

Fig. 14. Transmissivity of the Pleistocene aquifer system in Butler County, mid-1970s

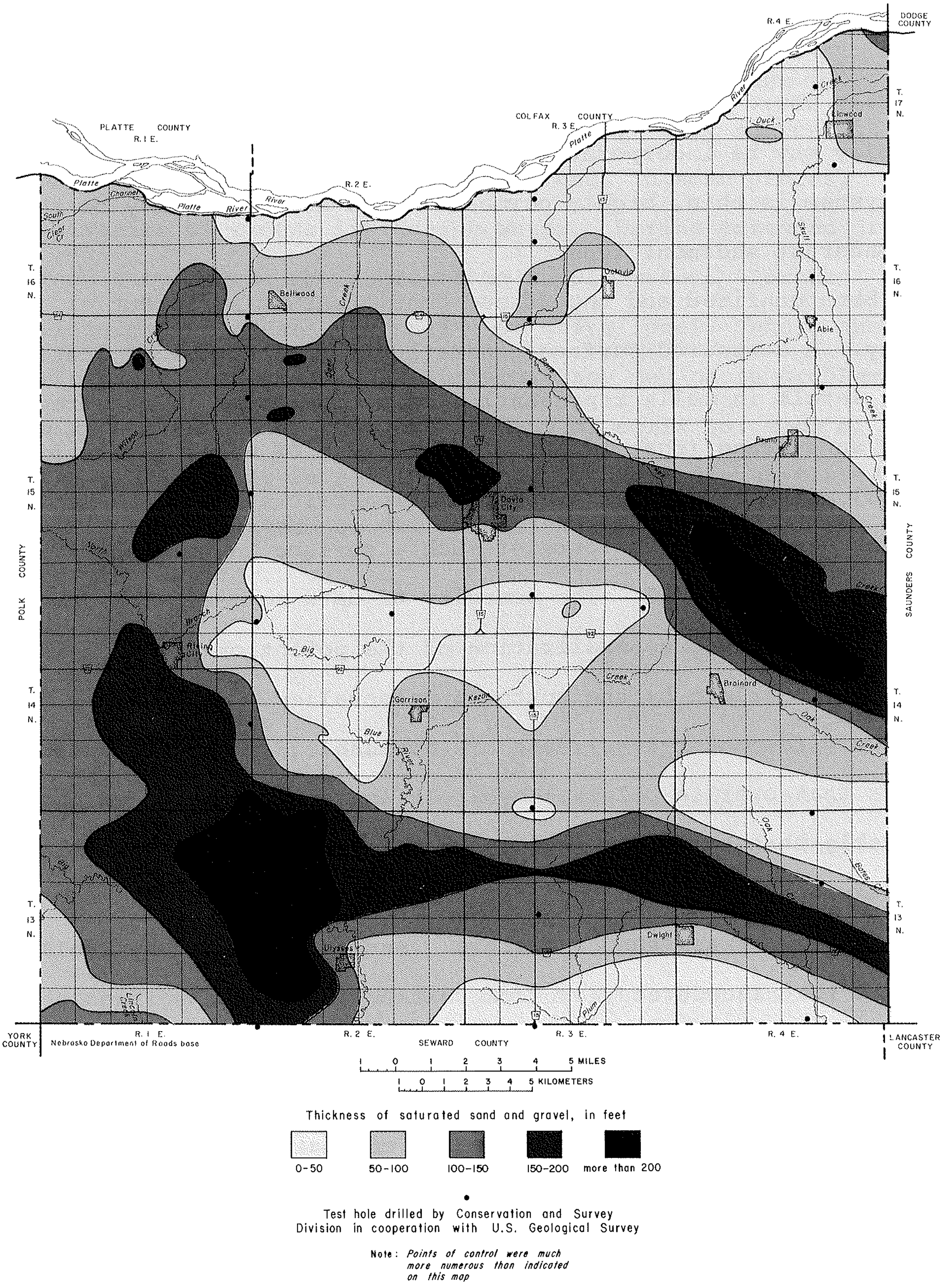


Fig. 15. Thickness of saturated Pleistocene sand and gravel in Butler County, mid-1970s

in areas where the aquifer system is thick, sequences of silt and clay may be incorporated within it; whereas, in areas where the system is thin, highly permeable sand and gravel may be the preponderant sediment type.

Both confined and unconfined conditions exist in Butler County. A contoured surface generated from altitudes of static water levels in wells representing both conditions is referred to as an average (that is, vertical average of water levels from several wells in a given area) potentiometric surface. A map showing generalized contours of such a surface in the late-1970s is given in figure 12. The scarcity of data necessitated interpretation and generalization of the potentiometric map in the area underlain by the southern paleovalley.

Very few water-level data are available for the thick sand layers that overlie paleovalleys. It appears from the few data available that the water in these sands probably exists under conditions ranging from confined to partially saturated.

Numerous small sand and gravel lenses, deposited by small streams that flowed near or from continental glaciers, are present in the till underlying the county. Water-level altitudes in wells screened in different lenses may differ by more than 100 ft in wells spaced as little as 1 mi apart.

Perched Aquifers

Perched aquifers occur where clay or silty clay layers underlie more permeable sediments above the principal saturated zone. These aquifers may not contain adequate storage to serve as perennial sources of water, because their only sources of recharge are from local precipitation and, in some places, infiltration of excess irrigation water. During extended dry periods they become too depleted to supply water. Perched aquifers may be areally extensive or quite local. Where these aquifers are near the ground surface, they may cause problems such as wet basements and waterlogging of soils for much or all of the year. Water levels in perched aquifers are unrelated, or only slightly related, to the potentiometric surface of the major underlying aquifer.

Dakota Aquifer

The Dakota Group, undivided, underlies all of Butler County. Water in the Dakota may exist under confined conditions at one location and under unconfined conditions at another. Where Pleistocene (or Holocene?) aquifers are not present, wells have been drilled into the Dakota. Because the Dakota may vary from sandstone to shale within short distances, development of a well in the Dakota at one site may indicate little about the possibility of developing a well in the Dakota at a nearby site. Only by test drilling can one determine the potential for well development at a specific site.

Few data are available on the quality of water from the Dakota in Butler County. However, data from wells elsewhere indicate that some water in the Dakota is excessively mineralized and thus may be unsuitable for human and livestock consumption or for irrigation. Nearly impervious shales may separate waters of different quality in overlying and underlying sandstone units. Because water in the upper layers may be diluted by recharge from precipitation, such water commonly is less mineralized than water in deeper layers. The only two wells in Butler County known to produce from the Dakota supply water to the village of Abie. These wells pump at an approximate rate of 150-200 gal/min.

Most test holes in Butler County have penetrated only a few tens of feet into the Dakota. However, several test holes near Abie penetrated more than 200 ft into the Dakota. One of these, test hole number 16N-4E-22, was drilled by Lane Drilling Company for Leonard Roh in 1957. Another, number 16N-4E-22A, was drilled by Layne-Western Company, Inc., for the village of Abie in 1964.

At the Roh test-hole site, the land-surface elevation is 1,451 ft above mean sea level. The test hole penetrated 79 ft of Pleistocene sediments, 74 ft of Greenhorn Limestone and Graneros Shale, and 362 ft of Dakota. In the 362 ft of Dakota penetrated, the rock sequence is one of alternating shale and silty sandstone.

At the village of Abie test-hole site, the land-surface elevation is 1,450 ft above mean sea level. The test hole penetrated 109 ft of Pleistocene sediments, 32 ft of Graneros Shale, and 280 ft of Dakota. The 280 ft of Dakota penetrated is principally shale with sandstone interbeds.

Water-Level Fluctuations in the Dwight-Valparaiso Area

The southernmost paleovalley in Butler County extends eastward under the town of Valparaiso in Saunders County (fig. 16). The rate of installation of irrigation wells producing from the paleovalley sediments in an area from just west of Dwight to between Dwight and Valparaiso increased in the mid- and late-1970s.

The major aquifer between Dwight and Valparaiso is the paleovalley sand and gravel, which according to information from well logs (fig. 17) is as thick as 140 ft in some places. Except where thin silt and clay deposits blanket the valley floor, the aquifer is in direct contact with bedrock. Overlying the sand and gravel in the paleovalley are silt and clay deposits of both glacial and nonglacial origin. These fine-grained deposits are nearly impervious and, therefore, confine the water in the paleovalley sand and gravel deposits. In some places, water levels in wells open to the paleovalley aquifer are more than 100 ft higher than the top of the aquifer itself. The confining conditions also cause water to flow from some wells in the area.

In about the eastern half of the area near the southern side slope of the paleovalley, the silt and clay overlying the sand and gravel aquifer extends to the land surface 100 to 200 ft above (fig. 18a). In most of the remainder of the area, however, the silt and clay averages about 70 ft in thickness and is, in turn, overlain by a sand aquifer. In the vicinity of Dwight, the sand aquifer is about 80 ft thick. The water within it probably exists under confined conditions, having a low artesian head. This sand aquifer thins toward the east and probably ends about

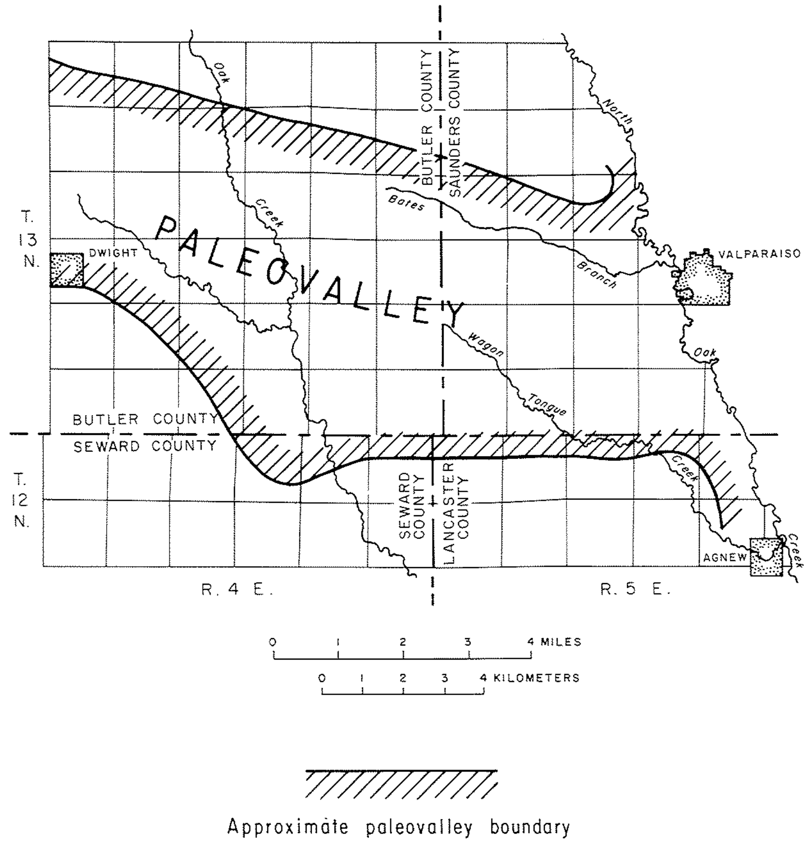


Fig. 16. Approximate boundary of the paleovalley underlying the Dwight-Valparaiso area in Butler, Seward, Saunders, and Lancaster counties

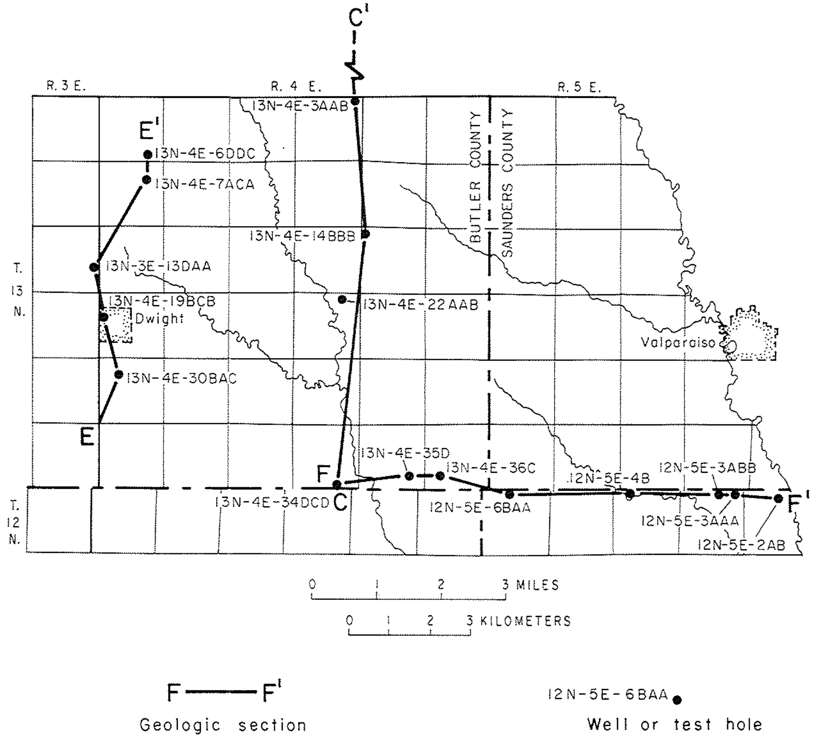


Fig. 17. Location of geologic sections in the Dwight-Valparaiso area in Butler, Seward, Saunders, and Lancaster counties

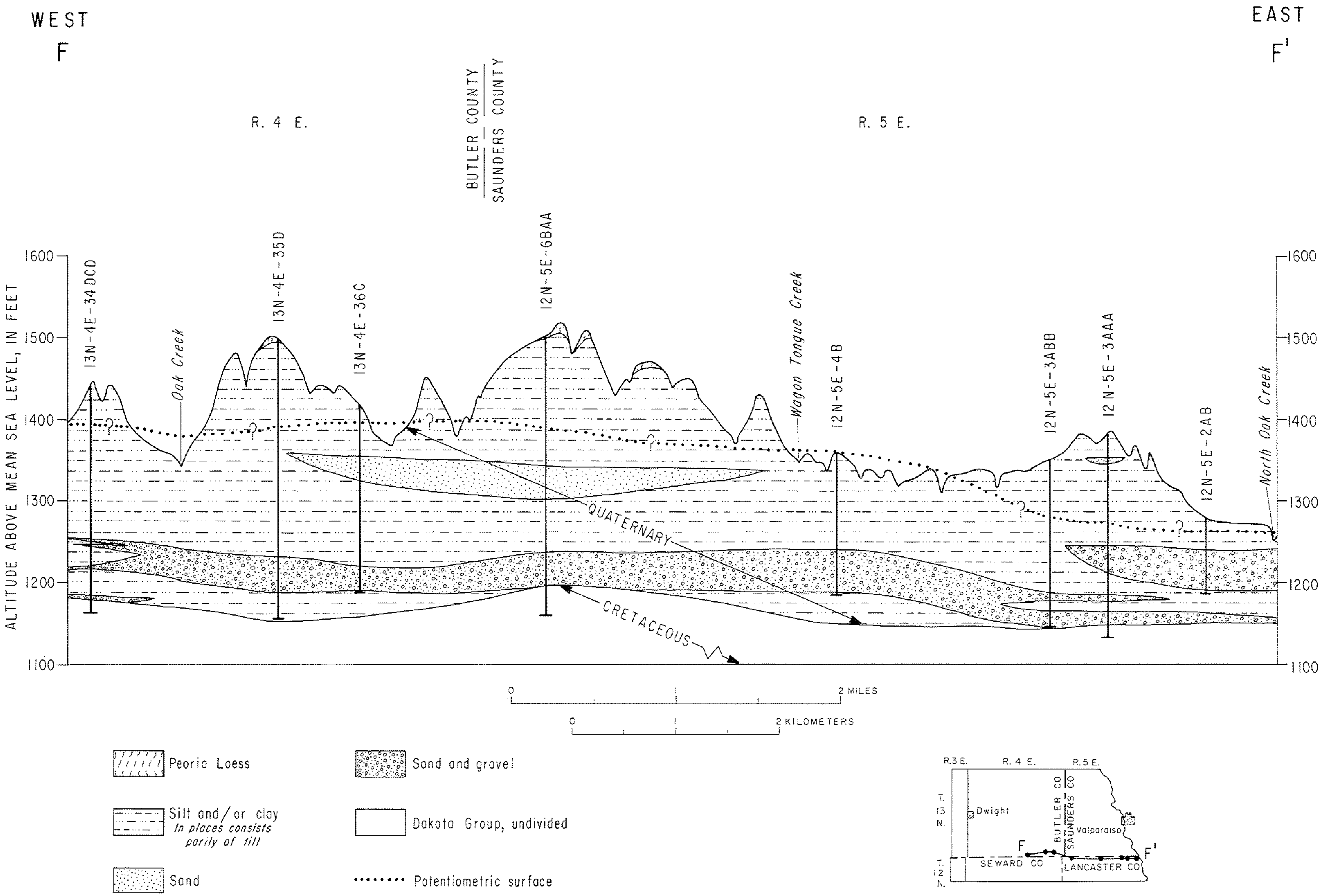


Fig. 18a. East-west geologic section near the southern boundaries of Butler and Saunders counties

2 mi west of Valparaiso. It is in this sand aquifer that most domestic wells are screened and from which they produce.

Some irrigation wells produce from only the lower aquifer, whereas some produce from both the upper and lower aquifers. Sometime around the mid-1970s, several springs along Oak Creek as well as some stock wells ceased flowing during the irrigation season. At the same time, some domestic wells producing from the lower aquifer either decreased in output or ceased altogether, resulting from a decline of the potentiometric surface below the pump intakes. Historically, neither the flowing stock wells, the springs along Oak Creek, nor the few domestic wells screened in the lower aquifer were known to have had such severe head loss during the summer season.

By comparing the north-south geologic section that passes through Dwight (fig. 18b) with the T. 13 N. part of the geologic section that lies about 4 mi to the east (fig. 8c), one can see important similarities in geology in this Dwight-Valparaiso area. In both geologic sections, the major paleovalley aquifer is about 100 ft thick and is overlain by a thick sequence of silt, clay, and/or till. Within this sequence lies a major sand aquifer which in places is as thick as 80 ft. The similarities in geology are somewhat obscured by differences of scale in the two figures; also in figure 8c till is clearly mapped separately, whereas in figure 18b till is mapped with silt and clay.

Examination of the east-west geologic section (fig. 18a), which lies near the southern side slope of the paleovalley wall, shows that wells producing from the sand and gravel underlying

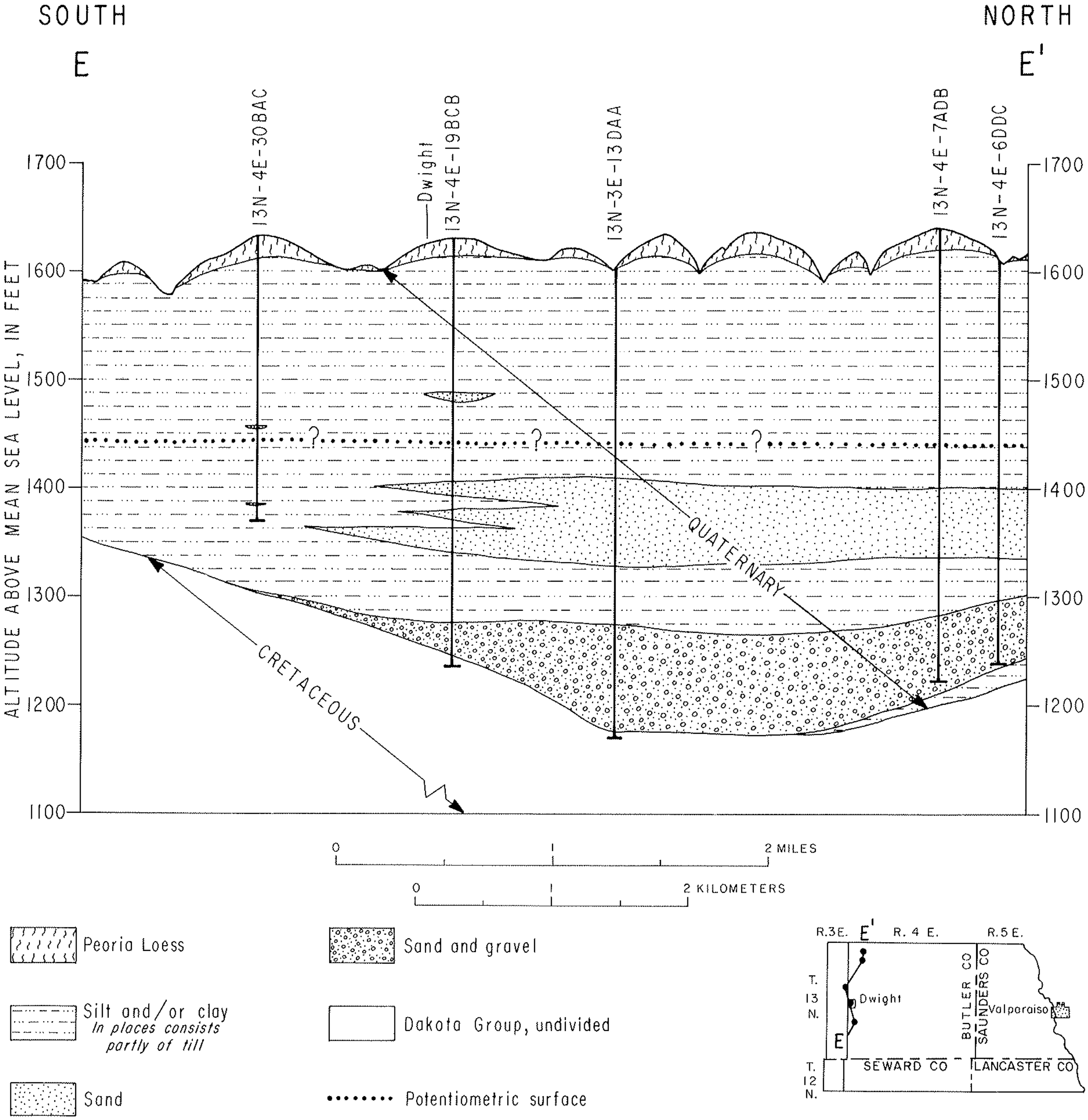


Fig. 18b. North-south geologic section through Dwight in southeastern Butler County

North Oak Creek valley are not in hydraulic connection with the major paleovalley aquifer. The sand and gravel beneath North Oak Creek valley, however, is in partial connection with North Oak Creek. This view is supported by the observation that water-level fluctuations detected in wells producing from the major paleovalley aquifer elsewhere are not detected in wells in the vicinity of North Oak Creek.

An observation well equipped with a recorder, installed at Dwight in 1976, provides data on water-level fluctuations. This well, number 13N-4E-17ABA1, is 376 ft deep. Because it is screened only in the bottom 20 ft, levels recorded probably represent the hydraulic head in the paleovalley sand and gravel aquifer only. Records for this well (fig. 10b) indicate significant head declines in the lower aquifer during the irrigation season. Declines of more than 60 ft occurred within one month of the onset of irrigation pumping. How far the head declines proceeded cannot be determined accurately from figure 10b because the well casing collapsed at a depth of 240 ft below land surface. A replacement well was drilled and equipped in 1979.

Loss of production from domestic wells can sometimes be related to the advanced age of the wells and the attendant deterioration of well installations. However, two things suggest that irrigation pumping is a major contributing factor in the decrease of flow observed in springs, flowing wells, and domestic wells. The first of these is the hydrology of the area. The second is the coincidence of head loss and recovery with the onset and end of pumping for irrigation.

Quality of Groundwater

Water quality depends on chemical constituents dissolved in the water and on several physical properties, such as temperature, associated with the water. As water vapor condenses and falls to the ground, it dissolves atmospheric gases and a variety of chemical constituents from particles in the air, usually becoming somewhat acidic in the process. After falling to the ground, it percolates through soil and rock material toward the groundwater reservoir. At this time, complex chemical and biochemical processes take place which cause water to dissolve a variety of organic and inorganic constituents. Concentrations of the constituents dissolved can vary greatly, depending mainly on the characteristics of the soil and rock materials contacted by the water. Concentrations of important constituents dissolved in the groundwater of Butler County and measurements of several important physical properties of the groundwater are given in table 2.

Location of the 27 wells for which chemical analyses are available is shown in figure 19. Sample numbers given in table 2 correspond with those shown in figure 19. All samples were collected and analyzed by the U.S. Geological Survey except the one from the well at Abie (number 26 in the table), which was collected and analyzed by the Nebraska Department of Health.

Examination of data in table 2 indicates that concentrations of dissolved solids in water from the Pleistocene aquifers, whether from the paleovalley sand and gravel aquifers or from the overlying sand aquifers, range from about 300 to about 700 mg/l.

TABLE 2

Chemical Analyses of Groundwater in Butler County

Sample No.	Well No.	Date of Sampling	Hydro-geologic Region	Silica (SiO_2) (mg/l)	Iron (Fe) (µg/l)	Manganese (Mn) (µg/l)	Calcium (Ca) (mg/l)	Magnesium (Mg) (mg/l)	Sodium (Na) (mg/l)	Potassium (K) (mg/l)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Sulfate (SO_4) (mg/l)
1	13-2-28AC	8/18/77	II	38	70	0	80	15	38	6.0	330	0	40
2	13-3-13DA	8/18/77	III	51	70	240	87	23	21	7.1	390	0	37
27	13-4-17ABAB1	7/09/79	III	36	730	510	75	15	16	5.9	317	0	17
24	13-4-19BB1	9/25/69	III	56	1,300	440	51	28	25	13	345	0	33
3	14-1-10DDBC	8/18/77	II	32	1,100	0	140	22	50	11.0	340	0	200
4	14-2-23AB	8/18/77	II	32	80	10	110	18	63	6.7	450	0	91
5	14-4-17CB	8/19/77	III	47	80	460	130	33	20	4.3	420	0	170
23	15-1-27DD2	9/14/77	II	45	10	30	140	18	34	7.8	390	0	160
25	15-3-19DD1	9/25/69	II	40	480	0	60	19	24	7.9	281	0	54
6	15-3-20CBC	8/19/77	II	39	40	400	96	22	24	7.6	380	0	65
7	15-4-10CAC	8/19/77	III	51	250	20	76	15	14	8.0	200	0	75
8	16-2-19CABC	8/18/77	I	40	80	670	110	17	22	6.5	340	0	110
9	16-3-2DA	5/22/67	I	36	---	---	46	58	28	9.6	416	0	57
10	16-3-10AD	5/22/67	I	38	---	---	58	43	22	6.7	385	0	51
11	16-3-13AB	5/22/67	I	40	---	---	71	57	21	18	496	0	45
12	16-3-14BC	5/22/67	I	43	---	---	103	27	36	12	420	0	97
13	16-3-19BC	5/19/67	I	45	---	---	54	48	25	11	371	0	76
14	16-3-22AA	6/13/68	I	43	90	10	88	19	20	9.3	372	0	30
15	16-4-6DD	6/13/68	I	44	50	10	85	22	22	11	397	0	26
26	16-4-27AA	9/--/74	II*	--	60	0	99	22@	270	--	380@	-	201
16	17-4-22DC	5/22/67	I	25	---	---	62	15	19	9.3	250	0	40
17	17-4-25AB	6/13/68	I	29	210	0	83	12	8.3	5	252	0	46
18	17-4-27AB	5/22/67	I	25	---	---	60	21	26	8.9	235	0	67
19	17-4-31CD	5/22/67	I	32	---	---	66	27	17	9.1	325	0	41
20	17-4-32BD	5/22/67	I	26	---	---	85	32	32	13	348	0	103
21	17-4-33AB	5/22/67	I	25	---	---	31	28	23	9.1	203	0	55
22	17-4-35AA	5/22/67	I	48	---	---	88	41	20	12	423	0	41

mg/l = milligrams per liter; µg/l = micrograms per liter; µmho = micromhos per centimeter at 25° Celsius; °C = degrees Celsius

@estimated

*Dakota aquifer

TABLE 2

(Continued)

Sample No.	Chloride (Cl) (mg/l)	Fluoride (F) (mg/l)	Nitrate as N (mg/l)	Nitrate+ Nitrite as N (mg/l)	Boron (B) (µg/l)	Dissolved phosphorus (P) (mg/l)	Ortho phosphate (PO_4) (mg/l)	Dissolved Solids: Residue at 180°C (mg/l)	Dissolved Solids: Sum of constituents (mg/l)	Hardness as $CaCO_3$ (mg/l)	Non-Carbonate hardness as $CaCO_3$ (mg/l)	Sodium adsorption ratio (SAR)	Specific conductance µmho	pH (units)	Temperature (°C)
1	12.0	0.4	--	5.1	60	0.37	--	--	415	260	0	1.0	668	7.5	19
2	5.6	0.4	--	0.44	90	0.07@	--	--	427	310	0	0.5	690	7.7	15
27	6.4	0.3	--	0.00	60	0.06	--	--	330	250	0	0.4	590	7.4	--
24	5.2	0.4	0.0	--	100	0.00	0.00	--	382	242	0	0.7	585	7.7	13
3	21.0	0.3	--	12.0	70	0.22	--	--	698	440	160	1.0	1,050	7.4	14
4	3.9	0.3	--	3.1	70	0.17	--	--	561	350	0	1.5	850	7.7	14
5	2.8	0.3	--	1.4	70	0.06	--	--	621	460	120	0.4	905	7.5	14
23	8.2	0.2	--	0.7	60	0.20	--	627	---	420	100	0.7	908	7.4	10
25	2.7	0.2	0.0	--	90	--	0.18	--	349	229	0	0.7	528	7.6	13
6	3.2	0.3	--	0.04	100	0.10	--	--	445	330	19	0.6	675	7.6	15
7	17.0	0.2	--	5.9	90	0.82	--	--	381	250	88	0.4	563	7.2	18
8	5.8	0.2	--	0.03	50	0.13	--	--	480	340	66	0.5	742	7.8	15
9	17.0	0.3	0.31	0.32	50	--	--	485	---	352	11	0.6	758	8.1	16
10	2.2	0.3	0.04	0.05	50	--	--	431	---	322	6	0.5	660	8.1	10
11	1.8	0.4	6.07	6.09	80	--	--	535	---	412	5	0.4	833	8.2	13
12	6.0	0.3	2.70	2.71	60	--	--	553	---	370	26	0.8	817	8.0	11
13	5.0	0.3	2.47	2.48	80	--	--	479	---	333	29	0.6	718	8.0	11
14	4.8	0.3	3.15	3.16	50	--	1.0	415	---	294	0	0.5	631	7.9	15
15	4.2	0.4	4.04	4.06	50	--	0.67	430	---	304	0	0.5	661	8.2	14
26	216	0.8	--	0.6	--	--	--	--	1,100	---	---	---	---	7.6	--
16	6.8	0.5	1.42	1.42	50	--	--	327	---	216	11	0.6	504	7.9	17
17	3.7	0.7	4.94	4.97	70	--	0.65	364	---	256	49	0.2	526	7.9	14
18	9.4	0.4	8.99	9.03	50	--	--	383	---	236	43	0.7	581	7.9	11
19	2.4	0.5	1.93	1.94	16	--	--	360	---	274	8	0.4	574	8.0	13
20	7.8	0.5	7.87	7.90	80	--	--	511	---	342	57	0.8	774	7.9	13
21	6.4	0.3	7.19	7.22	30	--	--	319	---	194	28	0.7	494	8.1	13
22	7.4	0.5	13.26	13.32	50	--	--	534	---	388	41	0.4	798	8.0	15

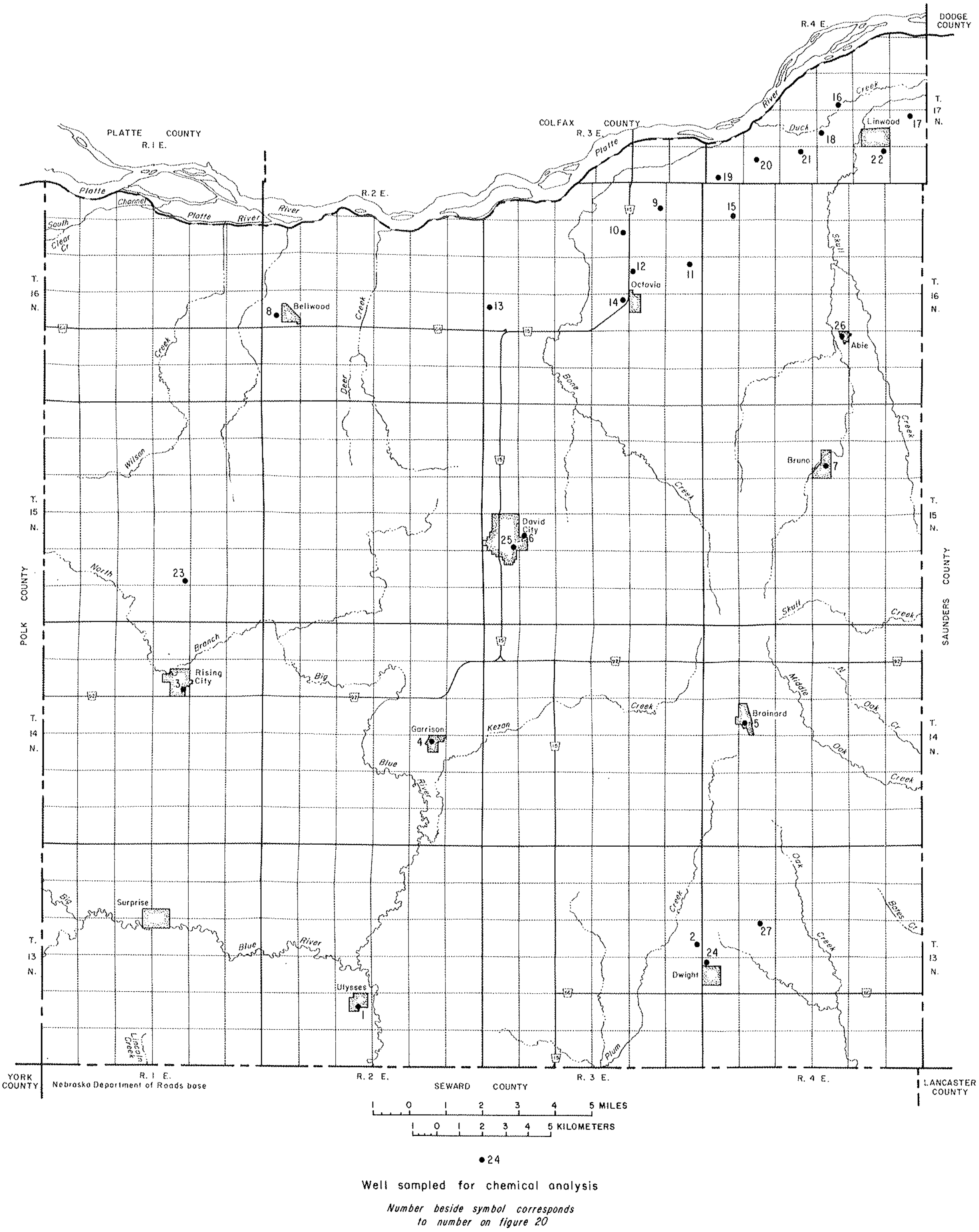


Fig. 19. Location of wells sampled for chemical analysis in Butler County

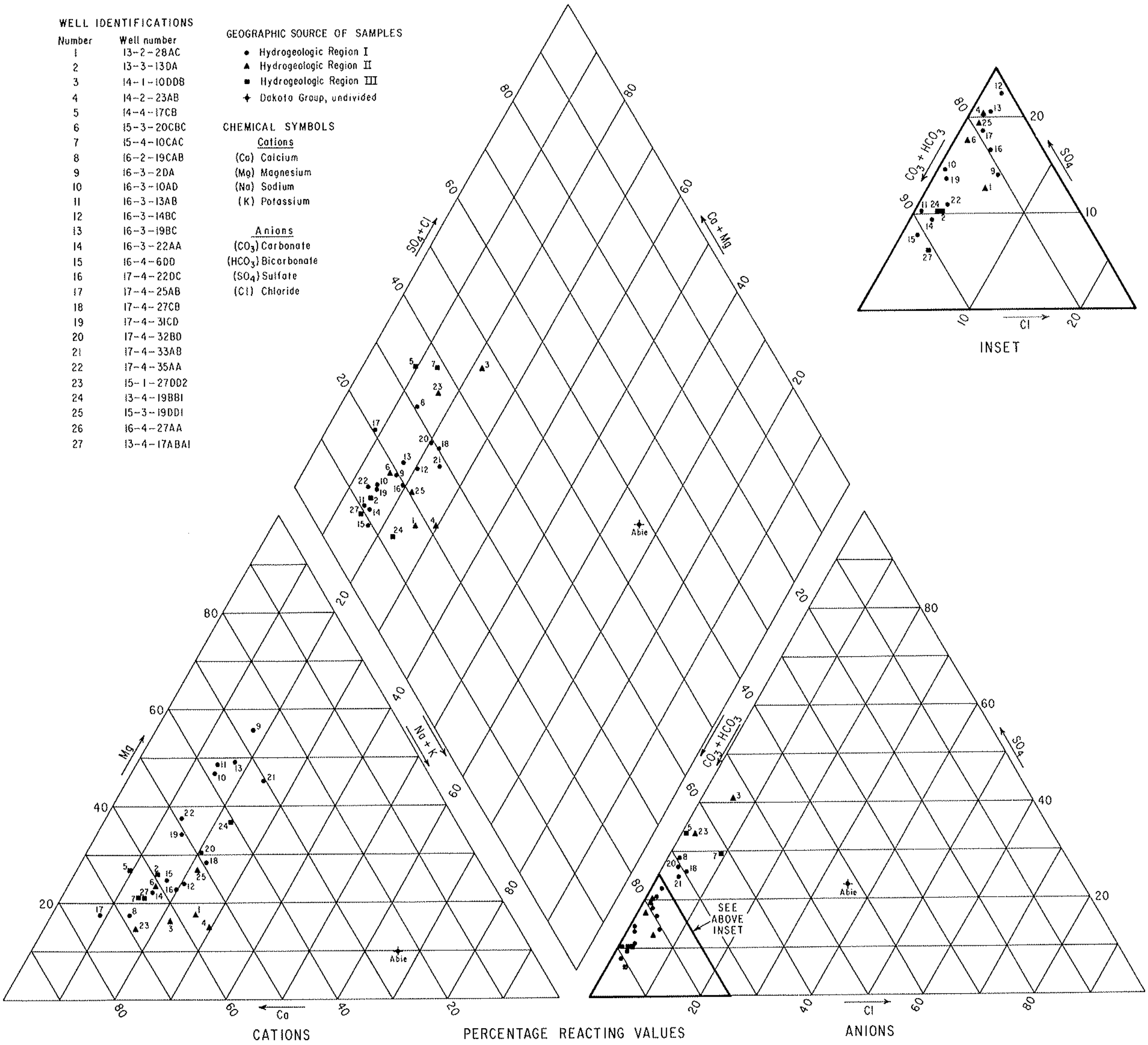
By contrast, the concentration of dissolved solids in the single sample collected from the Dakota Group, undivided, was 1,100 mg/l. This one concentration, however, ought not to be considered typical of water from the Dakota. The U.S. Environmental Protection Agency's secondary drinking water regulations recommend that dissolved solids not exceed 500 mg/l (U.S. Environmental Protection Agency, 1977). Nine of the 27 groundwater samples exceeded this concentration.

Concentrations of dissolved solids shown in table 2 for water from Pleistocene aquifers in Butler County are similar to those for water from Pleistocene aquifers in much of Nebraska. Engberg and Spalding (1978, p. 9) present a map showing that dissolved-solids concentrations in water in about two-thirds of the state are typically between 200 and 500 mg/l. Throughout the county, the water contains principally calcium bicarbonate or magnesium bicarbonate. It is very hard, ranging in hardness from 194 to 460 mg/l as calcium carbonate. The water is quite siliceous, similar in this regard to most water in the state, in addition to which it contains relatively large concentrations of iron and manganese. The dissolved-solids concentrations and the relatively large concentrations of silica, iron, and manganese, while detracting from the suitability of the water for domestic and industrial use, are not considered hazardous to health.

Nitrate or nitrite in water, although beneficial in irrigation, may be health threatening in water used for drinking by infants. When ingested by infants, nitrate may convert to nitrite in the intestinal tract and interfere with the oxygen-carrying capacity of the blood, causing a condition in infants known as methemoglobinemia. In severe cases, brain damage or death can result. To protect against this risk, the U.S. Environmental Protection Agency has set a limit for nitrite (as nitrogen) of 10 mg/l for drinking water (U.S. Environmental Protection Agency, 1976). This limit was exceeded slightly in water from two of the 27 wells sampled.

The hydrogeologic regions in which the wells sampled are located are indicated in table 2. From visual examination of the table, no significant differences in quality are evident in water of the Pleistocene aquifer from the several regions. Concentrations of the major cations (calcium, magnesium, sodium, and potassium) and of the major anions (carbonate, bicarbonate, sulfate, and chloride) were converted to "percentage reacting values" and plotted on a "chemical-analysis diagram" in figure 20. Plots of sample quality are scattered without regard to the regions from which the samples were taken.

Water from the Abie well, the only well producing from the Dakota Group, undivided, differs from water from other wells mostly in having greater percentages of sodium and chloride. Water from other wells differs mainly in the percentages of magnesium and sulfate. The differences probably reflect local differences in circulation patterns within the aquifer and local variations in the magnesium-sulfate content of the till through which the water percolated en route to the aquifer.



WELL IDENTIFICATIONS

Number	Well number
1	13-2-28AC
2	13-3-13DA
3	14-1-10DDB
4	14-2-23AB
5	14-4-17CB
6	15-3-20CBC
7	15-4-10CAC
8	16-2-19CAB
9	16-3-2DA
10	16-3-10AD
11	16-3-13AB
12	16-3-14BC
13	16-3-19BC
14	16-3-22AA
15	16-4-6DD
16	17-4-22DC
17	17-4-25AB
18	17-4-27CB
19	17-4-31CD
20	17-4-32BD
21	17-4-33AB
22	17-4-35AA
23	15-1-27DD2
24	13-4-19BB1
25	15-3-19DD1
26	16-4-27AA
27	13-4-17ABA1

GEOGRAPHIC SOURCE OF SAMPLES

- ● Hydrogeologic Region I
- ▲ Hydrogeologic Region II
- ■ Hydrogeologic Region III
- ✦ Dakota Group, undivided

CHEMICAL SYMBOLS

Cations

(Ca) Calcium
(Mg) Magnesium
(Na) Sodium
(K) Potassium

Anions

(CO$_3$) Carbonate
(HCO$_3$) Bicarbonate
(SO$_4$) Sulfate
(Cl) Chloride

Fig. 20. Chemical analysis of groundwater in Butler County

Interconnection of Groundwater and Surface Water

The two principal streams of Butler County are the Big Blue River, which originates in the county, and the Platte River, which originates in Colorado and Wyoming and forms the northern boundary of the county. Flow of the Big Blue River is gaged at Surprise, within the county, and at Seward, about 10 mi south of the Butler-Seward county line. Flow of the Platte River is gaged at Duncan, about 7 mi west of the Polk-Butler county line, and at North Bend, about 7 mi east of the Butler-Saunders county line. The 16-year average annual discharge of the Big Blue River at Surprise was 26.8 ft^3/s and the 27-year average at Seward was 111 ft^3/s (U.S. Geological Survey, 1981, pp. 343, 348). The 40-year average annual discharge of the Platte River at Duncan, from 1942 to 1981, was 1,469 ft^3/s (U.S. Geological Survey basic data files, 1942-81) and the 31-year average discharge at North Bend was 4,026 ft^3/s (U.S. Geological Survey, 1981, p. 206). The large increase in average annual flow of the Platte River between Duncan and North Bend is mostly due to inflow from the Loup River near Columbus.

The Big Blue River is in hydraulic connection with the underlying aquifer beginning about 2 mi northwest of Ulysses. West of that point it is not in hydraulic connection with the aquifer, and almost all water in the Big Blue River is direct overland runoff. A small component of streamflow, however, is water flowing from bank storage and water flowing laterally from locally perched aquifers. Historical water-level data indicate that even under predevelopment conditions, the Big Blue River at Surprise was not in hydraulic connection with the underlying aquifer. Under predevelopment conditions, hydraulic connection probably began about 4 mi northwest of Ulysses.

Scarcity of water-level data in the vicinity of the North Branch of the Big Blue River makes it difficult to determine where this stream starts being hydraulically connected with the groundwater system, but that point is probably not far north of the junction of the Big Blue River and the North Branch of the Big Blue River. Thus, most of the streamflow contributed by Butler County to the Big Blue River is overland runoff.

Plum Creek, which lies just east of the Big Blue River, receives no contribution of flow from groundwater.

The Platte River is in hydraulic connection with the underlying alluvial aquifer throughout most of its length along the northern border of Butler County. Contours of the potentiometric surface (fig. 12) indicate where interchange of water takes place. In ranges 1, 2, and 3 east, water in the alluvial aquifer discharges to the Platte River. In the western two-thirds of R. 4 E., little exchange of water occurs between river and aquifer. In the eastern third of R. 4 E., however, stream seepage recharges the aquifer.

Streams in the Hills Area flow on fine-grained sediments. In the Loess Hills, streams are not in hydraulic connection with any aquifers that may underlie them. In the Drift Hills, however, the following streams are in hydraulic connection: much of Oak Creek, Middle Oak Creek, and the downstream reaches of North Oak Creek. All these act as drains for the underlying aquifer.

SUMMARY OF GROUNDWATER RESOURCES

Geologic conditions are favorable for the storage and transmission of groundwater beneath about two-thirds of Butler County. The major water-bearing sediments, referred to in this report as the Pleistocene aquifer system, consist of sand, gravel, silt, and clay. Virtually all wells in the county are completed in this aquifer system.

Large-capacity wells are associated with thick sequences of saturated sand and gravel of the kind that underlie large parts of hydrogeologic Regions I and II but only a small part of Region III. In much of Region I, alluvial sand and gravel yield water to large-capacity wells. In Region II, large yields are produced not only from saturated sand and gravel in paleovalleys eroded into the bedrock of Cretaceous age but also from sand and gravel deposits that extend over the paleodivides and sediment-filled paleovalleys. In Region III, large-capacity wells are located in areas where thick deposits of saturated sands and gravels are limited to paleovalleys. Only small or negligible quantities of water are obtainable in areas where saturated sediments are thin or fine-textured, such as those that underlie much of Region III.

The direction of groundwater movement through the county is from west and southwest to northeast and southeast, the gradient being least in the southwestern part of the county and steepest in the extreme southeastern part.

Sandstones of the Dakota Group, undivided, a bedrock unit, are not laterally extensive. They supply a small volume of groundwater in the county. Water in the Dakota may be excessively mineralized and unsuitable for many purposes.

The Carlile Shale, the Greenhorn Limestone, and the Graneros Shale are not known to supply water in the county. Groundwater in the Pleistocene sediments contains principally calcium bicarbonate or magnesium bicarbonate. Dissolved solids range in concentration from about 300 to 700 mg/l. The different hydrogeologic regions are not distinguishable on the basis of water quality.

The Platte River, the Big Blue River beginning about 4 mi downstream from Surprise, and small streams in the Drift Hills are in hydraulic connection with the underlying groundwater system. The North Branch of the Big Blue River, Plum Creek, and small streams in the Loess Hills have little, if any, hydraulic connection with the underlying groundwater system.

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